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CICLO XXXI

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Verification and integration of the management and control software for the Near Infrared Spectrometer Photometer of the Euclid space mission

Coordinatore: Ch.mo Prof. Giampiero Naletto

Supervisore: Ch.mo Prof. Stefano Dusini

Co-Supervisore: Ch.mo Prof. Giampiero Naletto

Dottorando: Fulvio Laudisio

Summary

The thesis comprises five chapters covering different items and phases of the work accomplished during my Ph.D program. Such work is part of the Euclid Project, a very high-profile space-based scientific mission designed to accurately measure the expansion history of the universe and the growth of cosmic structures.

The first chapter is an introduction to the Euclid space mission and a description of Euclid's scientific goals and instrumentation. The payload is a telescope that hosts two instruments capable of taking images at different wavelengths. In particular, the chapter provides a detailed description of the Near Infrared Spectrometer Photometer (NISP).

The second chapter presents a detailed description of the NISP Warm Electronics (WE) with particular emphasis on the Data Processing Unit (DPU), the Instrument Control Unit (ICU), their application software (ASW), and the communication among them. The Assembly, Integration, Validation, and Testing (AIV/AIT) of such boards and the corresponding software are the main subjects of my Ph.D. study.

Chapters 3, 4, and 5 which take into consideration the AIV activities and the specifically designed software tools, detail my contribution to the NISP WE AIV. The AIV of the NISP on-board software required a careful design and the development of software tools to verify functionality and performances. Great care was taken in the development of the software of the DPU test equipment controlling the interface with the DPU. I developed it in close cooperation with the NISP AIV/AIT team, the NISP-Electrical Ground Support Equipment (EGSE) team, and two industries (OHB Italia for the DPU hardware design and construction and Temis for the procurement of the DPU TE). The developed software was delivered to the industries and is now used for the validation of the DPU Electro Qualified Model (EQM) and the Flight Model (FM).

Chapter 4 describes the DPU test campaign. I took part in the integration of the Application Software in the DPU board at OHB Italy and at INAF Padua.

Chapter 5 illustrates the AIV/AIT activity for the validation of the NISP Avionic Model (AVM) before delivery to Thales Alenia Space Italia (TAS-I).

Contents

Acronyms List

ADU	Analog Digital Unit
AGN	Active Galactic Nuclei
AIT	Assembly Integration & Testing
AIV	Assembly Integration & Verification
AOCS	Attitude & Orbit Control System
APID	Application Identifier
AR	Acceptance Review
ASI	“Agenzia Spaziale Italiana” Italian Space Agency
ASIC	Application Specific Integrated Circuit
ASW	Application Software
AVM	Avionic Model
BAO	Baryonic Acoustic Oscillation
BC	1553 Bus Controller
BM	1553 Bus Monitor
BSP	Basic Software Package
BSW	Boot Software
CAD	Computer Aided Design
CCD	Charge-Coupled Device
CCS	Central Checkout System
CDM	Cold Dark Matter
CDMS	Central Data Management System
CDMU	Command and Data Management Unit
CDR	Critical Design Review
CFC	Cryo Flexy Cable
CFRP	Carbon Fibre Reinforced Plastic
CISAS	“Centro di Ateneo di Studi e Attività Spaziali ‘Giuseppe Colombo’”
CM	Cryo Mechanism

CMB	Cosmic Microwave Background
COTS	Commercial Off-the-Shelf component
CNES	Centre National d’Etudes Spatiales
CPCI	Compact PCI bus
CRC	Cyclic Redundancy Check
CU	NISP Calibration Unit
CVT	Command Verification Table
DAS	Driving & Analogue Support module (ICU element)
DBB	Data Buffer Board (DPU Element)
DCU	NISP Detector Control Unit
DM	Demonstration Model
DMA	Direct Memory Access
DPB	Data Processing Board (DPU Element)
DPU	NISP Data Processing Unit
Dpusim	DPU Simulator
DRB	Data Router Board (DPU Element)
DS	Detector System
DSU	Debug Support Unit (ICU element)
EAS	Euclid Archive System
EBB	Elegant Bread Board
EC	Euclid Mission Consortium
ECSS	European Cooperation for Space Standardization
EDEN	EGSE data exchange protocol
EEF	Electrical Engineering Firmware
E-ELT	European Extremely Large Telescope
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electromagnetic Compatibility
EPS	Electric Power System
EQM	Electro Qualified Model

ESA	European Space Agency
ESD	Electro Static Discharge
EUT	Equipment Under Test
FAR	Flight Acceptance Review
FDIR	Failure Detection, Identification and Recovery
FFT	Full Functional Test
FGS	Fine Guidance Sensor
FM	Flight Model
FPA	Focal Plane Assembly
FSM	Finite State Machine
FWA	Filter Wheel Assembly
GC	Galaxy Clustering
GIT	Git is a distributed version control system
GPS	Global Positioning System
GWA	Grism Wheel Assembly
HAWAII	HgCdTe Astronomical Wide Area Infrared Imager
HK	Housekeeping
HSK	Housekeeping
H2RG	HAWAII 2048×2048 with Reference pixels and Guide window
ICU	Instrument Control Unit
ICU-EBB	Elegant BreadBoard
INAF	“Istituto Nazionale di Astrofisica”
INFN	“Istituto Nazionale di Fisica Nucleare”
IOCD	Instrument Operations Concept Document
IOT	Instrument Operation Team
IPC	Inter Pixel Capacitance
IRC	Icu Request Counter
IWS	Instrument Workstation
JWST	James Webb Space Telescope
kTC	kTC Noise

LEOP	Launch & Early Operations Phase
LAM	Laboratoire d’Astrophysicque de Marseille
LCL	Latched Current Limiters
LSS	Large Scale Structures
LVDS	Low-voltage differential signaling
LVPS	Low Voltage Power Supply module (ICU element)
MACC	Multiple Accumulated sampling
MIB	Mission Data Base
MLI	Multi-Layer Insulation
MMI	Man Machine Interface
MMU	Mass Memory Unit
MOC	Mission Operation Center
NAS	Network Attached Storage
NASA	National Aeronautics and Space Administration
NCR	Non Conformance Report
NISP	Near Infrared Spectro Photometer
NI-DCU	NISP Detector Control Unit Board
NI-CaLA	NISP Calibration Lens Assembly
NI-CoLA	NISP Collimator Lens Assembly
NI-CU	NISP Calibration Unit
NI-CUS	NISP Calibration Unit Simulator
NI-DPU	NISP Data Processing Unit board
NI-DS	NISP Detector System
NI-FWA	NISP Filter Wheel Assembly
NI-FGS	NISP AVM Filter and Grism wheels Simulator
NI-GWA	NISP Grism Wheel Assembly
NI-ICU	NISP Instrument Control Unit board
NI-OA	NISP Optical Assembly
NI-OMA	NISP Opto-Mechanical Assembly
NI-OMADA	NISP Opto Mechanical Assembly and Detector Assembly

NI-SA	NISP Structure Assembly. Part of NI-OMA
NI-SCS	NISP Sensor Chip System
NI-TC	NISP Thermal Control
NIR	Near Infrared
NNO	New Norcia Observatory
OBT	On Board Time
OGS	Operations Ground Segment
OVC	Over Current
PARMS	Plasma Assisted Reactive Magnetron Sputtering
PCB	Printed Circuit Board
PCDU	Power Conditioning and Distribution Unit
PDR	Preliminary Design Review
PFM	Proto Flight Model
PLM	Payload Module
PRR	Preliminary Requirements Review
PSB	Power Supply Board (DPU element)
PUS	Packet Utilisation Standard
PV	Performance Verification Phase
RbT	Robustness Test
RT	1553 Remote Terminal
RTOS	Real Time Operative System
SA	1553 Sub-Address
S/C	Space Craft
SCA	Sensor Chip Assembly
SCE	Sensor Chip Electronics
SCOE	Special Check Out Equipment
SCOS2000	Satellite Control and Operation System 2000
SCS	SideCar Simulator
SDC	Science Data Center
SDSS	Sloan Digital Sky Survey

SECOIA	Serial Control Interface Asic
SFT	Short Functional Test
SGS	Science Ground Segment
SiC	Silicon Carbide
SIDECAR	System for Image Digitization, Enhancement, Control And Retrieval
SNR	Signal to Noise Ratio
SOC	Science Operation Center
SPC	ESA Science Programme Committee
SPI	Serial Peripheral Interface
SSH	Sun Shield
STM	Structural and Thermal Model
STR	Star Tracker
SVM	Service Module
TAS-I	“Thales Alenia Space Italia”
TC	Telecommand
TCL	Tcl/Tk Command Language
TE	Test Equipment
TM	Telemetry
TRB	Test Review Board
TRR	Test Readiness Review
TSC	Test Sequence Controller
TSEQ	Test Sequence
TV	Thermo Vacuum
UAH	Universidad de Alcalá
UPCT	Universidad Politécnica de Cartagena
UTR	Up-the-Ramp
VCB	Verification Control Board
VIS	Visible Imager
VI-CDPU	VIS - Control and Data Processing Unit
VI-CU	VIS – Calibration Unit

VI-FH	VIS - Flight Harness
VI-PMCU	VIS – Power and Mechanism Control Unit
VI-SU	VIS – Shutter Mechanism
WE	NISP Warm Electronics
WL	Weak Gravitational Lensing
WMAP	Wilkinson Microwave Anisotropy Probe

Introduction

The focus of the work described in the thesis is testing and verification of the NISP Instrument functionality; testing and verification are challenging tasks that need to be adapted to the unique and specific characteristics of the system considered. The preparation and execution of these tests required a deep insight of the Instrument design and of the expected performance.

The verification of atomic and specific hardware/software requirements for each NISP element is crucial for the success of the whole Euclid project because they originated from top level scientific needs.

The Euclid science goals address some of the most fundamental questions about the Universe and its earliest stages. Two powerful methods for dark Universe investigation will be applied: Weak Gravitational Lensing (WL) and Baryonic Acoustic Oscillations (BAO). The payload will be equipped with two instruments, one providing wide-band visible images (VIS) and one capable of both Near Infrared (NIR) imaging and slitless spectroscopy (NISP). They will operate simultaneously by means of a dichroic filter that splits the light collected by the telescope in the two frequency ranges.

One of the top level scientific requirements for both WL and BAO probes is the extent of the whole Euclid Survey area: at least 15,000 deg^2 are to be observed in 6 years. The NISP instrument observation strategy was designed to optimize and maximize the observable area. This led to the requirement that the NISP on-board processing time should not exceed the data-taking time for a point in the sky. Likewise, the other scientific requirements were translated into a set of functional tests.

The NISP instrument operations are driven by Warm Electronics (WE), which comprises two units: the Instrument Control Unit (ICU) and the Data Processing Unit (DPU). The preparation and validation of their hardware components and of their on-board software had just started at the beginning of my Ph.D. study. Those activities were carried out up to the delivery of the NISP Avionic Model (NISP AVM) in which tests focused on the verification of functional requirements. The AIV will continue until the delivery of the Flight Model, expected for the end of 2019, and it will also include performance verification.

This thesis aims to illustrate the Assembly Integration Verification and Test (AIV/AIT) process used for NISP Warm Electronics.

Warm Electronics AIV/AIT strategy provides for the two components - ICU and DPU - to be tested separately (at unit level) before WE integration. The INFN Padua Group is involved in the DPU AIV/AIT and gave support to the hardware supplier (OHB-I) in the functional test campaign and to INAF Padua for the development of the DPU on-board software. The ICU on-board software is developed by INAF Turin and the integration of this software in the ICU hardware is under the responsibility of INFN Bologna.

The test activity at unit level required the development of dedicated software tools able to simulate the interfaces between the two units and the spacecraft. The use of simulators is a well-established strategy in AIV campaigns and their flexibility is essential to improve and debug the functionality of both hardware and on-board software. Notably also simulators are to be verified and validated against their specifications.

The development of the simulators followed the improvements of the ICU and DPU on-board software in their development and smoothened the approach to the first WE integration in the NISP Avionic Model (AVM).

The aim of the AVM model is to test, at room temperature, the NISP functional performances, the command flow from the spacecraft, and the science data and housekeeping production.

The test activity comprised a set of test procedures that verify the WE nominal operation and the functionality related to the recovery from faults. These tests were performed using specific hardware and software test equipment aiming to simulate the interfaces between the spacecraft and the WE.

NISP AVM integration and tests took place at INFN Padua in 2018. NISP functionality was verified and the models could be delivered to TAS-I to be integrated in the Euclid satellite engineering model.

1 The Euclid space mission

1.1 Science case

The present understanding of cosmology is that the Universe is expanding and that it is evolving from a homogeneous state to a hierarchical distribution of galaxies, clusters and super-clusters. The emission spectra of galaxies were first observed at the beginning of the XX century. Spectral lines from known elements were easily recognized but they were shifted from the positions measured in laboratory, where sources are at rest. In the case of the closest galaxies the lines were shifted toward the blue end of the spectrum, while for galaxies beyond our Local Group, the lines were shifted to the red. This effect is called *redshift* or *blueshift*, the explanation was a Doppler effect due to the relative motion of the galaxies. The redshift z can be defined as:

$$\lambda_{\mathrm{obs}} = \lambda_{\mathrm{emit}}\,(1+z)$$

Where λ_{obs} is the wavelength measured and λ_{emit} is the wavelength emitted by the source. When the relative velocity is small compared to the speed of light the redshift can be expressed as :

$$\frac{\Delta f}{f_{\mathrm{emit}}} = \frac{\Delta\lambda}{\lambda_{\mathrm{emit}}} = \frac{v}{c} = z$$

where f_{emit} is the frequency, Δf and $\Delta \lambda$ are the changes in frequency and wavelength, v is the relative velocity of the galaxy and c is the speed of light.

Vesto Slipher measured in 1915 the shifts for 15 galaxies and he evaluated their velocities of approach or recession. Later in 1929 Edwin Hubble, using the Hooker Telescope on Mount Wilson, measured the distances of galaxies using the Cepheid variables method [1]. He discovered that all galaxies, except the closest ones, are moving away from us with a recession velocity which is linearly proportional to their distances (see Figure 1.1).

He established the so called *Hubble's law*:

$$v = H_0\,D$$

the coefficient H_0 is known as the *Hubble constant* (although it is now known not to be constant). The best estimation of its value is:

$$H_0 = (67.74 \pm 0.46)\ km\ s^{-1}\ Mpc^{-1}\ [2]$$

Following the Hubble's law, we can say that the Universe is expanding and there is no privileged point in this process. Furthermore, the mass density of the Universe must have been higher in the past. Following this line of reasoning it is possible to imagine that there was a time in which the mass density had a maximum or, even worse, a singularity. The interval between this time and the actual era is usually considered the age of the Universe. Assuming that no acceleration occurred during the expansion, this interval can be evaluated as follows:

$$t_0 = 1/H_0 \approx 14\ \text{Gyr}$$

this result is in good agreement with independent measurements on the oldest stars.

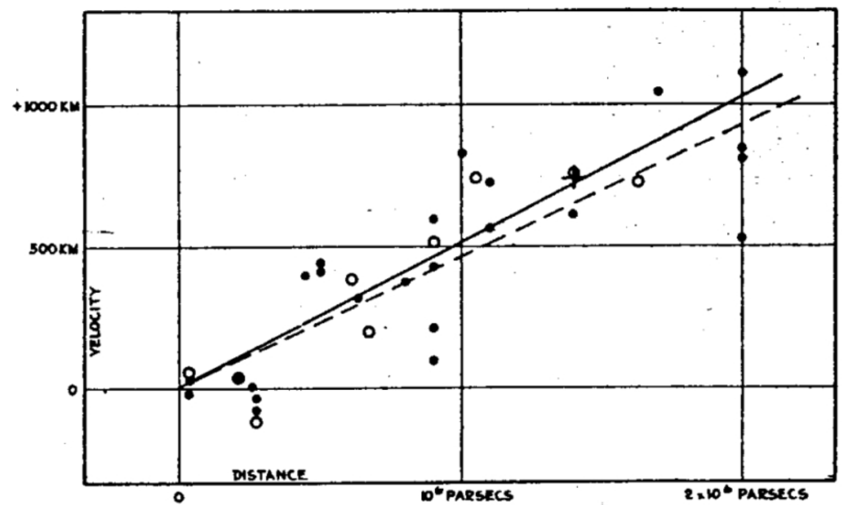


FIGURE 1

Figure 1.1: Original Hubble's diagram [1]. The velocity of distant galaxies is plotted against their distance from the Earth. The solid line is the best fit of the black points (the Sun's motion is not taken into account) while the dashed line is the best fit of the open points (the Sun's motion is taken into account).

As a simple consequence, when we find that a galaxy is observed at a redshift of z it means that we observe the galaxy at a time when the universe was smaller by the ratio *(1 + z)*.

By the end of 1990s there was evidence that the expansion of the Universe is accelerated. From the observation of the brightness curve of Type Ia Supernova as a function of their redshift (and thus their distance) [3]. In order to compute distances of far objects, astronomers use as reference a certain type of exploding stars called Type Ia Supernova that are among the brightest events in the sky. Type Ia Supernovae occur in binary systems (two stars orbiting one around each other), when one of the stars is a white dwarf. The white dwarf constantly captures mass from the nearby star and when its mass reaches 1.4 solar masses a chain of nuclear reactions occurs, causing the white dwarf to explode. The resulting light is 5 billion times brighter than the Sun.

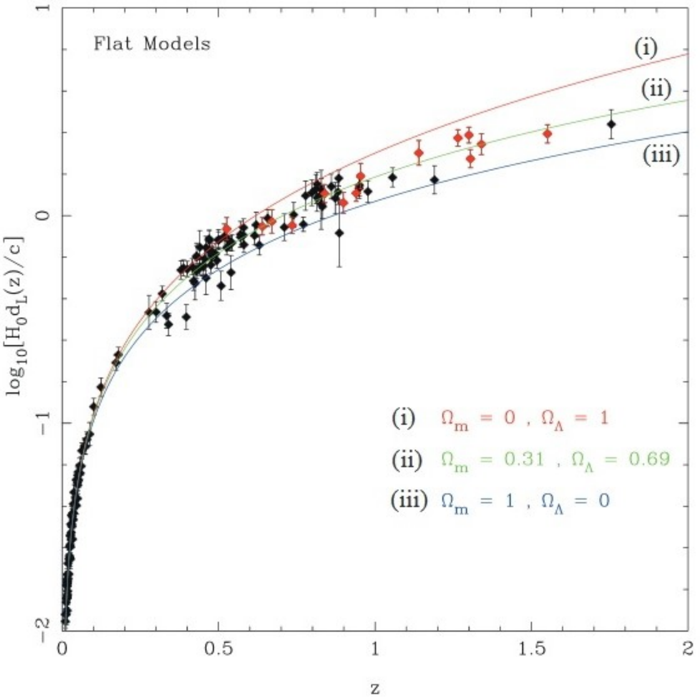


Figure 1.2: Plot of the luminosity distance versus the redshift z for a flat cosmological model of the Universe. The black points come from the data sets by Riess et al [3]. Red points show data from Hubble Space Telescope. Three solid curves show the theoretical values of luminosity distance for different energy contents of a flat Universe: (i) red curve $\Omega_m = 0$, $\Omega_\Lambda = 1$; (ii) green curve $\Omega_m = 0.31$, $\Omega_\Lambda = 0.69$ and (iii) blue curve $\Omega_m = 1$, $\Omega_\Lambda = 0$ [4].

The reaction starts when the star mass reaches a critical value so the brightness of these

Type Ia Supernovae is very regular. To find the distance of a galaxy that contains the Supernova, it is enough to compare how bright the explosion should be with how bright the explosion appears. After an extensive data collection, it turned out that they move faster than expected as shown in Figure 1.2.

In Figure 1.2 experimental points are fitted in three different hypotheses on the energy density content of a flat Universe. A flat Universe is a model in which the energy density is equal to a critical value that approximately is 10^{-29} g × cm^{-3}. Being Ω_m the ratio of energy density today in matter compared to the critical one and Ω_Λ the ratio of dark energy density in the cosmological constant to the critical one, the best fit is obtained in the hypothesis of a Universe having about 70% of the energy in the form of a cosmological constant, also called *dark energy*. Perlmutter, Riess and Schmidt were awarded the Nobel Prize in 2011 after this result.

Most recent studies of the Cosmic Microwave Background (CMB) performed by the Planck mission [5] demonstrate that baryonic matter contribution to the total energy density of the Universe is only 4.9% while 26.3% is a non-luminous matter called *dark matter* and the remaining 68.8 % is *dark energy*.

The existence of a dark energy field with negative pressure leads to a cosmic expansion which is accelerating at the present time. Since such discovery many observational efforts have been spent to measure with increasing precision the cosmological parameters over the largest achievable fraction of the age of the Universe, especially in the redshift range $0 < z < 2$. These efforts include large galaxy surveys, weak lensing analysis, baryon acoustic oscillation (BAO) searches and high redshift supernovae studies. Except for the supernovae, all other techniques rely on measurements of cosmological structure in order to deduce cosmological parameters. The observations related to CMB and Large Scale Structures (LSS) provide, indeed, an independent confirmation of the dark energy scenario. BAOs are frozen relics left over from the pre-decoupling Universe, and they can be exploited as standard rulers for cosmology. Since the Universe has a significant fraction of baryons, cosmological theory predicts that the acoustic oscillations in the plasma will also be imprinted onto the late-time power spectrum of the non-relativistic matter. The existence of dark matter was pointed out at first by Fritz Zwicky in the 1930s by comparing the dispersion velocities of galaxies in the

Coma cluster with the observable star mass. Typically, in spiral galaxies and galaxy clusters the member objects such as stars, gas clouds or galaxies follow a circular movement around the centre of the corresponding structure. Plotting this radial dependence of the velocities yield the rotation curves. These show a flattening at large distances from the centre which is an indication of the presence of non-luminous matter. Another strong indication supporting the hypothesis of dark matter is the correlation between the measured CMB anisotropy and the distribution of LSS. The observed CMB temperature fluctuation would generate gravitational potential wells unable to allow the formation of structures. By introducing dark matter, these gravitational potential become more consistent and, by simulating the distribution of the CMB, it is possible to see that they can reproduce a Universe matching today's observations of large structures of galaxies in filaments.

In 1980, thanks to the main contributions of Peebles, Bond and Blumenthal, the CDM (Cold Dark Matter) [6] model emerged. This model is consistent with the latest measurements of the Planck mission. The observation of clusters of galaxies implies a presence of dark matter, slowing down the expansion of the Universe by the action of gravitation.

Since the discovery of these two *dark constituents* of the Universe, many questions came out:

- is dark energy merely a cosmological constant?
- is dark energy instead a manifestation of a break-down of General Relativity and deviations from the law of gravity?
- What are the nature and properties of dark matter?
- What are the initial conditions which seed the formation of cosmic structure?

In order to investigate these open points cosmology entered a precision data driven era in the last twenty years. First observations of the CMB were performed by the COBE satellite in 1990 [7]. There have been a variety of CMB experiments, ground based such as the Atacama Cosmology telescope [8] in Chile, the South Pole telescope [9] at the South Pole, with balloons such as Boomerang [10] and two more satellites, the Wilkinson Microwave Anisotropy Probe (WMAP) [11] and Planck [5].

The first redshift survey was the CfA Redshift Survey, started in 1977 with data collection completed in 1982 [12]. The 2dF Galaxy Redshift Survey determined the large scale structure of one section of the Universe, measuring redshifts for over 220,000 galaxies; data collection was completed in 2002, and the final data set was released in 2003 [13].

The ground based Sloan Digital Sky Survey (SDSS) [14] is ongoing and aims to measure the redshifts of around 3 million objects. SDSS has recorded redshifts for galaxies up to 0.8, and has been involved in the detection of quasars beyond $z = 6$. The DEEP2 Redshift Survey [15] uses the Keck telescopes with the new "DEIMOS" spectrograph; a follow-up to the pilot program DEEP1, DEEP2 is designed to measure faint galaxies with redshifts 0.7 and above, and it is therefore planned to provide a high redshift complement to SDSS and 2dF.

Two powerful methods for dark Universe investigation are Weak Gravitational Lensing (WL) and Baryonic Acoustic Oscillations (BAO) study. From a technological point of view, it is not trivial to exploit the gravitational lensing as an investigation method for dark matter and dark energy studies. A sub-arcs-second angular resolution and the redshift of the sources are needed to estimate WL and BAO with the required accuracy. A great effort is being performed by the international community of scientists to collect in the forthcoming years observations with the goal of mapping hundreds of millions of galaxies, through imaging and redshift surveys conducted from ground and from space. Among these projects there is Euclid, a Medium Class space mission of the European Space Agency (ESA) belonging to the Cosmic Vision 2015-2025 programme; Euclid is designed as a wide survey in both optical and near-infrared bands. The launch of the EUCLID satellite is planned in 2021 and the mission life-time is 6 years. The primary goal of the mission is scientific; it is to investigate the nature of dark energy, dark matter and gravity by measuring shapes and redshifts of galaxies up to $z \sim 2$. This result will allow determining the evolution of the recent universe since the time when dark energy became important [16][17].

The Euclid wide survey will produce a visible image of a large fraction of the extra-galactic sky (15,000 squared degrees) with spatial resolution not possible from ground due to atmospheric instability. The Euclid Payload Module is equipped with a 1.2 m diameter Korsch telescope, a Visible Imager (VIS) and a Near Infrared Spectrometer and Photometer (NISP) instrument. The imaging and spectroscopy survey will be possible in the optical and near-infrared range (1.25 - 1.85 µm). The NISP instrument has one additional blue grism covering the wavelength range (0.92 - 1.3 µm). This extra grism is suited for the investigation of the high redshift Universe with the prospect of detecting luminous Lyman-alpha emitting galaxies at a redshift $z > 6.5$ and Active Galactic Nuclei (AGNs) over a broader redshift range and without a colour pre-selection. Euclid's deep field imaging with the visual instrument in the (550 − 900 nm) band and with NISP in the Near Infrared (NIR) bands will provide the complementary photometry for further target identification and characterisation.

Euclid will use a number of cosmological probes to measure the clustering properties but is optimised for two methods:

- Galaxy Clustering (GC): measurement of the redshift distribution of galaxies from their Hα emission line using NIR slitless spectroscopy
- Weak Lensing (WL): measurement of the distortion of the galaxy shapes due to the gravitational lensing caused by the predominantly dark matter distribution between distant galaxies and the observer. The resulting galaxy shear can be transformed into matter distribution. This is done in a number of redshift bins to derive the expansion of the dark matter as a function of redshift.

The GC method provides also direct information of the validity of General Relativity because it can help monitoring the evolution of structures subject to the combined effects of gravity, which forces clumping of matter, and the opposing force caused by the accelerated expansion. GC maps the distribution of the luminous, baryonic matter whereas WL measures the properties of the combination of both luminous and dark matter. The complementarity of the two probes will provide important additional information on possible systematics.

Moreover, Euclid will produce a legacy dataset with images and photometry of more than a billion galaxies and several million spectra, up to high redshifts $z > 2$. At low redshift, Euclid can resolve the stellar population of all galaxies within ~5 Mpc, providing a complete census of all morphological and spectral types of galaxies in our neighbourhood. It will also deliver morphologies, masses, and star-formation rates up to z~2 with a 4 times better resolution, and 3 NIR magnitudes deeper, than possible from ground. The Euclid deep survey data will contain thousands of objects at $z > 6$ and several tens of $z > 8$ galaxies or quasar candidates that will be critical targets for the James Webb Space Telescope (JWST) [18] and the European Extremely Large Telescope (E-ELT) [19] upcoming projects.

1.2 EUCLID MISSION DESIGN

1.2.1 Overview

The Euclid spacecraft (Figure 1.3) will be launched by a Soyuz ST 2.1-B rocket from Kourou Space Center (French Guiana). The target orbit is a large amplitude halo orbit around the second Sun-Earth Lagrangian point L2. This point is approximately 1.5 million km away from the Earth and allows observing the sky without any interference from the Sun light. The launch is foreseen in 2022 and the nominal mission duration is 6 years [16].

The Euclid spacecraft is composed by two modules: the Service Module (SVM) and the Payload Module (PLM). The Service Module hosts all the spacecraft service systems and the electronics serving scientific instruments. Moreover, the SVM provides the pointing accuracy required by the scientific objectives. The PLM hosts a 1.2 m diameter three-mirror telescope in Korsch configuration and the two scientific instruments: the Visible Imager (VIS) and the Near-Infrared Spectro-Photometer (NISP).

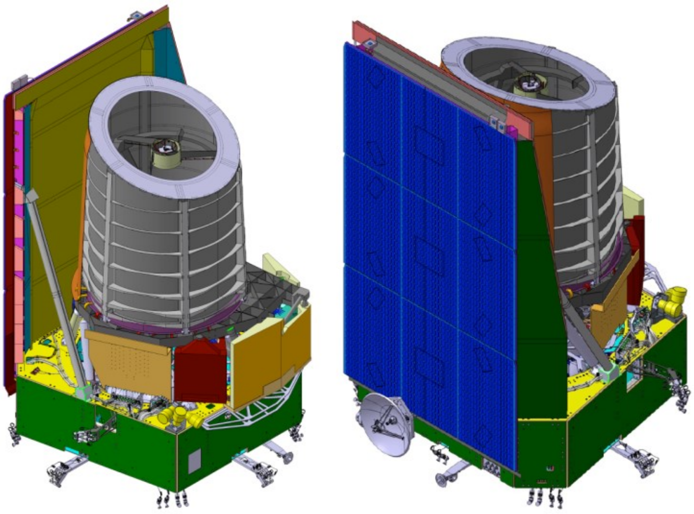


Figure 1.3: Overview of the Euclid spacecraft (SVM in the bottom and telescope and scientific instruments on top).

The sky observations will be performed in step-and-stare mode. Image dithering (small changes in the telescope position) will be applied at spacecraft level to fill gaps in the detector planes and to allow correction for cosmic rays. Each field of view is 0.5 deg^2 and it is observed at the same time by both VIS and NISP; the nominal observation cycle for each field of view is realized by a sequence of four exposures interleaved by dither steps (Figure 1.4). Each dither is composed by four exposures: the first one is for VIS and for NISP in spectroscopic mode; afterwards there are three photometric exposures in different bands [Y (920-1146 nm), J (1146-1372 nm) and H (1372-2000 nm)] that require the rotation of the NISP filter wheel. VIS closes its shutter while NISP performs photometric exposures in order to avoid disturbance to VIS images from vibrations caused by the NISP filter wheels actuations.

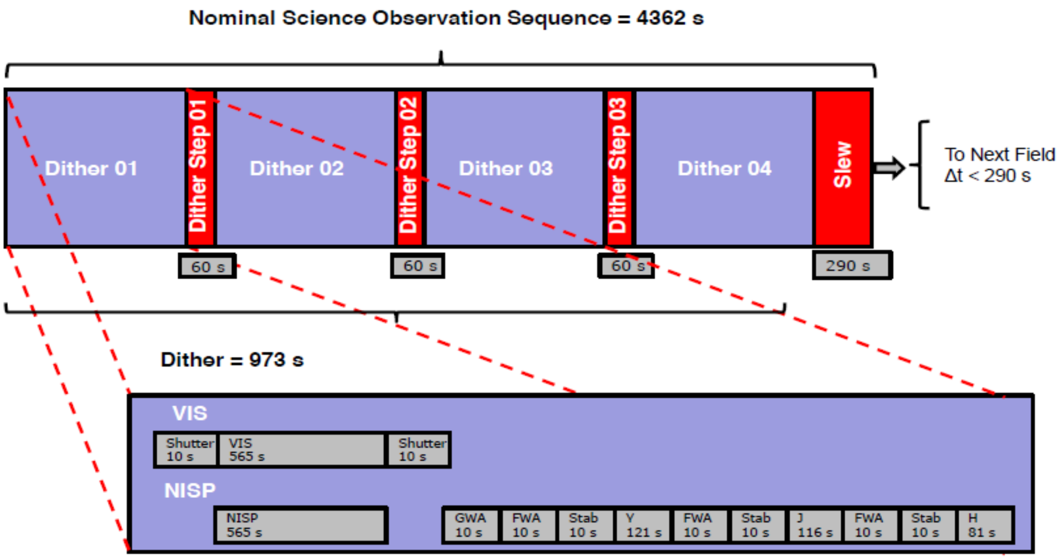


Figure 1.4: The nominal Euclid observation cycle for each point in the sky.

The whole Euclid observation program (Figure 1.5) consists of:

- **Wide Survey**: it covers about 36% of the entire sky, corresponding to 15000 deg^2 and each field will be observed only once. It is based on the observation diagram shown in Figure 1.4with an overall mapping which systematically avoids the Ecliptic plane and the galactic plane, areas where the density of stars is a source of important background in the visible and infrared bands. This wide survey will enable the measurement of shapes and redshifts of galaxies up to redshift $z = 2$

as required for weak lensing and BAO.

The photometric redshifts will be derived from three Euclid near-infrared (NIR) bands (Y, J, H) for objects reaching AB magnitude *ABmag = 24*. Such measurements will be complemented by information coming from ground based photometry in visible bands. The shear of the same objects is obtained by ellipticity measurements on VIS images. The BAO are determined from spectroscopic redshift measurements and they will be performed using a slitless spectrometer with constant $\lambda/\Delta\lambda = 500$ that will detect mainly *Hα* emission lines. The limiting line flux level will enable gathering about 70 million galaxy redshifts with a success rate of 35%. The total number of expected observed galaxies is 2.5×10^{7} for the galaxy clustering spectroscopic sample and 1.5×10^{9} for the weak lensing photometric sample.

- **Deep Survey**: it will cover about 40 deg^2 close to the Ecliptic Poles and it will help to calibrate the measurements and the redshift reconstruction algorithms. The deep survey fields will be observed periodically, thus they are a unique baseline for the discovery of variable light sources.

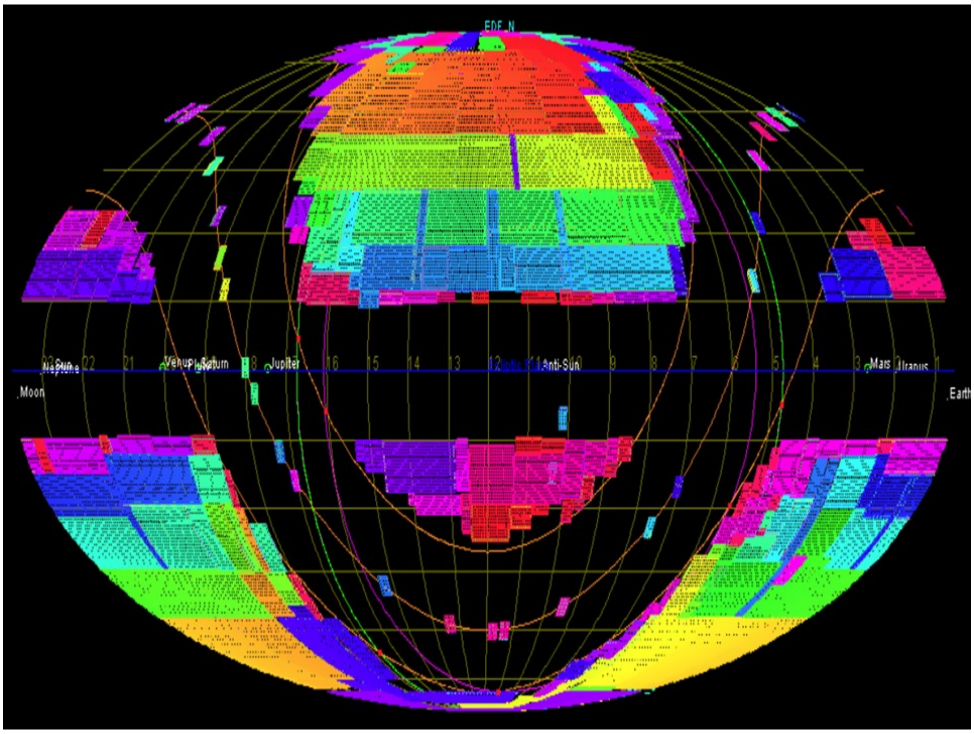


Figure 1.5: Fields of observation of the Euclid mission. The black areas correspond to the plane of the ecliptic and the galactic plane [16].

1.2.2 Service Module

The Service Module (SVM) hosts the spacecraft subsystems required for payload correct operations, the warm electronics of the scientific instruments and it also provides structural interfaces to the Payload Module (PLM) and to the launch vehicle (Figure 1.6). The temperature is kept around 280 K.

The Sunshield (SSH) is part of the SVM and protects the PLM from illumination from the Sun; it also supports the photovoltaic assembly supplying electrical power to the spacecraft. SSH is made of a carbon fibre reinforced plastic (CFRP) frame made of 2 vertical poles with diagonal stiffeners and 2 struts. The front side carries the photovoltaic assembly in 3 identical photovoltaic panels. On the top edge, an optical baffle consisting of three blades with decreasing height shields the sunlight diffracted towards the PLM. A dedicated structure is embedded on one corner of the SSH. It provides additional radiation shielding to the VIS Instrument focal plane.

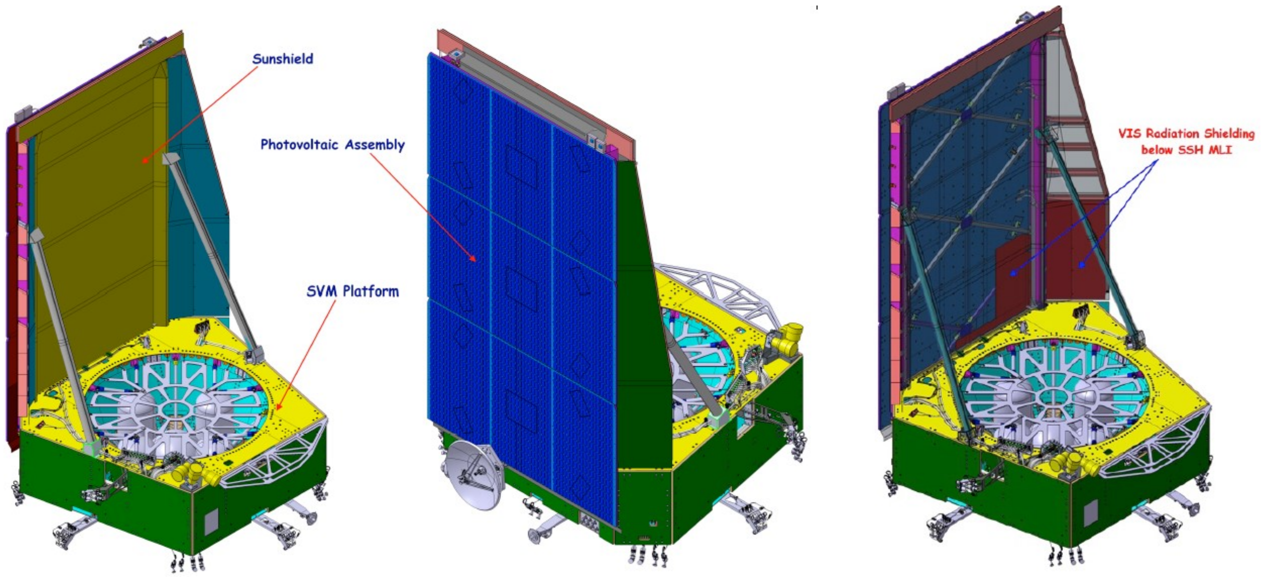


Figure 1.6: Overview of the Euclid SVM wth Sunshield module supporting photovoltaic assembly.

The SVM accommodates all the equipment on the six foldable side panels of the hexagonal base (Figure 1.7): Telemetry and Telecommand (TT&C), Attitude and Orbit Control System (AOCS), Central Data Management System (CDMS) and Electric Power System (EPS), Payload and Fine Guidance Sensor (FGS), scientific instruments warm electronics (WE) [20]. Each panel can be individually dismounted to allow the integration of equipment and their access. The PLM is connected to the SVM via three glass-fibre bipods attached to the SVM in six points along the central cone upper ring and in three points to the baseplate of the PLM. The thermal control is based on a passive design using radiators, multilayer insulation (MLI) and heaters. The design is optimized in order to guarantee the short-term temperature stability of the PLM conductive and radiative interface, and minimal (<25 mW) heat flux into the coldest NISP radiator. High performance Kapton MLI is installed on the on SVM top floor, PLM bottom and Sun Shield rear side to minimise the heat flux and thermal disturbances onto the PLM.

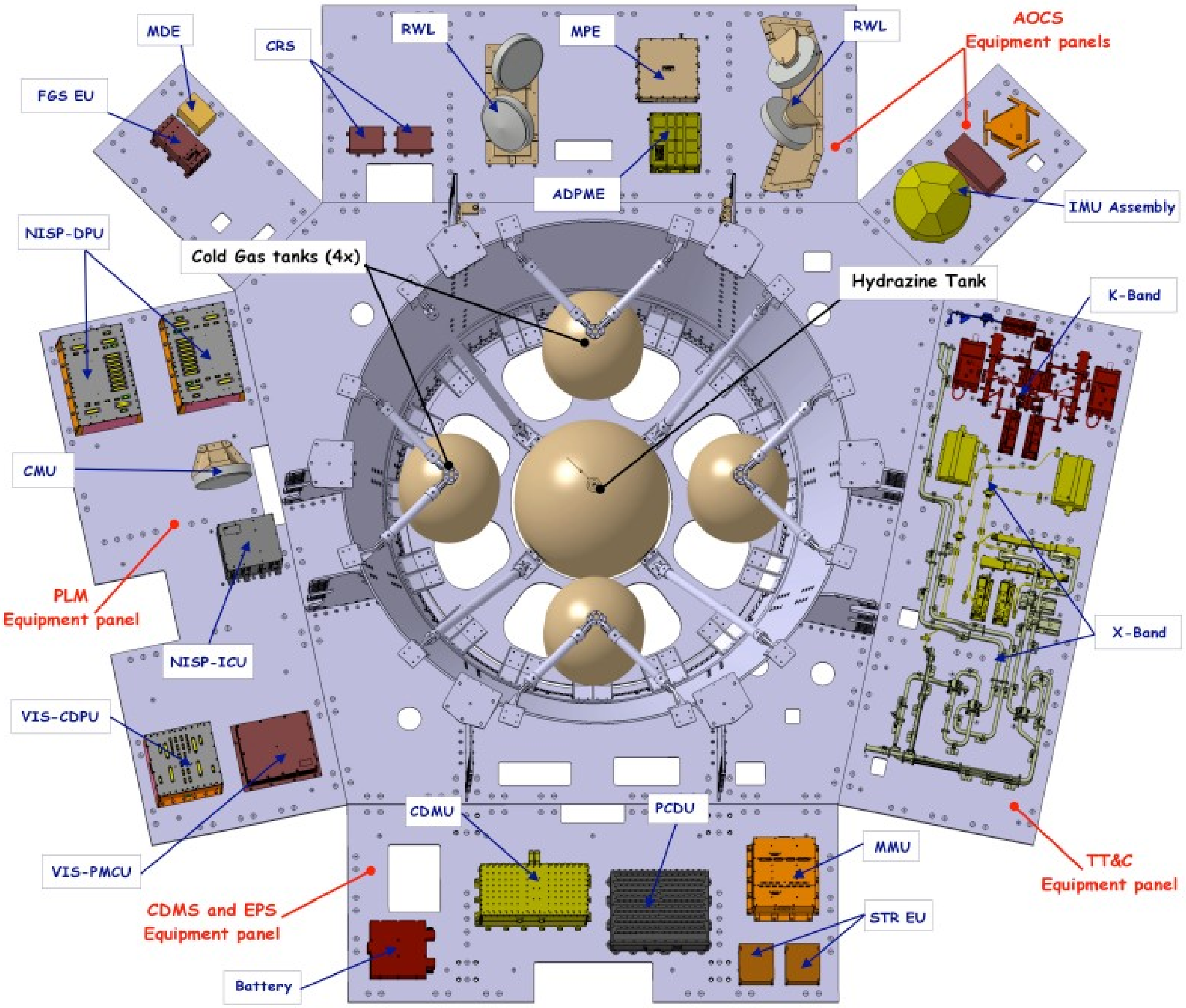


Figure 1.7: Layout of the different equipments mounted on the SVM baseplate.

The 28V electrical power is provided by the spacecraft through protected lines provided by the on-board Power Conditioning and Distribution Unit (PCDU) that controls the heaters and the charge and discharge of the battery (which is used only during the launch phase, then substituted by the photovoltaic panel of the sunshield).

One centralised on-board computer Command and Data Management Unit (CDMU) provides spacecraft and AOCS command, control and data processing. The CDMU is a modular unit including standard core boards; the Processor Module is based on a general-purpose space qualified microprocessor (LEON-FT). Two processor modules are integrated in a single-failure tolerant unit.

The number of scientific exposures and high-resolution images produce a high science data volume and require large on-board memory (850 GB to be handled daily). The Mass Memory Unit (MMU) has a capacity sufficient to store 72 hours of scientific data and 20 days of spacecraft telemetry. Commands and telemetries are routed and/or collected via two standard MIL-STD-1553 buses, one dedicated to the spacecraft equipment and another one to the instruments and mass memory. The instruments deliver high volume scientific data via high speed Spacewire links directly into the MMU. Files stored in the mass memory are downloaded to ground stations via X and K band communication links.

The telecommunications architecture includes two independent sections: an X-band section used for telecommands, monitoring and ranging and a K-band section dedicated to high rate telemetry. The X-band section supports uplink of telecommands at two different rates (4 kbit/s and 16 kbit/s) and the downlink of real time housekeeping at two different information rates (2 kbit/s and 26 kbit/s). The K-Band section supports downlink of recorded science and telemetry at two different data rates: nominal at 73.85 Mbps and reduced at 36.92 Mbps in case of adverse weather.

The AOCS provides 75 macs Relative Pointing Error over 700 sec and 7.5 arcsec of Absolute Pointing Error both with 99.7% confidence level. The FGS uses 4 CCD sensors co-located within the VIS imager focal plane to provide the fine attitude measurement. Cold gas thrusters with µN resolution provide the forces used to actuate the fine pointing. Three star trackers (STR) provide the inertial attitude accuracy. Four reaction wheels execute all the slews between dithers (50 – 100 arcsec); after each slew the wheels are controlled to slow down and are finally stopped by friction. Reaction wheels are at rest during operation, they ensure noise-free science exposures by eliminating the micro-vibration associated to reaction wheel actuation. The micro-propulsion employed for fine attitude control is based on cold-gas Nitrogen thrusters. Four high-pressure tanks provide storage of 70 kg Nitrogen, sufficient for 7 years of operation. Orbit control and attitude control in non-science modes are actuated by two redundant branches of ten hydrazine thrusters. Hydrazine storage is provided by one central tank with 137.5 kg propellant mass capacity.

1.2.3 Payload Module

The Euclid PayLoad Module (PLM) is designed in order to integrate the telescope, VIS and NISP instruments. It is built around an anastigmatic three-mirror Korsch telescope made of Silicon Carbide which directs the incoming light to VIS and NISP instruments (Figure 1.8-Figure 1.9-Figure 1.10). The light separation between the two instruments is performed by a dichroic filter located at the exit pupil of the telescope. Both instruments can cover a large common field of view of about 0.54 deg^2.

The telescope is built on a truss hexapod: 6 struts connect the secondary mirror (M2), mounted on a frame through spiders, to the optical bench of the primary mirror (M1). The upper part of the optical bench supports M1 and the M2 structure, the lower part supports the other telescope optics and both VIS and NISP instruments. The optical bench provides also interface points to the service module. M2 is mounted on a mechanism able to compensate in three degrees of freedom for launch and cool-down effects.

Except proximity electronics of the focal planes, all electronics are placed in the SVM to minimise thermal noise effects to the PLM. The passive thermal concept requires minimum heating power and provides best thermal stability. The telescope is cooled-down to its equilibrium temperature around 130K. In nominal operations, only local heating capacity at constant power is needed to adjust instruments interface temperatures to the prescribed value. The required heating power in operational mode is ~140 W.

Additional heating lines are installed for optics decontamination during commissioning phase and for survival mode. Heat leaks to cold instruments units are minimised, the PLM acts as a thermal sink for all units except NISP detector and VIS-FPA electronics which are connected to dedicated out-looking radiators. Specific harness design and highly decoupled conductive and radiative thermal interfaces allow minimising the heat leaks from the SVM and the sunshield.

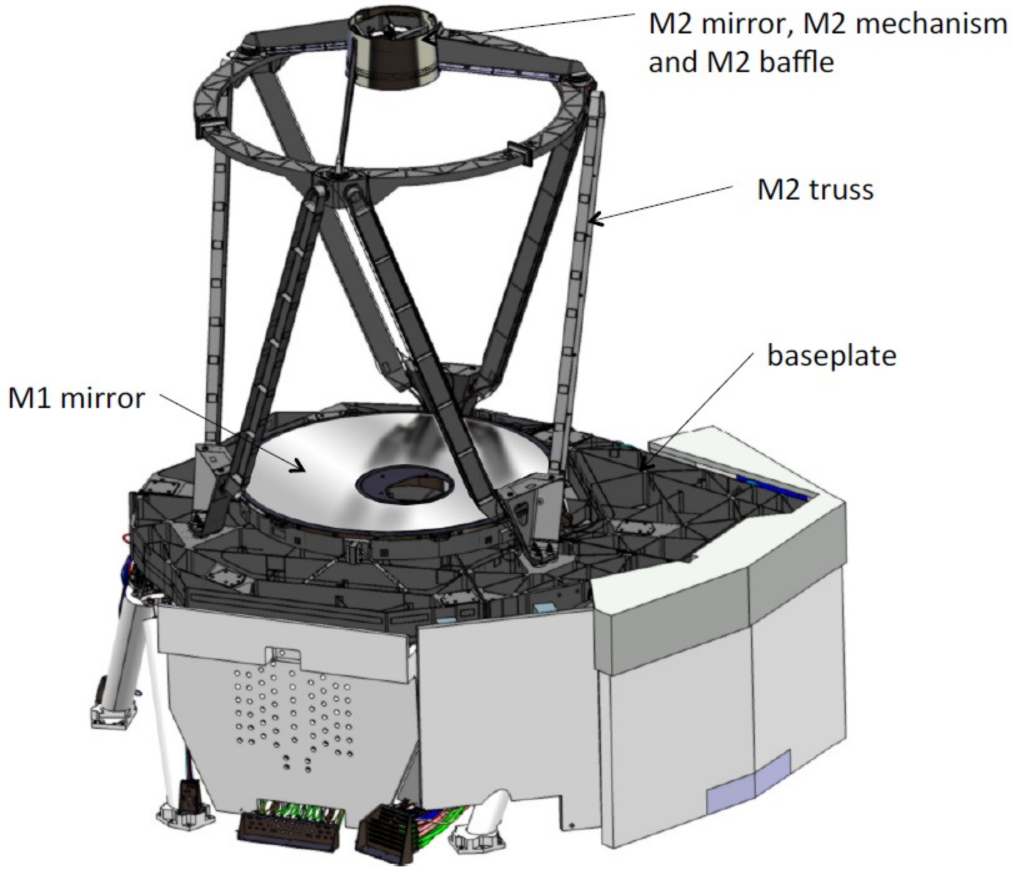


Figure 1.8: View of the PLM: telescope and the base hosting VIS and NISP instruments. The external baffle is missing in this mage.

This Euclid Telescope optical configuration (Figure 1.9) is a Korsch telescope. The useful pupil diameter is 1.2 m and the focal length is 24.5 m. The central obscuration has been minimised by designing a thin spider and careful design of M1 and M2 baffles. The telescope field of view is 1.25 × 0.727 deg^2 and the collecting area is about 1 m^2, so that the flux provided is sufficient for the operation of the two on-board instruments. The primary mirror (M1) collects the light and returns it to the secondary mirror (M2). The M2 mirror directs the beam, which passes through a filter, to the last mirror (M3). M3 delivers the luminous flux to the scientific instruments. The two folding mirrors FoM1 and FoM2 are placed between mirrors M2 and M3, they direct the light beam in the plane of the baseplate. A third folding mirror FoM3 is used to increase the efficiency of VIS radiative area. The transmission of the light flux towards the instruments is done by a dichroic plate located at the exit pupil of the telescope, it separates the light in two equal shares. More details on the telescope are summarized in Table 1.1.

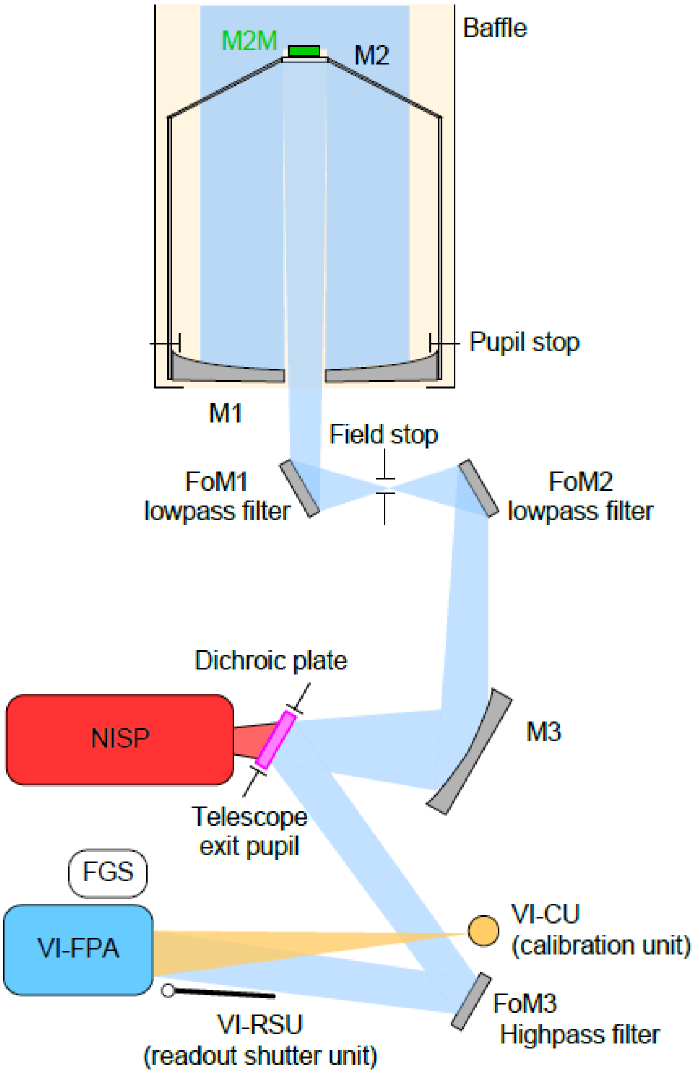


Figure 1.9: Schematic view of the telescope mounted inside the Euclid PLM.

Focal length	24.5 m
Entrance Pupil Ø	1200 mm
M1 Ø	1250 mm
M2Ø	350 mm
M3	535 x 406 mm2
FoM1	358 x 215 mm2
FoM2	283 x 229 mm2
FoM3	358 x 215 mm2
Dichroic plate Ø	117 mm
M1-M2 distance	1756 mm
Useful collecting area	1.006 m2
Offset along Y axis	0.47°
VIS FoV	0.787° x 0.700°
NISP FoV	0.779° x 0.727°

Table 1.1: Details of the Eucld Korsch telescope.

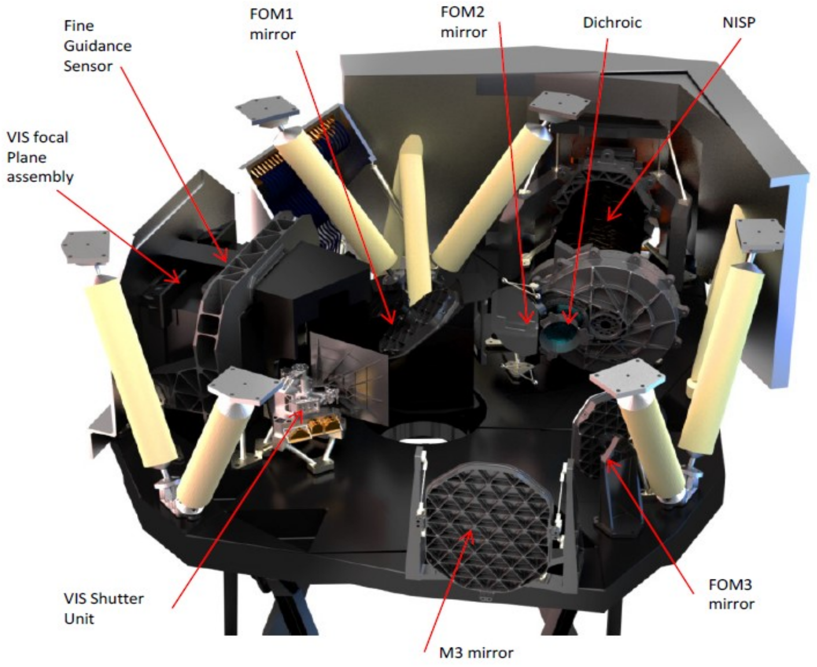


Figure 1.10: Base of the Eucld PLM, VIS and NISP instrument position inside the module are pointed out.

1.2.4 The VIS instrument

The Visible Imager (VIS) instrument is designed to produce images with high resolution in the 550 nm < λ < 900 nm wavelength range. Such images will be used to measure the deformations of the observed galaxies [21]. Astrophysical objects can be detected at a 10σ SNR limit for extended sources of AB magnitude 24.5 .VIS requires a large field of view sampled with the highest possible accuracy in order to measure typical galaxy shapes, galaxy sizes are about 0.3 arcsec, therefore a pixel sizes of 0.1 arcsec or smaller is required. These requirements are met with a VIS focal plane of 36 CCDs, each of 4k×4k 12µm pixels. VIS will have a 604 Mpix field of view, the second largest focal plane after Gaia in a space mission. More details are given in Table 1.2. All image data from the focal plane will be transmitted to ground. Such images will be combined with the NISP infrared photometric measurements and data from the ground based surveys, VIS implements a single broad red band. It is composed also by a shutter, a calibration unit for flat-field measurements and electronic units to process the data and to control the instrument.

The VIS sub-systems are the following:

- VIS Focal Plane Assembly (FPA) consists of 6×6 CCD matrix operated at 150 K. The geometric field of view is > 0.5 deg^2 (29 cm×29 cm).
- The shutter mechanism (VI-SU) is placed upstream of the focal plane and it has to be closed as soon as an observation ends to avoid stray light during data processing.
- The calibration unit (VI-CU) consists of a sphere equipped with 12 LEDs that provide uniform illumination over the entire focal plane.
- The Control and Data Processing Unit (VI-CDPU) controls the instrument, performs data processing and it provides interface with the Spacecraft for data handling. The compression of the whole 24k × 24k image is achieved in about 250 seconds; afterwards the data is transferred via Spacewire link to the MMU.
- The Power and Mechanism Control Unit (VI-PMCU) controls the instrument mechanisms and the calibration unit.
- The Flight Harness (VI-FH) connects all the units

Spectral Band	550 – 900 nm
System Point Spread Function size	≤0.18 arcsec full width, half maximum at 800 nm
System PSF	ellipticity ≤15% (using a quadrupole definition)
Field of View	>0.5 deg2
CCD pixel sampling	0.1 arcsec
Detector cosmetics including cosmic rays	≤3% of bad pixels per exposure
Linearity post calibration	≤0.01%
Distortion post calibration	≤0.005% on a scale of 4 arcmin
Sensitivity	mAB≥24.5 at 10σ in 3 exposures for galaxy size of 0.3 arcsec
Straylight	≤20% of the Zodiacal light background at Ecliptic Poles
Shear systematic bias allocation	additive sys ≤ 2 x 10–4 ; multiplicative ≤ 2 x 10-3

Table 1.2: VIS and weak lensing channel characteristics

Three of the five VIS assemblies, the focal plane, the shutter and the calibration unit are mounted and supported by the PLM structure below the telescope with separate interfaces to the structure (Figure 1.10). The other two parts are located in the SVM (Figure 1.7). The positioning of the focal plane with respect to the telescope focus is the most critical mechanical interface. A cold environment ~150K is provided in the PLM to ease the operation of the VIS CCDs, which show optimal efficiency at this temperature. On the other hand, the CCD readout electronics must stay at a temperature of ~250K. The total mass of VIS is 104 kg, including 10% margin.

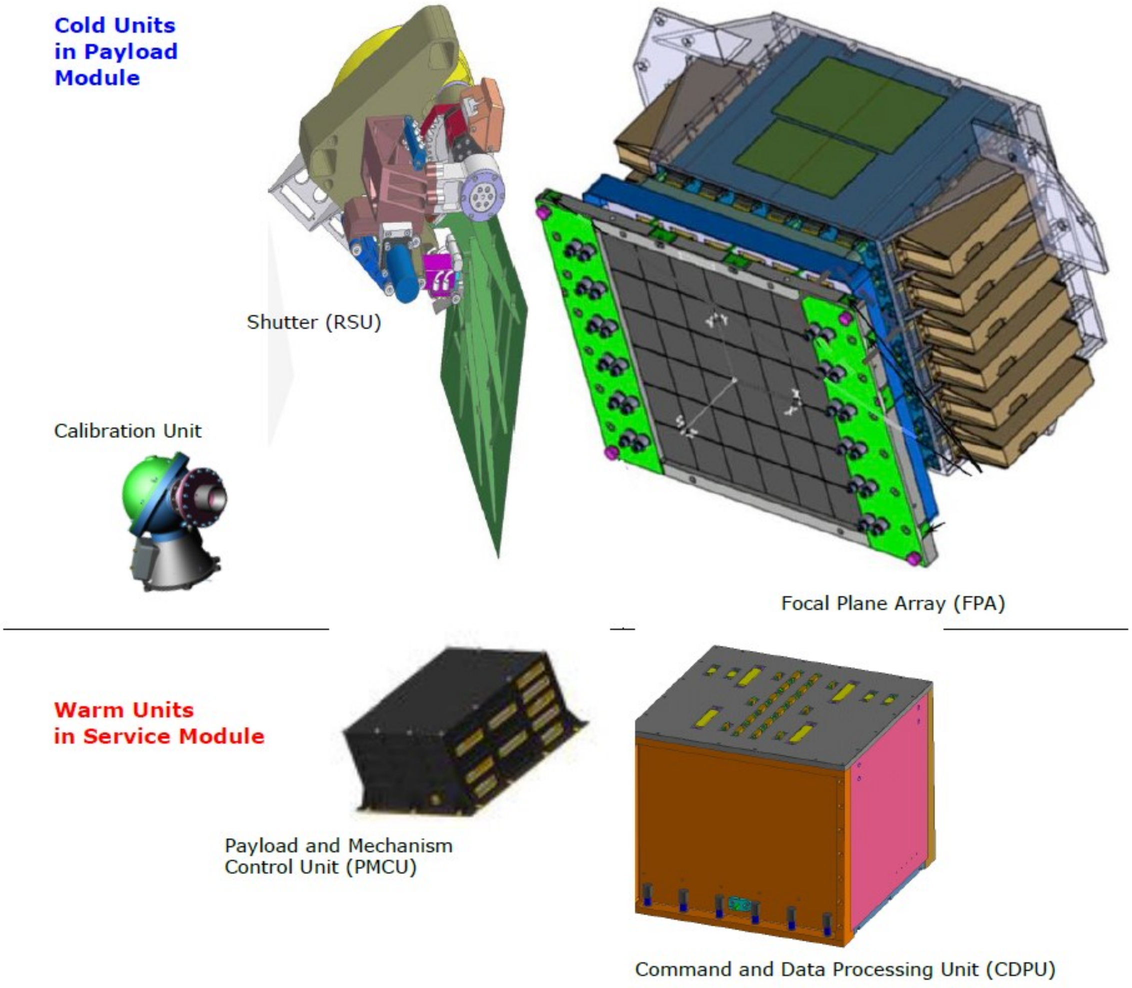


Figure 1.11: The five VIS units, the location inside the Euclid spacecraft is detailed in Figure 1.7 and Figure 1.10.

1.2.5 The NISP instrument

The NISP instrument is a spectro-photometer performing slitless spectroscopy and imaging photometry in the near-infrared (NIR) band; it will observe galaxies in the redshift range $0.9 < z < 1.8$ [22].

The NISP focal plane hosts 16 low-noise HAWAII-2RG (H2RG) detectors; HAWAII is an acronym for HgCdTe Astronomical Wide Area Infrared Imager. In the acronym H2RG, 2 stands for 2048×2048 pixels resolution, R for reference pixels and G for guide window capability. They are supplied by Teledyne and selected by NASA. Each detector system is composed of a Sensor Chip Assembly (SCA), a Cryo Flex Cable (CFC) and Sensor Chip Electronics (SCE). The resulting spatial resolution is 0.3 arcsec per pixel. The FOV of the instrument is 0.55deg^2 and it has a rectangular shape of 0.76° × 0.722°.

NISP instrument has two main observing modes: the photometric imaging mode with broad band filters, and the spectroscopic mode, for the acquisition of slitless dispersed images on the detectors. The near infrared spectra will be used to derive accurate galaxy redshifts and their 3D position in the Universe. NISP spectroscopic data of galaxies Hα emission lines will be used to describe the distribution and clustering of galaxies and how they changed over the last 10 billion years under the effects of the dark matter and dark energy content of the Universe.

In the photometric mode images are acquired in the wavelength range 920 nm – 2000 nm (Y, J, H bands). In the spectrometric mode the light of the observed target is dispersed by means of grisms covering the wavelength range of 950 nm – 1850 nm. In order to provide a flat resolution over a specified wavelength range, four grisms are mounted in a wheel. These four grisms yield three dispersion directions tilted against each other by 90° in order to reduce confusion from overlapping spectra.

The wavebands used in the Euclid configurations for spectroscopy and photometry are:

Three photometric bands:

- Y Band: 950 – 1192 nm
- J Band: 1192 – 1544 nm
- H Band: 1544 – 2000 nm

Four Slitless spectroscopic bands:

- Red 0°; 90° and 180° dispersion: 1250 – 1850 nm
- Blue 0° dispersion: 920 – 1300 nm

The spectral resolution shall be higher than 250 for a 1 arcsec homogenous illumination object. The flux limit in spectroscopy shall be 2×10^{-16} erg · cm^{-2} · s^{-1} @1600 nm wavelength.

The instrument has the following dimensions 1.0 m × 0.6 m × 0.5 m, a total mass of 155kg, a maximum power consumption of 178W and it will produce 290 Gbit of data per day.

The NISP instrument consists of three main sub-systems (Figure 1.12):

- **The Opto-Mechanical Assembly (NI-OMA)** is composed by the Mechanical

Support Structure (NI-SA) and its thermal control (NI-TC), the Optical elements (NI-OA), the Filter Wheel Assembly (NI-FWA), the Grism Wheel Assembly (NI-GWA) and the Calibration Unit (NI-CU). NI-OMA is operated at a temperature around 130K with a stability better than 0.3K for the full mission operation.

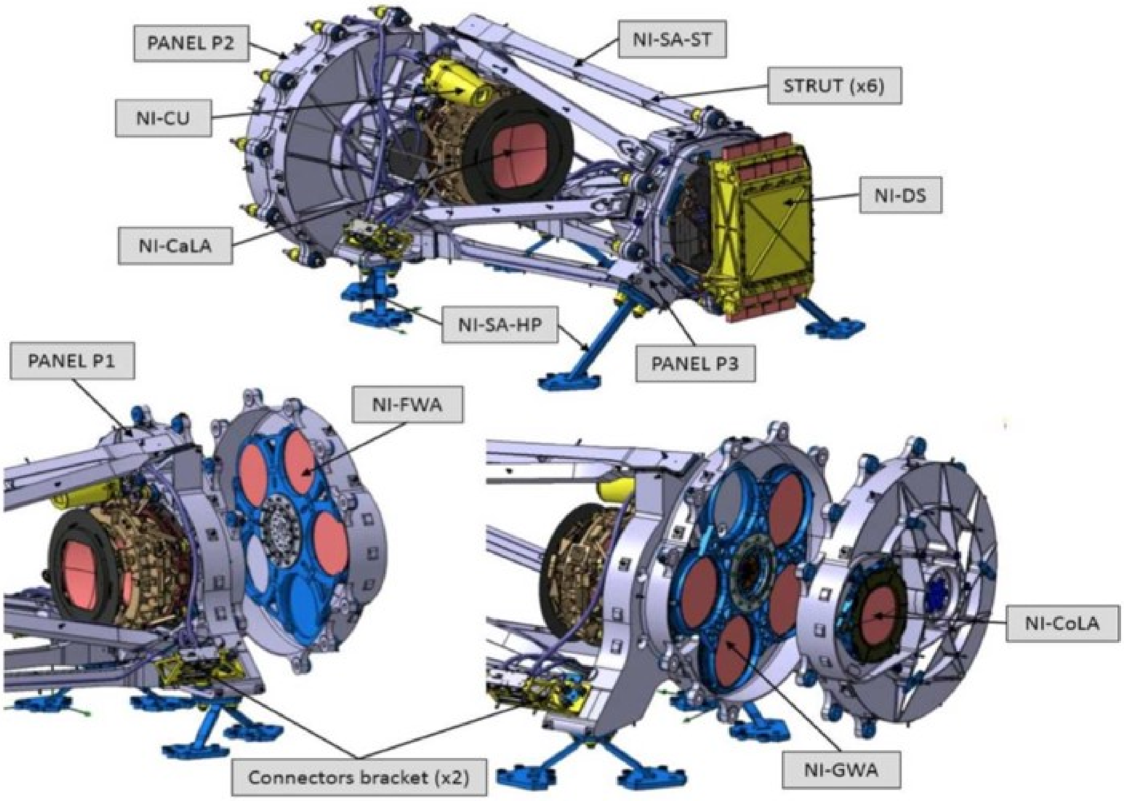


Figure 1.12: Overview of the NISP NI-OMA + DS. The NI-DS is screwed on the NI-OMA. The NI-OMA+NI-DS is located in the Euclid PLM in a cold environment (130K). The Warm electronic (NI-WE) is located in the Euclid SVM at about room temperature. A dedicated harness interconnects the NI-OMA, the NI-DS, the NI-WE and different spacecraft electronics boxes.

NI-SA structure is entirely made of Silicon Carbide (SiC) which, given its good thermal conductivity, ensures good temperature uniformity and an efficient heat extraction.

The optical chain is quite complex and starts just after the dichroic lens that transmits the light from the telescope. It is based on refractive elements: a Collimator Lens Assembly (NI-CoLA) and a Camera Lens Assembly (NI-CaLA), they both act as focal reducers.

NI-GWA holds the four grisms (Figure 1.14), each of them is composed by the grism itself (the optical element) glued on an Invar mechanical mount. Grisms (Figure 1.13) have a grating engraved on the hypotenuse of a prism (14 grooves/mm). The spectral wavefront correction is done by the curvature of the grating grooves; the spectral filter is achieved by a multilayer filter deposited on the first surface of the prism, the focus is done by the curvature of the first surface of the prism. NI-GWA provides 4 active positions in order to allow spectra confusion reduction in the spectroscopic observation mode. NI-FWA (Figure 1.14) holds the three filters (Y, J, H) for the photometric mode and keeps them in the optical beam (the rotation of the two wheels, NI-FWA and NI-GWA, is done by a cold mechanism that can operate in vacuum from 300 K to 20 K). The three infrared filters are double-sided interference filters coated with the PARMS (Plasma Assisted Reactive Magnetron Sputtering) process. Each side of the ~12mm thick filter substrate is coated with a stack of up to 200 individual layers, the final stack thickness is up to 20μm per side. The coating thickness homogeneity aims to reduce the transmissive wavefront error.

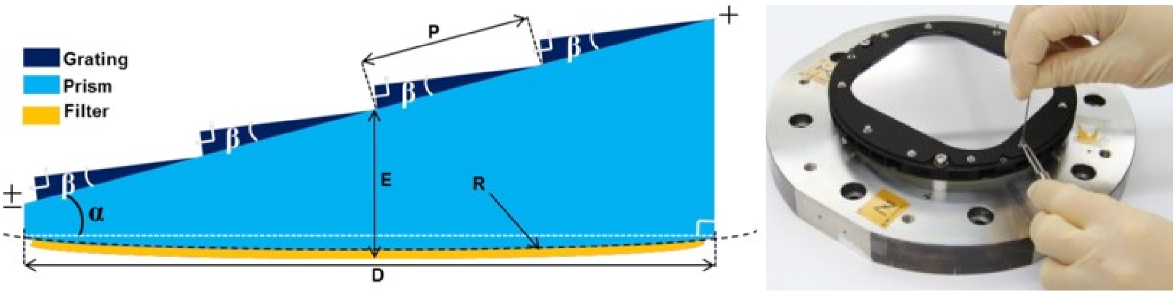


Figure 1.13: On the left a schema of the grism optical part, on the right the optical part of the grisms is glued in a mechanical Invar M93 ring. Nine flexible blades compensate the small thermal coefficient difference between grism, made of Suprasil 3001 and the Invar support.

NI-CU provides fixed calibration signal in the optical beam and allows in-flight calibration of the infrared detector array. The unit provides stable illumination of the focal plane at five different infrared wavelengths (provided by five different LEDs). The control of the LED brightness can be performed by the regulation of current and duty cycle regulation in the driving signal.

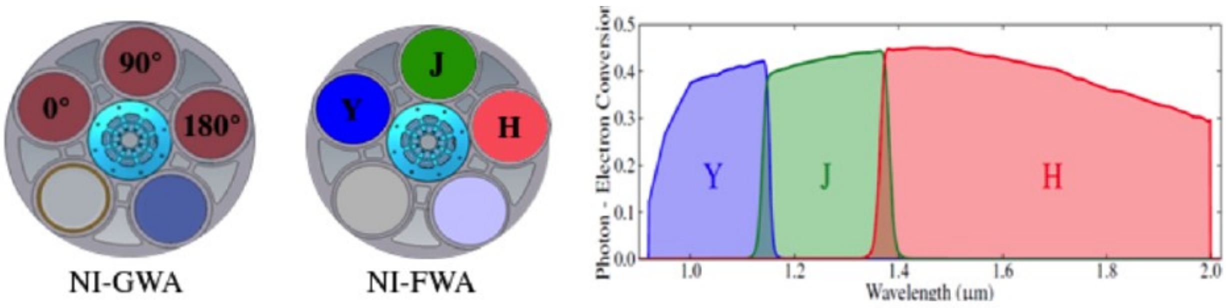


Figure 1.14: On the left a design of the two wheels hosting grisms and filters, on the right the profiles of the wavelengths bands for photometric measurements.

- **The Detector System (NI-DS)** is composed by the Focal Plane Assembly (NI-FPA), the mechanical part of NI-DS and by the Sensor Chip System (NI-SCS) (Figure 1.15). NI-DS hosts the 16 Infrared sensors hybridized on multiplexers and read out by the Sidecar Application Specific Integrated Circuits (ASICs). It is passively cooled at operating temperature (<100K for the detectors, 140K for the ASICs); thermal stabilization of the detector is provided by the Euclid PLM.

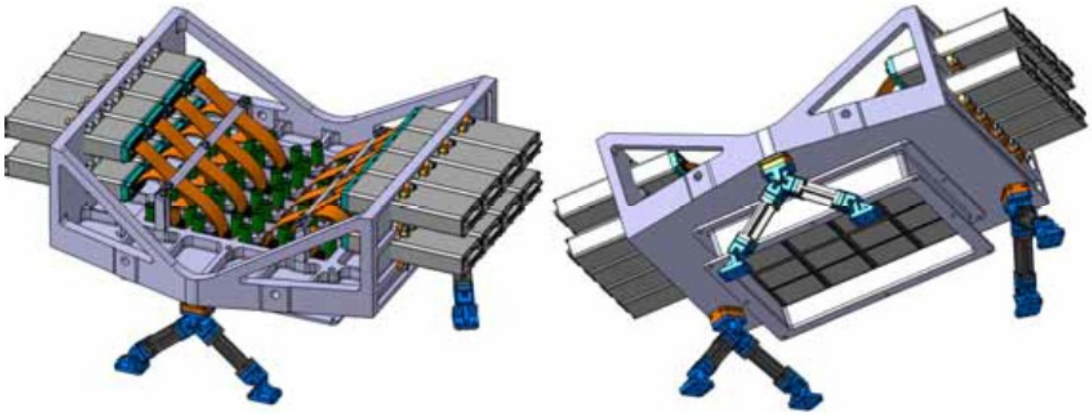


Figure 1.15: Design of the NI-DS, the detector mosaic and the titanium bipods are shown. The support base-plate is made of molybdenum and it is held by three titanium bipods on the SiC panel.

NI-DS mechanical part is composed by a SiC panel to be screwed directly on the SiC structure of the NI-OMA and a molybdenum plate that supports the detectors plane.

SCS is composed by 16 triplets (Figure 1.16), each triplet comprises the H2RG sensor with 2.3µm cut-off (SCA), a 10 cm cryo flex cable (CFC) and the Sidecar ASIC (SCE). Each image frame is sequenced and read out by the NI-DPU/DCU (see also

Chapter 2).

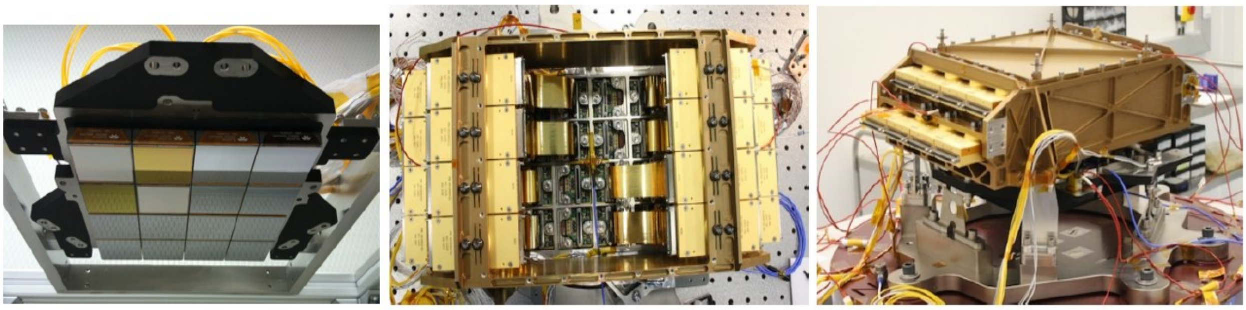


Figure 1.16: Pictures of the NI-DS demonstration model.

SCA/SCE operation synchronism is ensured partly by SCE firmware specifically developed for the NISP application and partly in the NI-DPU/DCU electronics. All the SCE systems are driven by a common master clock and all writings to the SCE internal registers are synchronized by shift-registers clocked by the same master clock and started by a common pulse. SCEs have several critical power supply lines: internal analog reference (VRef), analog supply (VDDA) and digital power supply (VDD2P5).

The specific SCE microcode, Electrical Engineering Firmware (EEF), has been customized for Euclid; it is used to perform the detector readout with a 100 kHz pixel sampling rate (one frame is produced in approximately 1.45 s). The EEF provides command validation, acknowledgement, command counters and internal telemetry of both the SIDECAR and the H2RG system (see also Chapter 2).

- **The Warm Electronics Assembly (NI-WE)** (see also Chapter 2) is composed by the Data Processing Unit (NI-DPU/DCU) and the Instrument Control Unit (NI-ICU). It is located in the SVM at a temperature higher than 240K. The NI-DPU/DCU controls the Sensor Chip System (NI-SCS), provides the basic image processing such as frames co-adding, the science on-board data processing and the compression and transfer of scientific data to the MMU using Spacewire links. Each DPU/DCU box controls eight infrared detectors, there are two DPU/DCU boxes for the whole focal plane management. The NI- ICU takes care of commanding and slow-control of the NISP instrument. NI-WE is interfaced with the SVM via a 1553 bus and a fast Spacewire link for image data transfer.

The elementary observation sequence of each field is composed by four frames, during each frame VIS and NISP perform exposures simultaneously. For the first frame the nominal integration time in the VIS and NISP is 574 s, afterwards there are NISP photometric measurements with the following integration times: Y = 124s, J = 120s, H = 82s. VIS has the shutter closed during photometric measurements.

NISP has seven observation modes in total

- GWA grism 1 with FWA in open position
- GWA grism 2 with FWA in open position
- GWA grism 3 with FWA in open position
- open GWA with FWA in position Y
- open GWA with FWA in position J
- open GWA with FWA in position H
- FWA closed

The first three modes are spectroscopic, the following three are photometric and the last one is the *dark mode* (for the measurement of the background noise). The combination of observation modes into an observation sequence is the so-called *science sequence*. The *science sequence* shown in Figure 1.4 can be divided into four steps: each of them is composed by a spectroscopic mode and three photometric modes; at the end of each step a dithering is performed. Once this *science sequence* is completed, the telescope moves to measure another point in the sky (such movement is called slew). During the slew, the instrument is in closed-mode (VIS shutter closed and NI-FWA in close position) and a *dark* measurement is performed.

1.2.6 The Ground Segment

The Spacecraft is the space-based segment of the Euclid mission, it needs big support from ground to be operated. As usual, the ground segment (Figure 1.17) is divided in the Mission Operations Ground Segment (OGS), which is managed directly by ESA, and in the Science Ground Segment (SGS), which is co-managed by ESA and the Euclid Mission Consortium (EC) [16].

The aim of OGS is to provide mission control and it is composed by Ground Stations Antennas and by the Mission Operation Center (MOC).

The ground station is a network of three Deep Space Antennas located in Australia, Spain and Argentina which are used during Launch and Early Operations Phase (LEOP), the commissioning phase and the routine mission. In addition, a small X-band antenna is available in New Norcia (NNO) for first acquisition during LEOP. The ground stations provide communication with the spacecraft in uplink and downlink mode. The stations will be used to perform ranging and Doppler measurements with the spacecraft for orbit determination.

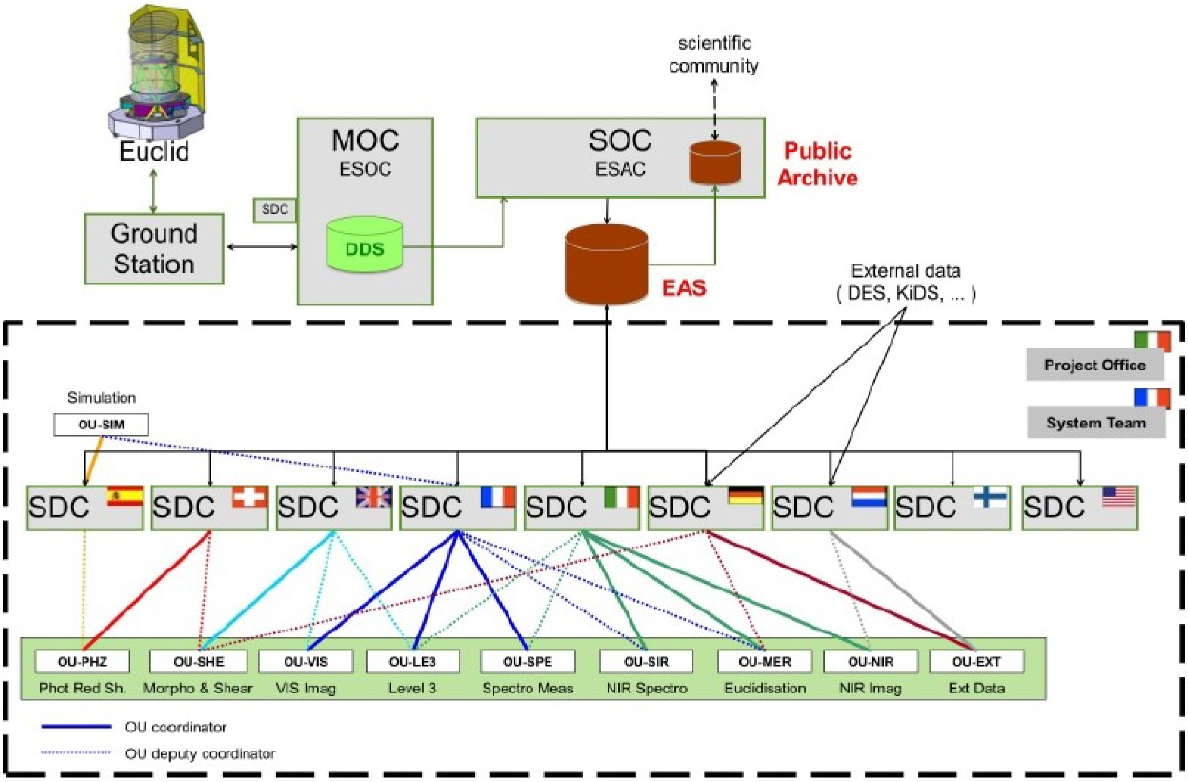


Figure 1.17: Schema of the Euclid Ground segment [23].

The MOC is located in ESOC (Darmstadt); it is in charge of mission operations planning, execution and monitoring. MOC has to monitor the spacecraft health and to handle commands and telemetry from the scientific instruments. It delivers routinely telemetry and flight dynamics products to the SGS.

The SGS is composed by the Science Operation Center (SOC), managed by ESA, the Instrument Operation Team (IOT), set up by the EC and Science Data Centers (SDCs), also managed and provided by the EC.

SOC is located in ESAC, Villafranca (Spain), it is in charge of scientific operations planning, performance monitoring of the PLM, providing interface with the SDCs, science data archiving and distribution.

IOTs, one for each instrument, guarantee instrument maintenance and operations. The computational needs of the IOTs are supported by the SDCs.

EC provides the fraction of the Ground Segment (the Euclid Consortium Science Ground Segment - ECSGS) performing the data processing from telemetry down to the mission data products. It is physically composed of a number of Science Data Centres (SDCs), in charge of instrument-related processing, production of science data, simulations and ingestion of external data. The Euclid Archive (EAS) is designed to provide centralised data management function and the science archive for both the EC and the scientific community. The processing of science data can be decomposed in ten logical data Processing Functions, they are defined considering that they represent self-contained processing units:

- LE1, in charge of telemetry management
- VIS, in charge of processing the VIS data and producing fully calibrated images and source lists
- NIR, in charge of processing the NISP photometric data and producing calibrated images and source lists
- SIR, in charge of processing the NISP spectroscopic data and producing calibrated spectral images and spectra
- EXT, in charge of loading in EAS the external data that are needed for Euclid science analysis
- SIM, providing the simulations needed to test, validate and qualify the whole pipeline
- MER, performing the merging of all the information
- SPE, extracting spectroscopic redshifts from the SIR spectra
- PHZ, computing photometric redshifts from the multi-wavelength imaging data
- SHE computes galaxy shape measurements on the VIS images
- LE3 is in charge of computing all the high-level science data products

1.3 EUCLID MISSION STATUS

Euclid was selected, in October 2011, by the ESA Science Programme Committee (SPC) as one of the two medium-class missions of the Cosmic Vision 2015-2025 plan. Euclid received final approval for the full construction phase in June 2012. At the same time SPC also set up an agreement between ESA and funding agencies of some of the Member States to prepare the two Euclid scientific instruments (VIS and NISP) and the distributed Scientific Ground Segment.

The Euclid Mission Consortium (EC) joins more than 1300 scientists from more than 100 institutes in the commitment of preparing the instruments and participating in the scientific data analysis of the mission. The EC has members of 13 European countries: Austria, Denmark, France, Finland, Germany, Italy, the Netherlands, Norway, Portugal, Romania, Spain, Switzerland and the UK. It also includes a number of US scientists nominated by NASA. NASA is also in charge of providing to the NISP instrument the H2RG infrared detectors and their readout electronic (manufactured by Teledyne Technologies, USA).

In December 2012, Airbus Defence and Space of Toulouse (France) was selected to design and build the PLM module; it includes the telescope and the baseplate for the instruments, which will be delivered by the EC. Thales Alenia Space in Torino (Italy) was selected in June 2013 as the Prime Contractor, it has the responsibility of the preparation of Euclid satellite.

Both instruments, VIS and NISP, have completed the Preliminary Design Review (PDR) in the first half of 2014. The VIS team is led by UCL-Mullard Space Science Laboratory of Holmbury St. Mary (UK). The NISP team is led by CNES and the Laboratoire d'Astrophysicque de Marseille (LAM) (France). The Euclid mission passed the PDR in 2015, all the mission elements advancement and the mission performance were assessed and considered fulfilling the scientific objectives within the programmatic constraints.

The instruments Critical Design Reviews (CDR) were both concluded in 2017, the spacecraft CDR and Ground Segment Design Review were completed in the first half of 2018. The mission level CDR is on-going (second half of 2018). The schedule foresees the delivery of both instruments for integration into the PLM (optical part and cold electronic) and into the SVM (warm electronics) by the end of 2019.

At this point the flight system integration and test will start and will be carried out through 2019 and 2020. The Flight Acceptance Review (FAR) is planned for the mid of 2021 and the launch is consequently planned for the end of 2021.

2 NISP Instrument Warm Electronics

The NISP Warm Electronics (NI-WE) is composed by two sub-systems, the NISP Data Processing Unit/Data Control Unit (NI-DPU/DCU or DPU) and the NISP Instrument Control Unit (NI-ICU or ICU).

The NI-WE functional diagram inside the complete NISP Instrument is shown in Figure 2.1, connections with the Euclid SVM and with Euclid NI-OMA and NI-DS are shown.

The NI-ICU is interfaced with the SVM through MIL-STD1553 communication channels, it executes and dispatches commands to all the NI-OMA subsystems and to the DPU. Moreover, it collects all the housekeeping data and re-routes them through MIL-STD1553 channels to the SVM with fixed periodicity.

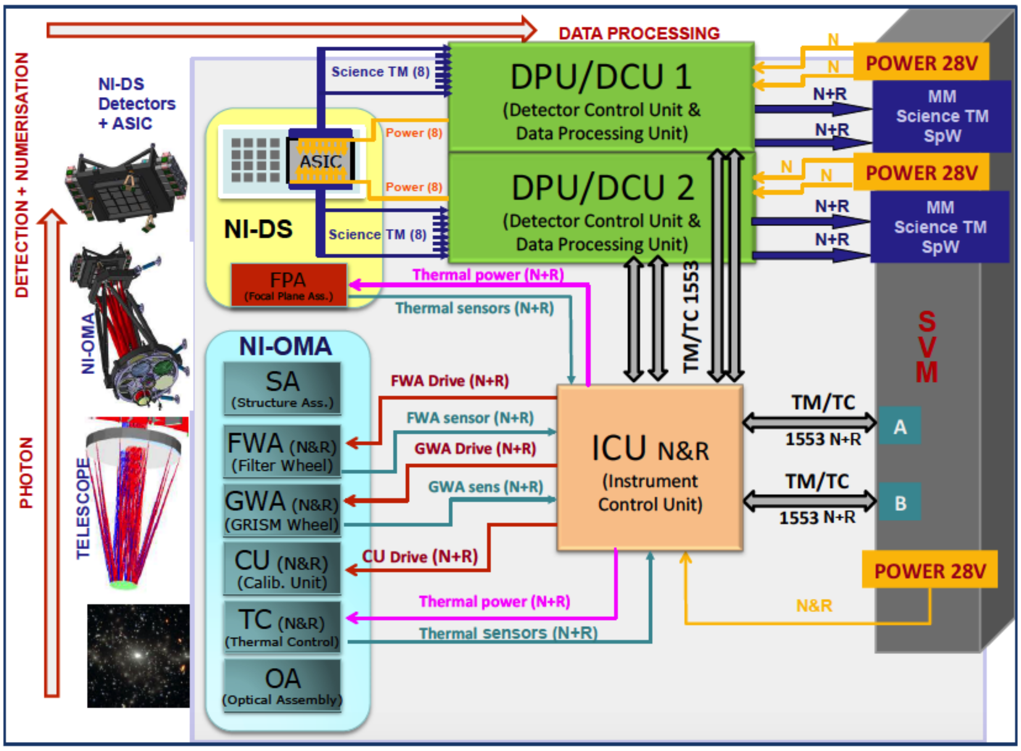


Figure 2.1: Overview of the NISP Instrument. The warm electronic components are high-lighted with green (DPU/DCU) and orange boxes (ICU), on the right side there are the interfaces with Euclid SVM, Nominal (N) and Redundant(R) channels, power lines, 1553 lines for command and housekeeping handling and Spacewire links for scientific data transmission to the MMU. On the left side there are the interfaces with NI-OMA and NI-DS.

There are two DPU units; each of them is connected to half of the focal plane and implements detector control, data acquisition and data processing functionality. DPUs are interfaced directly to the SVM for the 28V power line and they transfer scientific processed data through the fast Spacewire links to the SVM.

DPU and ICU and theirs Boot Software (BSW) and Drivers are provided to the NISP team by Industrial partners (OHB-I and Crisa) while both Application Software (ASWs) are prepared by INAF teams in Padua and Turin respectively.

In this chapter there is a brief overview of the hardware components of the NI-WE and a review of the main functions of DPU ASW and ICU ASW. Those ASWs are in the CDR phase and they were used for the functional tests that will be described in the following chapters.

In the final paragraph there is a short description of the NI-WE operation and of the Euclid scientific survey strategy.

2.1 NISP Data Processing Unit

2.1.1 NI-DPU/DCU hardware design and functionality

NI-DPU/DCU sub-system has to implement Infrared detectors control, data acquisition and data processing functionality. There are two identical units shown in Figure 2.1 as DPU/DCU1 and DPU/DCU2. Each of them manages half of the focal plane (8 detectors).

A single unit hosts:

- 2 Power Supply Boards (PSB) - Nominal (N) and Redundant (R)
- 2 Data Router Boards (DRB) - (N/R)
- 2 Data Processor Boards (DPB), each one hosting the CPU on a Maxwell SCS750 space qualified board - (N/R)
- 8 DCU boards (one per each Infrared detector)

The DPU/DCU redundancy design is driven by the fact that there is no redundant hardware in the focal plane and that only one failure the SCE data channel is allowed during the exposures.

These considerations suggested the cold redundancy approach only for the sub-units involved in data processing and internal power distribution. On the other hand, no redundancy has been foreseen for the DCUs. Following this approach, in each unit we can identify two sections (N/R) dedicated to science data processing and communication that are designed to operate in cold redundancy (DPB + DRB + DBB +PSB). They are highlighted in the yellow box in Figure 2.2. The single green section, highlighted in the same picture, includes the 8 DCU boards that handle power/data interface towards the corresponding 8 SCEs (this section can be powered by the PSB of the N/R active section).

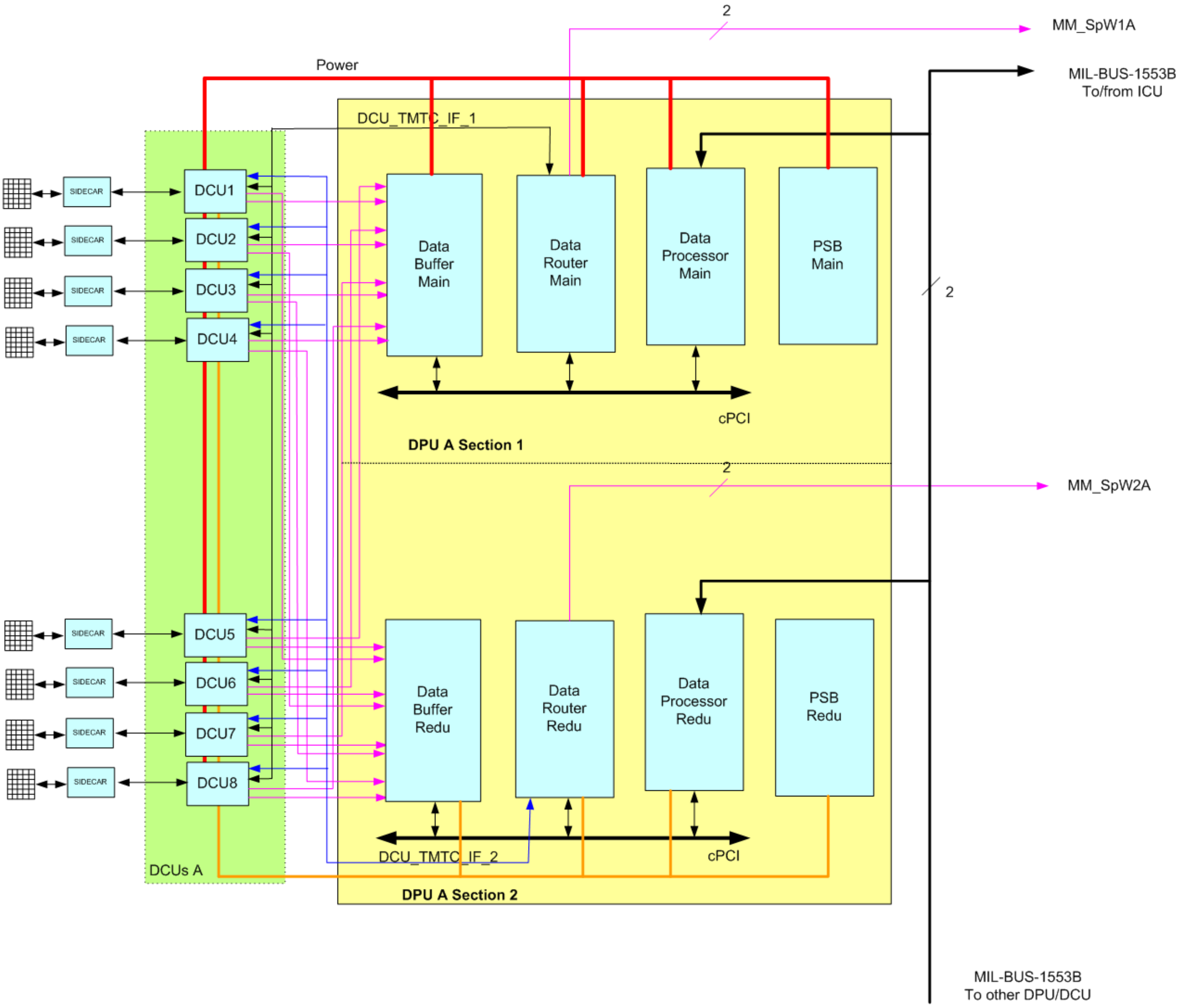


Figure 2.2: High level architecture of one DPU/DCU unit, only data paths is shown [24].

2.1.1.1 The Power Supply Board

The Power Supply Board (PSB) receives from the SVM the main 28V power line and distributes the following protected power lines:

- +3.3V_CPU for CPU core electronics
- +5.0V_CPU for MIL-STD1553 bus interface hosted in the CPU
- +5.0V_DRB for Data Router Board
- +5.0V_DBB for Data Buffer Board
- +5.0V lines for DCU set boards, each line for a single DCU for the data pre-processing section
- +28V line for all DCU boards to generate isolated supply voltages for the SCE

Such power distribution architecture aims to avoid the propagation of a fault and optimizes the internal grounding of the DPU (this minimizes the noise in the SCE power line).

The DCU power distribution section of the PSB is able to operate in cold-sparing. At DPU start-up, the section dedicated to the DCU supply is in OFF state. After the CPUs boot phase, the ICU has to send a configuration command to the CPU in order to declare the active section and activate the DCU power line.

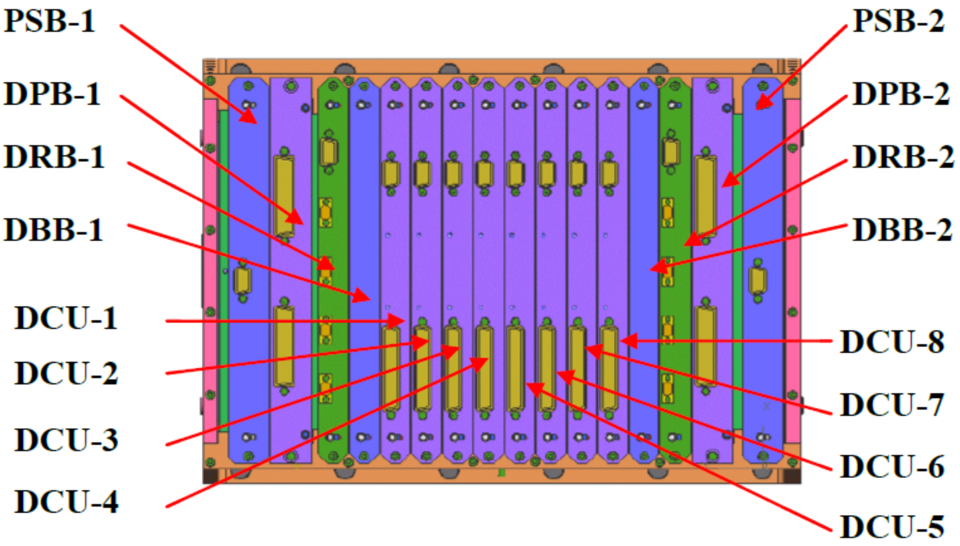


Figure 2.3: Top view of a complete DPU/DCU unit, nominal boards have the suffix -1 while redundant boards have the suffix -2 [25].

With such design, the overall inrush current at DPU start-up is minimized because different boards are activated in sequence. The PSB local power bus is distributed to the loads via Latched Current Limiters (LCLs) that provide protection against overcurrent. In case one overcurrent is detected on one line the faulty load is disconnected from the PSB local power bus. For example, the current consumption of each DCU can be measured and, in case of fault, each board can be isolated and the power can be removed only to the faulty DCU without affecting the operation of all other DCU boards.

The PSB has a Serial Peripheral Interface (SPI) link for housekeeping data acquisition. The link is implemented in the FPGA hosted in the DRB; it is controlled by the CPU via Compact PCI (CPCI) bus.

2.1.1.2 *The Data Buffer Board*

The Data Buffer Board (DBB) receives data from 8 DCUs and can be accessed by the main processor for control and data retrieval; it allows the storage of a complete data set for spectroscopy and photometry as foreseen during the Euclid survey.

In detail the DBB is designed in order to:

- acquire and store data from 8 DCUs through 8 Spacewire links active at the same time
- send data from Synchronous Dynamic Random Access Memory (SDRAM) array to the Data Processor board by 33Mhz PCI bus
- receive commands from the Data Processor Board

The total memory size required for Euclid in the scientific and instrument calibration operations is estimated to be 2.37 GB. Since the DBB implements a double buffering approach, the total memory should be of 4.74 GB. In order to take into account a margin and the worst combination in terms of memory buffer the DBB memory size is actually 6 GB.

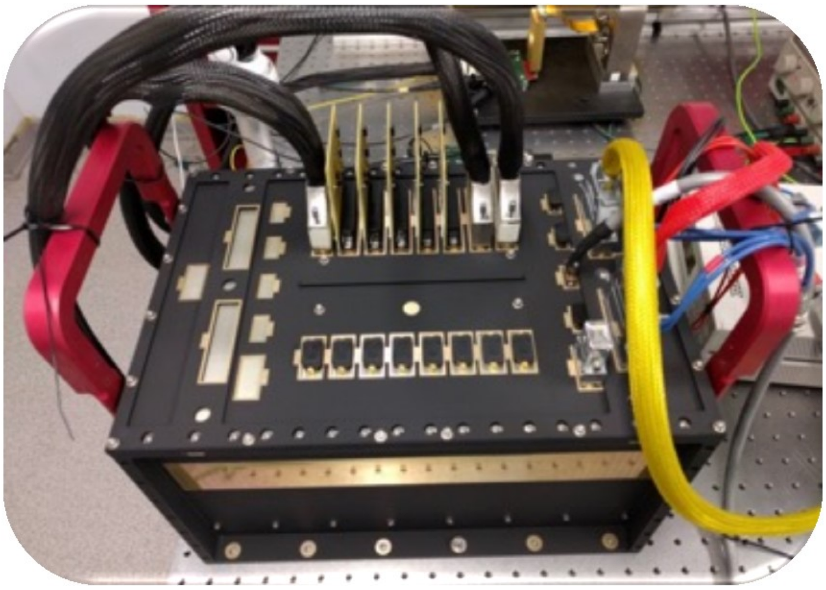


Figure 2.4: DPU EQM model. This unit has only the nominal section mounted in the black case. In the right side there are PSB, DPB, DBB and DRB, in the middle the 8 DCUs, three are connected with an SCE while five are connected to dummy loads.

2.1.1.3 The Data Router Board

The Data Router Board (DRB) has to transfer the processed scientific data from the DPU to the MMU via Spacewire links, manage a TM/TC interface for Telemetry acquisition (TM) and Command distribution (TC) between DPB and the eight DCUs and distribute the Master Clock Signal and the Master Synch Signal to the 8 DCUs and to the companion DPU/DCU unit.

All these functions are implemented using an RTAX2000S FPGA; the board contains the FPGA itself, 128MB of SDRAM memory buffer and all the necessary drivers/receivers (LVDS for Spacewire, synch and clock signals; RS485 for TM/TC interface).

The DRB is connected to the DPB through the CPCI bus. The DRB is charge for the following operations:

- manage TM/TC interface to DCUs (send commands and acquire telemetry)
- acquire digital housekeeping from PSB
- control the generation and distribution of Clock and Synch signals to DCUs
- save processed data packets into SDRAM local buffer
- configure and control the DMA operations of the Spacewire Controller.

The download of processed data from SDRAM to MMU is performed in DMA mode by the Spacewire controller block.

2.1.1.4 The Data Processor Board

The Data Processor Board (DPB) is implemented using a Maxwell SCS750 procured with the MIL-STD-1553B interface. The board hosts the main processors used for data processing and TM/TC handling towards all the other components of the DPU unit.

The DPB has the following characteristics:

- 3 PowerPC 750FX used in Triple Modular Redundant (TMR)
- 400 to 800 MHz SW programmable clock (400 MHz clock is used for DPU/DCU)
- 256 MB SDRAM memory with Reed Solomon EDAC
- 8 MB EEPROM
- CPCI interface, 33MHz, 3.3V
- MIL-STD-1553B interface
- 2 UART (one used for SW development)
- 32 GPIO
- 3.3V and 5V power input

The DRB and DBB board resources are mapped via a PCI bridge.

2.1.2 Interface with Infrared detector: SIDECAR ASIC (SCE) and DCU board

The interface between Infrared detectors and the Data Processing Board is realized by two elements: the read out electronics of the H2RG [26] active detectors and the Data Control Unit Board. For each detector there is one pair of these elements.

The readout of the H2RG is performed by the SIDECAR ASIC (SCE) [27], while the data storage and hardware processing of the data is performed by the Detector Control Unit (DCU), which is part of the DPU/DCU sub-system.

2.1.2.1 H2RG detectors and SIDECAR ASIC

An infrared detection chain converts incident infrared photons into an analogue signal, the amplitude of which is proportional to the incident photon flux, and then into a digital signal in order to record and process the data. The Euclid focal plane is based on semiconductor detectors made of Mercury-Cadmium Telluride (HgCdTe) photodiodes. When a known voltage is applied to the PN junction it is possible to measure the variation of the potential at one of the junction sides as a function of time and this variation is proportional to the incident photons flux. The analogic signal is then properly amplified and converted to a digital one by custom electronics.

Each Euclid detector is a 2D (2048 × 2048) matrix of CMOS type pixel sensors. Each pixel contains a photodiode and an amplifier that convert the charges into a voltage in the pixel itself. Each pixel can be read independently and the reading is non-destructive, so it is possible to perform several successive measurements and to average them in order to reduce the noise.

It has to be noted that for the Euclid mission, the wavelength range of interest is in the range 0.920 μm < λ < 2 μm. Given the proportion between the two elements Hg and Cd in the crystal, the energy of the band gap (that corresponds to the detectable wavelength range) is small and thermal agitation at ambient temperature is enough to create a parasitic current (*dark current*). That is why the detectors can only work at temperature around 100 K or below.

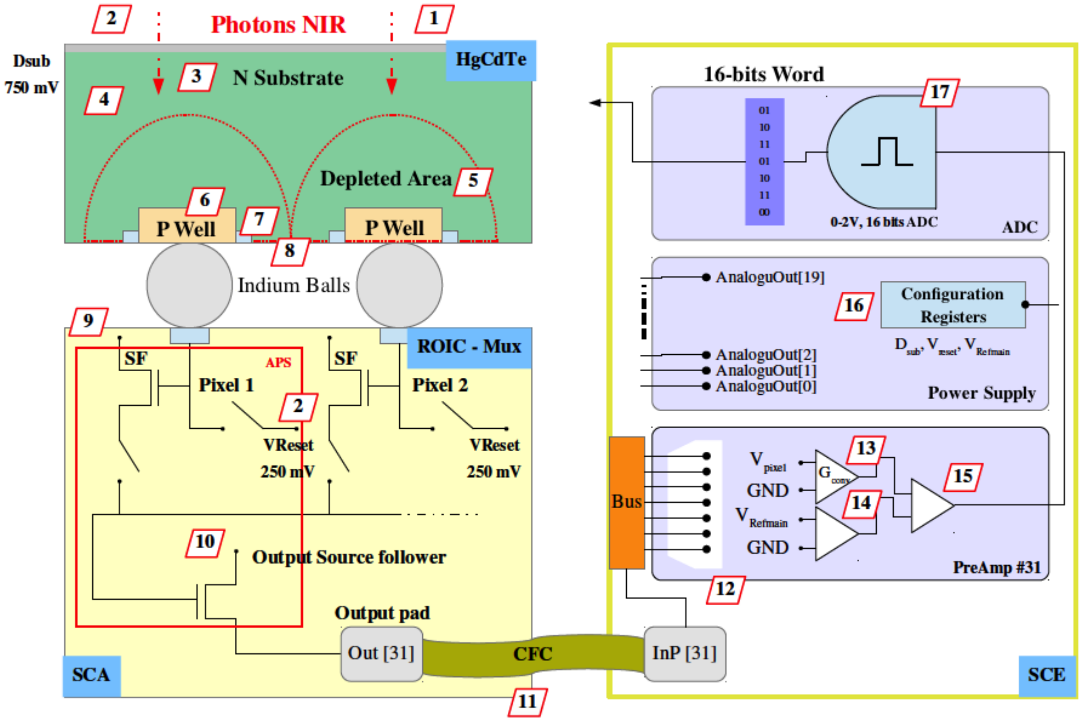


Figure 2.5: Simplified architecture of the Euclid infrared read out chain [28].

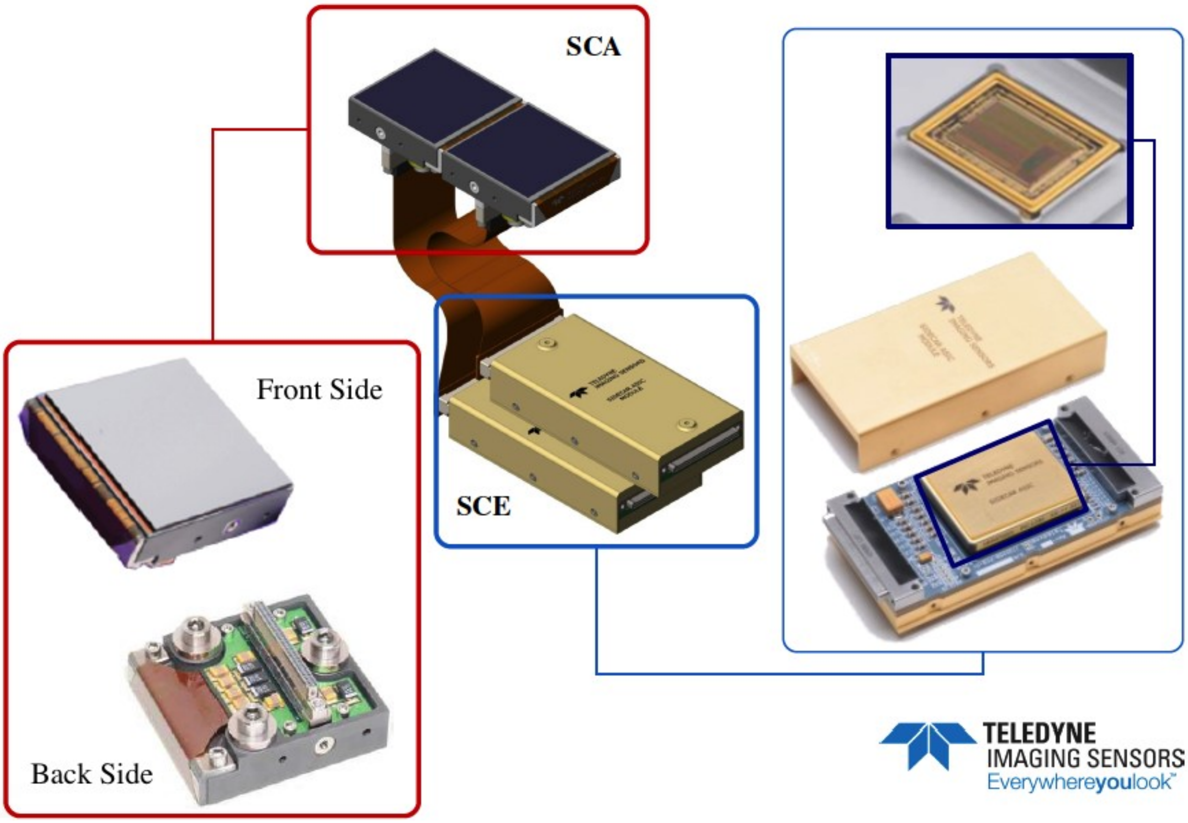


Figure 2.6: Images of the H2RG detector coupled with the SIDECAR ASIC, SCA is connected to the SCE with a cryo flexi cable (CFC); the triplet SCA+CFC+SCE is usually referred as SCS [29].

In the Euclid focal plane, the HgCdTe detector is associated with the electronics allowing the readout of the voltages. Such architecture is referred as hybrid and it was selected by Teledyne Imaging Sensors (TIS) in the detector called Hawaii 2k × 2k with Reference pixels and Guide mode (H2RG) [29]. A simplified design of H2RG is shown in Figure 2.5. The pixel matrix is coupled to a silicon chip called multiplexer by Indium balls. The multiplexer includes all the circuitry necessary to read out the 4 million pixels. The clock for the sequential readout of the pixels is ensured by a 100 kHz clock.

Each H2RG detector (SCA), as shown in Figure 2.6, is coupled with a SIDECAR ASIC (SCE) equipped with a dedicated firmware implementing the readout modes specified for the Euclid survey.

The architecture of the SIDECAR ASIC includes the following major sections: analogue bias generator, analogue to digital converters, digital control and timing generation, data memory/processing and digital data interface (see Figure 2.7).

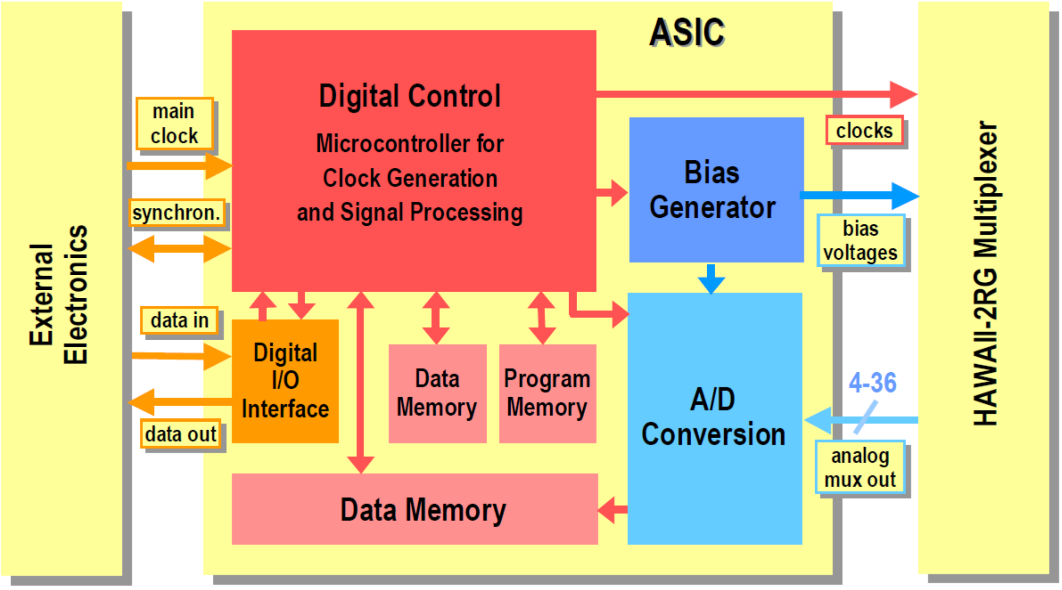


Figure 2.7: Sensor Chip Assembly for Astronomy: SIDECAR ASIC with HAWAII-2RG readout [29].

A fully programmable and application optimized microcontroller is responsible for the overall SCE control and for generating the specific timing patterns of the multiplexer clocks.

In order to reduce the reading time, the SCE supports a readout mode that uses 32 parallel output amplifiers. Each output addresses a 64 × 2048 vertical sub-array in the SCA. The acquisition firmware yields a minimum exposure time of 1.41 s with a pixel rate of 100 kHz.

Every 1.41 s the SCE allows reading the voltage present on the P side of the PN junction of the 2048 × 2048 pixels. Each of the pixels of the detector is encoded in 16 bits; the total size of the image is 8 MB. The photosensitive 2040 × 2040 pixels array is surrounded by 4 rows and columns of reference pixels which are not connected to the detector photodiodes; they are important to track biases and temperature variations over long exposures. The typical single frame read noise of the H2RG detectors is in a range from 10 to 20 *electrons*.

For science observations IR detectors usually acquire Up-the-Ramp (UTR) sampled data at a constant frame rate. The photon flux can be estimated, for example, by a linear fit of the points of the ramp. The amount of data to be stored and processed is considerable, but this method allows detecting the possible singularities that may occur during a ramp, in particular the impact of a cosmic ray.

In the case of the Euclid focal plane, the readout mode for the H2RG detectors was chosen on the basis of some constraints: the NISP instrument has a telemetry constraint of 290 Gbit/day, which requires that only few pieces of information per pixel can be transferred to the ground, therefore it is necessary to implement an in-flight data processing algorithm able to evaluate the flux received by each pixel.

If we define a frame S_i as the data resulting from a sequential readout of a rectangular area of pixels during a time t_f, the signal in a group G_k after averaging n_f frames is evaluated as:

$$G_k = \frac{1}{n_f} \sum_{i=1}^{n_f} S_{ik}$$

This readout technique is called multiple accumulated sampling and a common abbreviation MACC(n_g, n_f, n_d) is used where n_g is the number of equally spaced groups sampled UTR, n_f is the number of frames per group and n_d is the number of dropped frames between two successive groups (see Figure 2.8). The advantage of this ***co-adding*** procedure is the reduction of the Gaussian distributed pixel readout noise σ_R. If the Readout Noise in one group σ_{RG} is defined as:

$$\sigma_{RG} = \sqrt{\frac{\sigma_R^2}{n_f}}$$

it follows that if the number of frames per group is larger, the readout noise associated to each group after *co-adding* is lower [30].

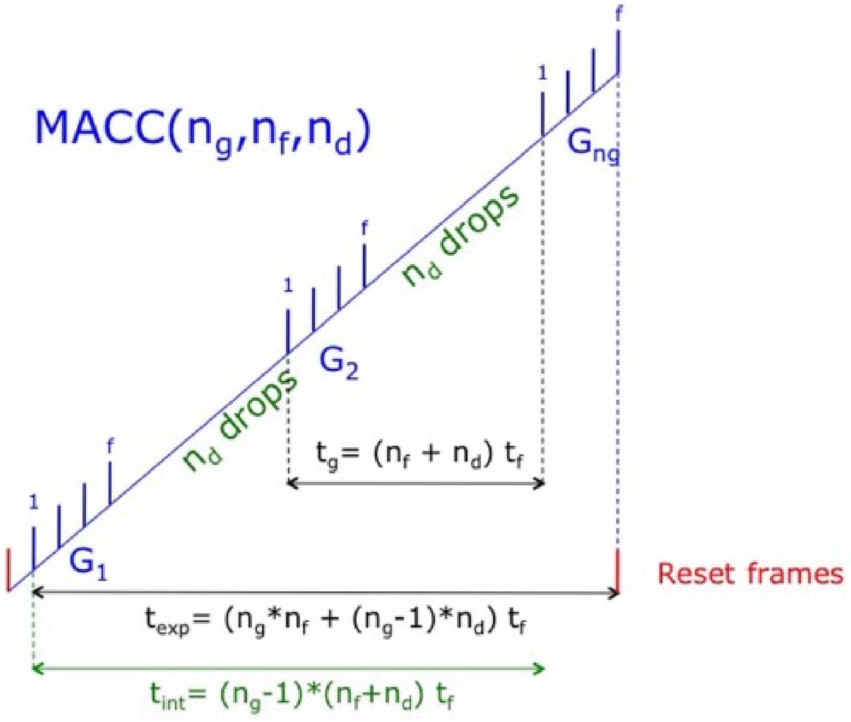


Figure 2.8: Multiple accumulated sampling MACC (n_g, n_f, n_d) with n_g is the number of equally spaced groups sampled up the ramp, n_f is the number of frames per group and n_d is the number of dropped frames between two successive groups.

For the NISP, an optimization of the MACC readout modes is performed with respect to the exposure times necessary for each MACC. The time required for the in-flight electronics to process the data is about 7s for each group acquired, therefore, 5 dropped images allow processing the data. Consequently, the MACC shown in Table 2.1 were defined for scientific observation modes.

Table 2.1: Readout modes adopted for each of the observation modes of the NISP instrument.In the specific case of Euclid SCE, the UTR sampling can be programmed using a few parameters:

Exposure Type	**N groups**	**N frames**	**N drops**	**Durations (s)**
Spectroscopy	15	16	11	574
Y-band Photometry	4	16	7	124
J-band Photometry	3	16	6	80
H-band Photometry	3	16	5	82

- Reset Frames corresponding to the reset mode of the detector before the acquisition

- Post Reset Drop Lines, tuneable number of lines not acquired after the detector reset
- Read Frames, frames where the detector is readout without reset (the value noted as n_f in the previous formula). It has to be noted that data packets are sent out line by line during a frame
- Post Read Drop Lines, lines that are read by detector but not transmitted (the value noted as n_d in the previous formula). These dropped lines are helpful for maintaining temperature stability and reducing the amount of data to be handled.

Read Frames and Drop Lines are combined into groups that can be repeated multiple times.

The SCE firmware (EEF) provides also internal telemetry of both the SIDECAR and the H2RG system. This includes digitized values of the H2RG's dedicated output as well as the biases provided to the system. It will also monitor internal SIDECAR temperature sensors and other SIDECAR biases. The EEF also provides command validation, acknowledgement, and command counters for external systems. While waiting for new commands, the ESF will operate in an idle loop, performing housekeeping tasks such as memory scrubbing and continual resets of the detector.

The EEF states and operations are summarized in Figure 2.9 [29].

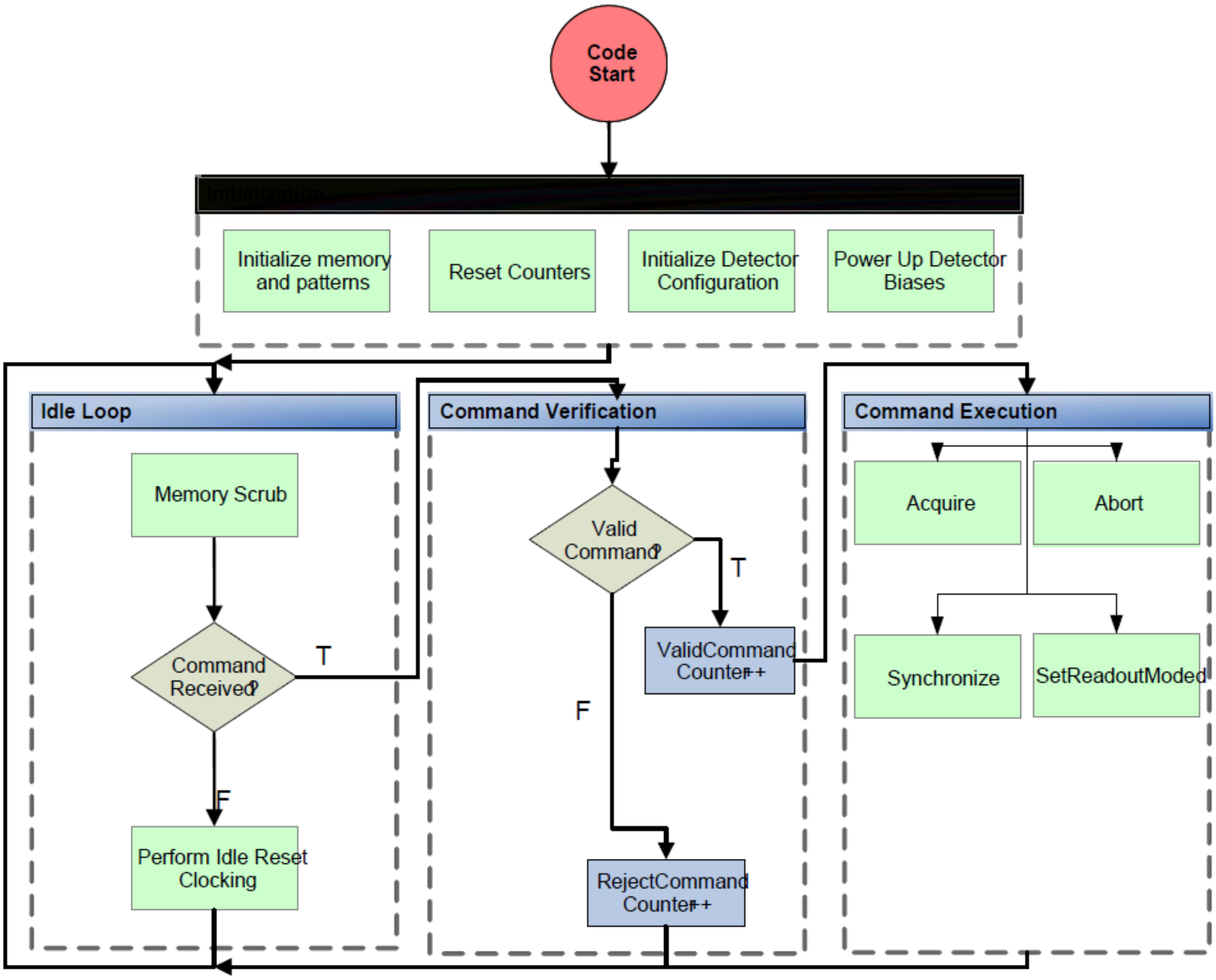


Figure 2.9: Main operations performed by the SCE EEF, the start-up phase and the first box on the top are usually referred to as the Boot phase of the SCE and must be commanded by the NI-ICU, power to SCE is provided by the DPU/DCU unit.

The following EEF fine tunings and specific functions were introduced after Euclid specific change requests:

- ✓ possibility to generate end of line and frame pulses. This feature is needed for debug tests
- ✓ implementation of SCE/SCA internal Inter Pixel Capacitance test (IPC exposure) by means of simulated exposure on a selectable pixel grid
- ✓ aliveness test has been implemented and is supported by an internal readable register incremented at each end of line, both during exposures and idle time

- ✓ numerical UTR simulator allows to produce directly by the SCE simulated Multi Accumulation Ramps where each frame level is constant and the level increases with a programmable step

2.1.2.2 Data Control Unit Design

The storage and hardware processing of the data acquired from the H2RG is performed by the Detector Control Unit (DCU). Each DPU unit hosts 8 DCU boards that are independently supplied by dedicated protected electronic switches hosted in the PSB. Each DCU receives the data of one detector from the SCE and performs the low level pre-processing: pixel co-adding, reference bias subtraction and frame data buffering. At the end of each MACC co-added groups are transferred with Spacewire internal links to the DBB (N/R section). Moreover, the DCUs have to provide low noise digital and analogue power lines to the SCE.

In order to complete the above mentioned tasks, the main functions required to each DCU board are:

- provision of multiple low noise power lines to the SCE (see Table 2.2)
- reception of scientific data and housekeeping telemetry from SIDECAR
- TM/TC interface to/from the SCE
- co-adding of frame data
- transmission of co-added data and telemetry/housekeeping to DBB
- TM/TC interface to/from the DPB

The DCU power block consists of four isolated sections:

- Digital section including the DCU pre-processing FPGA and relevant I/O devices
- Isolated power conditioning section dedicated to supply the digital section of the SCE
- Isolated power conditioning section dedicated to supply the analogue section of the SCE
- Isolated power conditioning section dedicated to supply the V_{REF} (3.3 V) to the SCE

The digital section of the board has the same digital ground of the whole DPU/DCU while the sections dedicated to the SCE power lines are fully isolated with respect to the DPU/DCU. Analogue and digital ground of the SCE are connected together at SCE board level. Each power section is provided with an isolated DC/DC converter that provides an isolated power bus. Each DC/DC converter is supplied via LCL that acts as power switch. In case of a fault in one element the LCL limits the faulty DCU input current within a safe level and disconnects both isolated sections from the +28V input power bus.

Power Line	**Output Current (nom value) (mA)**	**Output Current (max value) (mA)**	**Output Voltage (V)**
VDDA (Analogue)	60	80	3.3
VDDIO (Digital)	33	40	1.45
VSSIO (Digital)	33	40	0.95
2V5D (Digital)	16	24	2.5
3V3D (Digital)	2	10	3.3

Table 2.2: Power lines to be provided by the DCU to the SCE. It has to be noted that the VDDA has to be stable versus load variations foreseen on the SCE current. Each power supply shall have current and voltage monitors. All the supply provided to the SIDECAR shall have galvanic isolation and shall be referenced to the SIDECAR ground. In order to avoid injection of digital noise in the analogue signal, also analogue and digital power supply are kept separated. In addition to these there is the analogue VREF (3.3 V), the master reference voltage of the SCE that should not be shared.

The DCU digital section consists of the following main blocks (see Figure 2.10):

- Control/pre-processing FPGA
- SDRAM banks (1GB) to support data acquisition & pre-processing needs.
- LVDS interface for data exchange with the SCE
- Spacewire interface for data exchange with DBB at a speed of 48MB/s
- Redundant RS-485 bus for DCU control & configuration

The scientific and telemetry data produced by the SCE during normal operations are delivered through the LVDS interface to the DCU electronics. Each data packet contains a row of the acquired frame and some other information such as: header, line number, SCE ID and telemetry values.

Each DCU receives in total from the mated SCE an image composed by 2048 x 2048 pixels at 16 bits plus a column of temperature measurement of 64 x 2048 values at 16 bits. The image processing is divided into two main parts: co-adding and averaging.

The first block in the processing chain is the co-adding block in which is performed the pixel by pixel sum of each frame of a group. Pixel math is done using 24-bit precision. The result of this operation is a co-added frame stored in the temporary memory buffer.

When the last frame of the group in the commanded MACC has been received and co-added, the averaging is performed and a 16-bit frame is prepared and finally transmitted to the DBB.

The SCE is also interfaced with a serial line used to exchange commands and housekeeping between the SCS and the DPU. The DCU has a complete set of registers in which the commands to be sent to the SCE can be fully defined. There are two types of SCE commands: not synchronized (e.g. for the configuration read and write) and synchronized (e.g. for the exposure command sent to all sensors together). The first type of command is executed as soon as the command is received from the DCU. The second type of command instead, is only *armed* and not executed immediately. The SCE interface must wait until the sync pulse is received through an external synchronization signal to effectively perform the command. In this way, it is granted that the execution starts at the same clock cycle for all DCUs.

The DCU is controlled by the CPU via a custom UART I/F. Housekeeping requests, DCU configuration and register read/write are satisfied using a custom UART interface that is implemented on the data router board. It supports read/write in all internal DCU register, IP core registers and internal or external memory.

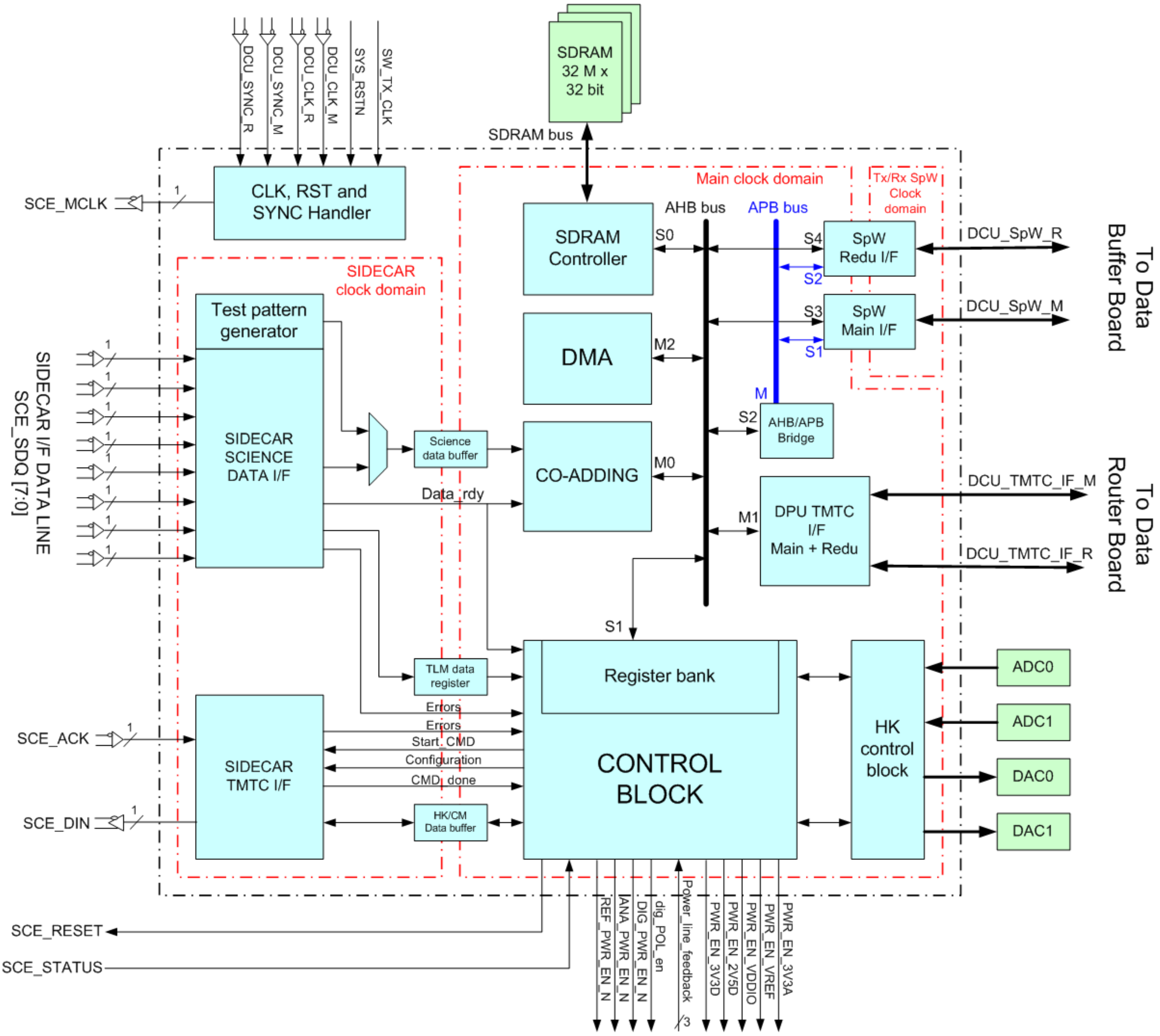


Figure 2.10: DCU FPGA block diagram.

2.1.2.3 DCU Image processing task

A Finite State Machine (FSM) handles the operation of the processing block. This FSM implements the reception algorithm described in the diagram shown in Figure 2.11.

On the Science Data Interface, the packet transmission is not directly handled by the DCU but is initiated by the SCE itself when an exposure command is sent. The total frame time and therefore the transmission speed is defined by the speed of the internal analogue conversion of pixels (100 kHz). Indeed, each analogue to digital video converter must sample 64 pixels each row with a sample time of 10 µs. Therefore, the minimum time between two consecutive packets containing a row only is 640 µs, giving a resulting frame time of 1.31s. In this time the SCE transmits the data packet in a single burst at the given clock.

Through the same interface the DCU can read and write internal registers or memory areas of the SCE. The SCE is controlled by setting specific values in dedicated registers. No autonomous transmission by the SCE is allowed and only the DCU can perform read/write operations. It is worth mentioning that the DCU does not manage directly the TM/TC interface but offers a complete set of programmable registers to the DPU. In order to operate on the SCE, the DPU ASW must configure the SIDECAR_CMD_CONFIG registers.

In detail, the image processing tasks foreseen by DCU are the following:

- Extraction of TM from scientific data. All values contained in the Digital TM are always overwritten, updating the entry with the new value while the values contained in the Analogue TM are co-added and averaged. These data are also packed with the processed frame in the DCU output packet.
- Extraction of the temperature values from the scientific data packet.
- Storage of up to 5 selectable raw rows each frame to be inserted into the DCU output packet.
- Co-adding of the pixel of the frames in groups composed by a predefined number of frames. The fixed point precision of the arithmetic core is 24 bits.
- Average the co-added image and truncate the values to generate a 16-bit frame.

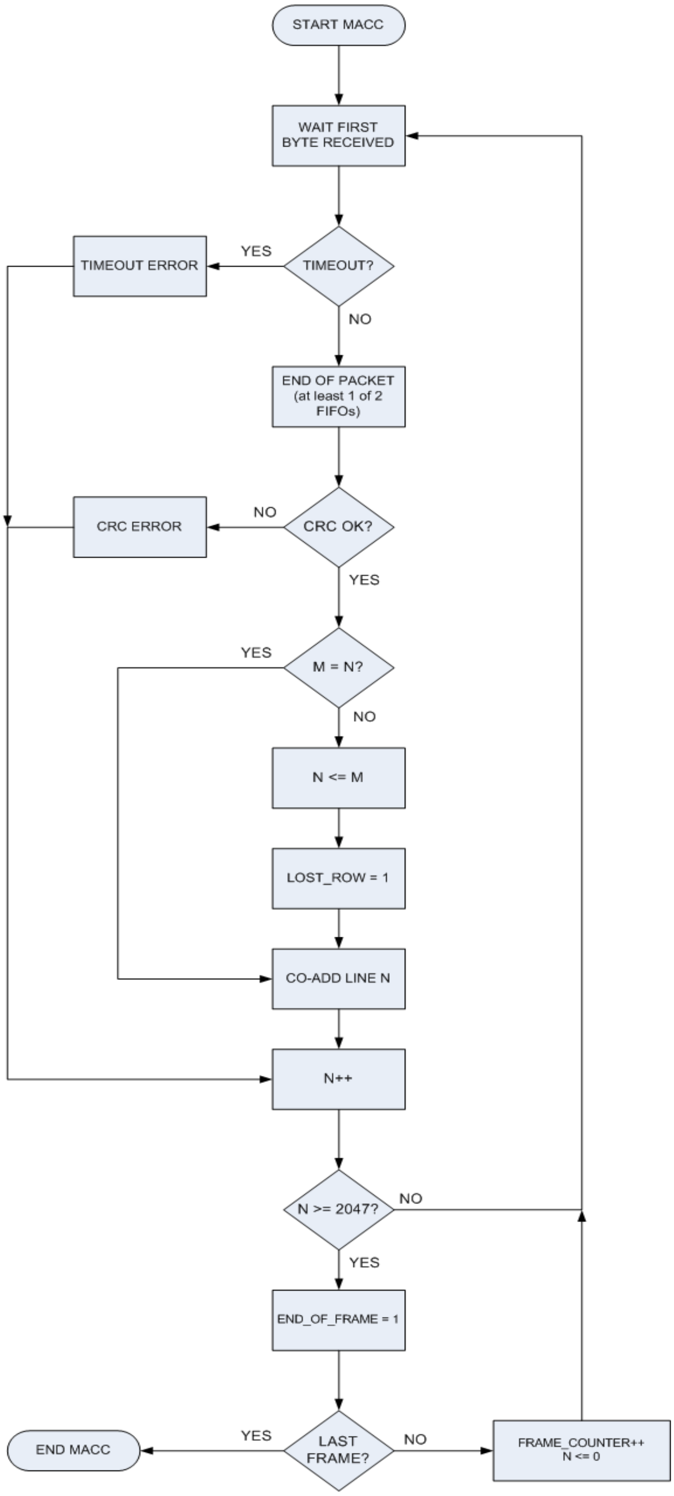


Figure 2.11: FSM block diagram. Every time a new row is correctly received by the DCU, the row counter N is incremented by one. The line number M is a field contained in the header of each packet. At the end of every packet (if the CRC is correct), N is checked against M and the proper action is taken consequently.

The main task of the processing block is to co-add all pixels of the frames of a given group into a temporary SDRAM buffer called *image buffer*. This job is done in real time during the reception of the data from the SCE. Therefore, meanwhile the new data has been received and stored in the buffer; the previous row is utilized by the processing block. The science data buffer (FIFO), of course, is large enough to ensure that no data will be lost during the real time operations. Therefore, as soon as a valid row is detected, the processing block reads the corresponding row from the image buffer and performs the co-adding operation. The row index of the science packet is defined by the field *line number* of the packet header. If a row is missing, the actual row is added always in the right place of the image buffer. The elaborated pixels are placed in the write buffer and this operation is repeated for each row received. This block implements also a mechanism to save up to five raw lines of each received frame into another memory area in the SDRAM. These rows will be directly inserted into the DCU output packet.

2.1.2.4 DCU Telemetry and errors handling

The DCU implements *error handling*, the foreseen types of errors are the following:

- transmission errors (between SCE and DCU or between DPU and DCU) are handled at DCU level discarding the data packet that are identified as corrupted. A CRC and/or parity protection mechanism on each interface is implemented.
- over-voltage or over-current detected on a protected channel. The DCU disables all power lines to avoid further damage. Also SCE power supplies are immediately disabled.
- other generic errors (i.e. DAQ error, timeout error) are not directly handled by the FPGA; they are reported to the DPU ASW updating the ERROR REGISTER.

2.1.3 NI-DPU ASW design and main functions

The main challenge of the warm electronics is to process the amount of data delivered by the detector during the acquisition of the following frame; this task is accomplished in-flight by the DCU and by the Processing task of the DPU ASW. Even if it is crucial for the Euclid mission, the data processing is only one of the tasks to be accomplished by the DPU ASW inside the NI-WE. The complete list is the following:

- the handling of the SCS infrared focal plane operations; all the operations are scheduled by the ICU and the DPU has to take care of them

- the completion of the on-board pipe-line providing SCS data processing
- the science data transmission to the MMU in the SVM
- the retrieval and the organization of the DCU, SCS and DPU housekeeping. The housekeeping has to be provided to the ICU via the MIL-STD-1553B bus.

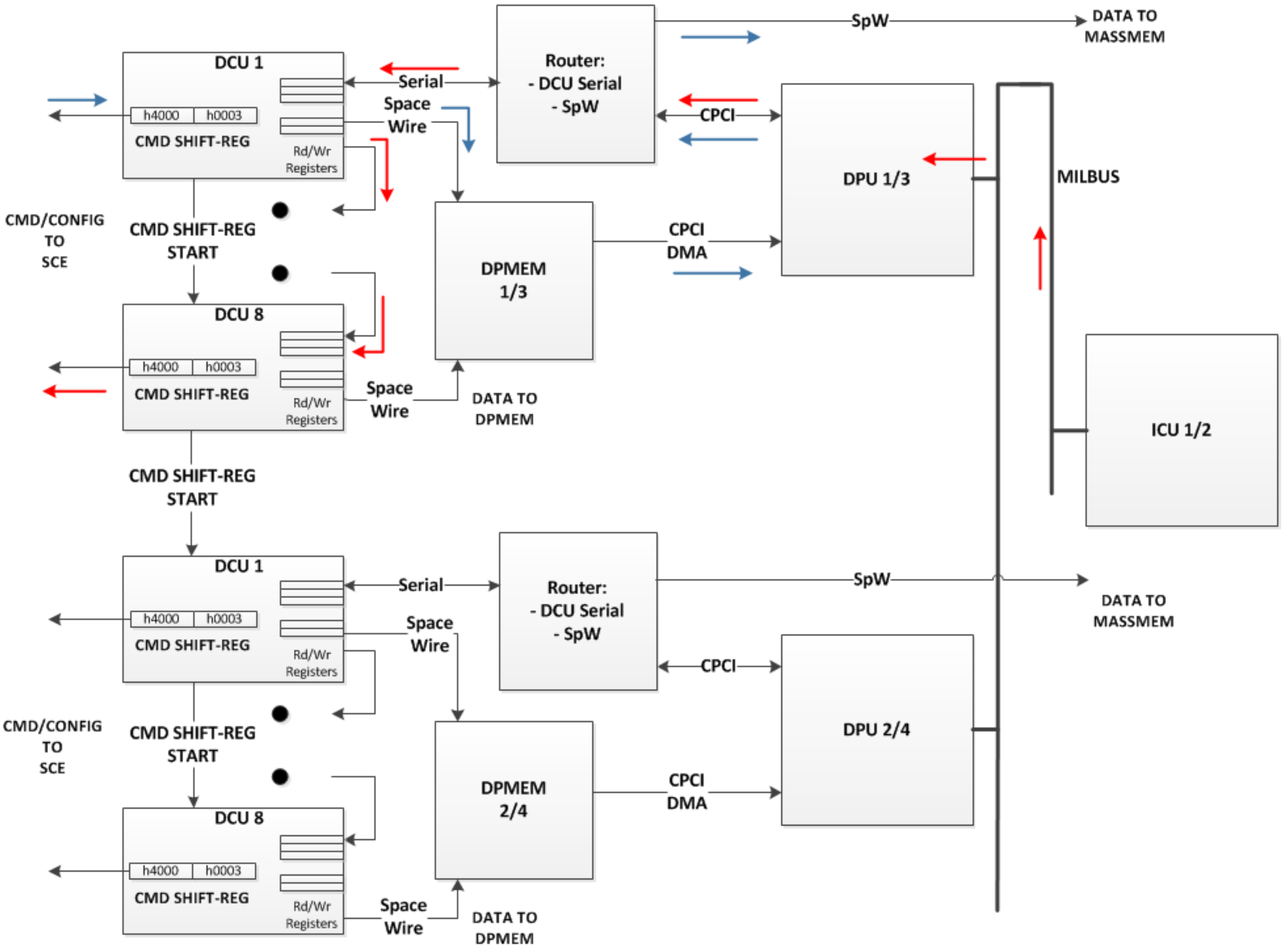


Figure 2.12: NI- WE HW interfaces. In red there is the path of a command issued by the ICU and arriving to SCEs, in blue there is the path of a data frame produced by SCE 1 (just as an example) up to the storage in MMU [31].

The data processing can be split into two main steps:

- the preliminary one is implemented in the DCU in real-time on the digital data stream provided by the SCE, as discussed in the previous paragraph
- the other one is implemented by the DPU ASW and comprises the processing and the compression of the final data frames

The two processing steps are asynchronous and rely on the availability of the double buffer memory (DBB) in the DPU unit.

The DPU ASW has to take care of the different hardware components of the unit and it has to handle the communication among them; all the needed interfaces are shown in Figure 2.12.

The DPU ASW runs on the Maxwell CPU (DPB) using VxWorks 5.5.1 Real Time Operative System (RTOS) [32]. Such platform has already been used in ESA and NASA space missions; Tornado 2.2.1 is used as Integrated Development Environment.

The Basic Software Package (BSP) provides basic functions and interfaces with hardware components. It is provided by OHB-I together with the Boot Software (BSW) [33]. The BSW is expected to run at DPU start-up and keeps the unit in a stable state where all hardware devices are initialized. At the end of the DPU Boot phase the full VxWorks kernel with the BSP and ASW images are transferred from one of the two EEPROM available areas to the dedicated DPU memory area and the ASW is in the Initial state (ASW_INIT). The BSW takes care also of updating in EEPROM the ASW and the SCE microcode if necessary. Figure 2.13 shows the different functions required to the DPU unit and the colour code assigns such functions to BSP, RTOS, BSW or ASW.

The required operations during the mission lifetime have to be performed having the DPU ASW in specific operating states, as shown in Figure 2.14.

All the ASW state transitions are commanded by the ICU through the MIL-STD-1553B link, DCU/SCE states are controlled internally by the DPU ASW. It records its state and the DCU/SCE ones in a dedicated register that are always available to the ICU. Here these states are reported briefly:

- **ASW_INIT** is a transition state during which needed initializations are performed before the regular operation
- **CPU_SAFE** is a stable state with the CPU, DBB and DRB operative only. The transition to this state can be requested in case of emergencies to the SCS system. On this occurrence all the active DCU are powered off.

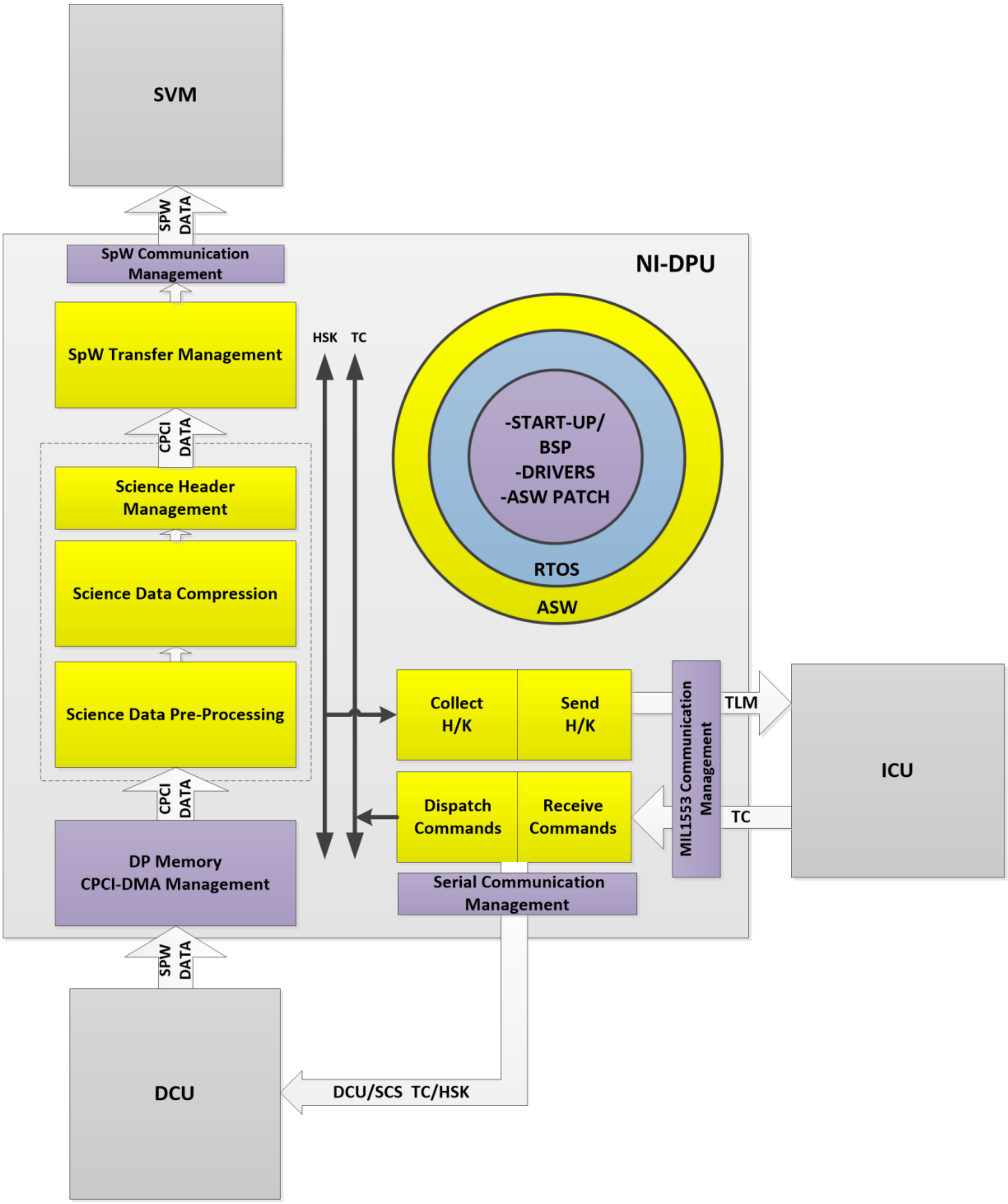


Figure 2.13: CPU/ASW deployed functions. Violet areas are parts covered by the DPU hardware provider (OHB-I) while yellow parts are covered by the DPU ASW developed by INAF Padua.

- **SCE_INIT** state is a stable one and can be reached from the ASW_SAFE state through an ICU command. In this state it is possible to provide power to the DCU/SCE system, check the telemetry and afterwards command the SCE EEF boot. This procedure has to be applied to each DCU/SCE sequentially and, once completed, leaves the system in a state ready for data acquisition. Once fully powered and initialized the DPU/DCU system can be operated in Manual or Observation mode.

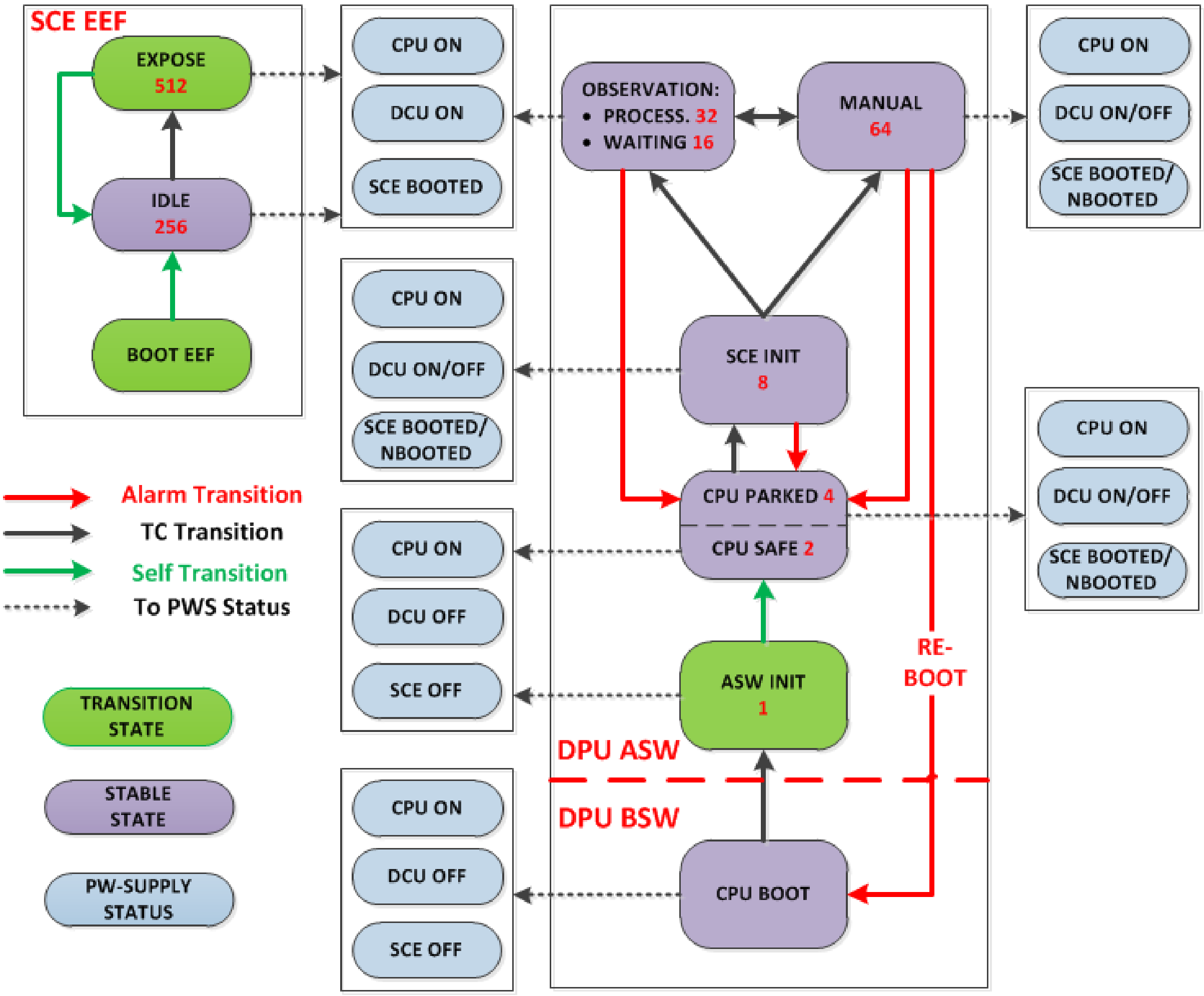


Figure 2.14: DPU ASW operational states and allowed transitions. Purple boxes indicate stable states, orange areas indicate the states which are only associated to a commanded transition, so they are temporary. The internal states of the SCE are detailed on the left. Red transitions are those commanded by ICU.

- The **MANUAL** mode is a stable state and can be accessed only as a transition from the SCE_INIT state or from the OBSERVATION one; it is provided to re-configure or debug the system. In this state it is possible to adjust voltages, to perform operations on memory areas (dump, load, check) and to configure data acquisition parameters. Data acquisition is also possible in MANUAL mode.
- The **OBSERVATION** mode is the main state to perform detector acquisitions and

processing during the survey and this is the state where the DPU ASW is expected to stay for most of the mission lifetime. The processing task is the main task that is active in this state and it can have two different states: Processing when active or Idle. The processing task state is a consequence of the SCE state that can be Idle or EXPOSE during data acquisition.

It is possible to re-boot the unit via a dedicated command. After this directive the BSW starts and the ASW is launched again while the DCU/SCE system is kept powered. After a re-boot the ASW state is CPU_PARKED and it is possible to move from this state to the OBSERVATION or MANUAL one.

2.1.3.1 ICU – DPU TM/TC interface

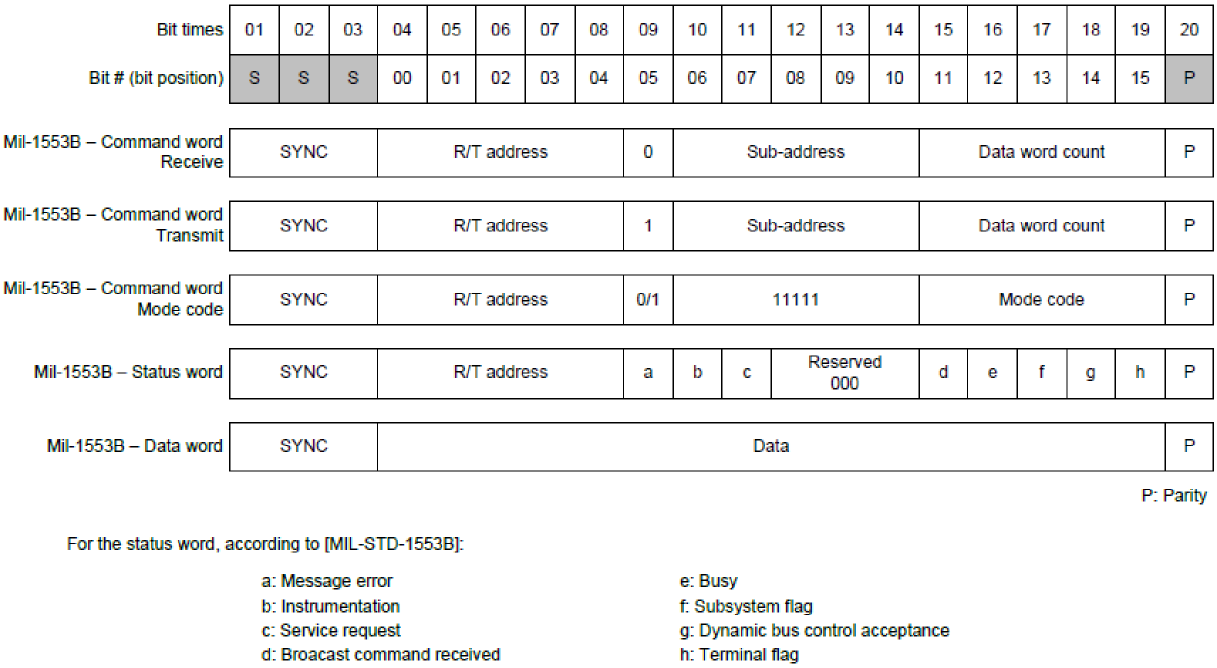
The TM/TC interface between ICU and DPU is achieved through a MIL-STD-1553 bus [34]. The peculiarity of this protocol influenced the DPU ASW development strategy and design [35].

The key elements in the MIL-STD-1553 transmission protocol are the Bus Controller (BC) and the Remote Terminal (RT). Optionally the bus can be monitored by a Bus Monitor (BM). The BC initiates all transmissions on the bus; it is the sole source of communication and the system follows a command/response method. BC can send messages to up to 31 RTs or to all the available ones using the Broadcast mode (RT=31).

The RT consists of an interface circuitry located inside a sensor or a sub-system directly connected to the data bus. Its primary scope is to perform the transfer of data in and out of the sub-system as commanded by the BC. The RT does not have any of the bus controller capability. However, RT is capable of properly responding to the BC in case of data transmission request according to a pre-defined protocol, buffering messages in specific memory addresses that are defined as Sub-Addresses (SA) (32 for each RT) and reporting the status of the communication.

The BM listens to all messages running through the bus; it is used to detect problems in any of the equipment connected.

Every message that is transmitted on the bus is made up by three types of 16 bits words: command word, data word and status word. The bit map of each of these three types of word is shown in Figure 2.15. Any transmission begins with the command word issued by the BC. The command word specifies the function that the destination RT has to perform. The data word represents the information carried by the message; a single message can carry a maximum number of 32 words. The status word contains the information about the status of the communication. The communication is based on the assumption that after the successful accomplishment of the transmission of a message, the RT notifies the event to the BC sending a status word.



<table>
<tr><td>Bit times</td><td>01</td><td>02</td><td>03</td><td>04</td><td>05</td><td>06</td><td>07</td><td>08</td><td>09</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td></tr>
<tr><td>Bit # (bit position)</td><td>S</td><td>S</td><td>S</td><td>00</td><td>01</td><td>02</td><td>03</td><td>04</td><td>05</td><td>06</td><td>07</td><td>08</td><td>09</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>P</td></tr>
<tr><td>Mil-1553B – Command word Receive</td><td colspan="3">SYNC</td><td colspan="5">R/T address</td><td>0</td><td colspan="5">Sub-address</td><td colspan="5">Data word count</td><td>P</td></tr>
<tr><td>Mil-1553B – Command word Transmit</td><td colspan="3">SYNC</td><td colspan="5">R/T address</td><td>1</td><td colspan="5">Sub-address</td><td colspan="5">Data word count</td><td>P</td></tr>
<tr><td>Mil-1553B – Command word Mode code</td><td colspan="3">SYNC</td><td colspan="5">R/T address</td><td>0/1</td><td colspan="5">11111</td><td colspan="5">Mode code</td><td>P</td></tr>
<tr><td>Mil-1553B – Status word</td><td colspan="3">SYNC</td><td colspan="5">R/T address</td><td>a</td><td>b</td><td>c</td><td colspan="3">Reserved 000</td><td>d</td><td>e</td><td>f</td><td>g</td><td>h</td><td>P</td></tr>
<tr><td>Mil-1553B – Data word</td><td colspan="3">SYNC</td><td colspan="16">Data</td><td>P</td></tr>
</table>

P: Parity

For the status word, according to [MIL-STD-1553B]:

a: Message error
b: Instrumentation
c: Service request
d: Broacast command received

e: Busy
f: Subsystem flag
g: Dynamic bus control acceptance
h: Terminal flag

Figure 2.15: Bit maps of the three types of 1553 messages exchanged between BC and RT.

In the specific case of NI-WE, the ICU implements the MIL-1553 BC function and the DPU provides 4 MIL-1553 RTs (one for each DPU section), whose addresses are uniquely defined by dedicated plugs. The channel between ICU and DPU has a Nominal and a Redundant line.

The 1553 messages to be implemented are:

- Command Word Transmission(Tx)/Reception(Rx).
- Broadcast Mode to be applied to all activated RTs
- Data Words Tx/Rx with data length up to 32 words at each SA
- Status Word Tx/Rx

As for the spacecraft (MIL-STD-1553B communication between SVM and ICU) the TM/TC transfer protocol is assumed to be based on 1-second cycle. Each cycle is split in 60 Communication Frames (CF) from 0 to 59. The CF 0 starts with a Time Synchronisation message in the form of a Command Word - Sync without Data Word that is sent by the BC in Broadcast mode. All other CFs start with a message in the form of Command Word -Sync with Data Word.

All the TM/ TC interface between ICU and DPU and the DPU ASW dynamic activity is based on shared tables, reported in Figure 2.16, that are exchanged as 1553 Data Word type messages. The amount of data in each table is limited to 32 words. The ICU can have write and/or read access to such data through the 1553 interface HW. All tables are internally stored in dedicated DPU ASW memory areas and can be identified by a Table ID which is the first word of a 1553 message.

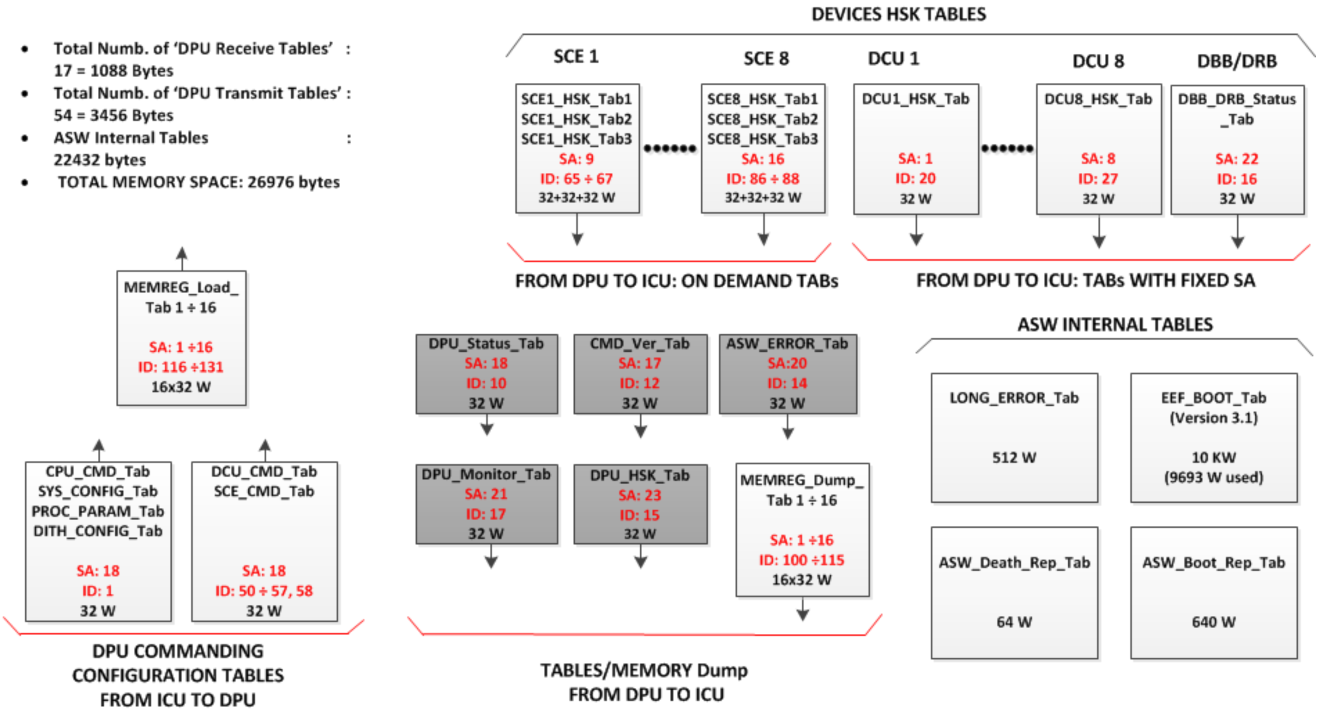


Figure 2.16– DPU internal tables dedicated to Command/Configuration/TM exchange with ICU through the 1553 link. On the left side there is the set of tables containing commands and configuration parameters that are routed on SA=18, in the middle in grey there are tables produced by the DPU ASW with a fixed periodicity, on the top left there are the tables containing data used for Memory Load and Dump operations and the tables containing DCU and SCE telemetries.

Commands and configuration tables are routed by the ICU on SA=18, while telemetries have dedicated SAs. The update of all SA follows a time-profile that is fixed and crucial for the TM/TC interface, as shown in the following chapter.

In order to check the regular arrival of tables both on the RT and BC devices, two counters have been defined:

- ICU_Request_Counter: incremented and inserted by the BC on each transmitted message as data to the RT. If this counter is not incremented correctly the command is refused by the DPU ASW.
- ASW_TLM_Counter: incremented by the DPU and inserted on each transmitted table to the BC. If this counter is not incremented the ICU ASW signals a fault in the 1553 communication flow

Copies of both counters are continuously cross-checked to verify the integrity and regularity of the tables exchange.

2.1.3.2 DPU ASW tasks

The DPU ASW structure is divided in several tasks, the most relevant ones are the following [31]:

- **DPU_START_TSK**: this is an initialization task and starts up all the software infrastructure and all hardware devices
- **ISR_Selec_TSK**: it initializes the available memory and initializes the DBB memory clean operation
- **1553 _TSK**: this is responsible of the TM/TC interface with ICU. The start of this task is triggered by physical interrupt occurring at any activity in the 1553 bus. This task handles separately 1553 Tx/Rx messages. The scope of RX_TSK is to manage received tables (configuration and commands) while TX_TSK has to manage transmit messages.
- **CMDEXEC_TSK**: it is triggered by the TX_TSK using a VxWorks message each time a command arrives through the bus. The task identifies the device to which the command is addressed and manages its execution. It also retrieves the status of the command after execution by preparing the associated telemetry.
- **PROC_TSK**: its goal is to process data. Processing is configured accordingly to the

dither cycle through the Dither_Config Table, and the parametrization given in the Proc_Param Table and Sys_Config Table which are made available via the 1553_TSK.

- **HSK_SCAN_TSK**: this task is dedicated to the scanning/generation of telemetry from the main HW components. SCE_HSK is obtained synchronously at the end of each exposure, DCU_HSK is obtained cyclically and in asynchronous mode from the DCU, DPU_HSK is obtained cyclically and in asynchronous mode from the DPU PSB. The refresh rate of the telemetry is programmable.
- **EOE_WD_TSK**: the action of this watchdog is complementary to the EEF Exp/Idle status. If the exposure is not concluded within the estimated time margins an alarm is issued.
- **EOD_WD_TSK**: if the processing of the current dither is not concluded within the programmed dither time an alarm is issued.

2.1.3.3 DPU ASW Exposure and Processing Cycle

The SCE data acquisition and processing is the main task of the DPU ASW. In order to fully operate the detector focal plane and configure the incoming data processing pipeline there is a defined procedure to be followed. At first the DCU/SCE sub-system must be powered ON and the SCE EFF must be started (also referred as SCE Boot commands), only afterwards the DPU ASW can be commanded by ICU in OBSERVATION or MANUAL mode. Three configuration tables are needed, the details of which will be shown in the next chapter:

- **SYS_CONFIG_TAB**: it is used to configure the DPU sub-systems and during normal activities. It is expected to be transmitted only at the beginning of the operations and for rare adjustments. In this table all the Watch-dog times are set and the temperature alarm thresholds for the HW components are defined.
- **PROC_PARAM_TAB**: it is sent at the beginning of the operations and in case of some change request in the data processing parameters, in fact this table contains parameters for data processing configuration.
- **DITH_CONFIG_TAB**: it is needed to begin each new exposure cycle or dither. It allows correct configuration/addressing of data and telemetry on the DBB, the desired MACC configuration and the exposure type as well. For each exposure in

a dither the needed exposure parameters are: the number of initial reset frames, the delay from last reset to first collected frame (in steps of 2048 D_{L1} detector lines), the number of groups during the exposure N_G, the number of consecutive frames acquired in each group N_F, the delay between programmed groups of frames (in steps of D_{L2} detector lines). With these parameters the duration of a single exposure can be evaluated with the following formula, also to be specified in the configuration table:

$$Texp = \left(D_{L1} + D_{L2} \times (N_G - 1)\right) \times L_T + N_G \times N_F \times F_T$$

where : $L_T = 689 \times 10^{-6}\ s$ is the readout line time and $F_T = 1.41s$ is the readout frame time

After the reception of a dither configuration each exposure is triggered by the ICU with the SCE_EXPOSE command. This command is sent in Broadcast mode to the 2 DPU units. After SCE exposure command a common SYNCHR pulse, in phase with the SCEs clock, starts all available SCEs exposures in parallel.

At this moment the readout, processing and final storage of data delivered by SCE will proceed, in an independent, asynchronous way on each involved DPU. The only way to stop an ongoing exposure is to send an ABORT command. It will stop the current exposure on a detector line boundary and force the SCE EEF to move to the Idle state waiting for new directives.

PROC_TSK starts when at least one complete exposure is co-added and copied in the DBB by the DCU. It loads in the DPB memory the specified MACC group sequence using the enqueue-dequeue mechanism and performs data processing as defined in PROC_PARAM_TAB.

At the end of the last exposure in the commanded dither and of the data transmission to MMU the PROC_TSK disarms the EOD_WD and a new exposure cycle can be commanded by the ICU.

2.1.3.4 Data processing and compression performed by DPU ASW

The full pipe-line adopted by the DPU ASW to process the data produced by the focal plane is detailed in Figure 2.18 [36].

The asynchronous processing is performed by the DPB on a given detector and it starts with the correction of frame non-uniformities and pixel-correlated noise. This is obtained subtracting the reference vertical and horizontal pixels after median filtering. The aim in this phase is to correct sensitive pixels and avoid propagating artefacts, i.e drifts in video inputs offset or thermally induced drifts.

The exposure signal extraction follows three different routines depending on the number of programmed groups:

- $N_G = 1$: the single frame is passed untouched to the compression. This is the case of some calibration exposures
- $N_G = 2$: frames are processed with the usual Fowler mode and passed to the compression.
- $N_G > 2$: frames are processed with a linear fit interpolation

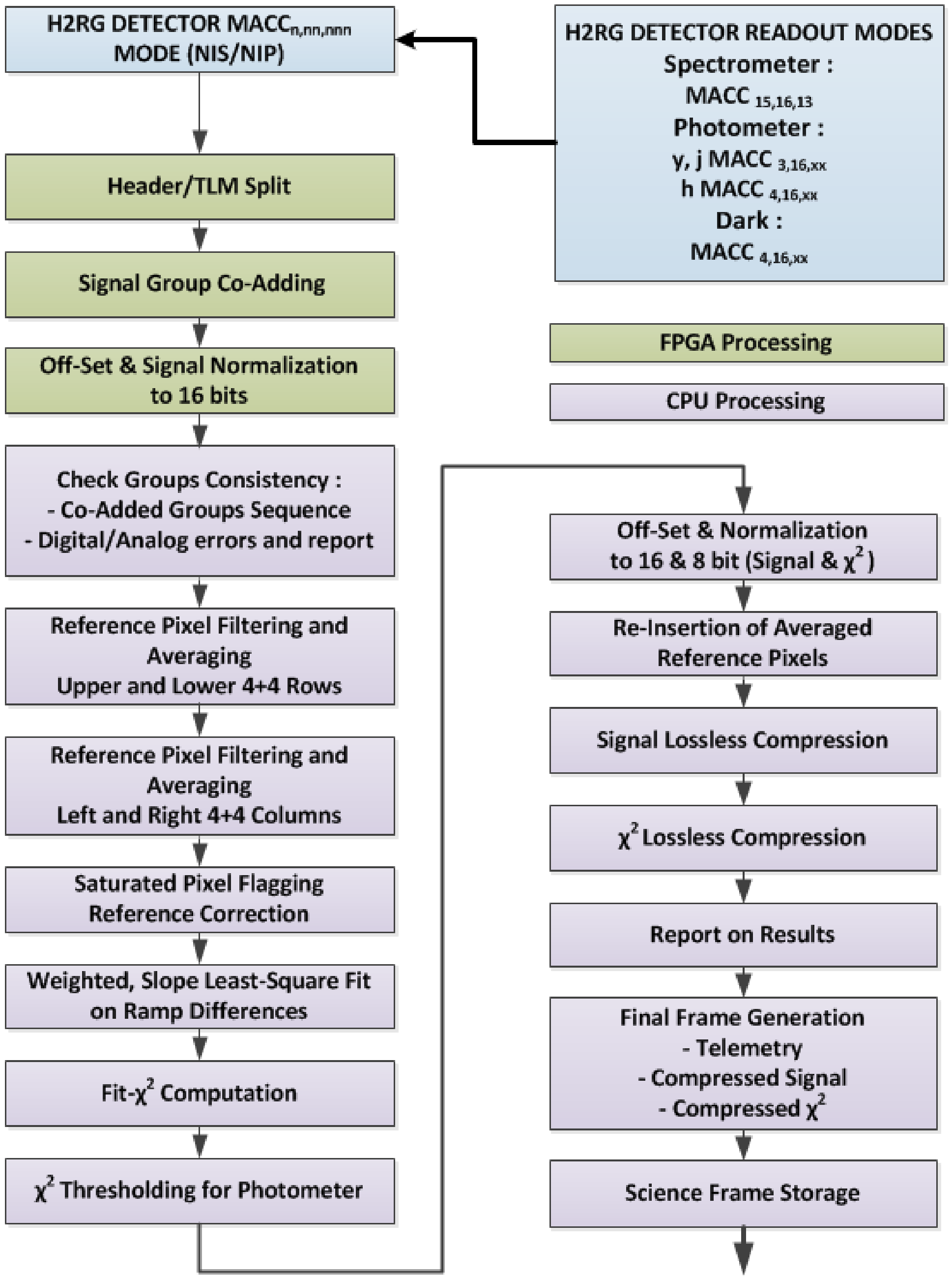


Figure 2.17: On-Board processing steps iterated on each detection channel (8 x triplets) upon reception of the programmed exposure frames on Dual Ported Memory. The first section in is performed, in real-time, in FPGA HW while the CPU section is performed in deferred time.

The core of the processing is a linear Weighted Least Square Fit. For all pixels signal ramps S_i , where $i = 1 \ldots M$ is the index of the M uniformly spaced groups, the differences $\Delta_i = S_i - S_{i-1}$ is computed and the slope b and χ^2 estimator as well are computed. The sequence Δ_i is different from the original signal ramp because of the correlated part of photon noise. A computation of the fit intercept, representative of the detector pedestal level, is not possible and estimate is independently obtained from the original reference pixels and transmitted to ground.

Formulas for slope b and χ^2 estimator are taken for time uniformly spaced samples, where the time coordinate is simplified in the $i = 1 \dots M$ integer sequence. For the noise weighted case:

$$b^2 = \frac{\sum_i \left(\Delta_i + 2 \times \frac{\sigma_r^2}{N}\right)^2}{M-1}$$

basically, on the discrete differences domain, the slope is reduced to a quadratic average, while the χ^2 is obtained in straightforward way by:

$$\chi^2 = 2 \times \left((M-1) \times b - \ (S_M - S_1) - 2 \times \frac{\sigma_r^2}{N} \times (M-1)\right)$$

Where:

M = number of MACC groups

N = number of samples per group

S_i = signal value at group-sample i

Δ_i= fitted signal differences

σ_r = read noise (RON) in ADU *rms*

Under nominal operation at the end of the pipeline two different frames are produced, one containing the computed signal for each pixel (ADUs, 16 bits) and one containing the computed χ^2 for each pixel. The χ^2 frame is decimated to 8x bits in the Spectrograph case and to 0/1 for the Photometer after comparison with a programmable threshold.

The last processing step before packaged file transmission to the Spacecraft Mass Memory is the data lossless compression. This is applied both to the final detector frames and to the Spectrograph/Photometer χ^2 frames. The algorithm used is an adapted version of the compression tool of the *cfitsio* public library, based on standard Rice algorithm. Figure 2.18 shows the compression factor achieved for the different available data sets at increasing signal level. Simulated data were generated without and with a 4% of pixels affected by cosmic rays as assumed usual for a spectrograph exposure on L2.

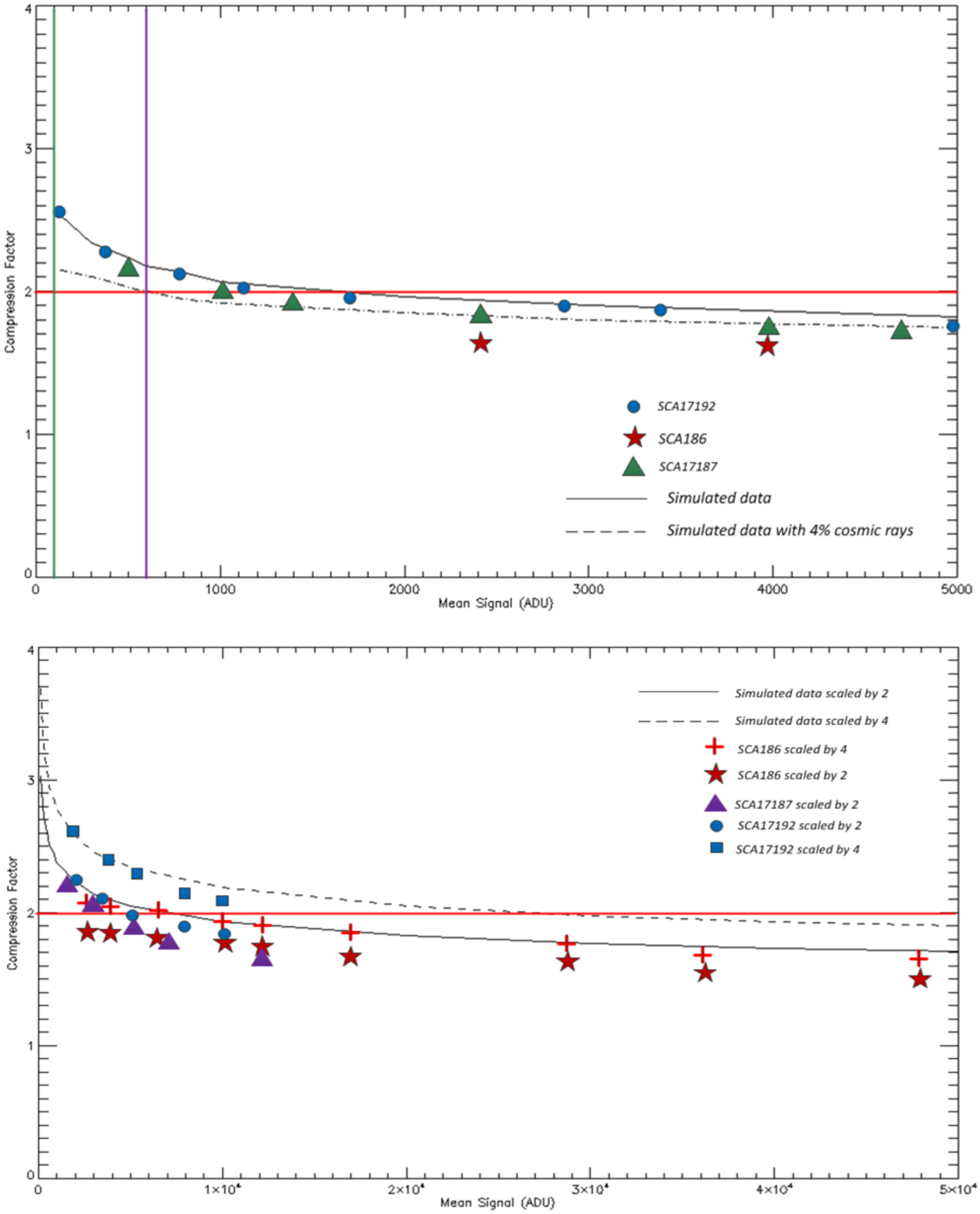


Figure 2.18: Compression factor versus the mean pixel signal for low and high signal level scales. The data are obtained from simulations, with and without cosmic rays added, and real H2RG data obtained during the NISP detectors pre-evaluation phase for three different detector samples. The red horizontal line is the reference NISP compression factor of 2 while the vertical bars in the top plot are representative for the Photometer and Spectrophotometer expected average background. On the bottom plot the effect of the application of a pre-scaling factor (2 and 4) on the data before compression is applied.

The time-budget of processing, compression and Spacewire transmission is consistent with the required one, as reported in Table 2.3 in the case of a single detector operation [37].

	DBB to DPB (s)	Processing (s)	DPU to MMU (s)	Total (s)
Spectro	9	15	3	27
Photo Y	3	8	3	14
Photo J	3	8	3	14
Photo H	2	7	3	12
				67

Table 2.3: Processing times for nominal science exposure, times for data transmission from DBB to DPB, processing and compression and Spacewire transmission are computed separately. Those data are obtained using 1 detector, the forecast for 8 detectors is 536s for the full dither processing time.

2.2 NISP Instrument Control Unit

2.2.1 NI-ICU Hardware design

The Euclid NISP Instrument Control Unit (NI-ICU) handles all the NISP functions and interfaces the NISP instrument to the SVM control system for TM/TC tasks. It exchanges data with the DPU using a dedicated MIL-STD-1553 interface. It provides the control electronics for the NI-FWA, the NI-GWA and the NI-CU. It is also responsible for the monitoring of the NI-OMADA temperature sensors, powering the heaters and handing the whole telemetry of the NI-WE.

The NI-ICU generates the secondary power supplies which are needed to perform all these functions except from the DPU-DCU. An overall view of a single NI-ICU box is presented in Figure 2.19. This figure is valid for both the nominal and the redundant sections, which are identical and operate in cold redundancy.

The ICU is based on three modules [38]:

- the Low Voltage Power Supply module (LVPS), providing DC/DC converters and 1553 transceivers for the connections with the NI-DPUs

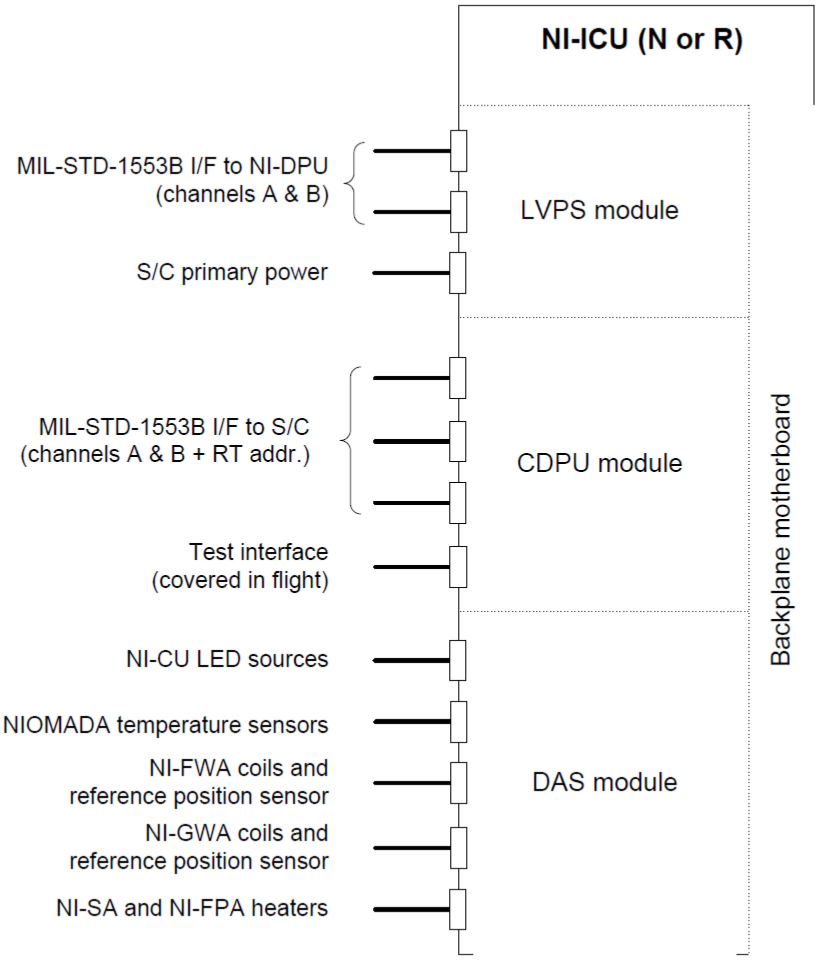


Figure 2.19: Overall view of the ICU

- the Central Data Processing Unit (CDPU), including a Multi-DSP Processor Architecture (MDPA), 1553 transceivers for the high level MIL-STD-1553 interface with the SVM and test connectors. The CDPU is the NI-ICU central processing unit hosting a LEON2-FT (Fault Tolerant) processor, embedded in the MDPA ASIC together with a Radiation Tolerant FPGA. It is used to integrate the MDPA standard functions and to make the CDPU board interact with the Driving & Analogue Support module (DAS) by means of a SPI link that goes through the ICU backplane. The CDPU allows loading, debugging, and monitoring an application through the Debug Support Unit (DSU) of the LEON2 processor. There are two cold-redundant Processing modules (CDPUs) per ICU. The ICU Processing modules (CDPUs) perform basically the software based control of the unit, as well as the processing, digital interfaces and management functions.

- the Driving & Analogue Support module (DAS), handling all the analogue acquisition and driving electronics for heaters, temperature sensors, calibration LEDs and filter and grism wheels. This section is driven by a SErial COntrol Interface Asic (SECOIA) and implements four passive protection circuits
    - Voltage reference protection
    - Motor driver protection
    - Motor phase A protection
    - Motor phase B protection

  Four SECOIA inputs are used to monitor the status of the DAS HardWare protections. The activation of any of these protections indicates a mayor DAS HardWare error.

  The DAS board implements one motor driver. The output of this single motor driver is connected to the FWA or GWA Cryo Mechanism (CM) by means of two SECOIA digital signals. Three SECOIA digital signals are used to activate/deactivate motor driver. One more SECOIA digital signal is used to guarantee that at most, one motor is connected to motor driver.

  The DAS board implements one motor Home Sensor excitation driver and two motor Home Sensor acquisition chains. The output of this single motor Home Sensor driver is connected to the FWA or GWA motor Home Sensor by means of two SECOIA digital signals. Two SECOIA digital inputs are used to acquire motor Home Sensor status of both acquisition chains.

  The DAS board implements one LED driver as well, each driver is composed by:
    - A programmable current source
    - A voltage level that defines the output current level of the programmable current source
    - A PWM that pulses the current source output.

  The output of the LED driver is connected to one of the calibration LEDs by means of five SECOIA digital signals. Eight SECOIA digital signals are used to select the current level of LED current source. A SECOIA PWM is used to pulse the current. A second SECOIA PWM is used to inform CDPU FPGA when the LED driver rise edge of the current source is commanded. This signal is used by

CDPU FPGA to synchronize the acquisition of LED voltage in the crest of the PWM.

One SECOIA digital signal is used to guarantee that at most one LED is connected to the LED driver.

Two SECOIA PWMs (one for each heater) are used to control the NI-OMA heaters.

The SECOIA ADC control module is used for all Analogue acquisition (external & internal).

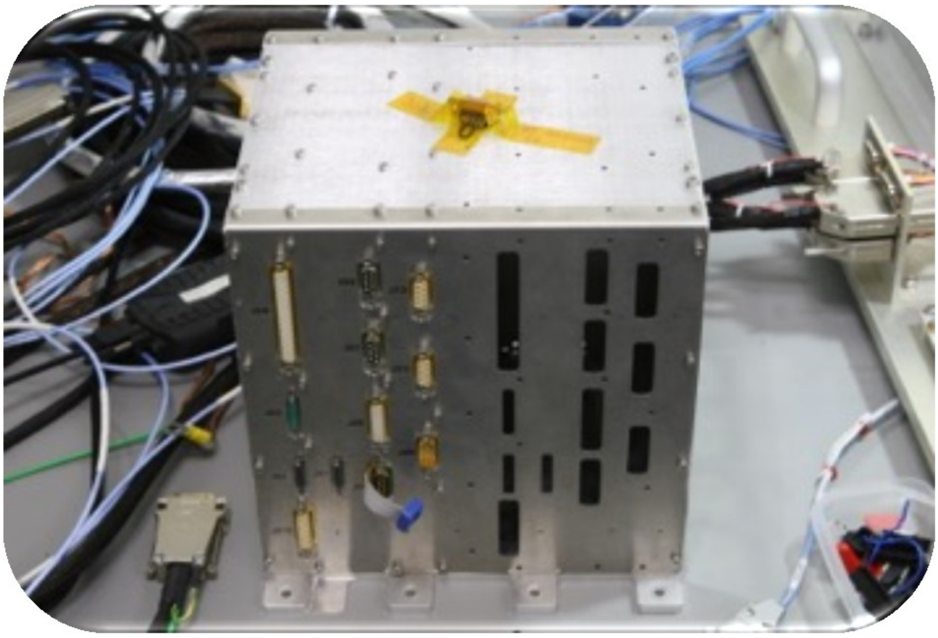


Figure 2.20: Picture of the ICU EM model

2.2.2 NI-ICU ASW design and main functions

The NI-ICU ASW is based on the space-qualified RTEMS v 4.8 RTOS provided and tailored by EDISOFT Defence & Aerospace Technologies [39].

The ICU-ASW is designed to handle:

- the satellite/platform communication interface
- the NI-ICU/NI-DPUs communication interface
- the NI-OMA subsystems commanding and monitoring

and it is in charge of several tasks:

- management of the operating modes of NISP instrument
- TM/TC exchange with the SVM CDMU in accordance with European Cooperation for Space Standardization (ECSS) standards, the implementation of MIL-STD-1553 communication protocol and TM/TC Packet Utilization Standard (PUS) packet formatting are prescribed (see Table 2.4).
- distribution of TCs to NI-DPUs via 1553 link and to NISP electronics connected to ICU through the DAS.
- global monitoring of TM produced by all NISP instrument modules.
- management of the software maintenance through patch and dump functions.
- management of On-Board Time (OBT) and telemetries time tagging.
- execution of Failure Detection, Identification and Recovery (FDIR) processes.

PUS service code	Service description
1	Telecommand verification
3	Periodic telemetry reporting
5	Event reporting
6	Memory management
8	Command management
9	Time management
17	Connection test

Table 2.4: Description of PUS standard services foreseen in the Euclid Software.

The NI-ICU ASW is organized in several layers:

- a hardware layer, which is represented by the drivers managing the NI-ICU-connected devices under RTEMS.
- an operative system abstraction layer, allowing software development

regardless of the used RTOS.

- a low-level services layer (PUS services, device management, TC handling, TM packetization)
- a high-level components layer.

Figure 2.21 shows the conceptual structure of the ICU ASW, with its main tasks, their logical interconnections and the related interfaces.

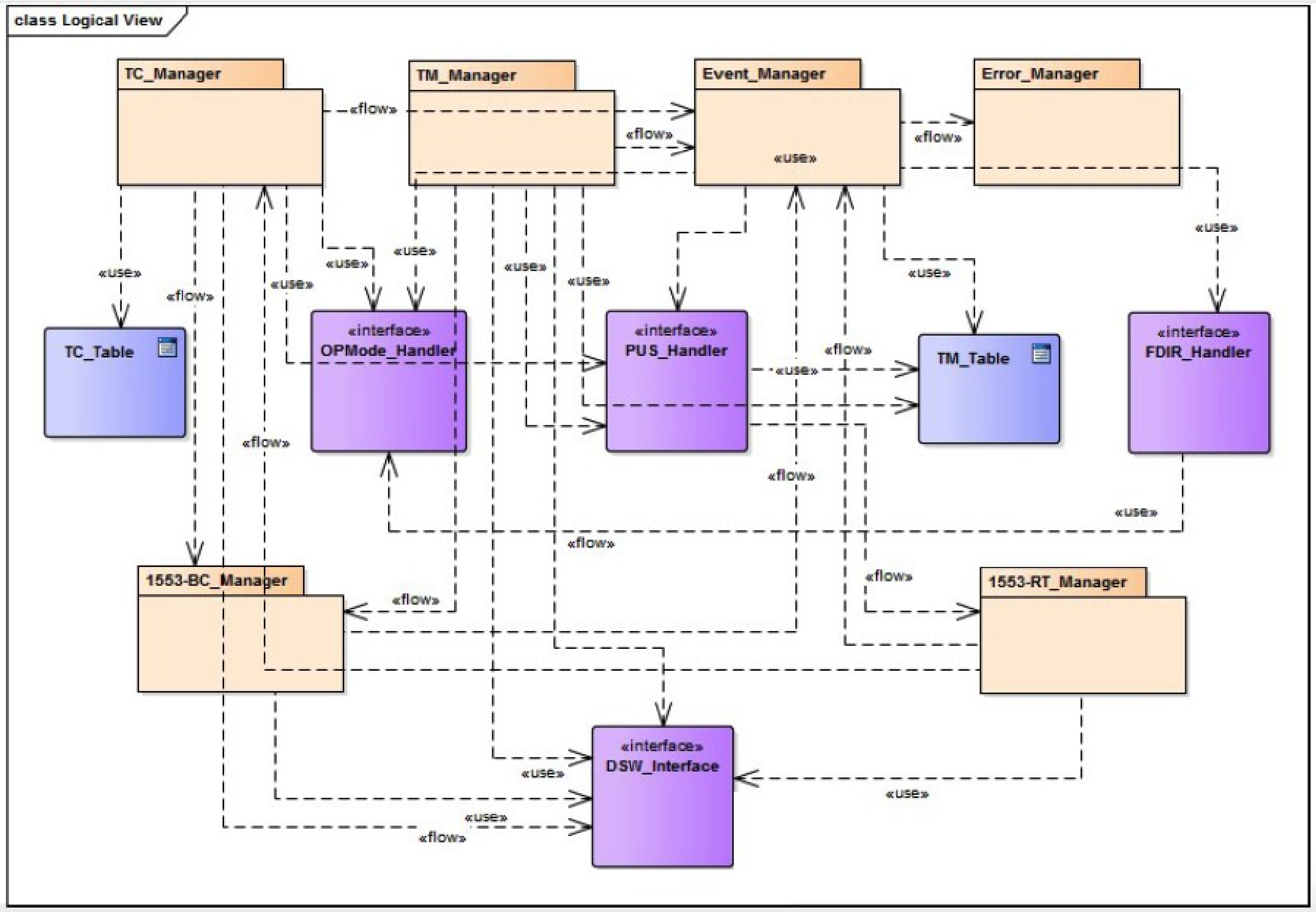


Figure 2.21: Block diagram of the ICU ASW.

The NI-ICU ASW is designed to handle the following categories of configuration data:

- configuration of the NI-ICU itself, which is installed on-board together with a redundant unit. The wheel operation profile is different between nominal and redundant unit because the home sensor is displaced by 180 degrees.
- configuration of the NISP instrument: it comprises the nominal

observation sequence settings, the NI-DPU readout mode selection and the configuration of the wheels and of the calibration unit.

- configuration of the NI-DPUs and of the related electronics.

The main tasks the ICU-ASW are:

- the ***command interpreter and sequencer***: it waits for the arrival of a TC and checks its formal validity, then it transmits the validated and decoded TC to the sequencer, which may execute an on-board procedure related to the command or deliver the command to the device in charge of its execution. The command interpreter is also responsible for the implementation of the PUS services.
- the ***time manager***: it receives the time information provided by the SVM via the corresponding MIL-STD-1553 interface and synchronizes the system time.
- the ***event manager***: it forwards events or alarms through the MIL-STD-1553 interface. Moreover, it can trigger the execution of FDIR processes.
- ***TM collection and formatting***: it is in charge of receiving and monitoring telemetry data sent by the active devices. It produces TM packets formatted in TM tables and sends them to the SVM; in case of anomalous values the intervention of the event manager is invoked.
- the ***error manager***: it manages software errors, providing error codes and sending events to the event manager.
- the ***SVM 1553 interface manager***: it consists of a 1553 RT and polls the 1553 buffer waiting for new data. When a TC is received, it is sent to the command interpreter. It reads incoming TM tables and transmits them to the SVM following a specific bus profile.
- the ***NI-DPU 1553 interface manager***: it consists of a 1553 BC, it sends TCs formatted according to an internal protocol and receives TM packets which are transmitted back. Moreover, it sends the OBT to the NI-DPUs, in order to maintain the internal synchronization of the system.

2.2.3 ICU ASW standard operation

The ICU ASW is launched by the Boot Software (BSW) that manages the start-up procedure, checks the integrity of the ICU CDPU EEPROM (containing 2 images of the NI-ICU ASW) and launches the selected ASW image.

The TCs are received by the ICU ASW and then either executed in the ICU itself, if they directly involve the NI-ICU action or the activation of one of the active devices, or are delivered to the DPUs. The expected rate of received TCs is typically one per second. Moreover, some commands (in particular those dispatched to the DPUs), have long execution times. A TC is processed according to the diagrams shown in Figure 2.22 or in Figure 2.23. Two types of TM packets are foreseen to be exchanged with the SVM in order to inform on the TC status: TM (1,1) that signals that the command has been received and TM (1,7) when a command has been executed or routed to the DPU that has accepted it. In case of failure the TM (1,2) or TM (1,8) are produced respectively.

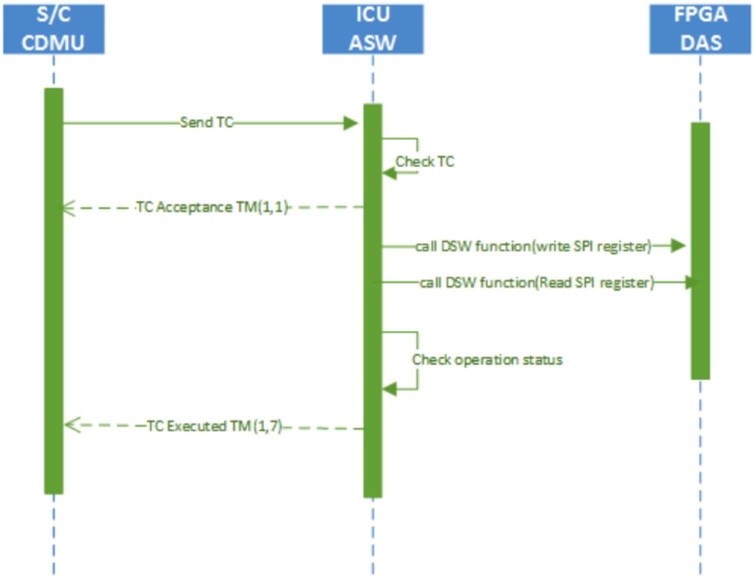


Figure 2.22: Diagram of a command to a device connected to the ICU trough the DAS Board.

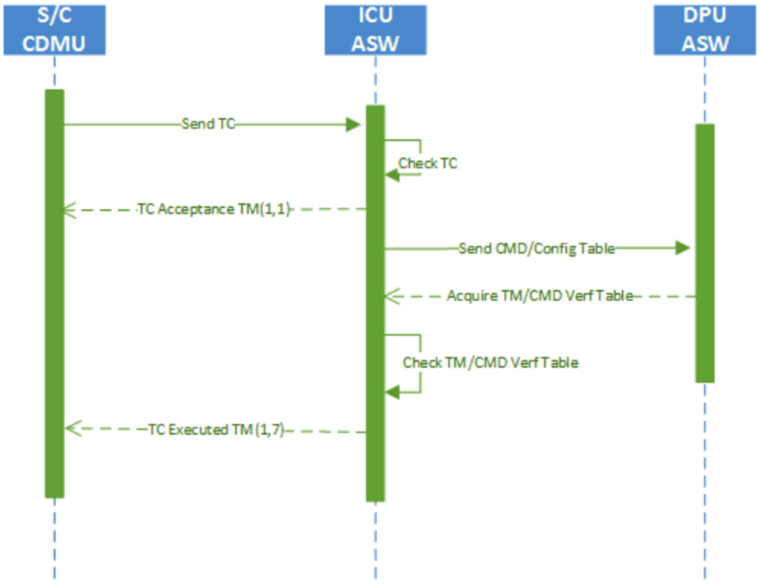


Figure 2.23: Diagram of a command to the DPU.

TC validation is performed by the ICU ASW according to the TC syntax check, operation mode and parameter check. Depending on the device, the TC successful completion report is issued based on measurements (for instance for the NI-CU) or on the basis of the logic state of the device (for the wheels).

The commands dispatched to the NI-DPUs are managed in a different way since the interface for TC/TM with the NI-DPUs is more complex. The TC acceptance is performed in a similar way as for the other commands. The TC completion report, successful or failed, is based on the DPU telemetry information contained in the Command Verification Table

A selection of parameters collected by the ICU ASW upon receiving telemetries from the various subsystems is regularly monitored and, if case of values exceeding thresholds, an error event is generated; in case of alarms, FDIR algorithms are triggered.

2.2.4 NISP operating modes

The NISP instrument operating modes are managed by the ICU ASW and are the same of the ICU ASW itself, which is in charge of handling the permitted transitions between modes [40].

An operating mode is defined by the set of hardware and software configurations of the sub-systems which are enabled and active. With the exceptions of ICU and DPUs, all NISP units can assume only ON and OFF operational states. The ICU and DPUs are able to perform transitions among several operating modes on the basis of specific selections rules managed by the ASWs.

Figure 2.24 shows NISP operating modes and allowed transitions, the indication of the mechanism used to implement the transition itself is also shown.

The currently foreseen NISP operating modes are the following:

- **OFF**: all NISP units are OFF. Wheels mechanism are powered off. NI-OMADA temperature is not controlled. This is the NISP mode at launch

- **BOOT**: in this mode only the ICU BSW is running. It is automatically started with the ICU power ON by a CDMU command from ground. BSW initializes and tests the processor module and memories and then launches the ICU ASW

- **STARTUP**: when the ICU has successfully completed startup and the ASW is running, it enters in STARTUP mode. It will stay in this mode until it receives from ground the command to go in STANDBY mode (or return in BOOT mode). The NI-TC, NI-FWA, NI-GWA and NI-CU cannot be activated in STARTUP mode (see Table 2.5). The two DPU's are OFF in STARTUP mode, full ICU telemetry is available from this moment

- **STANDBY**: in this mode ground commands can be sent to power ON and start the DPU units one by one. DPU boot procedure is divided in phases: the DPU BSW is executed automatically after the power ON, the DPU internal state is BOOT, afterwards a command from ground is required to launch the DPU ASW. After completing these operations, DPU is in CPU_SAFE mode and the DCU/SCE are OFF. The NI-FWA, NI-GWA and NI-CU cannot be activated in STANDBY mode. In this mode telemetries and events from FWA, GWA, CU, TC, ICU ASW and DPU BSW are available.

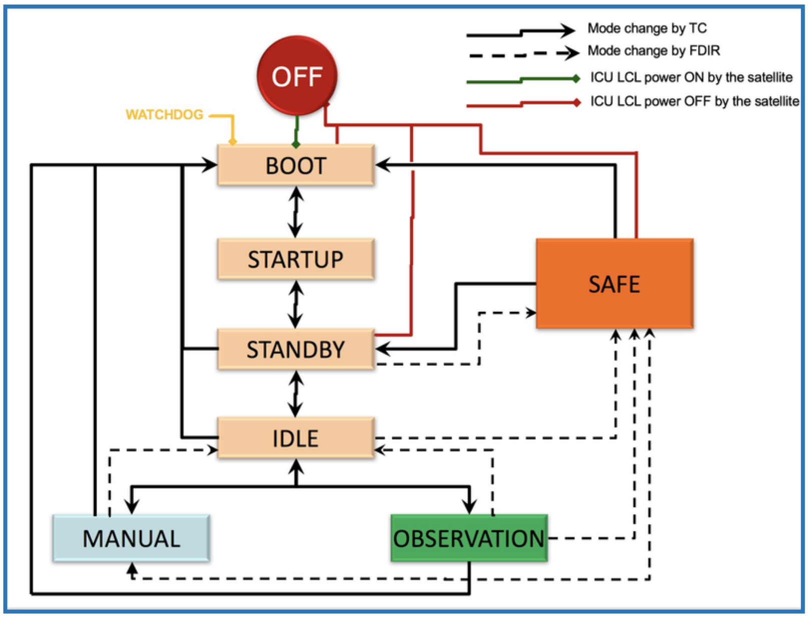
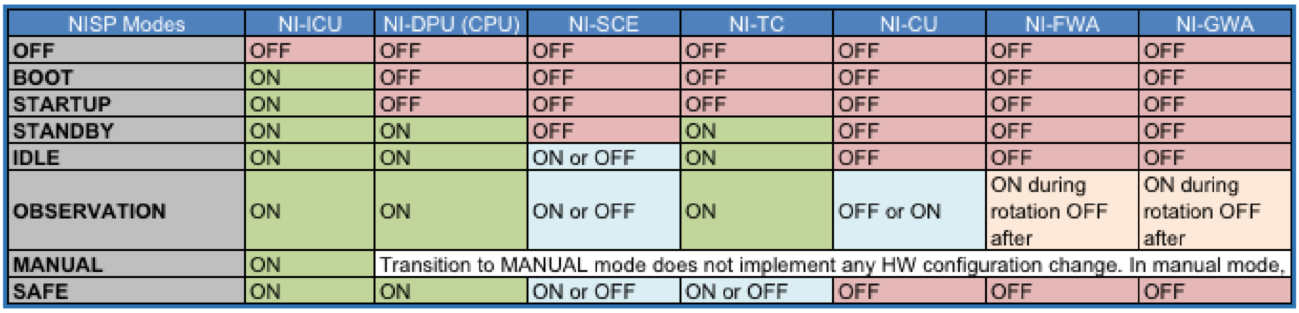


Figure 2.24: NISP operating modes diagram. Direct commands, sent by ground, to ask for mode change, are the baseline. Only the mode transitions shown in the figure are possible. Self-transition between stable modes is not allowed. NISP SAFE mode can be only invoked as the action of a NISP internal FDIR.

- **IDLE**: in this mode, DCU boards of each DPU can be powered ON and then the corresponding SCE can be booted. At the end of the last SCE initialization, NISP is ready to enter OBSERVATION mode, for nominal observations/calibration or in MANUAL mode. If one SCE fails to initialize and does not reach the IDLE state, the SCE is powered OFF the NISP is set back to SAFE mode, waiting for ground intervention. The full NISP telemetry is available and transferred to the SVM.

- **MANUAL**: this mode shall be used only during diagnostics, debug and any other non-routine operations. The goal of the MANUAL mode is to enable manual control (as much as possible) of the sub-systems.



NISP Modes	NI-ICU	NI-DPU (CPU)	NI-SCE	NI-TC	NI-CU	NI-FWA	NI-GWA
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
BOOT	ON	OFF	OFF	OFF	OFF	OFF	OFF
STARTUP	ON	OFF	OFF	OFF	OFF	OFF	OFF
STANDBY	ON	ON	OFF	ON	OFF	OFF	OFF
IDLE	ON	ON	ON or OFF	ON	OFF	OFF	OFF
OBSERVATION	ON	ON	ON or OFF	ON	OFF or ON	ON during rotation OFF after	ON during rotation OFF after
MANUAL	ON	Transition to MANUAL mode does not implement any HW configuration change. In manual mode,					
SAFE	ON	ON	ON or OFF	ON or OFF	OFF	OFF	OFF

Table 2.5: NISP modes table showing status of NISP sub-systems and units in the various operational modes, contingencies are not taken into account.

- **OBSERVATION**: this is the normal operational mode of NISP for science and calibration. The DPUs can be commanded to go to OBSERVATION mode and exposure cycles can be configured. Observation sequences of commands are defined by ground in the mission timeline. This sequence of command contains the commands to: configure the two DPUs, place the FWA and the GWA in the requested position and finally start each exposure. The DPU ASW shall detect the end of each exposure and report it in the telemetry, consequently an event shall be generated by the ICU ASW. The full NISP telemetry and the science data to the MMU are available in this mode.

- **SAFE**: this is a failure mode reached by the ICU ASW either as a consequence of a ICU or a DPUs error. While in SAFE mode, the allowed commands are limited to Mode transitions, Software reset requests, FDIR enable/disable commands and PUS services 3 (periodic telemetries), 5 (event generation), 6 (memory transfers),9 (time management) and 17 (connection test). In case of anomaly, an event with the failure code shall be immediately transmitted to the CDMU and the ICU ASW shall isolate the anomaly by putting the ICU and the two DPUs in SAFE mode. There are different cases:
    - if the anomaly is linked to the FWA, GWA or LED, the ICU FWA, GWA and LED drivers shall be switched OFF immediately. The NI-SA and NI-DS heater shall not be modified. The two DPUs configuration shall not be modified.
    - if the anomaly is linked to the NI-SA or NI-DS heaters, the ICU heaters and the NI-CU drivers shall be switched OFF. If the anomaly occurs during FWA

or GWA rotation, the rotation must not be interrupted and the FWA / GWA drivers shall be switched off at the end of the rotation. The two DPUs configuration shall not be modified.

- if the anomaly is not linked to FWA / GWA and if the anomaly occurs during a FWA / GWA rotation, the FWA / GWA rotation shall not be stopped
- if the anomaly is linked to an ICU over temperature (pre alarm limit), all the ICU drivers shall be switched OFF. The two DPUs configuration shall not be modified. In case the alarm limit is exceeded, the ICU shall ask CDMU for an immediate power OFF
- if the anomaly is due to a DPU, the faulty DPU shall manage by itself the actions to take to isolate the failure.

In SAFE Mode the full ICU telemetry, even if not completely meaningful, is available.

2.2.4.1 NISP Instrument nominal operation

After LEOP, during the first two days of operations, the LCL of the ICU nominal will be powered ON and the NISP shall be put in STANDBY to allow instrument cool-down monitoring and to perform a first health check of the ICU. The interface temperature of the NI-FPA shall be controlled in order to keep the temperature of the detector 10K above the temperature of the NI-OMA during the cooling down. The DPU 1 and the DPU 2 nominal LCL’s shall be turned ON and put in CPU SAFE (the DCU/SCE are OFF). This will allow the verification of the DPU health and the checking of the correct communication with the ICU. At the end of the spacecraft decontamination phase, the NI-SA heater shall be powered off and the NI-FPA heaters shall be set at proper power. When the NIOMA temperature will be at 150K, the NI-FPA detector heater shall be switched OFF in order to allow the cooling down of the NISP detectors. When the SCA temperature will be below 120K, all the DCU/SCE of DPU 1 and DPU 2 will be powered ON. Afterwards NISP will be moved to OBSERVATION mode. One day before the expected end of the detector cooling down, the NI-SA heater power shall be adjusted, on a daily basis, until the requested operational temperature is obtained. When the detector temperatures are stabilized (typically less than 5mK variation during 2000 s) the NISP final commissioning can be completed and the Performance and Calibration procedures will be exercised and validated before the formal start of the Performance Verification (PV) phase. All calibration observations will be performed in OBSERVATION Mode. MANUAL mode commanding will be available for diagnostic, debugging, or maintenance operations.

After the PV phase the nominal survey can be started, for each field of view the nominal sequence of exposures has the characteristics shown in Table 2.6. The nominal observing sequence for one dither will be repeated 4 times per field. The Dark exposure will be performed only during the slew at the end of the 4th dither. The foreseen NISP instrument nominal operation plan is reported in the following table.

	Exposure duration (s)	**FWA**	**GWA**	**Data output**	**Specific S/C operation**
Spectro (1a)	574	open	1,2,3,4	1 full image 1 Chi2 image (8 bit) 3-5 raw lines	Nominal survey pointing
Photo Y (1b)	124	Y	open	1 full image 1 Chi2 image (2 bit) 3-5 raw lines	Nominal survey pointing
Photo J (1c)	80	J	open	1 full image 1 Chi2 image (2 bit) 3-5 raw lines	Nominal survey pointing
Photo H (1d)	82	H	open	1 full image 1 Chi2 image (2 bit) 3-5 raw lines	Nominal survey pointing
Dark	Y, J, H	Closed	open	>=1 full image >=1 Chi2 image (2 bit) 3-5 raw lines	Nominal slew

Table 2.6: Exposure configuration of one dither during a nominal survey field pointing. The baseline is to have a dark sequence with photometric science readout modes (124s,80s and 82s respectively).

3 AIV of the NISP Warm Electronics

This thesis aims to illustrate the NISP Warm Electronics Assembly Integration Verification and Test (AIV/AIT) process. The process is presently on going and it has been completed up to the delivery of the NISP Avionic Model (NISP AVM). It will be continued up to the Flight Models as soon as the hardware will be available. The AIV is outlined from the first stages of the design, as soon as the requirements are identified. I have been involved in this process with INFN Padua Group for the last three years. I was involved in the setting up of AIV software tools, and afterwards in the DPU ASW integration, NI-WE functional tests and AIV of the NISP AVM model. All those activities will be described in this chapter and in the following ones.

In this chapter I will briefly review what is intended for AIT/AIV procedure in a space mission according to the European Cooperation for Space Standardization (ECSS) then I will describe the NISP Model Philosophy, the NISP AIV Test Plan and the software tools prepared for the NISP Warm Electronic AIV/AIT.

3.1 Verification and Validation procedure standard

The European Cooperation for Space Standardization (ECSS) has been established to develop a coherent, single set of user-friendly standards to be applied to all European space activities. According to the ECSS, the strategy to keep reasonable costs while ensuring to build successful equipment is to develop different models with programmatic constraints, and for each model a verification strategy and a test program that takes into account the development status of the model have to be implemented.

The typical project life cycle is represented in Figure 3.1; it is divided in 7 phases:

- Phase 0 – Mission analysis/needs identification
- Phase A – Feasibility
- Phase B – Preliminary Design
- Phase C – Detailed Definition
- Phase D – Qualification and Production
- Phase E – Utilization

- Phase F – Disposal

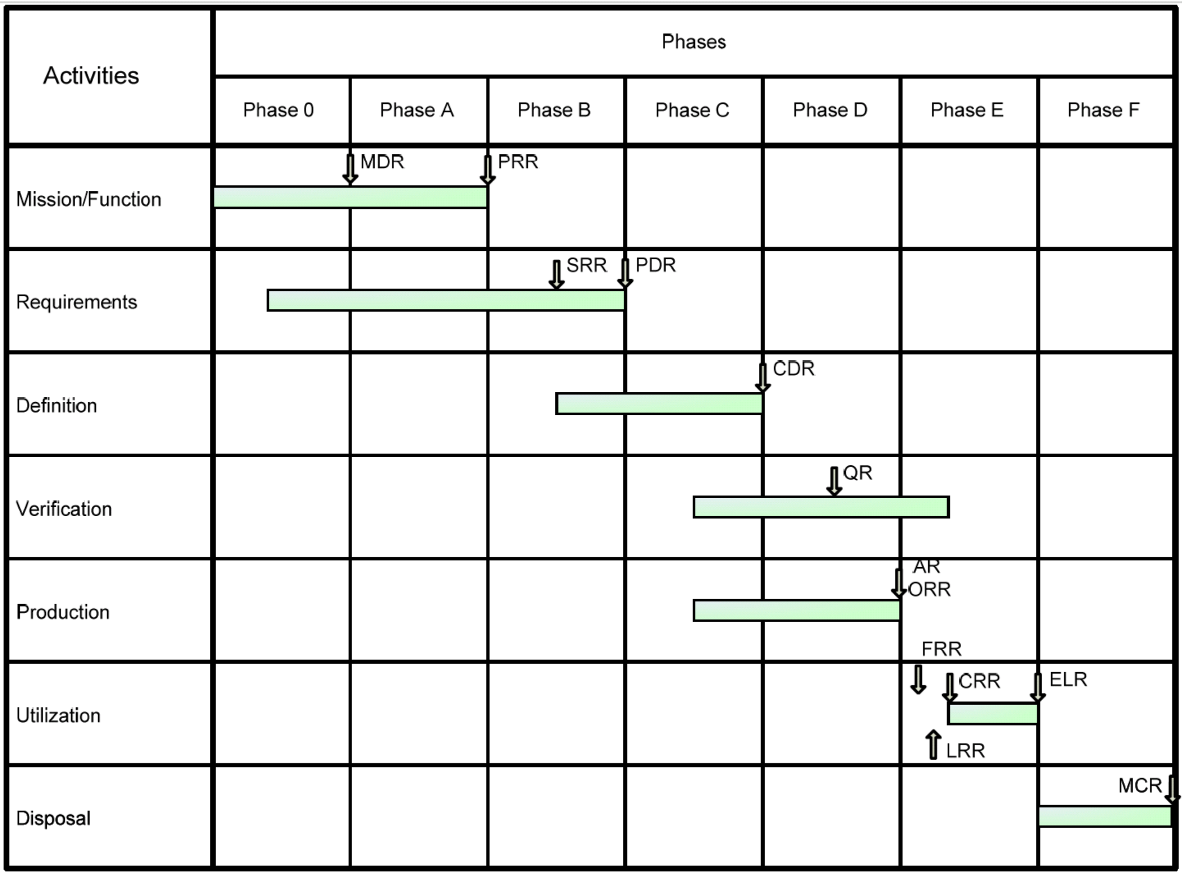


Figure 3.1: Typical project life cycle. The different phases and the related activities and reviews are outlined.

Project phases are linked to the development and test activities of the equipment; they are usually closed by reviews which represent milestones in the development.

At the end of phase B the design of the item is completed and all the requirements have been fixed. A Verification Program has been established, which includes the adopted Model Philosophy, and a Risk Assessment has been carried out. The verification aims to demonstrate, through a dedicated process, that the equipment meets the specified requirements and that it is capable of fulfilling the mission needs.

Two documents are produced at this stage: the *Verification Plan* and the *Assembly, Integration and Test Plan*. These two documents can be combined in one document, the *AIV Plan*.

The Verification can be performed at different levels:

- Equipment

- Subsystem
- Element
- Segment
- Overall System

The Verification is performed at different stages in the project life-cycle, the usual stages are:

- Qualification
- Acceptance
- Pre-Launch
- In Orbit (including commissioning)
- Post Landing

The verification process starts near the end of phase C where the design is definitely reviewed and completes the first stage at the end of phase D. The importance of the verification cannot be overemphasized, experience has demonstrated that when the verification process is not conducted properly the risks of late discovery of design or workmanship problems increases drastically, leading to retarded schedule and increase of costs.

In the ECSS an iterative chain is defined of *customer-supplier* that starting from the *top level customer* ends with one or more *lowest level supplier* (see Fig 3.2). In each intermediate level the customer has the role of supplier for his higher level customer.

The AIV Plan is presented by the supplier but needs to be accepted by the customer. Each customer has the responsibility, with the higher level customer, to ensure that his suppliers are compliant with project requirements and constraints.

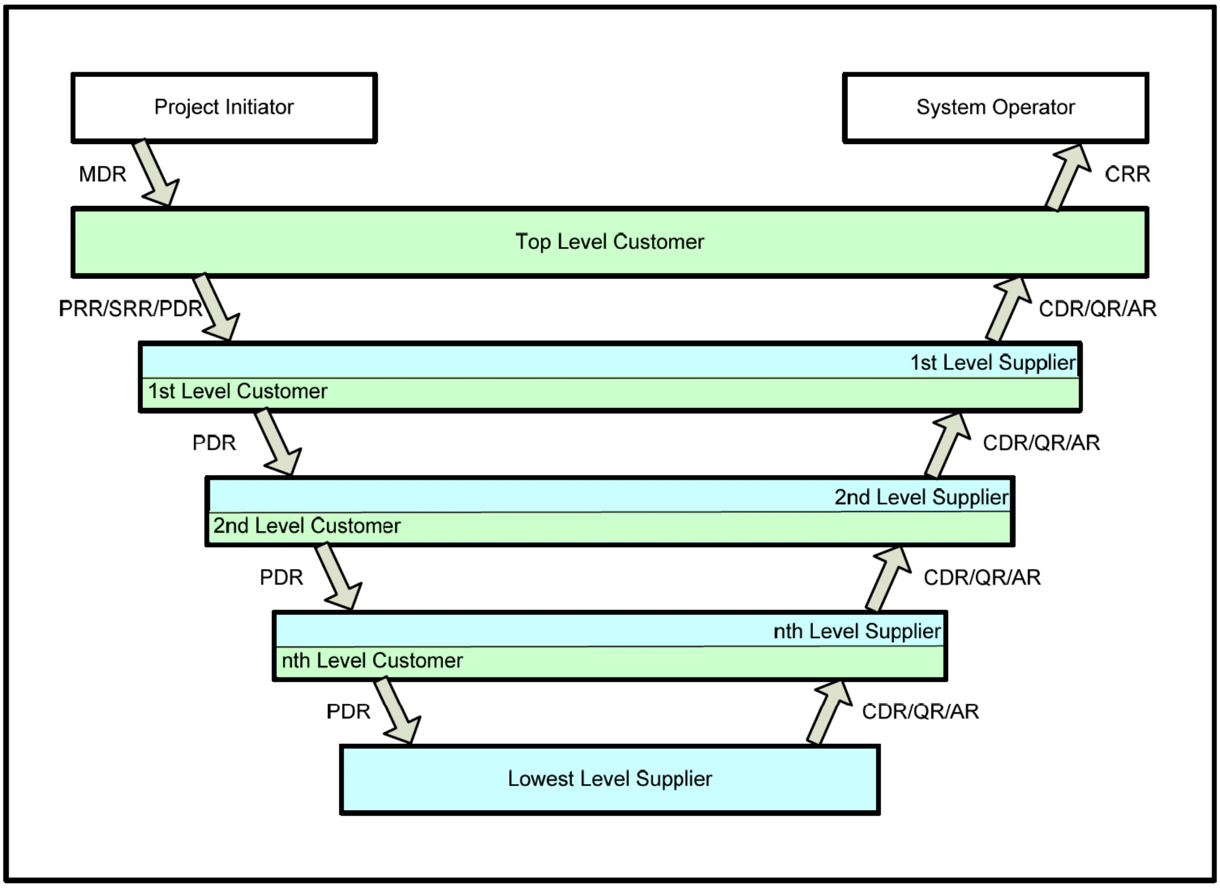


Figure 3.2: Customer Supplier Hierarchy and V-model for PDR/CDR

The usual way to ensure the correct implementation and planning is through reviews. From the Preliminary Requirements Review (PRR) to the Preliminary Design Review (PDR) the sequence of reviews is *top down*, it starts from the top level customer and his suppliers and then from these suppliers, in the role of customers, with their suppliers down, in the customer supplier chain, to the lowest level supplier. The main objectives of the PDRs are:

- the verification of the preliminary design against project and system requirements
- the release of the documents Management Plan, Engineering Plan and Product Assurance Plan
- the release of the Product Tree, and the Specification Tree
- the release of the Model Philosophy and the *Verification Plan*

From the *Critical Design Review* (CDR) to the *Acceptance Review* (AR) the sequence of reviews is reversed to *bottom up*, starting from the lowest level suppliers and their customer, up to the first level suppliers and top level customer. This is called *V Model* (see Figure 3.2). The main objectives of the CDR are:

- to assess the qualification status of all processes and their readiness for deployment
- to confirm the compatibility of all interfaces
- release the final design
- release the final AIV Plan
- release flight hardware/software parts and testing
- release the user manuals

The verification process is monitored in its execution by the *Verification Control Board* (VCB) composed by representatives from the supplier and from the customer. The VCB monitors the verification process and assesses that requirements are met.

The main four objectives of verification are:

- demonstrate the qualification of design and performances
- demonstrate that the product respects the qualified design, there are no workmanship defects and is acceptable for use.
- confirm product integrity and performance
- confirm that the overall system is able to fulfil the mission requirements

In order to reach a satisfactory verification, all the HW/SW tool and simulators used in the process must undergo a verification procedure. At the end of the testing activities a test report for each test has to be prepared. In this document all the steps and parameters of the test as well as data produced and telemetries will be documented with emphasis on the requirement close-out, including any deviation.

If any problem or non-compliance with the design or the requirements appears a *Non Conformance Report* (NCR) is prepared. Finally, a verification matrix with all the requirements and test results is prepared, for approval by the customer.

Validation is achieved through the Verification process demonstrating that the item can accomplish reliably his function.

Up to now the NISP Instrument is in the Middle of Phase D and AIV/AIT activities are on-going up to the integration and delivery of the Flight Model that will start at the end of 2018. NISP-WE is a logical sub-element of the NISP instrument, so it follows the same model philosophy and the AIV/AIT activity follows the same path.

3.2 NISP model philosophy

Four NISP models are foreseen consequently, four models for the NISP Warm Electronic are foreseen [41]:

- **NISP Structural and Thermal Model (STM)**

This model was prepared to validate the design of the NI-OMADA structure and thermal control. It has been successfully tested with vibration and Thermo-Vacuum (TV) tests. Concerning the Warm Electronics, no tests were foreseen for this model. This STM model has been delivered to ESA (see Figure 3.3).

- **NISP Engineering Model (EM)**

The NISP EM model is under development. It is built with all NISP subsystems Qualification Models (QM) except the structure and the optics. Flight representative harness will interconnect the NI-ICU, NI-DPU, NI-DS, NI-TC, NI-FWA, NI-GWA and NI-CU as for flight. The NISP EM will be tested under vacuum at cold operational temperatures. The purpose of this model is to qualify the functional behaviour of NISP (only the nominal side, no redundancy) at cold operational temperature, to perform EMC conducted susceptibility and emission and to prepare the full NISP TV performance to be done on the NISP FM. In this model the Warm Electronics will be composed by the DPU/DCU EQM model and ICU EQM model.

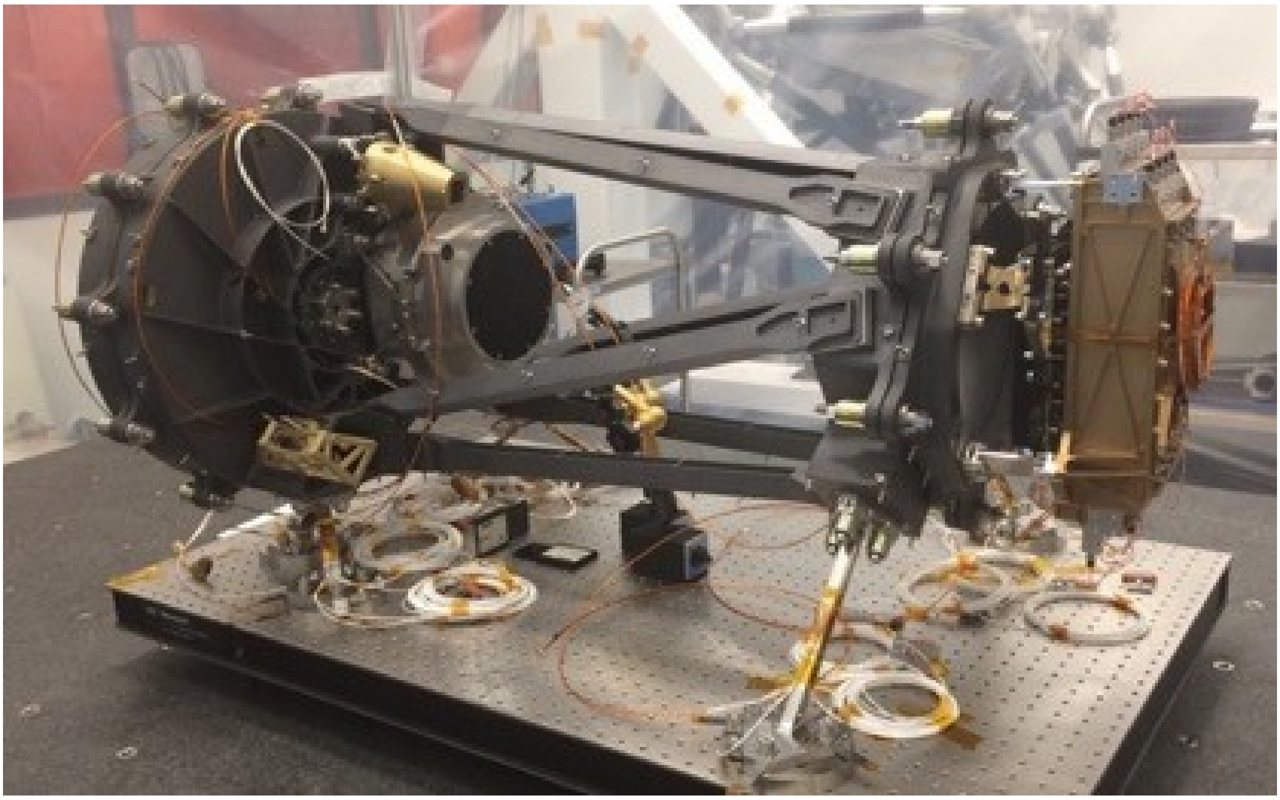


Figure 3.3: NISP STM model

- **NISP Avionic model (AVM)**

The NISP Avionic Model is composed by a DPU/DCU EM with only one DCU, an ICU EM, a NI-OMA electrical simulator and a SCE Engineering model, no redundancy is present (see Figure 3.4). The objective of the AVM is to test, at warm temperature, the NISP functional performances, the command flow from SVM and the science data and housekeeping data production. CDR level versions of the DPU ASW and of the ICU ASW are installed on the AVM. The NISP AVM has been delivered to ESA in June 2018.

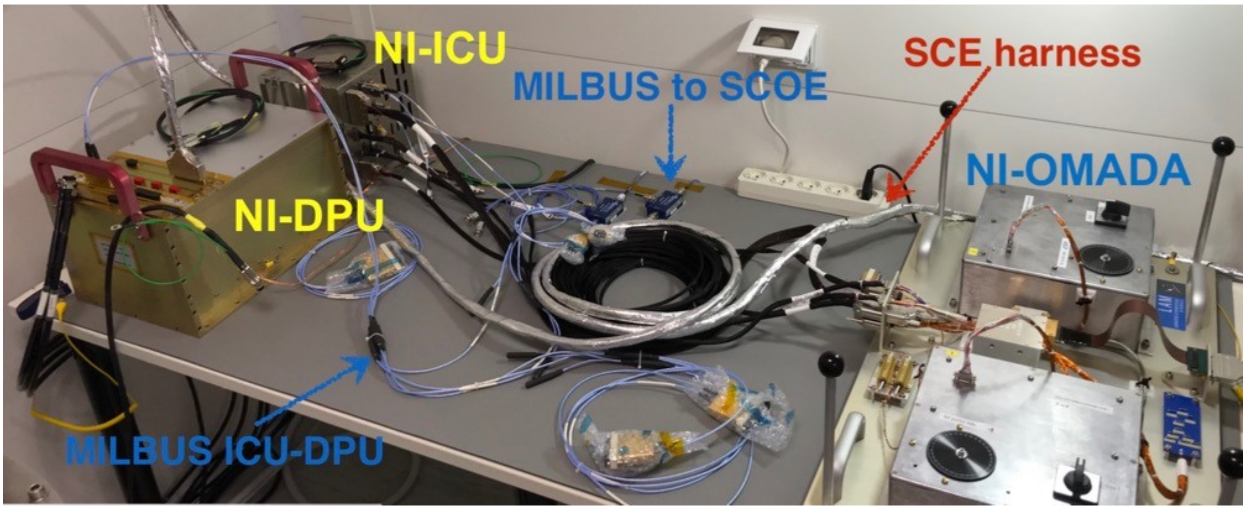


Figure 3.4: NISP AVM model

- **The NISP FM model**

The NISP FM integration is ongoing and is expected to be completed in 2019 (except FM detectors). The first TV test will be performed with this quasi-FM configuration. When the SCE FM will be available, they will be installed on the NISP FM and a second TV test will be done in order to finalize the SCS FM characterization. The NISP FM will then go to vibration test and finally to TV and performances / calibration test will be done. In the FM the NI-WE is composed by the NI-ICU FM and by the NI-DPU/DCU FM (2 boxes).

3.2.1 NISP-WE model philosophy

The NI-WE is the assembly of the NI-DPU and NI-ICU. Therefore, the NI-WE model philosophy reflects the NI-DPU and NI-ICU model philosophy.

During the NISP development, additional models have been introduced both for the NI-ICU and the NI-DPU/DCU. They are used to test early HW design/functionality and to allow on-board SW development (ASW and basic SW/HW drivers).

3.2.1.1 NI-ICU Model philosophy

- **Elegant Breadboard (EBB):** this model is built by CRISA to test NI-ICU HW configuration and to allow Basic SW development (HW drivers) and ASW development. The build standard is reported in Table 3.1. The NI-ICU EBB model is commercially available to the EC: 2 units are in Italy (INAF Torino and INFN Bologna), 2 in Spain (UAH and UPCT).

- **Engineering Model (EM):** this model has the same HW design as the FM unit. The build standard is reported in Table 3.1. This model is available to the NISP Italian team for ASW development and testing. It is also planned to pre-integrate it with the NI-DPU E(Q)M for early compatibility and functional test. Afterwards the ICU EM will be part of the NISP AVM and it will be delivered to ESA for the AVM test campaign in TAS-I.
- **Engineering Qualification Model (EQM):** this model will be delivered to the EC to be integrated in the NISP EM and tested in TV environment. The build standard is reported in Table 3.1.
- **Flight Model (FM):** this is the fully functional, flight standard model. The build standard is reported in Table 3.1. The NI-ICU FM will be delivered to Italy for early integration with the NI-DPU FM and Focal Plane simulator. This approach has been planned to de-risk the integration at NISP level with early compatibility test. After these test at NI-WE level (Flight model), the NI-ICU and the NI-DPU/DCU will be delivered to EC at LAM for integration at instrument level. After the test at instrument level, the NISP PFM (which is the build standard at instrument level) will be delivered to ESA for integration in the PLM and on the S/C.

Model	**CPU**	**1553 interface**	**DAS Board**	**LVPS Board**	**Boot Software**	**Application software**	**Build standard**	**Redundancy**
EBB	FM	2 channels	--	--	--	Development version	COTS	--
EM	FM	FM	FM	Complete design	v1	v.05 (pre-CDR)	Extended range	--
EQM	FM	FM	FM	FM	FM	v1 (post-CDR)	Extended range	--
FM	FM	FM	FM	FM	FM	v2	Extended range	YES

Table 3.1: NI-ICU build standard for the available models. COTS is an acronym for parts defined *Commercial Off-the-Shelf components.*

3.2.1.2 NI-DPU/DCU model philosophy

The NI-DPU/DCU model philosophy was originally planned on 3 models: STM, EQM, and FM. During the development, two additional models were introduced to allow the development of the ASW on a representative HW and to anticipate the test of the SCE interface (see Table 3.2).

- **NI-DPU Elegant BreadBoard (EBB):** this model was developed and built by the INAF Padua team in the early project phase (already in phase A). It is composed by a Motorola 5100 CPU board with a commercial MIL-BUS 1553 I/F.
- **NI-DPU/DCU Demonstration Model (DM):** this model was built by OHB-I to test the DCU/SCE interface using a representative DCU board (no power section) and to allow development of the DPU ASW v0 in a representative environment. It is based on a commercial Maxwell CPU board, a DBB, a DRB and a DCU prototype. These boards are mounted on a commercial CPCI crate. Basic SW drivers can also be tested and integrated in the DPU ASW in a FM representative configuration. This is an internal INAF development model and it has not been delivered to EC or ESA.
- **NI-DPU/DCU Engineering Model (EM):** this model is built with the NI-DPU/DCU

flight configuration. Although it can host 8 DCU boards it is used with 1 DCU board so it can be operated with only one SCE. The NI-DPU EM boards are mounted on a flight-like box. This model is delivered to ESA as part of the NISP AVM.

- **NI-DPU/DCU EQM**: this model is composed of 1 out of 2 NI-DPU/DCU boxes. No redundancy is present and only 1 Maxwell board is installed. The EQM unit is completely equivalent to a FM one, although components are not at flight-standard. The mechanical structure of the Unit is flight representative. Boards components are of extended range (compatible with vacuum environment), while the Maxwell board is a FM unit.
- **NI-DPU/DCU Proto Flight Model (PFM):** this is the complete flight unit. It is composed by 2 boxes (each identical to the other). Each one is able to control 8 SCSs. The first delivered is called PFM, since it will be submitted to PFM environmental test. The second one, being identical to the first one, will be submitted to acceptance environmental test (FM-level) only. The NI-DPU/DCU build standard is flight-level. This model is a deliverable to EC/LAM and, as a part of the NISP FM, to ESA for further integration.

MODEL	CPU	1553	DBB	DRB	DCU	PSB	ASW	Redundancy
EBB	COTS	COTS	COTS	--	--	--	prototype	--
DM	FM	COTS	FM	EM	EM	--	v0	--
EM	FM	FM	FM	FM	FM (only 1)	FM	v0.5	--
EQM	FM	FM	FM	FM	FM (8 DCUs)	FM	v1	--
FM	FM	FM	FM	FM	FM	FM	v2	YES

Table 3.2: NI-DPU models

3.3 NISP AIV Test Plan

According to the NISP product tree (see Figure 3.5), the NI-WE should follow its own AIV before the integration in the NISP Instrument [41]. This approach is valid for all the models.

As shown in Figure 3.6 the NI-WE AIV is expected to be performed at first on the single units detailed in the product tree, NI-DPU HW, NI-DPU ASW, NI-ICU HW, NI-ICU ASW.

The activities on the Hardware part are performed by the suppliers, OHB-I for the DPU and CRISA-Spain for the ICU. The DPU HW validation is performed trough electrical, functional, Thermo Vacuum (TV) and *Electromagnetic Compatibility* (EMC) tests. These tests are performed using a prototype ASW version (provided by INAF Padua) and a dedicated Electrical Ground Support Equipment (EGSE) which includes MIL-STD 1553 interface, Spacewire interface and SCE simulators, called Test Equipment (TE).

The ICU HW validation is performed by CRISA using an EGSE but without the ICU ASW.

The integration of the on-board software on the units is performed by INFN. Padua group is responsible for the DPU ASW integration while the Bologna Group is responsible of the ICU ASW integration. The integration is foreseen for EM, EQM and FM models and dedicated AIV tools were prepared.

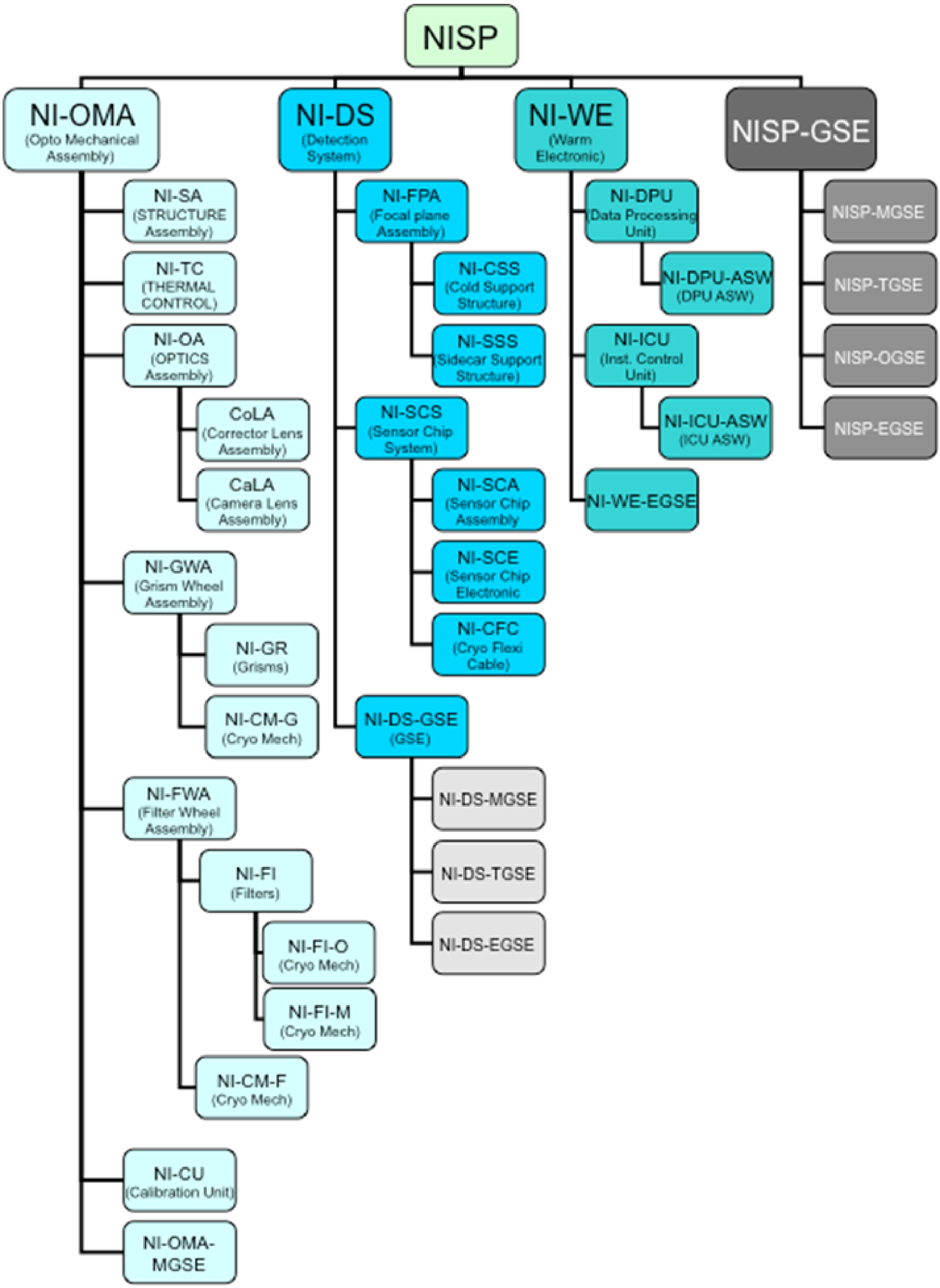


Figure 3.5 NISP Product Tree [41].

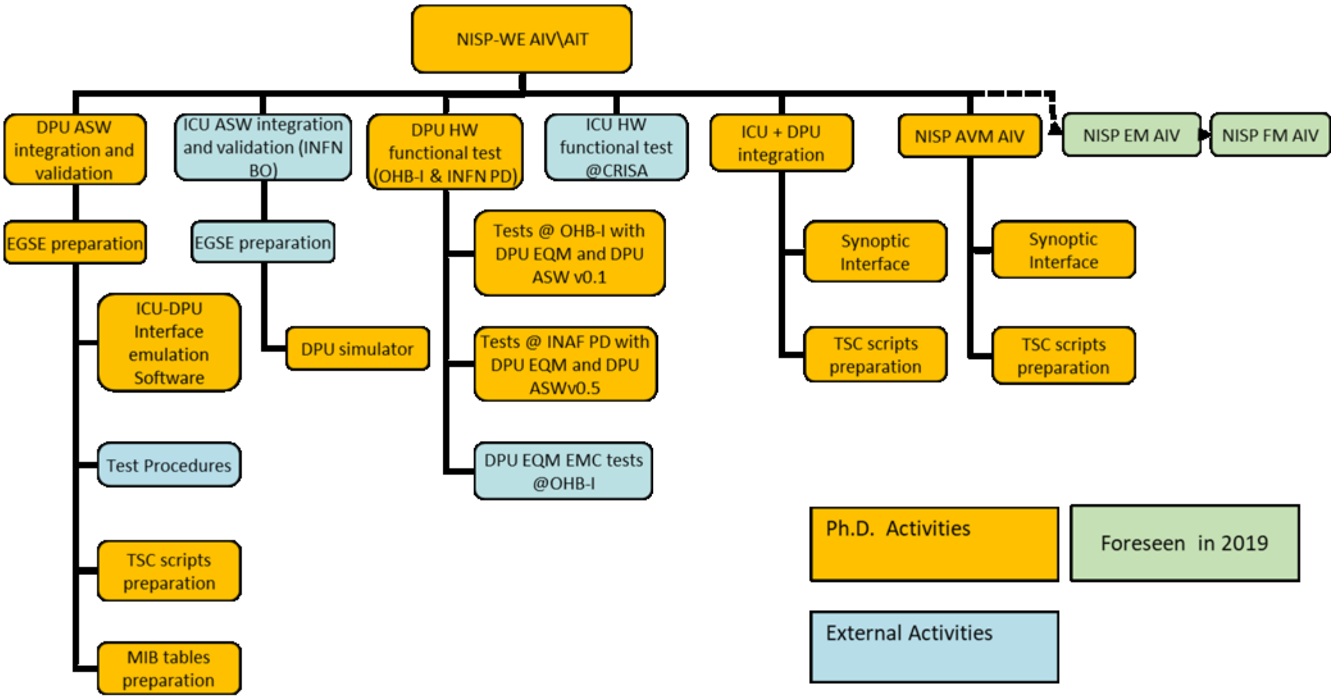


Figure 3.6: Work breakdown structure of the NISP-WE AIV/AIT plan.

The work breakdown structure for NISP AIV/AIT is shown in Figure 3.6. I gave my contributions to the packages highlighted in yellow, up to NISP Avionic Model (AVM) delivery to TAS-I. Tests on NISP EM and NISP FM models are foreseen in 2019.The activity is arranged in parallel tasks up to ICU and DPU Application software integration, afterwards the plan moves to ICU+DPU coupling tests and, in the end, NI-OMA is added. Such strategy is repeated for all the foreseen NISP models (AVM, EM and FM).

3.4 Electrical Ground Support Equipment (EGSE)

In order to test the requirements, it is always necessary to produce dedicated equipment that simulates flight equipment or simplified models of them. This is necessary at every stage of the verification and of course it must take into account the development status of the unit under test.

All this equipment, the simulators, the software, the testing framework and the testing facilities as well are normally referred to as ***Electrical Ground Support Equipment (EGSE)***. Ground segment software is generally more complex than the flight one. The elements of the ground segment are usually developed to work within a generic and mission independent highly customizable infrastructure. Each project builds the needed functionality within this framework for addressing mission specific needs. This is done not only to reuse an important part of the software, but also because the reuse of the infrastructure solves many engineering design aspects that work as a reference system architecture and establish standard interfaces among the different parts. Furthermore, the software developed to be interfaced to this infrastructure does not need to start from the system related software requirements engineering phase, because it uses the system design provided by the infrastructure.

Ground software is requested to undergo a validation procedure. Often the developed software relies on commercial software for which a validation campaign is not feasible since the source code is not available and limited information regarding their test coverage is available; the reliability of these tools is founded mainly on the experience. On the other hand, tools developed for testing purposes must be validated for their intended use. The risks in using a non-validated tool are to define a wrong system requirement, or fail to detect non-compliance of the system.

3.4.1 EGSE standard components

I have been involved in the testing of DPU functions, for both EM and EQM models; in particular, I contributed to the development of the software to be integrated in the testing–environment and in the development of the test scripts. The NI-WE AIV plan foresees that each unit, ICU and DPU, has to be tested separately. In particular, we have to verify the ability of the DPU Hardware and Application Software to control and acquire images from the SCE The full set of requirements and the verification strategy is described in [42] and it will be discussed in detail in the next chapter.

In order to test DPU hardware functions it was necessary to have a working version of the ASW, tagged as version V.0.3, and to run the entire test using simulators of the ICU-DPU interface and of the focal plane electronics.

The verification of the DPU electric requirements has been carried out by the hardware supplier (OHB-I), INAF Padua prepared a working version of the ASW.

The DPU Test Equipment (TE) [43] is prepared by Temis and provides the power supply for the DPU unit, eight SCE Simulators, the MILBUS-1553B interface to issue commands to both DPU-BSW and DPU-ASW, and two Spacewire links for data logging (see Figure

3.7). The TE includes two workstations that control the subsystems, an Isolation Transformer and a local grounding reference.

The control of all interfaces is mediated by the Test Sequence Controller (TSC) application described in the next section via Tool Command Language (TCL) scripting.

The INFN Group had to supply the software that is able to interface the TSC with the MILBUS-1553B hardware and the Test Scripts (TSEQ) to verify all the requirements.

The TE includes also SideCar Simulators (SCS), they give the possibility to change on request the current loads, allowing testing the OverCurrent (OVC) protection of the DCU boards; the testing of transmissions in the Spacewire channels requires an external monitoring tool.

After a first test campaign held in Milan at OHB-I venue in July 2017 a set of improvements on the DPU-ASW and Test Sequences were request by the OHB-I quality assurance in order to held a more reliable test campaign.

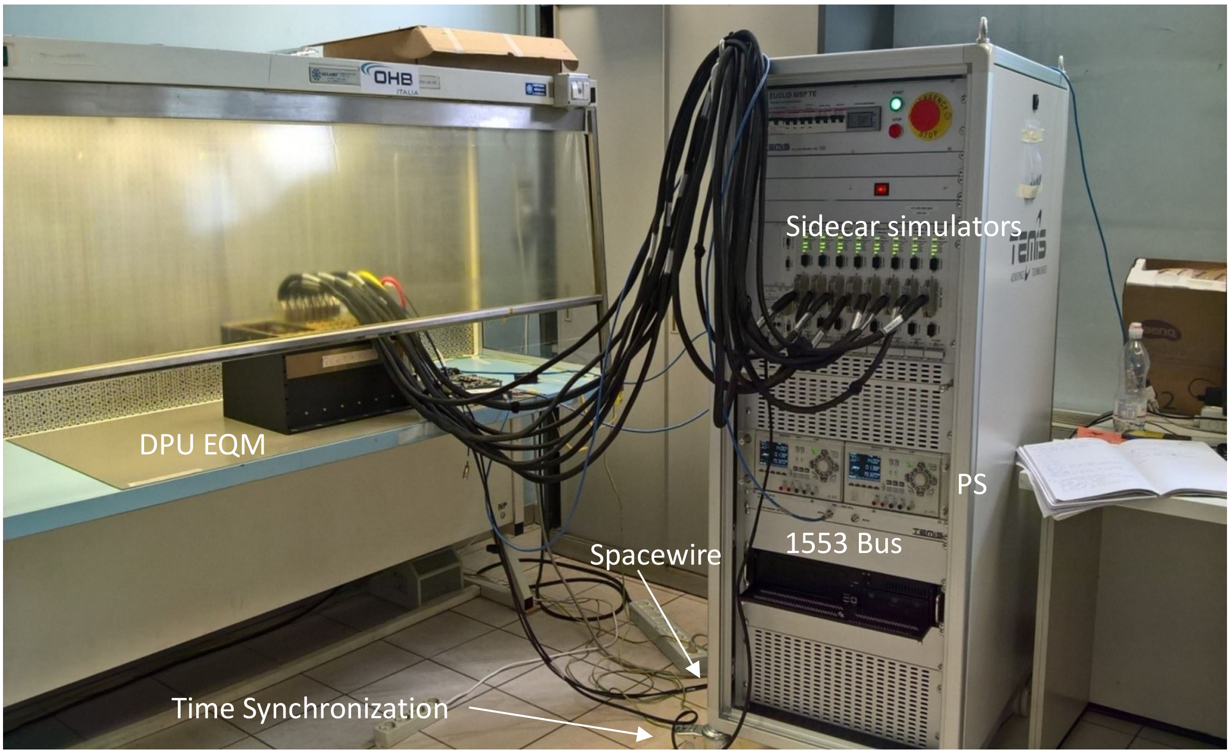


Figure 3.7: Test Facility at OHB-I, the DPU is connected to the TE.

A second test campaign was run on March 2018 in “Osservatorio Astronomico di Padova” premises to validate the requested upgrades, then finally the DPU and the TE where delivered to OHB-I to execute the final tests and step into phase D.

In the following paragraph there is a detailed description of the software environment and tools used to develop the custom EGSE software.

3.4.1.1 Test Sequence Controller (TSC)

Test **S**equence **C**ontroller (TSC) [44] is an application, developed by TERMA, that allows the user to control, through TCL scripting, the Equipment Under Test (EUT) and all the equipment necessary to simulate the environment where the EUT will actually work.

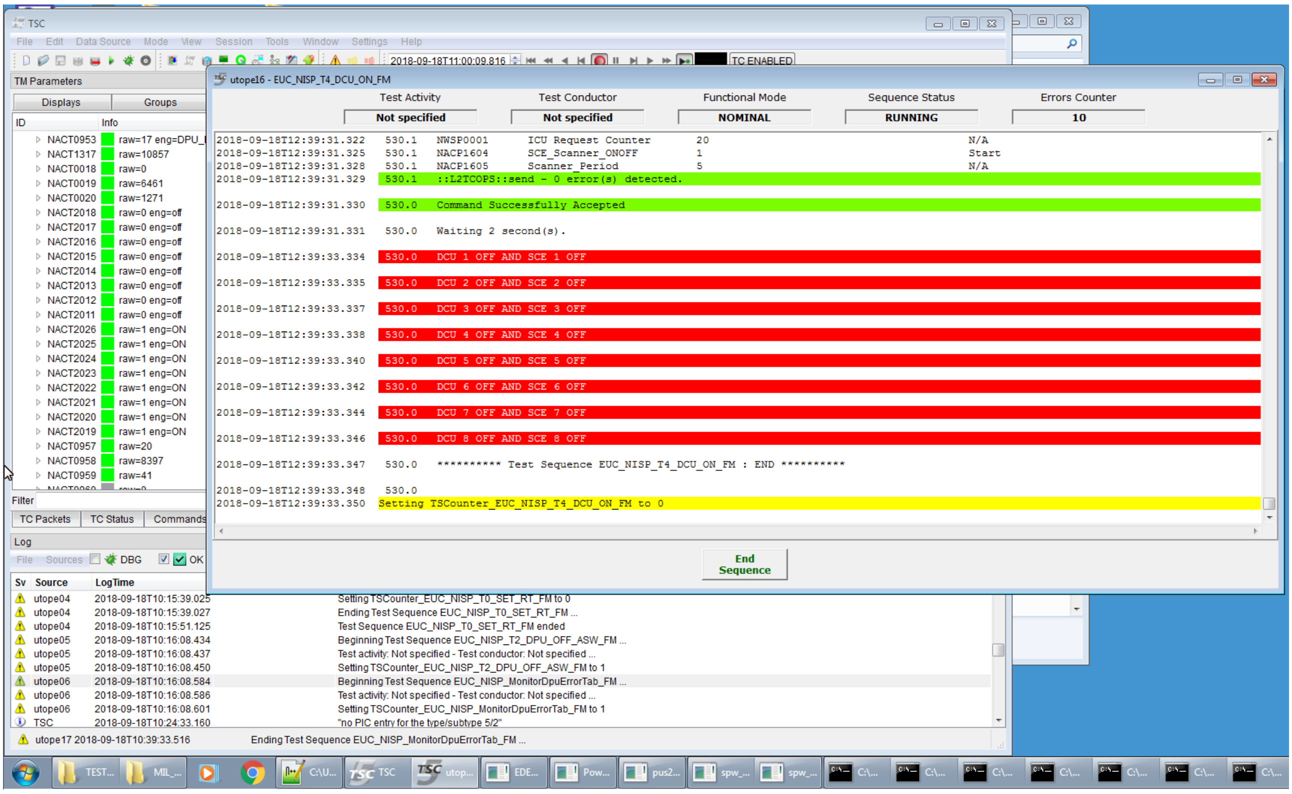
TSC is an integrated framework offering a common infrastructure to all the subsystems used during tests; it permits to interact in real time with the equipment and to save all the data in different sessions. Telecommands (TC) and Telemetries (TM) exchanged between the different parts are stored, in binary raw format, in a local DB file allowing offline data analysis. The TSC framework applies automatically to the binary data calibrations and decalibrations showing to the user both raw values (ADU) and engineering values (e.g. Voltages, Current) of every bit field. All the information necessary to the correct interpretation of TC/TM are stored in the Mission Data Base (MIB).

The TE can be connected to TSC in many ways; the standard connection is by Ethernet following the EDEN communication protocol, which encapsulates Packet Utilisation Standard (PUS) packets. When connected to TSC each equipment is seen as Special Check Out Equipment (SCOE). The information necessary for the connection as well as the list of commands and telemetries that can be exchanged with the SCOE are specified in the MIB. One or more Application Identifier (APID) are associated to each SCOE, TCs and TMs are univocally associated to the APID.

The main purpose of TSC is to allow automated testing in the form of scripts and to allow full control of the system input and output by means of an advanced user interface. Furthermore, TSC maintains a high level of compatibility with SCOS2000 based mission control and checkout systems used by Mission Operations Center (MOC) at ESA.

Thanks to its advanced graphical user interface, which can be further improved with synoptic interfaces and custom views, and to the unlimited possibilities of the scripting language, the development of the ground segment software based on such framework is simplified and a significant part of the software intelligence can be delegated to the

TSEQ, thus simplifying also the verification procedure of the ground software.



ID	Info
NACT0953	raw=17 eng=DPU_
NACT1317	raw=10857
NACT0018	raw=0
NACT0019	raw=6461
NACT0020	raw=1271
NACT2018	raw=0 eng=off
NACT2017	raw=0 eng=off
NACT2016	raw=0 eng=off
NACT2015	raw=0 eng=off
NACT2014	raw=0 eng=off
NACT2013	raw=0 eng=off
NACT2012	raw=0 eng=off
NACT2011	raw=0 eng=off
NACT2026	raw=1 eng=ON
NACT2025	raw=1 eng=ON
NACT2024	raw=1 eng=ON
NACT2023	raw=1 eng=ON
NACT2022	raw=1 eng=ON
NACT2021	raw=1 eng=ON
NACT2020	raw=1 eng=ON
NACT2019	raw=1 eng=ON
NACT0957	raw=20
NACT0958	raw=8397
NACT0959	raw=41

Test Activity	Test Conductor	Functional Mode	Sequence Status	Errors Counter
Not specified	Not specified	NOMINAL	RUNNING	10

```
2018-09-18T12:39:31.322   530.1   NWSP0001     ICU Request Counter      20                               N/A
2018-09-18T12:39:31.325   530.1   NACP1604     SCE_Scanner_ONOFF        1                                Start
2018-09-18T12:39:31.328   530.1   NACP1605     Scanner_Period           5                                N/A
2018-09-18T12:39:31.329   530.1   ::L2TCOPS::send - 0 error(s) detected.

2018-09-18T12:39:31.330   530.0   Command Successfully Accepted

2018-09-18T12:39:31.331   530.0   Waiting 2 second(s).

2018-09-18T12:39:33.334   530.0   DCU 1 OFF AND SCE 1 OFF

2018-09-18T12:39:33.335   530.0   DCU 2 OFF AND SCE 2 OFF

2018-09-18T12:39:33.337   530.0   DCU 3 OFF AND SCE 3 OFF

2018-09-18T12:39:33.338   530.0   DCU 4 OFF AND SCE 4 OFF

2018-09-18T12:39:33.340   530.0   DCU 5 OFF AND SCE 5 OFF

2018-09-18T12:39:33.342   530.0   DCU 6 OFF AND SCE 6 OFF

2018-09-18T12:39:33.344   530.0   DCU 7 OFF AND SCE 7 OFF

2018-09-18T12:39:33.346   530.0   DCU 8 OFF AND SCE 8 OFF

2018-09-18T12:39:33.347   530.0   ********** Test Sequence EUC_NISP_T4_DCU_ON_FM : END **********

2018-09-18T12:39:33.348   530.0
2018-09-18T12:39:33.350  Setting TSCounter_EUC_NISP_T4_DCU_ON_FM to 0
```

Sv	Source	LogTime	
⚠	utope04	2018-09-18T10:15:39.025	Setting TSCounter_EUC_NISP_T0_SET_RT_FM to 0
⚠	utope04	2018-09-18T10:15:39.027	Ending Test Sequence EUC_NISP_T0_SET_RT_FM ...
⚠	utope04	2018-09-18T10:15:51.125	Test Sequence EUC_NISP_T0_SET_RT_FM ended
⚠	utope05	2018-09-18T10:16:08.434	Beginning Test Sequence EUC_NISP_T2_DPU_OFF_ASW_FM ...
⚠	utope05	2018-09-18T10:16:08.437	Test activity: Not specified - Test conductor: Not specified ...
⚠	utope05	2018-09-18T10:16:08.450	Setting TSCounter_EUC_NISP_T2_DPU_OFF_ASW_FM to 1
⚠	utope06	2018-09-18T10:16:08.584	Beginning Test Sequence EUC_NISP_MonitorDpuErrorTab_FM ...
⚠	utope06	2018-09-18T10:16:08.586	Test activity: Not specified - Test conductor: Not specified ...
⚠	utope06	2018-09-18T10:16:08.601	Setting TSCounter_EUC_NISP_MonitorDpuErrorTab_FM to 1
ⓘ	TSC	2018-09-18T10:24:33.160	"no PIC entry for the type/subtype 5/2"

⚠ utope17 2018-09-18T10:39:33.516 Ending Test Sequence EUC_NISP_MonitorDpuErrorTab_FM ...

Figure 3.8 TSC graphical Interface example.

The lists of issued telecommands and acquired telemetries are easily accessible in chronological order trough the TSC. TC section reports all the verification stages that are defined in the MIB, while TM section allows checking the value and the status for every parameter. All this information is accessible from the TCL scripting through a set of libraries called TOPE and uTOPE. Data are saved in a session database and can be replayed at will allowing offline analysis or development when part of the equipment is missing. Test Sequences and library can be collected in different directories that are easily managed by TSC application. All run test sequences are copied, with a copy of the MIB at the moment of the run, in the session directory allowing for a later reconstruction of every detail of the test.

3.4.1.2 PUS Standard

Packet Utilisation Standard (PUS) is selected as standard TC and TM formatting in the EUCLID Mission. TSC and CCS work natively with PUS packets and all the relevant information are automatically extracted and showed in the user interface. The structures of a generic Packet and of the Packet header are defined in MIB tables PCDF and PCPC. They have the structure reported in Table 3.3, Table 3.4, Table 3.5, Table 3.6. Among all the fields in the packet header, the most relevant ones are:

- **Application Process ID (APID):** it identifies the recipient/sender of the packet when it is a TC/TM.
- **Source Sequence Counter (SSC):** it is supposed to be incremented by one unit each time a new packet is issued.
- **Type and Subtype:** they identify univocally the way the application data has to be interpreted.

A large set of service type and subtype values have a standard meaning, while other values can have a different interpretation for different equipment. For example, service type 1 is assigned to TM reporting the Acceptance and Execution of any TC. Service type 8 with subtype 1, is assigned to "Perform Function" commands.

PUS Telecommand Packet Definition (Max 1024 Bytes)					
Packet ID	**Sequence Control**	**Packet Length**	**Data Field Header**	**Application Data**	**Packet Error Control**
2	2	2	4	Max 1012 Bytes	2

Table 3.3: Generic structure of a PUS packet prepared to issue a Telecommand. The byte ordering of all the bit fields is Big Endian while the application data can contain fields with any ordering.

PUS Telecommand and Telemetries Packet Header Details (Bits)												
Packet ID				**Sequence Control**		**Packet Length**	**Data Field Header**					
16				16		16	32					
Version Number	Type	*	APID	Sequence Flag	SSC		Secondary Header Flag	TC PUS Version	Ack	Type	Subtype	Source ID
3	1	1	11	2	14	16	1	3	4	8	8	8

Table 3.4: Description of the header of a PUS packet, the column * is the Data Field header Flag. The byte ordering of all the bit fields is Big Endian while the application data can contain fields with any ordering.

Due to the generality of this category the first four bytes in the application data have a special meaning: they identify the function (this 32bit field is called Function ID). The byte ordering of all bit fields is Big Endian while the application data can contain fields with any ordering.

PUS Telecommand Packet Definition For TC(8,1) (Max 1024 Bytes)						
Packet ID	**Sequence Control**	**Packet Length**	**Data Field Header**	**Application Data**		**Packet Error Control**
				Function ID	App Data	
2	2	2	4	4	Max 1008 Bytes	2

Table 3.5: PUS packet structure in case of a TC (8,1). The byte ordering of all the bit fields is Big Endian while the application data can contain fields with any ordering.

PUS Telemetry Packet Definition (Max 1024 Bytes)						
Packet ID	**Sequence Control**	**Packet Length**	**Data Field Header**	**On Board Time**	**Application Data**	**Packet Error Control**
2	2	2	4	6	Max 1006 Bytes	2

Table 3.6: PUS packet structure for a telemetry message. The byte ordering of all the bit fields is Big Endian while the application data can contain fields with any ordering.

A set of standard checks is usually performed on the PUS packets. These checks are detailed in Table 3.7 and they are performed in the same order of the table. When one of these checks fails the Acceptance Failure telemetry, TM (1,2), is returned encapsulating as rejection reason the rejection code.

Table 3.7 Checks performed on each PUS packet and consequent rejection codes.

Rejection Codes		
ILLEGAL_APID	0	If APID is unknown on board
ERROR_TC_LENGTH	1	If TC length ≠ current TC length OR if TC length < MIN_TC_SIZE_C OR if TC length > MAX_TC_SIZE_C
INCORRECT_CHECKSUM	2	If PEC fields inconsistent
ILLEGAL_TYPE	3	If type is unknown on board for the APID
ILLEGAL_SUBTYPE	4	If type is unknown on board for the APID and the type
ILLEGAL_PACKET_HEADER	5	If Packet ID Version NUMBER ≠ 0 OR if Packet ID Type (T) ≠ 1 OR if Packet ID Data Field Header flag (H) ≠ 1
ERROR_APPLICATION_DATA	6	Non Standard Check: pus2dpu specific: Error found in the Application Data Field

3.4.1.3 Mission Data base

The definition of the Mission Data Base (MIB) is the way used by TSC to gain in the simplest way the highest customizability of the application. The MIB is a relational database with a predefined set of tables saved on ASCII files. These files are usually under a sub-versioning system integrated in the TSC. Records are separated by newlines while fields are separated by tabs. Each field has its own length and type. The MIB is composed by two independent set of files, one set defines the TCs and the other one the TMs. Additional files with the same format are used to specify some configuration parameters, for example the SCOEs list with their IP addresses and the list of APID associated to each SCOE. TSC allows specifying multiple directories, each containing the information for one or more SCOEs; each MIB should be self-consistent in order to work properly.

The MIB section related to Telecommands is structured in as in Figure 3.9. The headers of the PUS packet are defined in the three files TCP, PCDF and PCPC. The definition of a command starts from table CCF where each record represents a different command; in this table, for each command, the header, the number of parameters, the destination APID, the type and subtype for the PUS standard, a short description and other technical information are specified. In CDF table there is, for each command specified in the CCF table, the list of parameters associated to that command. The complete description of these parameters is stored in CPC table where a description, the type, the default value and the type of decalibration (ADU to engineering value) are reported.

The two different types of decalibrations, textual or numerical are defined in the files PAF and CCA. In PRF table we find the allowed ranges for parameters subject to restrictions. For each command many verification stages can be specified (different steps in the execution of the command). The verification stages are associated to specific telemetries; the link between the verification stages and the TMs are declared in the three tables CVP, CVS and CVE. In the Euclid framework only two stages, acceptance and completion, are used.

The section of the MIB related to Telemetries is shown in Fig 3.10. PUS packet header is the same as TCs but is followed by 6 Bytes reporting the On Board Time (OBT). TMs are identified by the APID and the type and subtype, specified in PID table; additionally, a family of TMs identified by the same type and subtype can be split in many different TMs by assigning a specific value to two fields denoted as PI1 and PI2. They are declared in tables PID and PIC; the value of this field is specified in PID table while the bit offset in the packet is in PIC table. Each telemetry packet is identified by a unique number called SPID, it is reported in the PID table together with the APID, the PUS type and subtype and a short description. In the TPCF table there is also a name associated to each SPID, it is referred to as mnemonic.

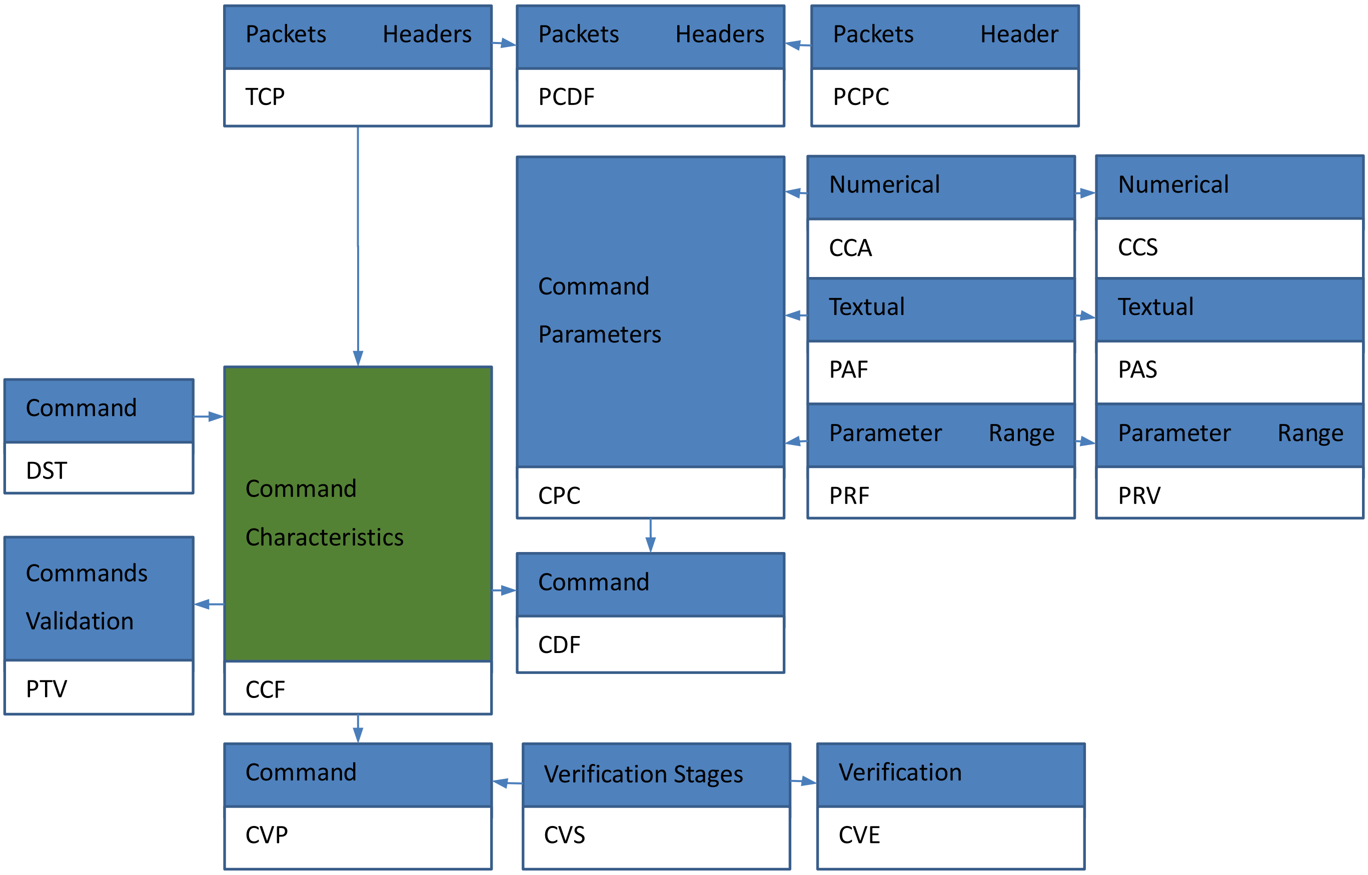


Figure 3.9: Schema of the MIB section prepared for Telecommands definition. The arrows show foreign keys and relationships between tables.

Parameters contained in each TM packet with their relative offset in bits are specified by name in the PLF table. A detailed description of each parameter, the type, the size, a description and the calibration to evaluate the engineering values are listed in PCF table. Each TM can have multiple parameters and each parameter can be contained in more telemetry packets. Four typologies of calibrations are foreseen: logarithmic, polynomial, numerical and textual. It is also possible to declare, in tables OCF and OCP, two ranges of validity for each parameter. When a value is outside the first range the TSC automatically signals the problem highlighting the TM entry in the Telemetries panel, with a yellow square. An acoustic alarm is also generated. When the parameter value is outside the second range, the parameter is highlighted with a red square. The calibration used can be conditioned by another telemetry parameter specified in table CUR The decoding of variable-length packets is specified in the VPD table.

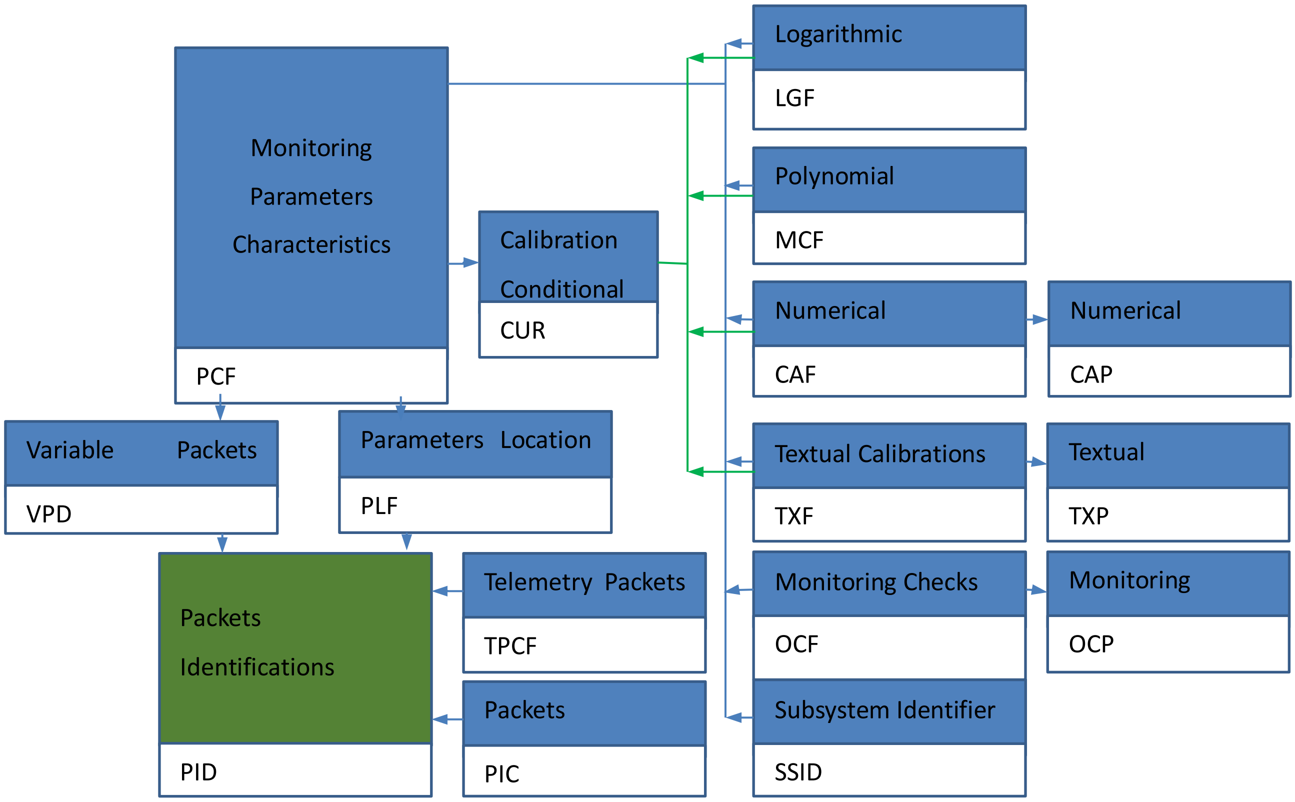


Figure 3.10: Schema of the MIB section prepared for Telemetries definition. The arrows show foreign keys and relationships between tables.

TSC allows unloading/reloading of the MIB while in operation. This is really useful when developing and testing the MIB but it is not advisable during formal testing since changes in the MIB are not saved in the Session Log.

3.4.2 EGSE custom software: PUS2DPU

The major contribution of my work to the DPU test campaign is the preparation of an application that allows to submit commands and configuration directives to the DPU as well as to retrieve digital and analogue Telemetries through the MIL-STD-1553B bus. It was necessary to develop from scratch an interface between the TSC and the commercial hardware implementing the MILBUS. This interface application is called **pus2dpu** and it can be seen as a simulator of the 1553 interface between ICU and DPU.

The commercial hardware, chosen at preliminary design review, is the Ballard® USB-1553 MILBUS UA1120 board that has to be programmed by the application as Bus Controller. pus2dpu exchanges TC/TM with the TSC from a TCP/IP connection in the form of PUS packets. It is mediated by a tool that is seen by the TSC as a SCOE implementing an EDEN communication and that encapsulates/extracts PUS packets into/from EDEN packets.

Pus2dpu is a tool that has to be used for the verification of the EQM and FM model of the DPU, so it has to accomplish the general requirements for space mission software. Thus it was necessary to plan and develop tests to verify the correct behaviour of the pus2dpu.

The software development was based on the GIT versioning framework, hosted in the INFN facility BALTIG. It is written according to the coding standards of C++ 14 and a continuous integration runs the tests to verify all the requirements; the software can be compiled under Linux and under Windows. An experienced software analyst was in charge to periodically review the software; the detailed design has been implemented by a team of four programmers, I have been in charge for the detailed design of the 1553 communication. All the team was involved in the product assurance.

Pus2Dpu is developed in a general framework called ***NISP MILBUS*** maintained by INFN Padua and INFN Bologna Groups, such framework includes also a Spacecraft simulator, a DPU simulator and Bus Monitor. All the applications are prepared to support ICU and DPU ASWs development and deals with the 1553 MILBUS interface realized with the same hardware (Ballard USB boards). The Spacecraft simulator and the Pus2Dpu act as Bus Controllers while the DPU simulator is a Remote Terminal; several general C++ classes were developed and used in all the applications. The native Ballard drivers are also wrapped in C++ classes; such approach makes all the applications independent from the 1553 specific hardware supplier.

Pus2dpu has to provide 1553 interface for DPU ASW and DPU BSW, the PUS Services and APIDs to be managed are shown in the Appendix in Table A.1 and Table A.2. A customized MIB was developed on the basis of the ICU-DPU interface via 1553 messages (see chapter 2). All the DPU ASW telemetries are codified as event reporting TM (5,1), they are identified one from the other using the first field (PI 1). TCs and TMs have a progressive counter that is used by the ICU to identify new messages. It is referred as ICU request Counter in case of TCs and DPU ASW counter in case of TMs. The application is designed to be used with all of the 4 DPU units, each of them being identified by a different APID.

3.4.2.1 PUS2DPU requirements

The pus2dpu requirements are:

- ability to drive a MIL-STD-1553B device as Bus Controller
- the Bus Controller shall implement a periodic message schedule according to the requirements established for the ICU
- the Bus Controller shall send messages in broadcast mode
- the application is controlled as an EDEN device using an external EDEN-to-PUS packets converter provided by TEMIS
- the application shall act as TCP/IP server and shall receive/transmit TCP/IP packets formatted as PUS packets
- the application shall perform standard PUS packet checks
- commands described in the DPU ASW documentation [45] are encapsulated into PUS packets which are sent asynchronously to the application by TSC
- the application shall interpret the PUS packet, translate the command into a MIL1553 message and send the MIL1553 message to the DPU according to the Bus Controller schedule
- the application shall retrieve telemetries from the DPU, encapsulate the telemetries into PUS packets to be transmitted asynchronously to TSC
- the application shall interface with both nominal/redundant units of two DPUs
- the application shall communicate through both channels of the dual redundant MILBUS
- the application shall manage PUS services (6,2) and (6,5) with the limitation of one memory block per packet. The block shall be no larger than 1024B. The following data transfer mechanism has to be applied (see Figure 3.11, Figure 3.12 and Figure 3.13):
    - after a Service (6,2), memory load command, is received, the application splits up the memory block into 16 (or less) MIL1553 messages and sends

  a MIL1553 message containing the memory load command for the DPU. All MIL1553 messages are transmitted in the same major frame according to the bus controller schedule
  - after a Service (6,5), memory dump command, is received, the application sends a MIL1553 message containing the memory dump command for the DPU and reads the relative 16 (or less) MIL1553 messages with the out coming memory block. All MIL1553 messages are transmitted/received in the same major frame according to the bus controller schedule. Then, the application merges the memory data into one memory block to be sent asynchronously as PUS Service (6,6) packet. In case a DPU ASW is running, every MIL1553 message with memory data is encapsulated into a PUS packet and sent as telemetry

- the application shall implement PUS service (17,1), connection test
- the application shall be configurable from TSC
- the application shall be able to interrupt the traffic on the 1553 bus

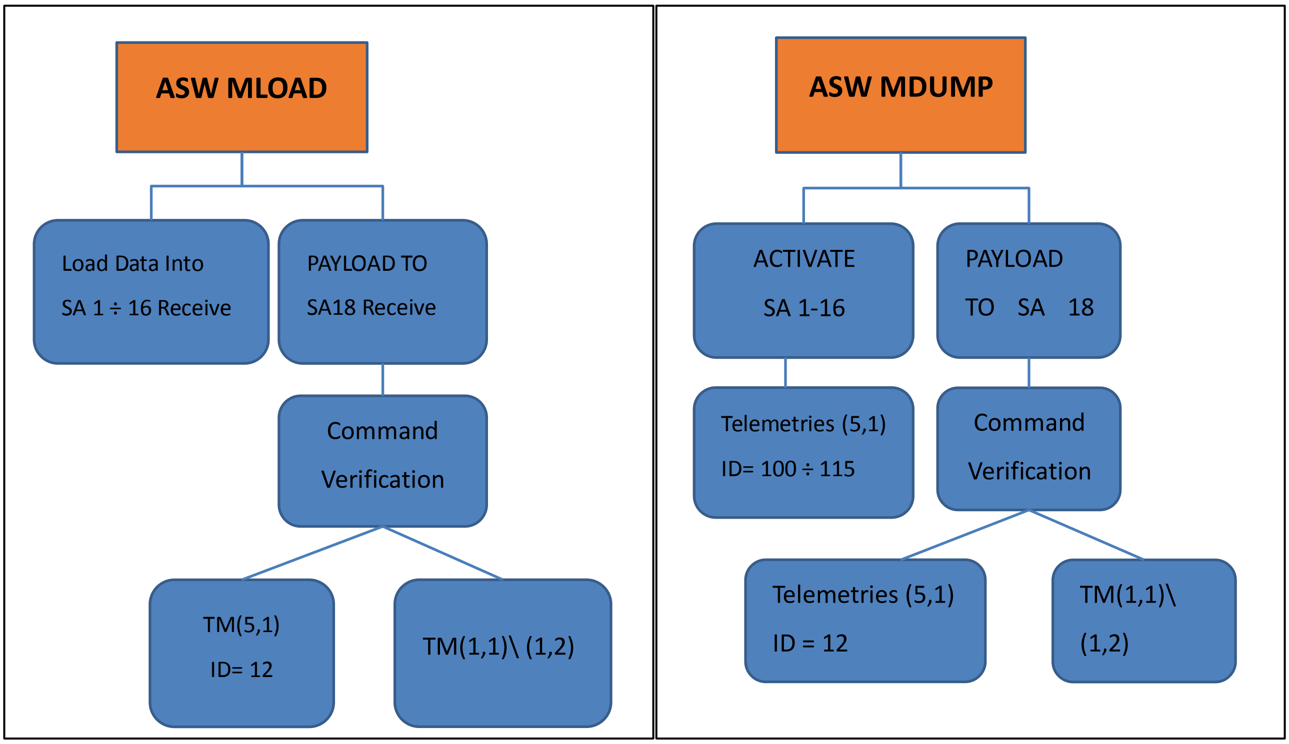


Figure 3.11: Data Flow for ASW Memory Management Services.

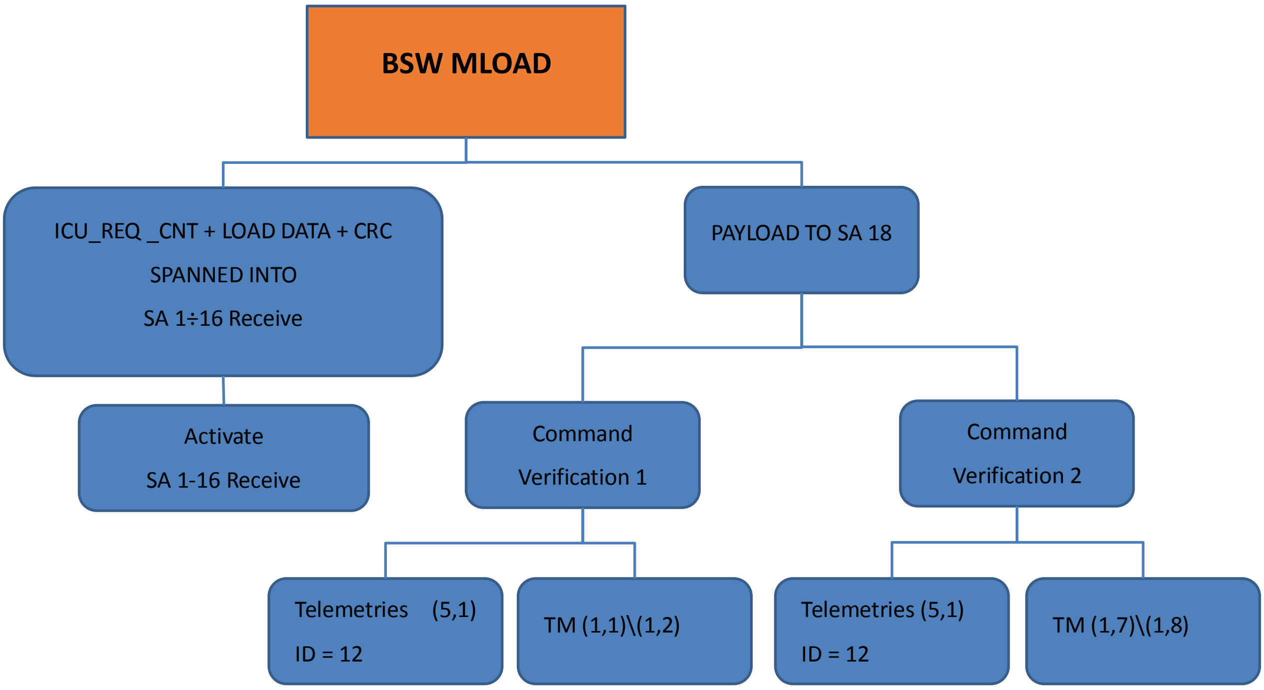


Figure 3.12: Data Flow for BSW Memory Load.

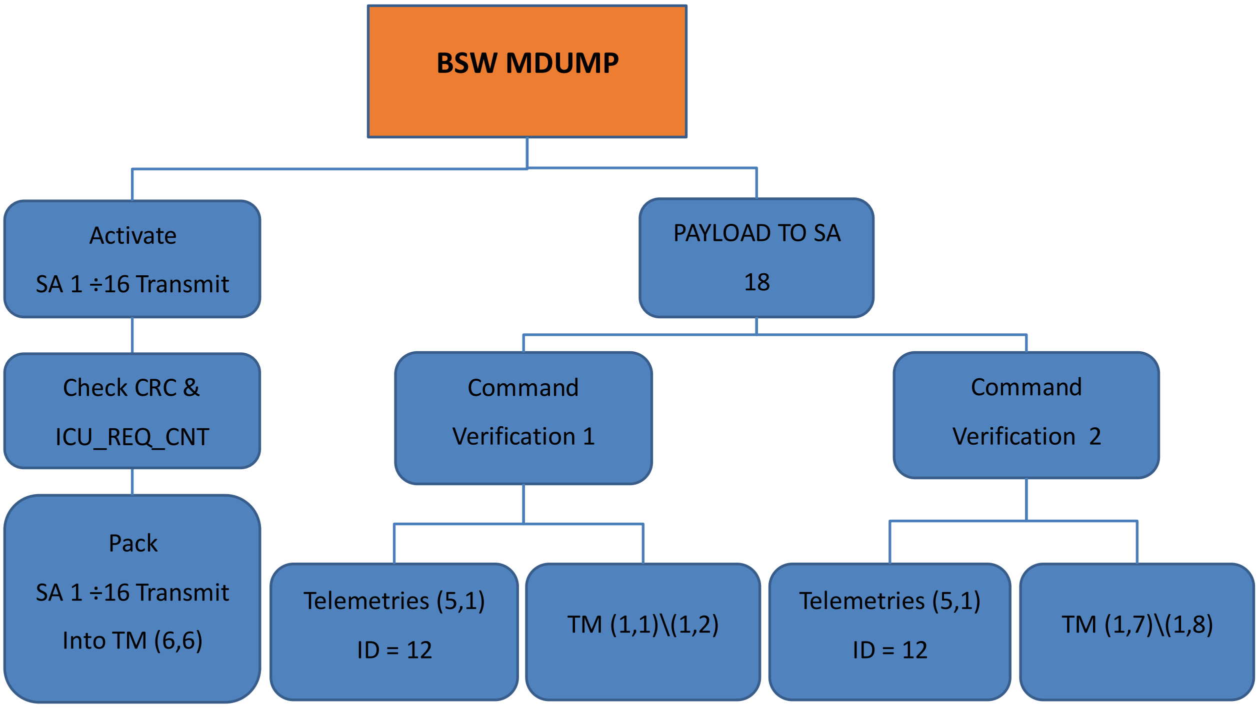


Figure 3.13: Data Flow for BSW Memory Dump.

PUS2DPU Requirements verification matrix			
Requirements	**Rationale**	**Verification**	**Result**
The application shall drive a MIL-STD-1553B device as Bus Controller	By design the application plays the role of ICU	The bus is monitored against a reference Log File while a test sequence issues a set of predefined commands	**OK**
The Bus Controller shall implement a periodic message schedule according to the requirements established for the ICU			**OK**
The Bus Controller shall send messages in broadcast mode			**OK**
The application is controlled as an EDEN device using an external EDEN-to-PUS packets converter provided by TEMIS	Work is shared with TE supplier	Connection of the three application is tested and TC/TM are successfully exchanged with TSC	**OK**
The application shall act as TCP/IP server and shall receive/transmit TCP/IP packets formatted as PUS packets			**OK**
The application shall perform standard PUS packet checks	Standard Requirement	A custom application connects as client to pus2dpu and feeds PUS packets with errors, generation of TM [1,2] is checked	**OK**
Command described in the ICDs are encapsulated into PUS packets which are sent asynchronously to the application by TSC	Main purpose of the application	A custom application connects as client to pus2dpu and feeds a reference set of commands in the form of PUS packets while the MILBUS is monitored and checked against a reference Log File	**OK**
The application shall interpret the PUS packet, translate the command into a MIL1553 message and send the MIL1553 message to the DPU according to the Bus Controller schedule			**OK**
The application shall retrieve telemetries from the DPU, encapsulate the telemetries into PUS packets to be transmitted asynchronously to TSC	Main purpose of the application	A custom application implementing four Remote Terminal is connected to the MILBUS and generates a set of Telemetries similar to that of DPUs. A test	**OK**
The application shall interface with both nominal/redundant units of two DPUs			**OK**

		sequence checks the incoming TMs with a predefined set	
The application shall manage PUS service 6,2 and 6,5 with the limitation of one memory block per packet. The block shall be no larger than 1024B.	To check the ability of DPUs to perform memory management functions	Commands are fed to the application connected to the RT simulators. Bus is monitored and traffic is checked against reference	**OK**
The application shall implement PUS service (17,1)	Standard Requirement	PUS packet is fed to application and TM (1,1) is checked	**OK**
The application shall be configurable from TSC	Functionalities should be modified from Test Sequences	A test sequence issues changes in the configuration and behavior is monitored and checked against expected one	**OK**
The application shall be able to interrupt the traffic on the 1553 bus	Multiple equipment can be connected to the MILBUS and could be useful silence the Bus Controller without any action on the physical connections	Command to stop the traffic is issued while the MILBUS is monitored	**OK**

Table 3.8: Pus2dpu requirements verification Matrix.

In Table 3.8 there is reported a summary of the test performed to verify pus2dpu conformity against the requirements. Requirements are grouped in sets according to the rationale and each set is studied with different strategies. A custom application was developed that connects as client to pus2dpu and feeds PUS packets with or without errors, the generation of TM (1,1) / (1,2) is then checked. The same application can feed a reference set of commands in the form of PUS packets while the MILBUS is monitored and checked against a reference Log File. Also a custom application was developed, that implements four Remote Terminals and generates a set of Telemetries similar to that of DPUs; in this case a test sequence checks the incoming TMs with a predefined set.

3.4.2.2 Pus2Dpu operation

Pus2dpu implements the MIL1553 schedule reported in details in Table A.3 in the Appendix [35]. A cycle lasting 1 second called Major Frame is subdivided in 60 communication frames which last approximately 16.66 ms. At the beginning of the first communication frame the broadcast *modecode,* called *sync without word* is scheduled. It is a standard signal in MIL-STD-1553 communication, consisting of one single word; it is used to synchronize the OBT of all the listening remote terminals. The next communication frames start with the broadcast modecode *sync with word*, consisting of the command word and a data word filled with the number of the communication frame.

Telecommands for the different DPUs are scheduled in subsequent communication frames, the same applies for Telemetries. Communication Frames from 2 to 5 are assigned to the transmission of the data, from the bus controller to the remote terminal, for the memory load operations. Communication frames from 7 to 10 are assigned to the transmission of commands and configuration tables. At communication frames from 21 to 24 the RTs are requested for the *Command Verification Table;* this message contains the feedback, at acceptance level, that RTs return to the BC after receiving a new command. At communication frame 35 the BC transmits in broadcast mode the OBT. RTs will synchronize to this time stamp at the arrival of the next *sync-without-word*. In the communication frame 35 the BC requests to RTs the transmission of their own OBTs. DPU digital and analogue telemetries are available in communication frames from 40 to 47. Communication frames from 48 to 51 are assigned to the transmission, from the remote terminal to the bus controller, of the data for the memory dump operations. This cyclic schedule is common for the communication between Pus2Dpu and DPU ASW and DPU BSW. It has to be noted that DPU BSW returns, as feedback to commands to the BC, also information about the completion of the commands. Such info is contained in the *Command Verification Table 2* in the communication frames 56 to 59.

Figure 3.14 shows the Pus2Dpu operation when a PUS packet is received. If the PUS service is a managed one, the message is forwarded the DPU BSW or to the DPU ASW, depending on the APID.

When a command is issued the Command Verification Tables (CVT) are expected to be updated. Commands are identified by the first word called *Command ID* and the second word called *ICU Request Counter* (IRC), consistency checks are performed on these two words for each command, the IRC of a new command is requested to be different from the previous one. Transmission sub-addresses are checked every major frame and the data are stored in a buffer. When the DPU ASW counter is different from the last copied the content of the 1553 message is encapsulated in a Telemetry (5,1). If the message is not well formatted, data are encapsulated in a Telemetry (5,2) to which it is prefixed the identifier of the expected message. The list of handled telemetries is shown in Table 3.9.

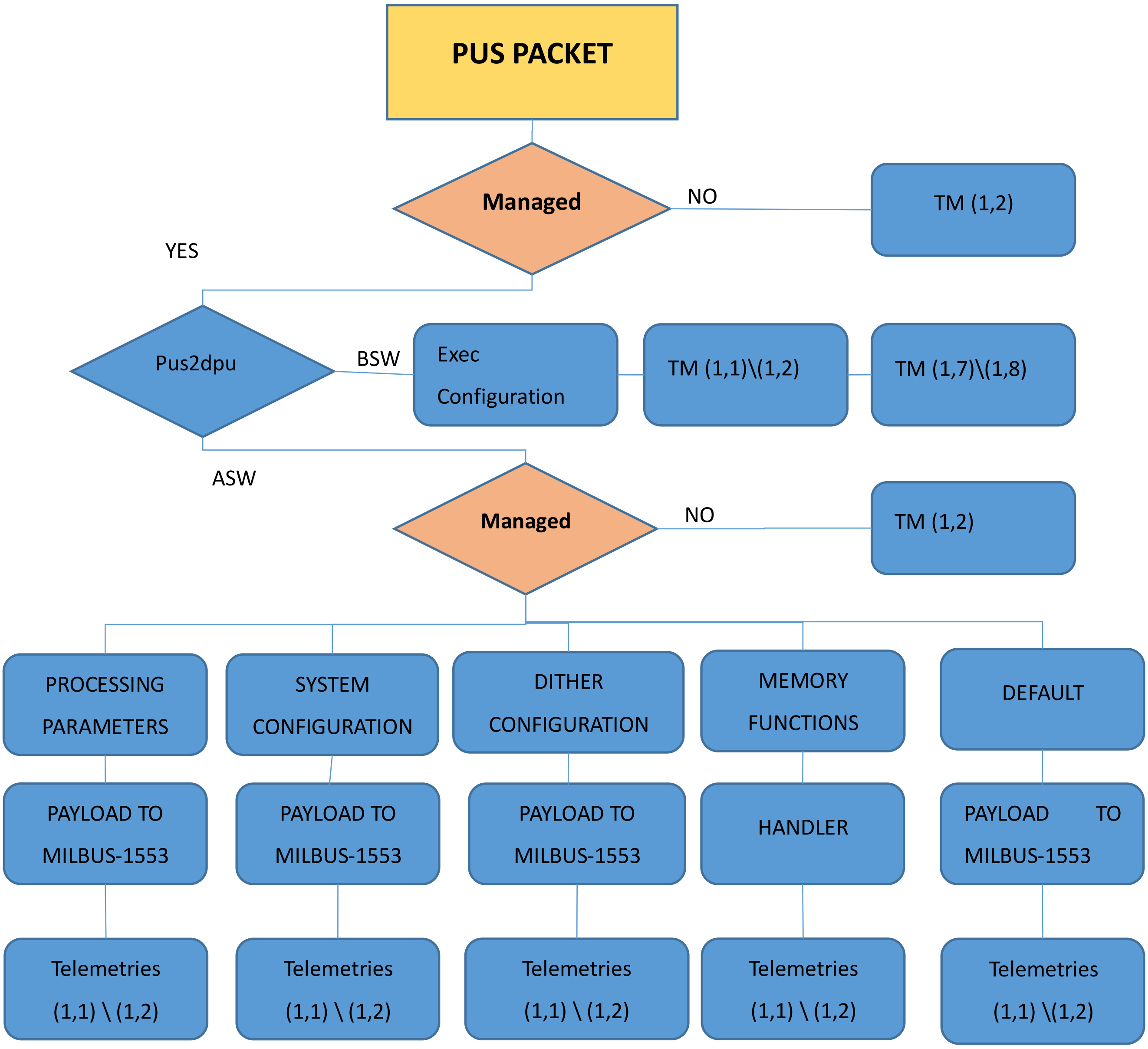


Figure 3.14: Telecommands flow followed by the pus2dpu application.

Message	**Software**	**Type**	**Sub Type**	**Event ID (16 bit)**
Command Verification Table	ASW	5	1	Word 0 (12)
Status Table	ASW	5	1	Word 0 (10)
Monitor Table	ASW	5	1	Word 0 (17)
Error Table	ASW	5	1	Word 0 (14)
DPU Housekeeping	ASW	5	1	Word 0 (15)
DCU Housekeeping	ASW	5	1	Word 0 (20-27)
SCE Housekeeping	ASW	5	1	Word 0 (65-88)
DBB DRB Status Table	ASW	5	1	Word 0 (16)
Event Table	BSW	5	1	Bits 11-13 of Word 6
BSW Housekeeping 1	BSW	3	25	1*
BSW Housekeeping 2	BSW	3	25	2*
Command Verification Table 1	BSW	5	1	Word 0 (767)
Command Verification Table 2	BSW	5	1	Word 0 (767)

*prepended to message data

Table 3.9: List of Telemetries from ASW and BSW.

When pus2dpu issues a command it also stores it in an internal queue. When the CVT (see Table 3.10) is found different from the previous, a TM (5,1) is sent to the TSC, then the command ID and the IRC are checked with the values stored in the internal list and if the error code is null a TM (1,1) is sent to the TSC otherwise a TM (1,2) with the full 1553

Message is sent to the TSC.

The same applies for the DPU BSW command verification tables but the data are packed in a different way. When the Command Verification Table 2 is different from the previous one, a TM (5,1) is sent to TSC with the full content of the table and then if the error code is *NO ERROR* a TM (1,7) is sent to the TSC otherwise a TM (1,8) with the full content of the table is sent to TSC (see Table 3.10, Table 3.11, Table 3.12).

Word #	**Definition**	**Comment**
0	12	CMD_VER_TAB ID = 12
1	ASW_COUNTER	Wrap-Around counter generated by ASW
2	OBT1	Time values $2^{31} – 2^{16}$ s
3	OBT2	Time values $2^{15} – 2^{0}$ s
4	OBT3	Time sub seconds
5	DUMMY	
6	Command ID	Copy of received command ID
7	ICU_REQ_CNT	Copy of received IRC
8	Verification Code	0 -> NOT OK ; 1 -> OK
9	Error Code Data	Error Code

Value	Rejection Code
0	NO ERROR
1	Command Counter not monotonic
2	Command Not compatible with ASW status
3	Hardware availability failure
4	Command Parameter out of range

Table 3.10: CVT produced by the DPU ASW and possible Rejection Codes produced [35].

Word Offset	Bit Offset	Size (Bits)	Definition	Value	Description
0	0	8	Table ID	2	Packet Identifier
0	8	8	Reserved	0xFF	Reserved
1	0	16	TM Counter	Any	Wrap Around Counter
2	0	16	Time Word #1		Time Message Word #1
3	0	16	Time Word #2		Time Message Word #2
4	0	16	Time Word #3		Time Message Word #3
5	0	16	Time Word #4		Time Message Word #4
6	0	16	Command ID		Copy of the received Command ID
7	0	16	Command Counter		Copy of the received Command Counter
8	0	2	Verification Type		0x1 Table 1; 0x2 Table 2
8	2	14	Reserved2	0	Reserved
9	0	16	Return Code		Return Code (see next tables)
10	0	16	Return Code Data Word #1		Variable Field based on the return code. (CVT2 only)
…	…	…	…		…
30	0	16	Return Code Data Word #21		

Table 3.11: BSW Command Verification Tables 1 and 2 [33].

Value	Return Code
0xF0	NO ERROR
1	CRC DATA PKT ERROR
2	COMMAND MODE NOT CORRECT
3	COMMAND TYPE NOT CORRECT
4	COMMAND SERVICE OUT OF RANGE
5	COMMAND COUNTER ERROR
6	COMMAND LENGTH WRONG
7	COMMAND PARAMETER ERROR
8	MEMORY TYPE ERROR
9	DATA COUNTER WRONG
10	TC REJECT (previous command not completed yet)

Table 3.12: Return Code (WORD 9) for CVT 1.

Value	Error Code	Return Code Data
0xF0	Execution Completed Successfully	None
0xF0/0x0F	Memory Report	Details in [33]

Table 3.13: Return Code (WORD 9) for CVT 2.

3.4.2.3 *Custom MIB for Pus2DPU*

A custom MIB was developed in such a way that pus2dpu, with very few exceptions, does not need to know the content of the Application Data field that is copied into the body of a 1553 message and scheduled for transmission at the proper time. The only exceptions for this rule are the memory management functions since they require the handling of the data exchanged.

For each command handled by the DPU ASW and specified in [45] one or more entries in the CCF file are defined, each command having a name according to the EUCLID naming conventions. In case of DPU ASW all the commands should have a name formed by an alphanumeric code composed by four characters and four numbers. In our case the prefix NAS univocally identify a command for the NISP DPU ASW and the fourth character should be: C in case of a command, P in case of a command parameter and T in case of a telemetry data. The four numbers are the same as the Command ID reported in the first word of the 1553 message. For each entry in the CCF file there is specified the number of parameters, usually each word of the 1553 message is a different parameter. The nature of each parameter and their engineering decalibration is specified in the CPC file with default values and a range of validity as well. Once the MIB for TCs is defined any command can be sent by simply writing its name followed by all the parameters, in engineering form.

As an example, if we want to command to the DPU ASW a mode change we have to issue the command with the 1553 message reported below:

Word #	Definition :	Comments :
0	513	1 + 2×256
1	ICU REQUEST COUNTER	Wrap Around Counter
2	Item 1	ASW mode : 2 : CPU SAFE 4 : CPU PARKED 8 : SCE INIT 16 : OBSERVATION (WAITING) 64: MANUAL

Table 3.14 Example of DPU ASW command

In the MIB we have the command NASC0201 (0x0201 = 513 is the Command ID) and it has three associated 16 bit parameters (one for each word), if we want to command the transition to SCE_INIT mode we have to issue the following TSC command:

```
tcsend NASC0201 {NWSP0001 1} {NASP0202 SCE_INIT}
```

The value of the word0 is associated to a parameter declared as fixed to 0x0201 in the MIB so there is no need to specify its value in the tcsend function.

The TSC, relying on the information on the MIB and integrating missing parameters with default values, will produce the entire PUS packet inclusive of the CRC error control code. The packet is then encapsulated in an EDEN packet and sent to the SCOE associated to the corresponding APID. In case of any error or if the SCOE is not connected the process stops and signals the error to the user.

Similarly, for each TM, the PUS packet arrives through Ethernet encapsulated in an EDEN packet and is interpreted relying on the information stored in the MIB. Depending on the values of APID service type and subtype and eventually on the values of PL1 and PL2 fields as specified on the MIB, the telemetry packet is identified and its SPID is assigned to it. Then from the MIB the Calibration criteria are applied and the engineering values are showed on the user interface of the TSC. If ranges are specified in the MIB are exceeded, TSC will automatically highlight values in the graphical interface and will activate the audible alarm.

Each 1553 telemetry message prepared by the DPU ASW has its own definitions in the MIB allowing a full decoding from the user interface and from the TCL scripts.

3.4.3 EGSE custom software: DPU Simulator

Since the beginning of the development of the test environment the need of an application interfaced to a MIL-STD-1553B device playing the role of the DPUs was evident. There were three main tasks that such an application could accomplish:

- support the development and testing of pus2dpu by our group
- support the development of ICU ASW by the Turin INAF group
- support the development of the ICU test environment by the INFN Bologna group

Furthermore, the development of a DPU simulator helped me in a deeper understanding of the inner working of the DPU ASW.

Since the three groups in the need of a DPU simulator had also different requests the application has been developed in different branches of the GIT repository.

Dpusim is the application used to simulate telemetries from the DPUs in the 1553 Bus. Dpusim was very useful for the verification of the pus2dpu requirements; furthermore, it was used extensively in the development of the test sequences for the DPU validation.

The application cannot imitate exactly the behaviour of DPUs because of the hardware limitations and architectural differences with respect to the on-board software.

The MIL-STD-1553B Device, when configured as a remote terminal, requires the activation of the sub-addresses that will be used. The sub-addresses in use are then referred as *legalized*. The device then, with a latency of few microseconds, automatically stores the messages from the BC in its internal memory and answers to the requests of transmitting messages reading data from its internal memory and acknowledges the Bus Controller with a status word.

The main hardware limitations appear when switching from DPU BSW to DPU ASW or vice-versa, because once the hardware is configured to respond to a specific message, i.e. send back the status word and eventually the data words, it is not possible to illegalize the response without a full reset of the card. Thus the switch of one of the simulators from ASW to BSW requires to interrupt all the others.

The architectural difference with the on-board software are related to the different number of interrupts used to control the flow of the operations and to the different number of asynchronous tasks performing all the operations.

These architectural differences, on the other hand, do not interfere with the working of the Bus Controller, in the current implementation of the on-board software, and they can be totally ignored.

3.4.3.1 Dpusim functions

Dpusim implements all four Remote Terminals associated to the 4 DPUs. Each DPU can be independently activated or not, and it can behave like BSW or ASW. The functions implemented in the simulator are:

- receive and set the OBT at sync without word
- respond properly to all commands updating the Command Verification Tables
- execute the following commands updating the corresponding parameters in telemetry packets:
    - Reset Counters
    - Change Status
    - Set Mastership
    - Set DCU mask
    - Enable DCU housekeeping
    - Enable SCE housekeeping
    - Dither Config
    - Exposure
    - Dither Abort

  - DCU Power On-Off
  - SCE Boot
- manage memory load and dump functions. Data are stored in internal buffers for both software
- generate a semi-static version of all DPUs Telemetries, incrementing the internal ASW Counter and the OBT
- restart of the DPU by telecommand.

3.4.3.2 Dpusim implementation

The application implements an RT that can interact with the Bus Controller (BC) played by the ICU. It can read and update the memory in the 1553 device. It is possible to perform a polling of this memory or to ask the driver to raise an interrupt when messages are received. Dpusim implements an interrupt for each receive message except for the *sync with word*. The interrupt is enabled also for the *sync without word* that is technically classified as a transmit message.

The interrupts enabled and triggering a Dpusim reaction are:

- Sync Without word
- Receive Sub-addresses 1 ÷ 16 for Memory Load data
- Command Table Sub-address 18
- ASW Only: Sub-addresses 19, 20, 21 for Configuration Tables
- OBT SA 29.

3.4.3.3 Handling of sync without word mode-code (DPU ASW simulator)

When the Dpusim receives the Sync Without word mode-code it updates the OBT with the last received one and it increments of one unit an internal counter that is used as internal clock. When an exposure is in progress Dpusim decrements the internal exposure timer when it expires the following status variables are updated:

- SCE status is set to IDLE
- ASW status is set to PROCESSING
- exposure counter is decremented
- the internal counter for processing time is updated

- the dither status flag set to Dither OFF

The processing counter is decremented, once for each detector and for each exposure and afterwards:

- if processing counter has reached 0 the transmission flag is activated
- the transmission flag counter is decremented
- if the transmission flag counter has reached 0 the transmission flag is deactivated.

3.4.3.4 Handling of sync without word mode-code (BSW simulator)

When the Dpusim receives the sync without word mode-code the OBT is updated to the value received in the previous major frame. The following telemetries are updated: the OBT message, the two housekeeping messages and the Boot Report event. The five different Boot Report Events are transmitted on the same sub-address only once soon after the DPU start-up. In the real DPU this happens 40s after the Power ON; in the simulator this time is shortened to 12s.

3.4.3.5 Handling of a Receive Message on SA 1÷ 16 (ASW and BSW simulator)

When Dpusim receives message data on SA 1 ÷ 16, they are copied from the device memory to the application memory. This data will be copied in the destination buffer when the Memory Load command is received on SA 18 and there are no errors.

3.4.3.6 Handling of a Command (ASW simulator)

When Dpusim receives a command on SA 18 it performs the following actions:

- checks that no pending command is running, otherwise it rejects the incoming command and it updates the CVT with the value ASW_STAT_ALLOW as rejection code
- checks that ICU_REQ_CNT is different from zero and from the last one received otherwise it updates the CVT with the value MONOTONICITY as rejection code
- checks that the Command Id is in the list of managed commands, otherwise it updates the CVT with the value PARAM_RANGE as rejection code.

If no error is found Dpusim acts differently depending on the command, as follows:

- **Processing Parameter Table**: copies data in the application memory
- **System Configuration Table**: copies data in the application memory
- **Dither Configuration Table**:
  - copies data in the application memory
  - sets the Dither Status to ON
  - sets an internal variable to the number of exposures in the configured Dither
- **GTAB**: sets an internal variable to the incoming value that will be used in the preparation of the SCE housekeeping
- **MDUMP:**
  - checks all the parameters
  - spannes the requested memory block on SA 1 ÷ 16 and copies them into the device
- **MLOAD:**
  - reads data as soon as they arrive and copies them into application memory
  - checks the data header with the parameters received in the MLOAD command
  - copies data into the internal Memory Block that emulates the destination Memory
- **DCU SHSK:** sets two internal variables to the incoming values; they will be used in the generation of telemetries. This command starts the periodic DCUs housekeeping transmission
- **SCE SHSK:** sets two internal variables to the incoming values; they will be used in the generation of telemetries. This command starts the periodic SCEs housekeeping transmission
- **CPU STM:** sets an internal variable to the incoming value, this command sets the Master RT
- **CPU STDM**: sets an internal variable to the incoming value, this commands sets the active DCU bit mask that is used for the simulation of the processing time

- **CPU RSTC**: depending on the value of the incoming parameter resets to zero the simulated ASW counter and the last received IRC
- **CPU SST**: sets an internal variable to the incoming value, this command sets the ASW mode
- **CPU DABT (Dither abort):**
    - checks that the Dither is ON otherwise sets in the CVT the rejection code to ASW_STAT_ALLOW
    - sets the Dither flag to OFF
    - sets the ASW status to OBSERVATION_WAITING
    - sets the SCE status to IDLE
    - sets Number of exposures, processing and transmission flags to zero
- **DCU POWER ON OFF**:
    - checks the ASW status
    - updates the internal variable storing the status of the DCUs with the new value
    - updates the internal variable storing the specific DCU status register
    - updates the internal variable storing the HK Protection Fault register of the selected DCU
- **SCE microcode BOOT**:
    - checks that the DCU associated to the specified SCE is powered on, otherwise it sets in the CVT the rejection code value to ASW_STAT_ALLOW
    - updates the internal variable showing the SCE status bit mask.

In order to simplify the behaviour of the simulator during ICU ASW development steps, the CVT is always positive; it can be negative only issuing a specific command.

3.4.3.7 Handling of a Command (BSW simulator)

When Dpusim receives a command for BSW it checks that there are no pending commands then prepares positive CVT1 and CVT2

3.4.3.8 Handling of the On Board Time message (ASW simulator)

When Dpusim receives the OBT stores the value in a variable that will be used at the time of the next Sync Without Word. At the arrival time of OBT Dpusim refreshes ASW Telemetries and writes them in the internal memory of the 1553B device. If a memory dump has been requested, Sub-addresses 1 ÷ 16 are filled with the requested memory.

3.4.3.9 Handling of the On Board Time message (BSW simulator)

When Dpusim receives the OBT value stores it in internal memory; the stored OBT will be used at next Sync Without Word.

4 DPU ASW integration and DPU functional tests

The Warm Electronics AIV strategy foresees that the two components, ICU and DPU, have to be tested at unit level before the integration. The INFN Padua Group is involved in the DPU AIV at unit level and gave support to the DPU supplier (OHB-I) in the functional test campaign for the DPU EQM unit. Testing tools used were described in Chapter 3.

A stable version of the DPU ASW, to be integrated in the DPU HW, was necessary in order to perform DPU functional tests. The test campaign had a first run in July 2017 and it was held in OHB-I. At that time the DPU-ASW had not completed the CDR but the need for demonstration software boosted its development; the development of the test sequences, necessary to validate the equipment was boosted as well. At the end of the campaign a pre-CDR release of the DPU ASW, initially tagged as v0.0.3, was delivered. Formal tests were performed by OHB-I with positive results but a list of improvements for both ASW and Test Sequences were defined after the tests. A second test campaign was then held in OAPD laboratories in March 2018 after having implemented all the requested improvements in the ASW and in the test sequences. After this last test campaign a final release of the ASW was prepared that could be used by OHB-I to perform successfully the validation of the DPU EQM model and step into the production of the flight models. In this chapter the tests developed to validate the DPU-EQM are described.

4.1 Test configuration

The Equipment Under Test (EUT) is the DPU/DCU EQM assembled with the main boards (see Chapter 2) and all the 8 DCU boards in the configuration shown in Figure 4.1.

The complete DPU digital section is referenced to the same ground and consists of:

- 1 Power Supply Board (PSB) Main
- 1 Maxwell SCS750 CPU Data Processing Board (DPB) Main

- 1 Data Router Board (DRB) Main
- 1 Data Buffer Board (DBB) Main

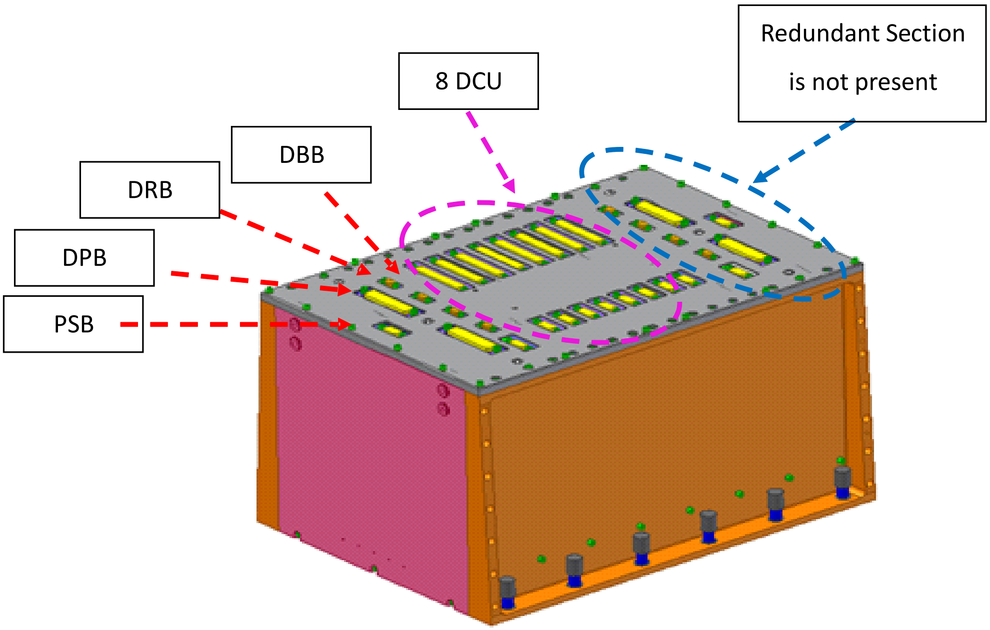


Figure 4.1: CAD drawing of the external chassis of the DPU/DCU EQM unit. It is equipped with the Power Supply Board, the Data Processing Board (Maxwell SCS750) the Double Buffer Memory Board, the Data Router Board and 8 DCUs. The redundant section is not present.

Sections dedicated to the SIDECAR power conditioning are fully isolated with respect to the digital section ground. Analogue and digital grounds of the SIDECARs are assumed to be connected together at SIDECAR board level and reported to the instrument ground via dedicated chassis connection.

During the functional tests the following SWs were loaded into the EUT:

- BSW version 2.0.0 provided by OHB-I
- ASW version 0.0.3 provided by INAF Padua

The tests were performed on a laboratory table provided with Electro Static Discharge (ESD) antistatic grounding mat on which the unit has been placed. The EUT grounding reproduced the flight electrical conditions. The electrical bond to ground has been implemented through a bonding strap; the DC resistance of the grounding has been measured and resulted less than 1Ω as required. The interconnecting wiring and interface connectors are similar to those that will be used on an integrated satellite with regards to electrical grounding.

4.1.1 EGSE configuration

The DPU unit is connected to the EGSE (see Figure 4.2) with the following test harness:

- EGSE power cable (3 meters long)
- Spacewire cables (3 meters long)
- SCE simulator cables (3 meters long)

The test harness is fully representative of the spacecraft configuration in terms of wire types (twisting, shielding and gauge) and connector back shell technology.

The EGSE is composed by the EQM DCU/DPU Test Equipment (TE) provided by Temis [43] and the Instrument Workstation (IWS) provided by INAF OAS Bologna. The TE has to simulate interfaces with Euclid SVM, ICU and NI-DS; it is equipped with (see Figure 4.3):

- 2 Spacewire channels (Nominal/Redundant)
- 1 MILSTD-1553B channel (Nominal/Redundant)
- 1 Power supply line
- 8 SCE simulators (SCS)

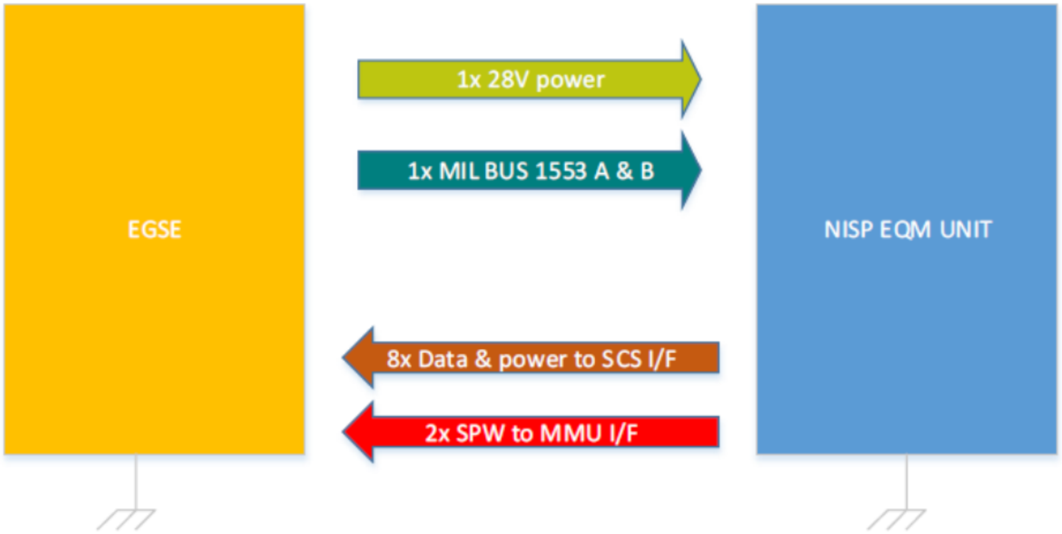


Figure 4.2: EUT interfaces with the EGSE.

The TE allows, through the TSC user interface, to fully configure and control the DPU/DCU by:

- sending commands and receiving digital telemetries through a TSC EDEN interface to the power supply, the spacewire logger, and the STD-MILBUS-1553 interface (pus2dpu described in Chapter 3)

- acquiring Science Data through the spacewire channels
- sending commands and receiving telemetries from DPU/DCU trough the STD-MILBUS-1553B interface
- transferring science data and telemetries to the IWS allowing the verification of the instrument functions and performances by executing online quick look analysis

The TE is composed by one rack with dimensions 596 mm x 1570 mm x 81 8mm (see Figure 4.4).

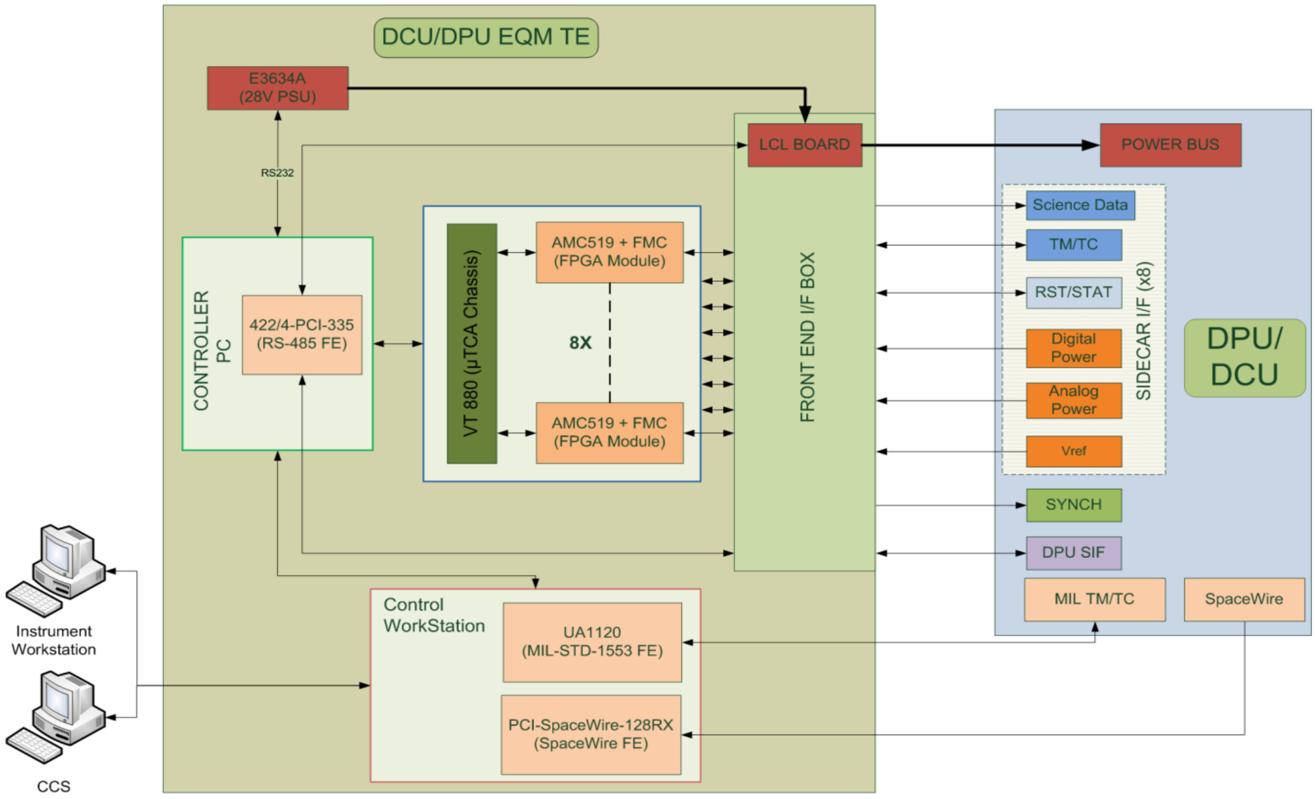


Figure 4.3: DPU/DCU EQM TE Functional Overview.

The primary power output is galvanically isolated from the DPU power supply. The same applies for the Sidecar power loads. The MIL-STD-1553B bus is intrinsically isolated by means of the transformer couplers. Sidecar bi-levels signals are opto-isolated, the Spacewire and Sidecar LVDS links are not isolated.

Figure 4.4: TE and DPU/SCE box with one SCE.

TCs are routed to the DPU/DCU unit via MIL-BUS-1553 using the pus2dpu software. TCs are arranged into TCL scripts that can be easily executed from the TSC. In addition, the scripts generate a Man Machine Interface (MMI) that allows the user to have a quick look of the status of the unit checking the digital and analogue telemetry arriving from DPU ASW.

The DCU/SCE interface is emulated by 8 SCE simulators that require to be configured by TSC coherently with the requests submitted to the DPU. The TE runs a Spacewire Logger that receives and logs data via Spacewire interface. Two instances of the Spacewire logger are active and can be controlled independently via TSC. Once the Spacewire link is established the log session can be started or stopped with a telecommand, or the logging can be switched to another file.

In summary, the TE SW is mainly composed by four core applications controllable from TSC:

- the Spacewire logger

- the SIDECAR Simulation Manager
- the Power Manager
- the DPU MIL1553 Control SW (composed by Eden protocol entity and PUS2DPU)

All this SW pieces have an EDEN I/F that can be commanded via TSC once the proper MIB is loaded. These applications are automatically started at system start-up in form of console applications. Each application has a proper APID and can be launched separately if needed.

4.1.2 DPU/SCE interface simulation

The DPU/SCE interface is emulated in terms of power loads and simulated MACC can be produced.

Three galvanically isolated sections are used for Analogue, Digital, and Reference power interfaces (see Chapter 2). For each SCS different power loads emulate the power consumption of a real SCE, a fuse provides Over Current (OVC) protection. A cable simulator (RLC network) is also provided for each load. It is possible to bypass the cable simulator via a TSC command. A green led on the front panel indicates the activation of each cable simulator. For each power load the applied current is converted into analogue voltage and connected to dedicated pins of SCE measurements connector for complementary external measurement.

Three variable power loads are required for digital I/F, indicated as: 3V3D, 2V5D and VIO. For each of them three different loads can be selected via TSC command, in order to set current as:

- Nominal = 10mA (9,5mA with cable simulator active)
- Fault1 = 20mA (18,5mA with cable simulator active)
- Fault2 = 200mA (110mA with cable simulator active)

The analogue section emulates the VDDA power line and the three possible currents are:

- Nominal = 100mA (92mA with cable simulator active)
- Fault1 = 200mA (170mA with cable simulator active)
- Fault2 = 400mA (350mA with cable simulator active)

The last section emulates the VREF line and the three possible currents are:

- Nominal = 1mA (0,9mA with cable simulator active)
- Fault1 = 2mA (1,9mA with cable simulator active)
- Fault2 = 20mA (15mA with cable simulator active)

The primary power I/F simulation is controlled configuring the load to be applied and activating the cable simulator.

4.1.2.1 SCS

The SCS emulate the Science data transmission from the SCE to the DPU/DCU and the TM/TC communication between them. There are three available simulation modes:

- Single row: a single detector line is produced
- Single frame: an entire frame composed by 2048 lines is produced
- MACC mode: a series of frames simulating a programmed MACC (NGroups, NReads, NDrops) are produced. The MACC mode allows also the creation of a stack of MACCs to be transmitted one by one every time an acquire command is received, thus simulating the scientific data taking in dithers.

SCS is a state machine with four major states (see Figure 4.5):

- **Idle**: the Scientific Data interface is not active, waiting for the user to configure the test session. When the setting-up is completed, the SCS moves to Loading state. It is the state at application start-up and it is also reached after the execution of a Stop TC.
- **Loading**: the Scientific Data interface is being prepared for a simulation, the scientific data is computed and loaded inside the uTCA FPGA boards. This state is reported in the SCS telemetry and its value is in the range 0-100 (representing the configuration completion rate). This state automatically switches to Running state.
- **Running**: the Scientific interface is ready to send lines/frames. Waiting for the transmission TC to start transmitting data.
- **Transmitting**: the Scientific interface is busy because a transmission has been requested. When transmission ends the SCS automatically goes back in Running state.

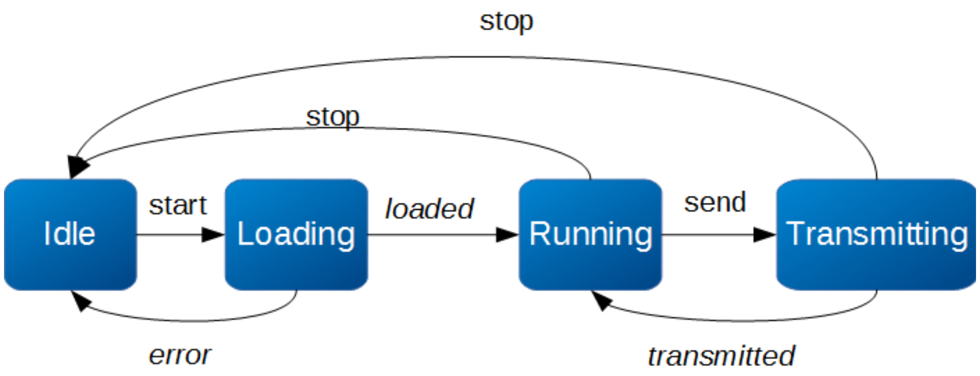


Figure 4.5: SCE simulators are realized as state machines, the possible states and transitions among them are shown in the scheme.

When an *acquire* telecommand is received, the transmission of the configured image sequence is immediately started. The data can be simulated in different configurations that can be selected via TSC. Each frame can be simulated in a deterministic or random way as shown in Figure 4.6.

Pixel Mode						
Deterministic	A set of 25 different frames are available which will be used cyclically. So, after the 25th used frame the first frame will be used again and so on. The pixels, for the 25 frames, are calculated according the following formulation: [Pixel_offset + Pixel_gain * Pixel_index + Row_gain * (Row_index + 1) + Frame_gain * (Frame_number + 1)] mod 2^{16}					
	Set of 25 available frames	⇒	Deterministic Pixels for frame 1/25	Deterministic Pixels for frame 2/25	…	Deterministic Pixels for frame 25/25
	Each MACC will start transmitting from the first frame.					
Random	A set of 25 different frames are available which will be used cyclically. So, after the 25th frame the first frame will be used again and so on. The value for each pixel, for the 25 frames,, is random in the range $[0, 2^{16} - 1]$					
	Set of 25 available frames	⇒	Random Pixels for frame 1/25	Random Pixels for frame 2/25	…	Random Pixels for frame 25/25
	Each MACC will start transmitting form the first frame.					

Figure 4.6: Algorithms used to simulate data frames pixel by pixel.

4.2 DPU/DCU Equipment Testing

For the validation of the DPU/DCU all the requirements established in the design phase must be verified. There are five different test types:

- Functional Tests
- Mechanical
- Electrical

- Electromagnetic Compatibility (EMC)
- Thermal - Vacuum (TV)

All these tests have been defined at the time of the Preliminary Design Review with the corresponding requirements and specified for the different models [46] (see Figure 4.7).

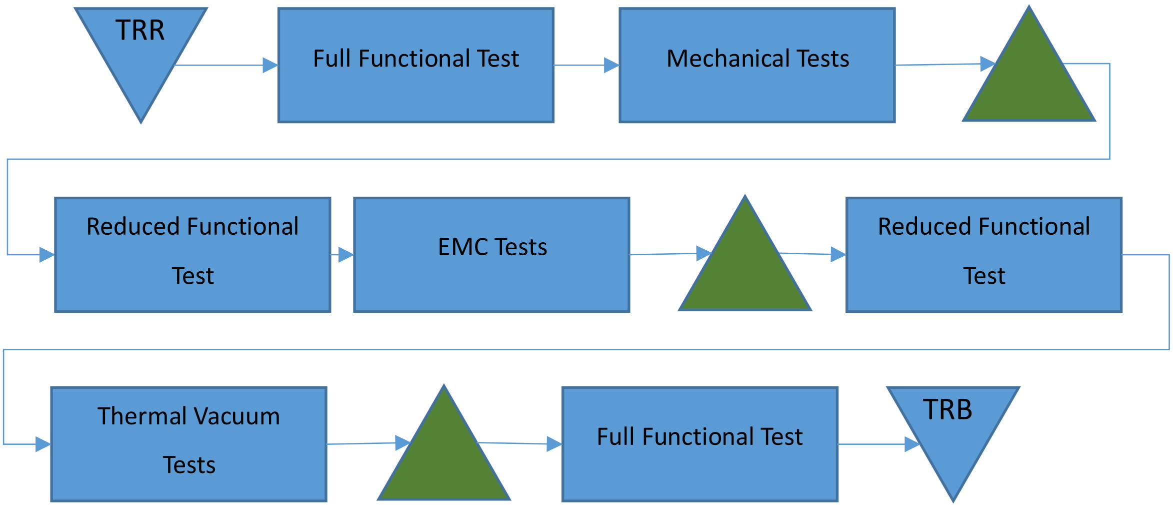


Figure 4.7: Test Flow for the DPU/DCU Unit, the green triangles represents Visual Inspections of the EUT.

The aim of Functional Tests is to demonstrate the functionalities of the EUT. After the Test Readiness Review (TRR) the test campaign is started performing the full range of tests to establish a benchmark to be taken into account when evaluating the results in the subsequent tests. A reduced functional test is performed after mechanical, EMC, and Thermal Vacuum tests to demonstrate that no degradation has been introduced during those tests. The results of these test is then analysed during the Test Review Board (TRB). All this testing was in charge of the DPU/DCU hardware supplier but, before they started, the NISP-Team had to deliver to them a stable version of the DPU ASW, capable of executing all the necessary operations, and a complete set of TSEQs that run through these functionalities.

The set of test is defined in [46]. Those tests are summarized in the following tables. Electrical tests are performed by direct hardware measurements. All the measurements were performed by OHB-I team and showed that the DPU/DCU EQM hardware is compliant with the requirements.

Functional tests requiring the use of the DPU ASW are labelled as FNC-xx and they are summarized in Table 4.1. They check the hardware performance during nominal DPU/DCU operations and the conduct of redundant MIL 1553 and Spacewire channels. DCU functions are also checked in functional test, the power distribution, overcurrent protection towards SCS anomalous power consumptions and frames co-adding by DCUs. The full range of possible programmable MACCs is investigated and the image processing time is checked. The impact of DPU memory scrubbing and resynchronization functions during a simulated nominal exposure is also evaluated. Each functional test allows testing the compliance of the EUT to one or more requirements that are reported in Table 4.2.

Test name	**Description**	**Scope**
FNC-1	1. EUT is powered ON, all DCU are powered ON and connected to EGSE. 2. SCS data&power test jigs are inserted in a transparent mode. 3. Set an overcurrent (OVC) load on one DCU board. 4. Test is repeated for each DCU. This configuration is also used for unit reboot verification. By forcing a reboot it is verified that analogue supplies of powered DCUs are not influenced and remain stable.	Verification of OVC protections of DCU towards SCS lines and EUT reboot
FNC-2	Unit is fully operative in continuous acquisition and processing endless loop mode of the frames coming from all the 8 Sidecar simulators.	Baseline configuration for tests of power consumption verifications.
FNC-3	Same as FNC-2 but the transmission is achieved on MIL-BUS and MMU redundant channels.	Redundant configuration check.
FNC-4	Same as FNC-2 but a specific MACC is configured with DPU memory scrubbing and resynchronization functions activated.	Verification of DPU performance in the applicable full range of possible MACC. Evaluation of the impact of DPU memory scrubbing and resynchronization functions.

Table 4.1: Functional test of the DPU that require the DPU ASW functions.

Requirements listed in Table 4.2 are related to the basic functions of the DPU/DCU system, the failure of any of them is critical for the mission. The DPU unit design has redundancy for the main power, interface and processing boards but there is no redundancy for the DCU boards therefore the reliability, flexibility and stability of them have to be verified.

Special care is given to the verification of the data processing time, as already mentioned in the thesis; the on-board processing time should not exceed the data taking time. This requirement is critical for the Euclid survey completion in a 6 years' period.

TEST	Requirement	Remarks
DPU/DCU nominal dither execution	Capability to execute the nominal dither according to Table 2.3 as defined as: • spectroscopic: MACC (15,16,11) • Y band: MACC (3,16, 6) • J band: MACC (3,16, 5) • H band: MACC (4,16,7)	
DPU/DCU MACC processing	Capability to process incoming SCS science frames executing co-adding of raw frames in groups.	
DPU/DCU SCS command	Capability to command SCS.	
DPU/DCU configuration for SCA temperature value processing	Capability to execute different types of possible required SCA temperature processing.	
DPU/DCU science data reception	Capability to receive science data on rise or fall edge of 10 MHz dataclock.	
DPU/DCU raw data extraction	Capability to extract up to 5 full lines (2048px) for each detector readout without any processing or compression.	
DPU/DCU processing capabilities with worst case MACC	Capability to execute dither.	
DPU/DCU deterministic processing	Verification of deterministic output of processing chain inside DPU/DCU stimulated with internal numeric frame generator.	
DPU/DCU frame time reception	Capability to receive a frame in at least 1.31sec	1.31 sec represents the worst case for DPU/DCU. Testing this value validates the requirement for all values greater than this.
DPU/DCU frame drop reception	Capability to receive frame drops between 1 and 1000.	1 represents the worst case for DPU/DCU.
DPU/DCU frame pixels reception	Capability to receive frames of 2048x2048 total pixels	

DPU/DCU frame delay reception	Capability to receive frames with a delay between two frames of a group from one SCE line time (690 µsec) to 0.2 sec, limits included.	690 µsec represents the worst case for DPU/DCU.
DPU/DCU time dither duration	Capability in one dither period (1048 s) to complete acquisition, processing and transmission to MMU of one spectroscopic image and 3 photometric images.	
DPU/DCU memory scrubbing	Capability to perform memory scrubbing and to mask it via TC.	
DPU/DCU boot	Capability to boot strap boot SW code after any on-board processor reset.	
DPU/DCU individually device command	Capability to command individual DPU/DCU device via TC of memory load and dump into device registers.	
DPU/DCU health monitoring	Access to DPU/DCU health monitoring, In particular the internal HK parameters reported in Table 4.4 will be verified to be inside allowed ranges.	
DPU/DCU TC/TM MIL-BUS-1553 link functionality	Ability to communicate via MIL-BUS TC/TM.	
DPU/DCU protections	Verification of protections and their reset via TC.	
DPU/DCU time to safe	Capability to enter in a safe condition within 120sec from any configuration via TC.	The safe condition in this test is considered as the capability to switch off all SCS and DCUs inside the required time.
Verification of DCU synchronization	Capability to synchronize the DCU SCS I/F.	Not possible to be performed via TC.
DPU/DCU unit reboot	Capability to perform a unit reboot without affecting powered DCUs.	

Table 4.2: DPU/DCU requirements that are tested during functional tests running.

Listed requirements are tested alone or mixed up in a series of test scripts that will be detailed and discussed in the following sections.

During the functional test the correct image acquisition and elaboration is verified checking the CRC of the received image on the EGSE with respect to the expected CRC that will be pre-calculated offline in the EGSE over the deterministic pattern of test images. This procedure is performed quasi-online by a dedicated SW which performs the comparison of received images with respect to the ones sent and elaborated by the DPU ASW.

During functional test several telemetries (see Table A.4 in the Appendix) are checked to be inside ranges expected by the DPU Hardware design.

4.3 Test sequences and test results

In order to perform the functional test and check the analogue and digital telemetries the INFN Padua Group prepared a set of atomic Test Sequences. The Test Sequences (TSEQ) developed for all the NISP AIV/AIT campaigns are compliant with a specific framework prepared by TAS-I for the Euclid EGSE software.

This framework foresees naming and programming conventions in a layer-based TCL/uTOPE coding architecture characterized by five growing levels of abstraction. The two lower levels contain basic TSC/CCS SW functions (already included into the supplied EGSE systems) and low-level and general purpose functions customized for Euclid AIV/AIT activities (developed and provided by TAS-I).

The three upper levels are the so-called project layers containing the scripts related to the specific test campaign. In the case of NISP, these layers were developed by the NISP Team, starting from the provided Test Procedures and exploiting the appropriate version of the NISP MIB tables.

This approach guarantees a straightforward reuse of the developed TSEQ in the subsequent Euclid AIV/AIT phases.

The scripts have a graphical user interface, called MMI, that allows following the execution on-line; every TC sent and TM received is printed on the screen and in the end of the execution a log file is saved.

For each command issued to DPU ASW the Command Verification Table is checked and a corresponding value in the telemetry is checked, if one of such checks fails the script is paused and the error is notified to the user.

4.3.1 EUC_NISP_T1_DPU_OFF_BOOT

The first script, EUC_NISP_T1_DPU_OFF_BOOT tests the capability to start the DPU BSW, the requirement tested is **DPU/DCU boot**.

This script switches on the DPU/DCU, lets the unit to perform the boot and checks the Housekeeping. The steps implemented in the script are the following:

- the TE power supply output is configured at 28V, this value is a parameter that can be changed if needed.
- the LCL giving power to the DPU is activated.
- after 3 seconds the DPU power consumption is checked to be in the allowed range.
- the reception of BSW report is checked after 50 seconds. This report is composed by five TM (5,1) events that report the results of BSW preliminary checks. Each event has a flag that should be OK.
- wait for the reception of BSW periodic telemetry packets within 15 seconds.
- check the following parameters in the BSW housekeeping:
    - BootSW version = 2.0.0 with PFM flag
    - Watchdog = enabled
    - SDRAM resynch = off
    - Memory scrub = enabled
    - CPU resynch = enabled
    - SW data word#2 = LOBT synchronized
    - CPU Voltage = (5 ± 10%) V
    - CPU Current = 0.08 A < I < 0.85 A
    - DBB Voltage = (5 ± 10%) V
    - DRB Voltage = (5 ± 10%) V
- the LCL giving power to the DPU is deactivated.

The script is executed with no error, the BSW boot report is received within 50 seconds with all checks passed, all the digital BSW telemetries are as expected and all analogue periodic telemetries are in the allowed ranges; housekeeping values are reported in Table 4.3.

Parameter	Value	Range
DPU Voltage	28.02 V	26 ÷ 30 V
DPU Current	0.919 A	0 ÷ 5 A
CPU Voltage	5.165 V	4.5 ÷ 5.5 V
CPU Current	0.105 A	0.08 ÷ 0.85 A
DBB Voltage	5.150 V	4.5 ÷ 5.5 V
DRB Voltage	5.169 V	4.5 ÷ 5.5 V

Table 4.3: Analogue telemetries acquired after the BSW boot.

4.3.2 EUC_NISP_T2_DPU_OFF_ASW

The second script, EUC_NISP_T2_DPU_OFF_ASW switches on the DPU/DCU, waits for BSW start-up and performs the transition to DPU ASW. The requirements tested are **DPU/DCU boot, DPU/DCU TC/TM MIL-BUS-1553 link functionality.** The steps implemented in the script are the following:

- same as EUC_NISP_T1_DPU_OFF_BOOT, only the final LCL deactivation is excluded
- after 10 seconds command the BSW to copy ASW image to RAM, the image A or B can be selected by the user
- verify the acceptance TM (1,1) and execution TM (1,7) of the command
- command the BSW to jump to ASW image address (the address is specified in the first page of the EEPROM)
- check that no TM is produced by BSW, a TM (1,2) or (1,8) is produced only if an error occurs
- verify DPU power consumption
- wait for the reception of the ASW periodic telemetry within 30 seconds
- verify that the digital and analogue telemetry produced by ASW are correct and inside allowed ranges.

The script is executed with no error; the BSW report is received within 50 seconds with all checks passed, all the digital BSW telemetries are as expected and all the analogue periodic telemetries are in the allowed ranges. TCs sent to BSW were accepted and executed, within 30 seconds the ASW is running in CPU_SAFE mode as expected and analogue and digital telemetries are as expected, analogue telemetries are reported in Table 4.4.

Parameter	Value	Range
DPU Voltage	28.02 V	26 ÷ 30 V
DPU Current	1.136 A	0 ÷ 5 A
CPU Voltage	5.150 V	4.5 ÷ 5.5 V
CPU Current	0.105 A	0.08 ÷ 0.85 A
DBB Voltage	5.150 V	4.5 ÷ 5.5 V
DRB Voltage	5.169 V	4.5 ÷ 5.5 V

Table 4.4: Analogue telemetries acquired after the ASW start-up procedure, note that the DPU current consumption is increased when the ASW is in execution.

4.3.3 EUC_NISP_T3_DPU_link_MMU

The script EUC_NISP_T3_DPU_link_MMU manages the Spacewire links between DPU and TE, it permits to activate the main, the redundant or both Spacewire channels of the DRB. There are no specific requirements tested with this script, it is used to configure the Spacewire link, such action is specific of the EGSE configuration. Furthermore, the script is used to check that both nominal and redundant DRB Spacewire channels can work properly. The steps implemented in the script are the following:

- configure Spacewire interface: nominal, redundant or both
- activate the Spacewire link: nominal, redundant or both
- provide the status of the link after 3 seconds.

The script is executed with no errors and the status of both links is ACTIVE.

4.3.4 EUC_NISP_T4_DCU_ON

The script EUC_NISP_T4_DCU_ON switches on the DCU boards. It is possible to switch on a single board, a subset or all the DCUs. The analogue output (VDDA and VDD2V5) can be configured by the user.

The requirement tested is **DPU/DCU health monitoring.** The steps implemented in the script are the following:

- configure DCU board analogue values
- check DPU Housekeeping
- move the ASW to CPU_SAFE state
- configure the RT address of the active DPU, the chosen value is RT1
- set the bit mask of the DCU that will be powered ON
- move the ASW to SCE_INIT state
- switch ON DCU boards, one by one, with a delay of at least 10 seconds
- activate DCU Housekeeping transmission
- send the TC to synchronize the DCU signals
- verify DPU power consumption after 3 seconds
- check DPU/DCU Housekeeping.

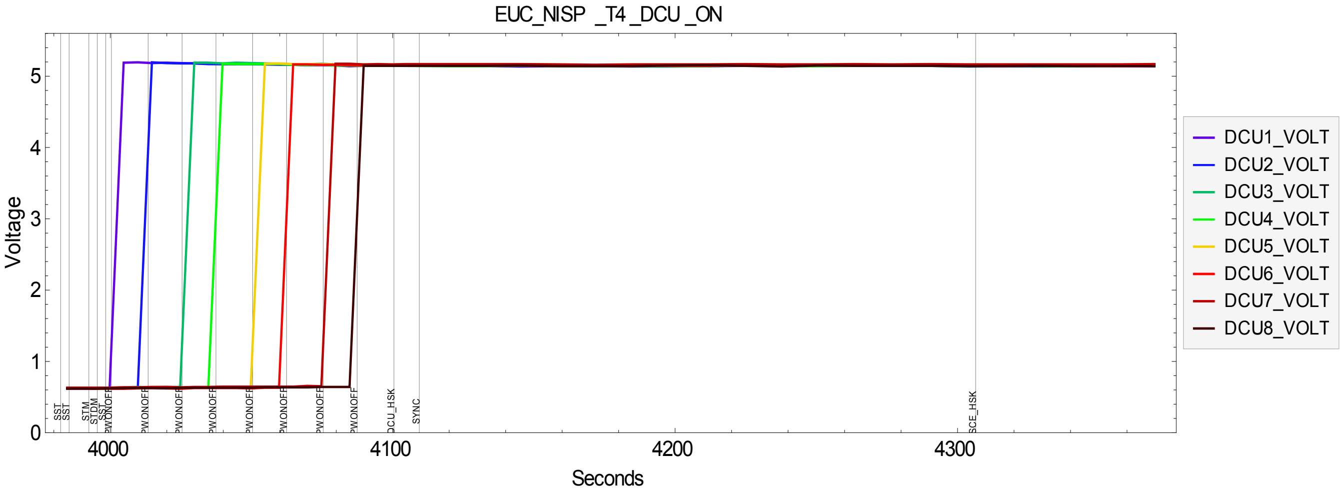


Figure 4.8: DCU Voltages from DPU housekeeping during the execution of the script EUC_NISP_T4_DCU_ON (on horizontal axis there is time elapsed from the beginning of TSC session). Vertical lines represent commands sent to the DPU: two state changes (SST), mastership assignment (STM), DCU mask assignment (STDM), ASW status change (SST), power ON of the 8 DCUs (PWONOFF), start the DCU housekeeping scanner (DCU_HSK), synchronization command to DCUs (SYNC).

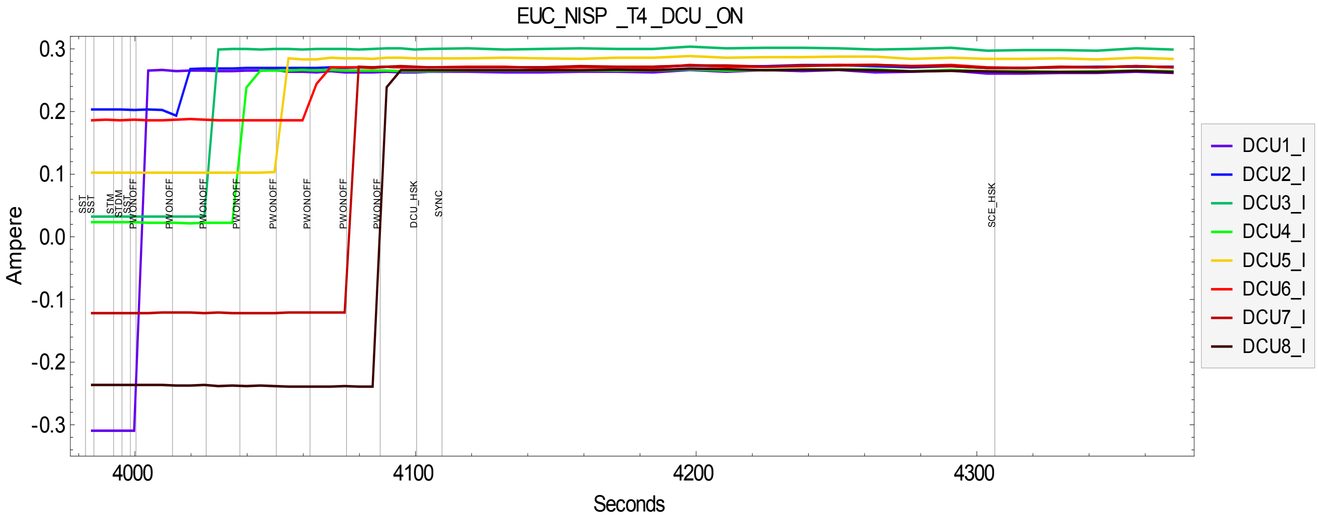


Figure 4.9: DCU Currents from DPU housekeeping during EUC_NISP_T4_DCU_ON. It is worth to mention that the housekeeping value recoded before the DCU is switched ON is meaningless.

The script is executed with no error, all the TCs are accepted and executed, DCU are switched ON one by one and the final state of DPU ASW is SCE_INIT. As shown in Figure 4.8 and Figure 4.9 the DCU Voltage and Current are always in the allowed ranges.

4.3.5 EUC_NISP_T5_DCU_OFF

The script EUC_NISP_T5_DCU_OFF switches off the DCU boards. It is possible to switch off a single, a subset or all the DCUs. There is no specific requirement demonstrated with this script.

The steps implemented in the script are the following:

- check DPU/DCU Housekeeping
- switch OFF DCU board(s)
- verify DPU power consumption after 3 seconds
- check DPU/DCU Housekeeping.

The success criteria are to receive the correct voltage from the DPU housekeeping and check that current drained from the power supply changes when DCU are turned off. This is automatically checked by the TCL script and the result is positive.

4.3.6 EUC_NISP_T6_SCS_ON

The script EUC_NISP_T6_SCS_ON activates the Sidecar simulators including analogue supplies I/F of DCU board(s). It is possible to activate a single, a subset or all the SCS. The requirement tested is **DPU/DCU SCS command.** The steps implemented in the script are the following:

- set SCS nominal analogue loads and activate data interface
- stop the DCU housekeeping generation
- activate DCU SCE interface channel(s), this command is executed with the directive SCE_BOOT
- verify DPU power consumption after 3 seconds
- restart the DCU Housekeeping generation
- check DPU/DCU Housekeeping
- check SCS housekeeping using the GTAB command.

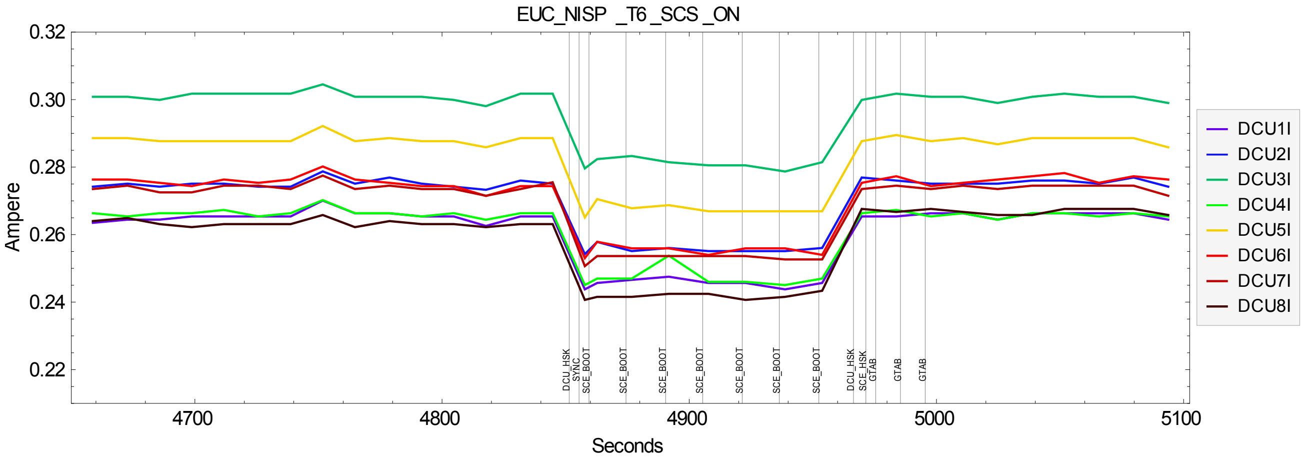


Figure 4.10: DCU Current from DPU housekeeping. When the telemetry scanner is deactivated, before the SCE_BOOT command, the current drained lowers a little; it returns to the ordinary value when the scanner is reactivated. No appreciable difference is noted after the boot.

The script is executed with no error, all the TCs are accepted and executed, SCS are activated one by one and the final state of DPU ASW is SCE_INIT. As shown in Figure 4.10 the DCUs Voltage and Current are always in the allowed ranges.

4.3.7 EUC_NISP_T8_SCS_WrRe_functionalTest

The script EUC_NISP_T8_WrRe_functionalTest verifies that it is possible to write and read a single word on accessible DCU memory areas. The test can be performed on a single, a subset or all the DCUs. The word to be written is prepared by the user.

The requirement tested is **DPU/DCU individually device command.**

The steps implemented in the script are the following:

- Stop DPU/DCU/SCS Housekeeping
- Move the DPU ASW to Manual mode
- For each DCU accessible area write the word 0xA5F0
- dump the memory area and verify that the word has been correctly written
- restart the DPU/DCU/SCS Housekeeping.

The script is executed with no errors; all the TCs are accepted and executed.

4.3.8 EUC_NISP_T9_SCS_OVC

The script EUC_NISP_T9_SCS_OVC provokes an overcurrent on one of the analogue interfaces of a DCU board. After the protection intervention it is possible to reset the protection and restart the SCS connected to the DCU where the OVC has been created. It is possible to create OVC on a single DCU, a subset or all. The following parameters can be set to not nominal Load: Vdda, Vref, Vdd3V3, Vdd2V5, Vddio, Vssio. The requirement tested is **DPU/DCU protections**.

The steps implemented in the script are the following:

- verify DPU power consumption
- set one of the TE analogue loads to Load1 (not nominal) for the DCU board under test
- verify DPU power consumption after 3 seconds
- check the DCU status register value that signals the OVC protection
- check the DCU HK_protection_fault register that signals the load that has provoked the OVC
- check that the SCS is deactivated by OVC protection
- reset the protections of the DCU board under test
- set TE analogue loads to the nominal value for the DCU board under test

- switch on the DCU that has been reset
- verify DPU power consumption after 3 seconds
- check DPU/DCU Housekeeping

The steps should be repeated for each DCU, for each OVC load to be set and for the two possible not nominal loads allowed in the TE.

The script is executed with no error, all the TCs are accepted and executed, OVC protection is always triggered and properly reported in the DCU digital telemetry.

4.3.9 EUC_NISP_T11_SCS_Conf_raw

The script EUC_NISP_T11_SCS_Conf_raw configures the SCS simulator for the science data transmission, all the parameters related to frames and groups to be transmitted have to be specified by the user. It is possible to configure a single, a subset or all the SCS.

The requirement tested is **DPU/DCU SCS command**. The steps implemented in the script are the following:

- configure SCS, the configuration is prepared by the user in a configuration file. Such parameters have a large allowed range and will be used in the offline analysis to verify the correct data acquisition and processing.
    - Frame time (1.31 ÷ 1.45 s)
    - Frame gap (690 ÷ 2000 µs)
    - Clock Edge (Rising or Falling)
    - Pixel Mode (Deterministic or Random)
    - Pixel offset (0 ÷ 65535)
    - Pixel gain (1 ÷ 65535)
    - Row gain (1 ÷ 65535)
    - frame gain (0 ÷ 65535)
    - TLM file (filename.txt)
    - Offset T (0 ÷ 65535)
    - Range T (0 ÷ 65535)

- Offset OFS (0 ÷ 65535)
- Range OFS (0 ÷ 65535).

The set of parameters used to configure a nominal Spectroscopic MACC (15, 16, 11) is in Table 4.5.

The SCS configuration takes several seconds to be applied, the completion rate is accessible in the SCS telemetry file and it is monitored by the script. The execution of the configuration is successful.

Parameter Mnemonic	Parameter description	Value
NSSP0002	Clock_Edge	Rising Edge
NSSP0004	SCS_Id	1 ÷ 8
NSSP0029	Telemetry_File	def_telemetry.txt
NSSP0031	Macc_G	15
NSSP0032	Macc_R	16
NSSP0033	Macc_D	11
NSSP0011	Pixel_Mode	Deterministic
NSSP0012	Pixel_Offset	0
NSSP0013	Pixel_Gain	1
NSSP0014	Row_Gain	2
NSSP0015	Frame_Gain	4
NSSP0016	Offset_Temp	0
NSSP0017	Range_Temp	65535
NSSP0018	Offset_Offset	0
NSSP0019	Range_Offset	65535
NSSP0020	Frame_Time (s)	1.41
NSSP0034	Frame_Delay (ms)	0.690

Table 4.5: Set of parameters used to configure Sidecar Simulators.

4.3.10 EUC_NISP_T12_MACC_Start

The script EUC_NISP_T12_MACC_Start configures and starts the science acquisition with standard or arbitrary MACC parameters on DCU boards and then starts the science data transmission from SCS. Science data are processed by DPU, with the possibility to configure DBB scrubbing and DPU scrubbing and synchronization. Data compression can be applied or not. Finally, data are sent to MMU. It is possible to start the MACC on a single, a subset or all the SCS. The MACC is performed using the DBB memory bank chosen and at the end unit is ready to be commanded for a new operation. The MACC parameters are loaded in a configuration file prepared by the user, they are:

- Groups# (1 ÷ 15)
- Reads# (1 ÷ 16)
- Drops# (1 ÷ 1000)
- Rawlines (YES, NO)
- Rawlines addresses (0 ÷ 2047)
- DBB scrub (YES, NO)
- DBB Memory Bank (A, B)
- DPU scrubbing (YES, NO)
- DPU syncronization (YES, NO)
- Scientific data compression (YES, NO).

Many requirements are tested: **DPU/DCU MACC processing, DPU/DCU SCS command, DPU/DCU configuration for SCA temperature value processing, DPU/DCU science data reception, DPU/DCU raw data extraction, DPU/DCU processing capabilities with worst case MACC, DPU/DCU deterministic processing, DPU/DCU frame time reception, DPU/DCU frame drop reception, DPU/DCU frame pixels' reception, DPU/DCU frame delay reception, DPU/DCU memory scrubbing.**

The steps implemented in the script are the following:

- move the DPU ASW to OBSERVATION mode
- send configuration tables to ASW to start MACC, namely Processing Parameters Table and Dither Configuration Table (set MACC#=1)
- configure SCS(s) to prepare simulated data with the same MACC parameters used in the Dither Configuration Table
- start the transmission to DCU(s) of the frames simulated by SCS(s)
- start MACC on DCU(s) with the SCE_EXPOSE command broadcasted to all the active DCUs
- verify DPU power consumption after 3 seconds.

The Dither Configuration Table prepared for a single MACC (15,16,11) in Spectroscopic mode is the following, it is compatible with the parameters shown in Table 4.5 used for SCS configuration.

Parameter Mnemonic	Parameter Description	Value
NWSP0001	ICU Request Counter	Counter
NASP4703	DBB Pointer	DPM_Mem_Bank_A
NASP4704	Exposure Number	1
NASP4705	Dither Total Time (s)	1114
NASP4706	Number of Groups	15
NASP4707	Frames per Group	16
NASP4708	Droplines HighWord	0
NASP4709	Droplines LowWord	22528
NASP4711	Keyword	Grism_RGS0
NASP4710	Instrument Configuration	Science

Table 4.6 Parameters for SCE_EXP command

The script is executed successfully, the MACC is simulated and processed by the ASW, the file is sent to MMU simulator trough the Spacewire link and the consistency is verified on the IWS.

4.3.11 EUC_NISP_T13_Dither_Start

The script EUC_NISP_T13_Dither_Start configures and starts a sequence of MACCs with standard or arbitrary parameters. It is possible to start the DITHER on a single, a subset or all the SCS. Note that dither configuration is the same for all DCUs. The DITHER is performed one time using the DBB memory bank chosen and at the end unit is ready to be commanded for a new operation.

For each MACC the user has to specify the following parameters:

- MACC# (1 ÷ 7)
- Groups#_MACCx (1 ÷15) with x depending on MACC#
- Reads#_MACCx (1 ÷16) with x depending on MACC#
- Drops#_MACCx (1 ÷1000) with x depending on MACC#

The requirements tested are the same of EUC_NISP_T12_MACC_Start plus two more related to the time needed to complete the dither, data processing and data transmission to MMU, namely **DPU/DCU nominal dither execution and DPU/DCU dither time.**

The steps implemented in the script are the following:

- send configuration tables to ASW to start MACC, namely Processing Parameters Table and Dither Configuration Table (set MACC# > 1)
- configure SCS(s) to start MACCs with the same parameters used in the Dither Configuration Table
- start the transmission to DCU of the frames simulated by SCS(s)
- start MACC on DCU(s) with the SCE_EXPOSE command broadcasted to all the active DCUs
- verify DPU power consumption after 3 seconds
- register the value of OBT1 when the SCS status is changed to EXPOSING in AW telemetry
- verify DPU power consumption after 3 seconds
- repeat those steps for each MACC programmed in the dither
- register the value of OBT2 when the DITHER flag is set to OFF and the ASW status changes from Observation Processing to Observation waiting.
- evaluate the difference between OBT2 and OBT1 and check that it is less than 1048 s.

The script is run simulating a Nominal Dither (1 spectro + 3 photometric exposures), the time needed to complete the processing and data transfer to MMU is 640 s, which is in the specifications. The data transferred to MMU is as expected.

4.3.12 EUC_NISP_T14_Science_Abort

The script EUC_NISP_T14_Science_Abort should abort any MACC on DCU boards and the relative processing. The requirement tested **is DPU/DCU SCS command.**

The steps implemented in the script are the following:

- Start the script EUC_NISP_T13_Dither_Start

- send the command CPU_DABT to abort an exposure
- stop MACC data transmission from SCS(s)
- verify DPU power consumption after 3 seconds
- check the Dither flag is set to OFF by the ASW in the digital telemetry.

The script is executed with no error, the MACC is stopped, there is no file transferred to MMU and the DPU digital telemetry is updated as expected concerning the Dither and the Exposure flags.

4.3.13 EUC_NISP_T15_DPU_Reboot

The script EUC_NISP_T15_DPU_Reboot forces a CPU reboot via TC, after the reboot the DCU should be still powered ON and the ASW is in the CPU_PARKED state. The requirement tested is **DPU/DCU unit reboot**.

The steps implemented in the script are the following:

- verify DPU power consumption
- send command CPU_RBT to reboot the CPU
- verify DPU power consumption after 10 seconds
- execute the same steps as EUC_NISP_T2_DPU_OFF_ASW
- verify that ASW status is CPU_PARKED
- check in the Housekeeping and in ASW digital telemetry that DCUs are ON and SCSs Booted.

The script is executed and all the TC are accepted, the DPU reboot is successful, after the re-start of the ASW the state is CPU_PARKED, DCU are powered ON and SCS activated. The DPU digital telemetry flags are updated as expected.

The full test plan was completed without errors and all the DPU functional requirements were verified. After this test campaign OHB-I delivered the DPU EQM model to the NISP Italian team and launched the production of the DPU FM units.

DPU/DCU performances were found compliant with functional requirements, infrared detector control and on-board data processing can be handled in a proper way to ensure the completion of the scientific survey. In particular, the demanding requirement concerning the DPU/DCU dither duration is verified.

The software tools prepared by INFN team on purpose for this task were appropriate and are currently in use for DPU FM models debugging and validation. The 1553 TM/TC interface was tested and the possibility to issue Telecommands and retrieve digital Telemetries and Housekeepings with a cyclical bus profile is verified. This test campaign addressed mission critical functions of the DPU Hardware and software components by atomic and basic test procedures; it represents a promising starting point for the NISP Warm Electronic AIV/AIT campaign.

5 NISP Avionic Model integration and test

The purpose of the NISP Avionic Model (AVM) is to test, at room temperature [47][48]:

- the NISP functional performances
- the command flow from Service Module
- the science data (compressed image files) and housekeeping data production and transmission to SVM interfaces

The NISP AVM model is intended to represent a realistic emulator of the NISP Instrument, it will be used by TAS-I as a reference during the Service Module integration and test campaign.

The AVM is the first NISP model that foresees the integration of the NISP Warm Electronic therefore, a CDR level version of the DPU ASW and of the ICU ASW are installed on the AVM.

Full NISP AVM integration started in December 2017 in the dedicated ISO-8 Clean Room prepared at University & INFN Padua. The test campaign was supported by the NISP EGSE, it is composed by the NISP-SCOE, the CCS and the Instrument Workstation (IWS).

After the integration there was the preparation of test sequences and finally the execution of functional tests (Short Functional Test, Full Functional Test and Robustness Test). Finally, in June 2018 the NISP AVM was delivered to TAS-I for the integration with the Euclid Service Module.

I participated to the integration and test activity and I contributed in the preparation of the test scripts and in the preparation of a Synoptic Telemetry display that allows on-line monitoring of the NISP operating modes and main housekeeping data.

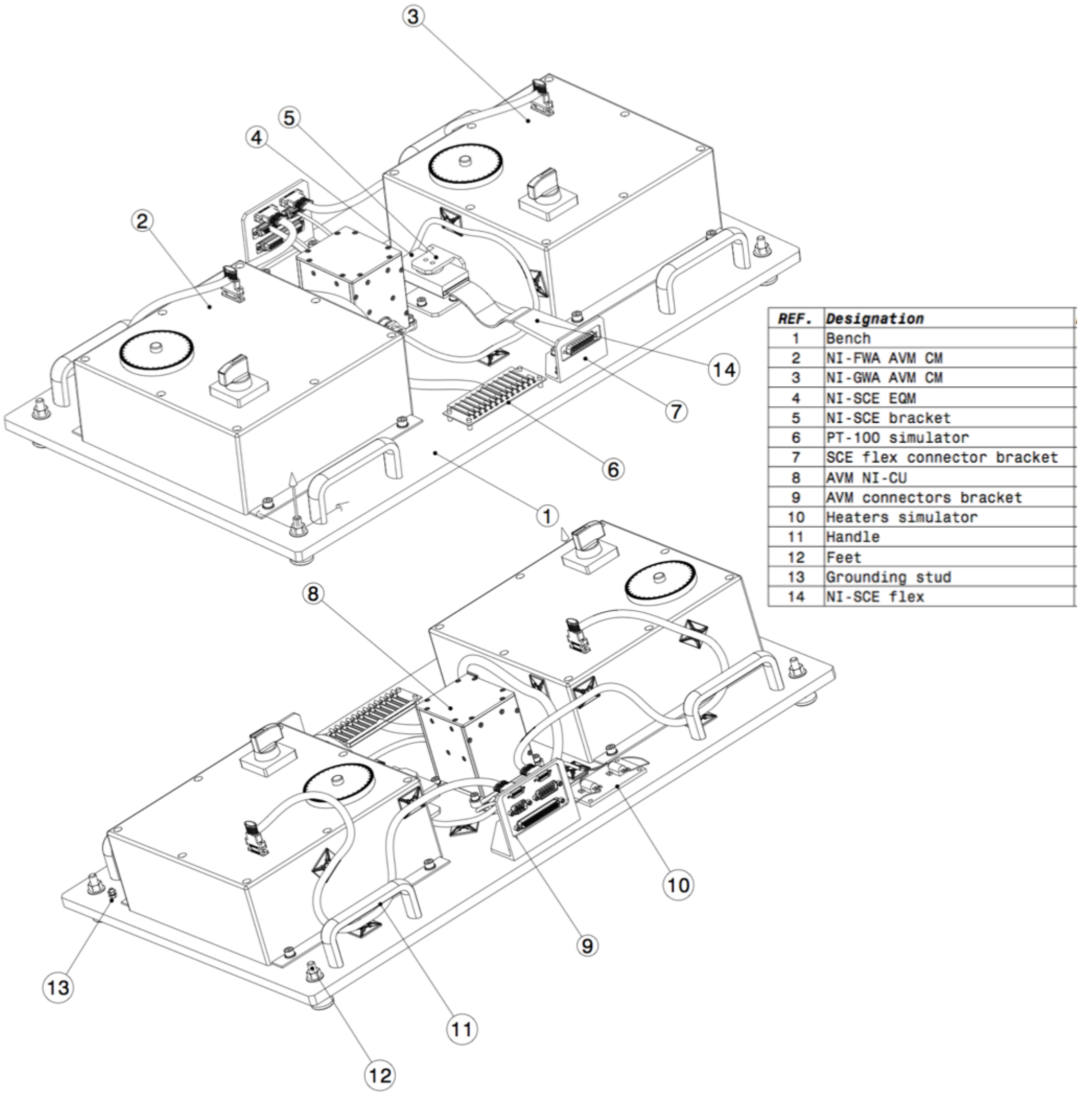
5.1 NISP AVM hardware components

The NISP AVM is composed by the **NI-OMADA** electrical simulator, the **DPU/DCU EM with only one DCU**, the **ICU EM**, and an **SCE Engineering model**.

5.1.1 NIOMADA AVM Bench

The NI-OMADA AVM bench is prepared by LAM (Marseille) and shipped to Padua Laboratory for NISP AVM integration (see Figure 5.1), it provides interface and simulators for five NISP subsystems:

- Filter Wheel Cryo Mechanism (FWA CM)
- Grism Wheel Cryo Mechanism (GWA CM)
- Calibration Unit (CU)
- NISP Thermal Control
- one NI-SCE **EM**.



REF.	Designation
1	Bench
2	NI-FWA AVM CM
3	NI-GWA AVM CM
4	NI-SCE EQM
5	NI-SCE bracket
6	PT-100 simulator
7	SCE flex connector bracket
8	AVM NI-CU
9	AVM connectors bracket
10	Heaters simulator
11	Handle
12	Feet
13	Grounding stud
14	NI-SCE flex

Figure 5.1: CAD design of the NIOMADA AVM bench.

The NI-OMADA AVM is assembled with commercial components; its purpose is to provide to the ICU an electrical simulator of the NI-OMA and to provide to the DPU/DCU unit the interface with one SCE.

The NI-OMADA bench is a 750 x 450 mm² plate made of aluminium alloy, it hosts the simulator and two brackets for harness proper connections.

One connection bracket is designed for NI-OMA simulators and one is dedicated to the connection between the DCU and the SCE via a dedicated harness prepared by INFN Padua.

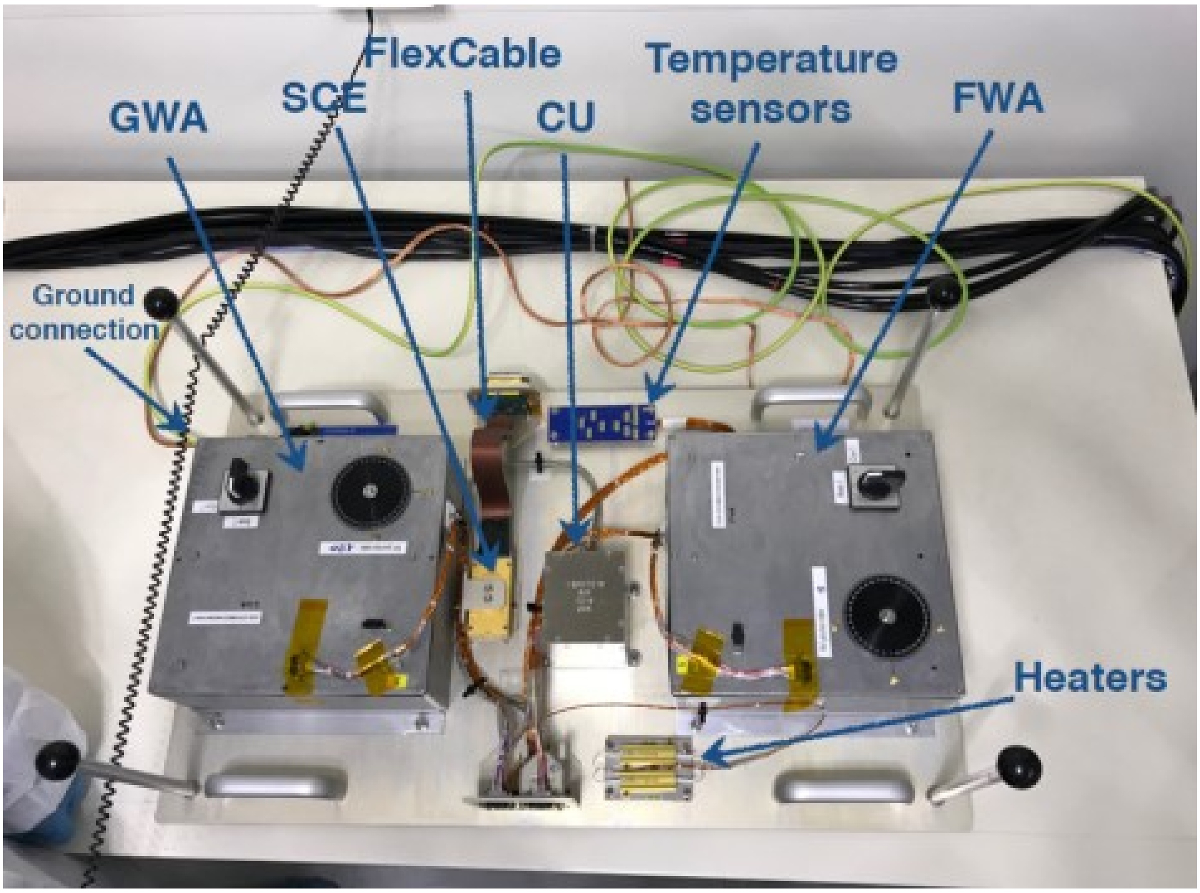


Figure 5.2: Picture of the NI-OMADA AVM bench.

5.1.1.1 NI-FWA/GWA CMs AVM

The Cryo Mechanisms AVM are two aluminium boxes; their approximate dimensions are 25 cm x 25 cm x 10 cm (see Figure 5.2). Each box contains containing RL circuits equivalent to the windings of the FWA and GWA motors (NI-FGS), step motors are emulated by a 480mH inductance in series with a 270 Ω resistor.

The purpose of NI-FGS is to emulate the behaviour of FWA/GWA in order to check the ICU. It can receive the driving signals from the ICU and consequently generate signals needed by ICU to monitor the status of the FWA/GWA, for example the home position sensor status. The NI-FGS provides the same electrical conditions of the FWA/GWA motor but it will not simulate error conditions. The activation of the home position signal has to be operated manually by the rotation of the graduated knob.

5.1.1.2 NI-CU AVM

The NI-CU Simulator (NI-CUS) emulates the behaviour of NI-CU in defined operating condition. The system simulates five LEDs and can be connected to only one NI-ICU section (nominal or redundant) at a time. It has the same electrical behaviour of the NI-CU LEDs but no error is simulated.

5.1.1.3 NI-TC AVM

The NI-TSH simulator is a passive components board that represents the NI-OMADA Thermal Sensors and Heaters from the electrical point of view. It is made by 1 PCB supporting 10 resistors simulating the PT-100 and by a couple of power resistors that simulate the NI-SA heaters and the NI-SS heaters (see Figure 5.3).

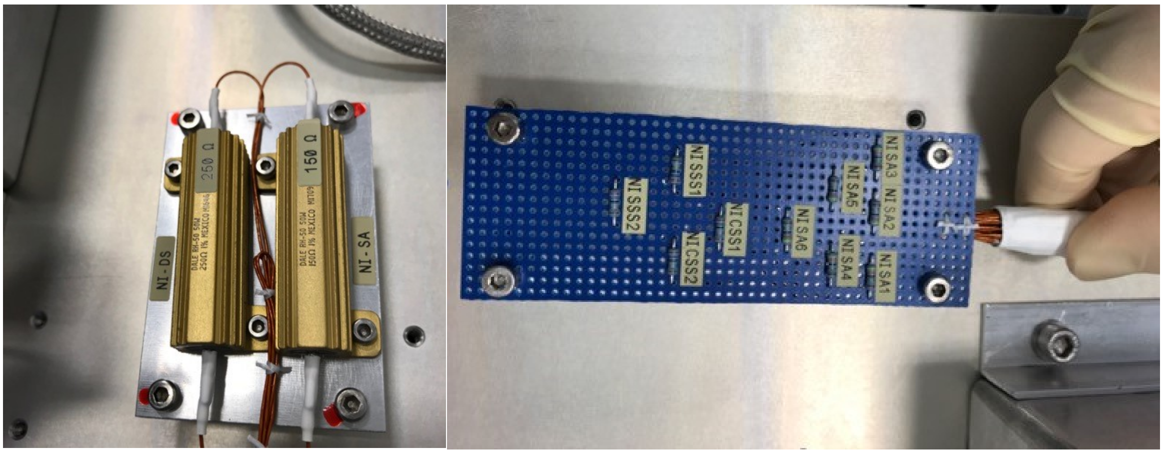


Figure 5.3: PCB supporting the 10 resistors on the left and NI-SA and NI-SS heaters simulators on the right.

5.1.1.4 NI-SCE EM

The Detector System Assembly (NI-DS) simulator is composed by one real SCE EM (serial number 39-17496) with a Flex Cable (serial number 003-002 (1013)) working at room temperature (see Figure 5.4).

In order to perform functional tests at room temperature, the SCE can be configured, with a dedicated TC, to set the signal inputs to ground. In this operating mode the SCE is fully representative in terms of operations and functions. The SCE can be also programmed, with a proper TC, to generate a predefined data pattern in order to validate the DPU ASW data processing pipeline and Spacewire data transmission to the MMU.

Figure 5.4: Sidecar ASIC (SCE) and flex adapter cable.

5.1.2 NI-DPU AVM

The NISP AVM Data Processing Unit (DPU/DCU) is equipped with the following boards as shown in Figure 5.5:

- 1 DCU board at EM level quality, it provides interface and power to the SCE and performs data co-adding.
- 1 Data Buffer Board (only the nominal one) at EQM level quality, it provides co-added images storage up to 6 GB.
- 1 Data Router Board (only the nominal one) at EQM level quality, it handles

MIL1553 and Spacewire interfaces.

- 1 Data Processing Board (only the nominal one) at EM level quality, it is realized by a MAXWELL SCS750 board and supports the DPU ASW running.
- 1 Power Supply Board (only the nominal one) at EQM level quality.

The AVM DPU mounts only one DCU connected to the SCE installed on the NI-OMADA. This Sidecar ASIC is not connected to any detector but it is possible anyway to deliver frames to the DCU: they can be SCE electrical noise frames or simulated frames (either simulated pixel-by-pixel or as a *flat* image).

The DPU EM is flight representative in terms of mechanical parts, electrical design and ASW functions. Each PCB Board is provided with its own electronics and front panel where several connectors are mounted onto for electrical interfacing. Figure 5.6 shows an overview of the NISP DPU/DCU mechanical design.

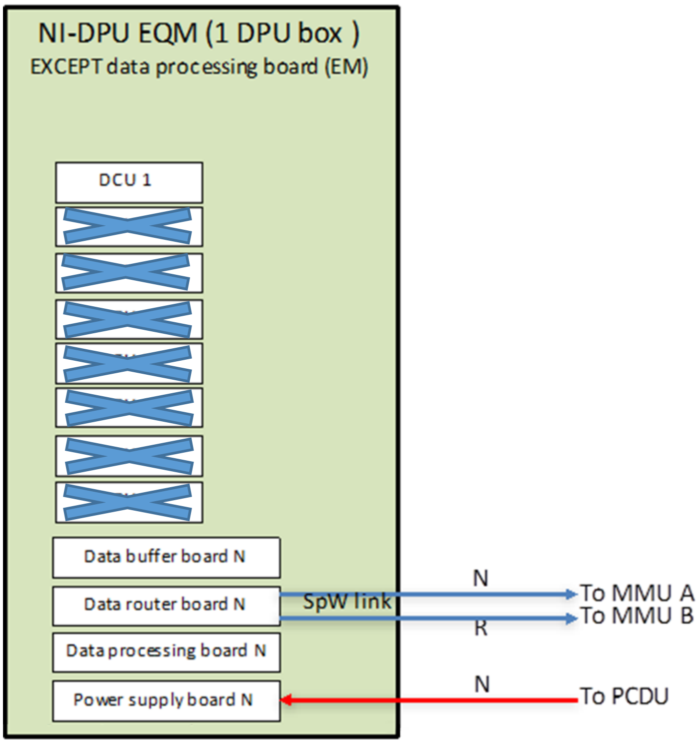


Figure 5.5: DPU AVM (EM), the unit has one link to the Power Supply, one MIL1553 channel (A/B) to interface the ICU and two Spacewire channel (N/R) to interface the MMU.

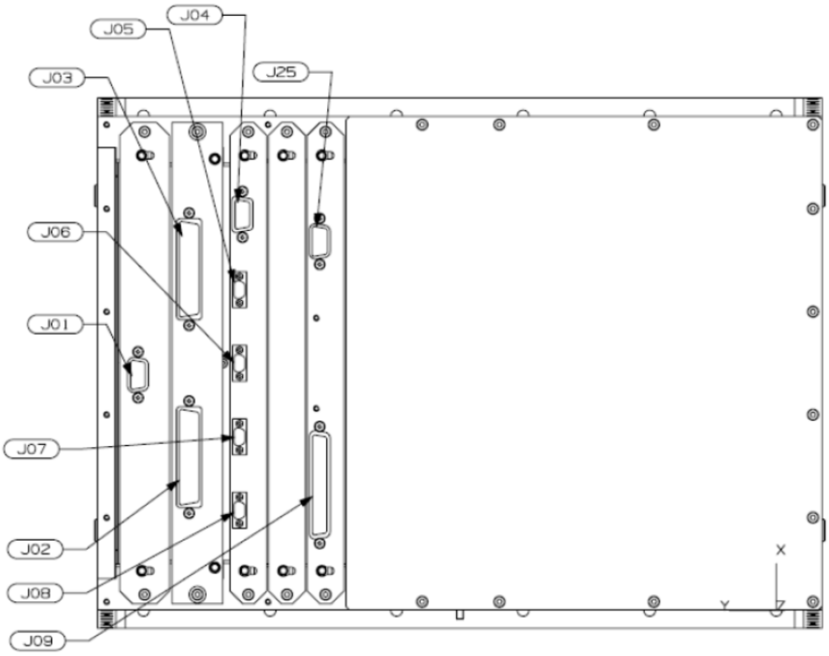


Figure 5.6: J01 is the power supply connector, J02 is the MIL1553 connector, J04-J05 are the Spacewire links, J09 is the DCU/SCE interface.

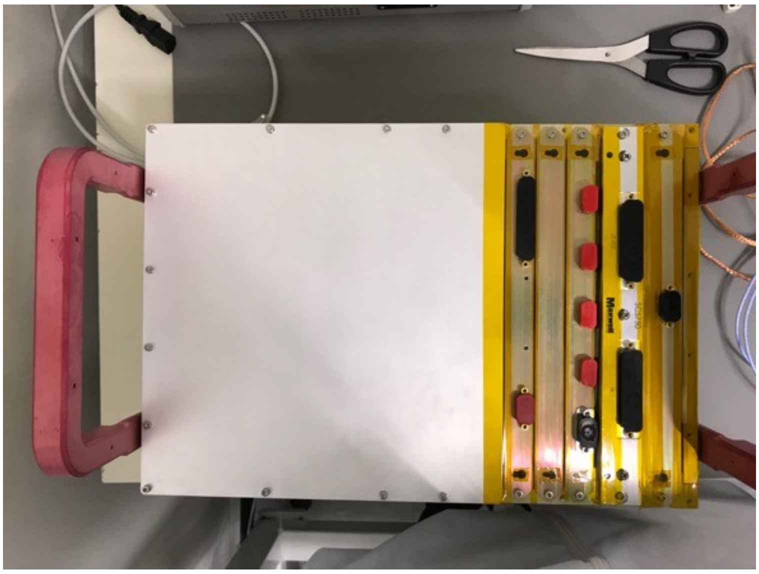


Figure 5.7: Picture of the DPU EM.

5.1.3 NI-ICU AVM

The ICU model used for the AVM is the ICU EM. This ICU EM does not have the redundant functionalities of the ICU FM. It is composed by the following boards (see Figure 5.8):

- LVPS board (only the nominal one) at EQM level quality, it powers the internal electronics and the NI-OMA subsystems.
- DAS board (only the nominal one) at EQM level quality, it hosts the drivers and DAQ of NI-OMA subsystems
- CDPU board (only the nominal one) at EQM level quality, it hosts the main processor and handles the MIL1553 buses and timers
- dummy modules for the redundant section.

The ICU handles all the NISP functionalities and interfaces the NISP instrument to the S/C control system for TM/TC tasks. It exchanges TM/TC data with the NI-DPU using an internal MILBUS-1553B bus and provides the control electronics for the NI-FWA, the NI-GWA, the NI-CU and the NI-OMADA temperature sensors and powering the heaters. The ICU generates the secondary power supplies which are needed to perform all these functions except for the DPU/DCU, which are powered by the primary power supply.

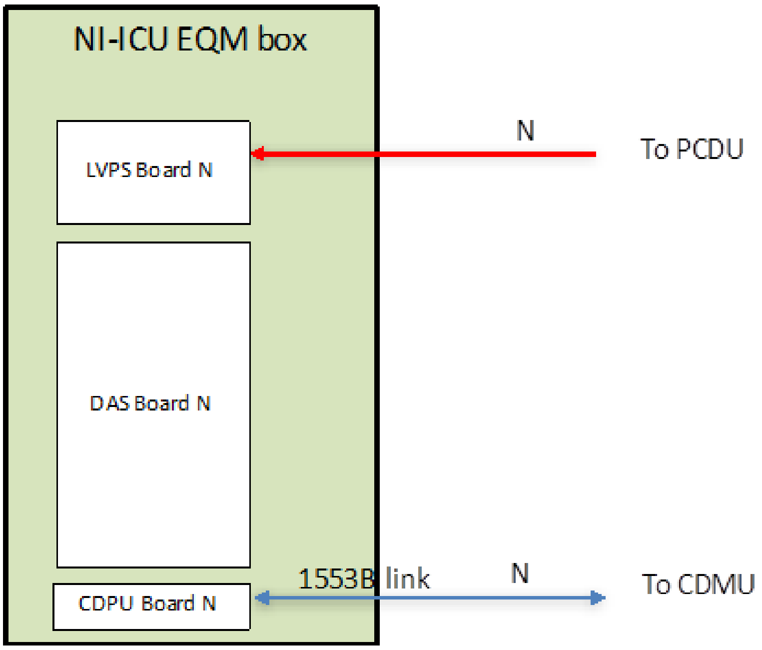


Figure 5.8: ICU AVM diagram.

ICU functionalities achieved with the EM model and to be tested during functional test are:

- communicate with the spacecraft via MIL-1553 bus for all the NISP Housekeeping and Telecommand management
- control the rotating mechanisms FWA, GWA
- control the Calibration Unit
- control the Thermal level of NI-DS and of the NI-OMA
- acquire Housekeeping telemetry from all the NISP subsystem
- send commands to the DPU.

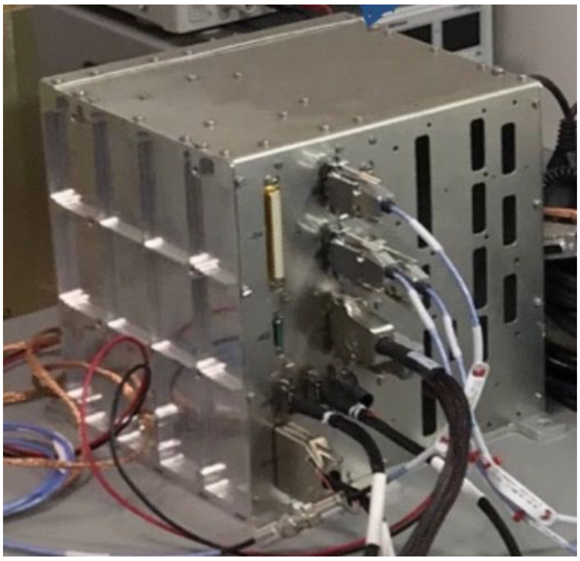


Figure 5.9: Picture of the ICU EM. It is connected to: the power supply, the 1553MILBUS from the EGSE (SCOE), the 1553MILBUS to the DPU, the filter wheels, the heaters and temperature sensors of the NI-OMADA and a dongle assigning to the ICU the RT 21.

5.2 NISP AVM EGSE

The EGSE hardware used for NIS AVM AIV/AIT is composed by three main components; their configuration is shown in Figure 5.10:

- **NI-CCS (Central Check-out System)**, the hardware is provided by ESA. It is the main control system; it includes also Mission Data Base, Test Sequences, TC/TM History Panels and Monitor displays that are provided by the NISP EGSE Team.
- **NI-SCOE (Special Check-Out Equipment)**, provided by ESA. It is the SVM

simulator supporting the payload under test. It is made of 3 modules: the 1553 I/F (playing the role of the CDMU), the SpW I/F (as for the MMU), and the power supply.

- **NI-IWS (Instrument WorkStation)**, provided by INAF/OAS-BO. It runs a specialized Quick Look monitoring system that processes raw data and generates the corresponding FITS files (for both HK and Science data), to allow offline data analysis.

5.2.1 The NISP CCS

The Central Checkout System (CCS) is a software application by TERMA intended for automatic monitoring and controlling of a target system. Such system can range from a full spacecraft to a science instrument or other payload.

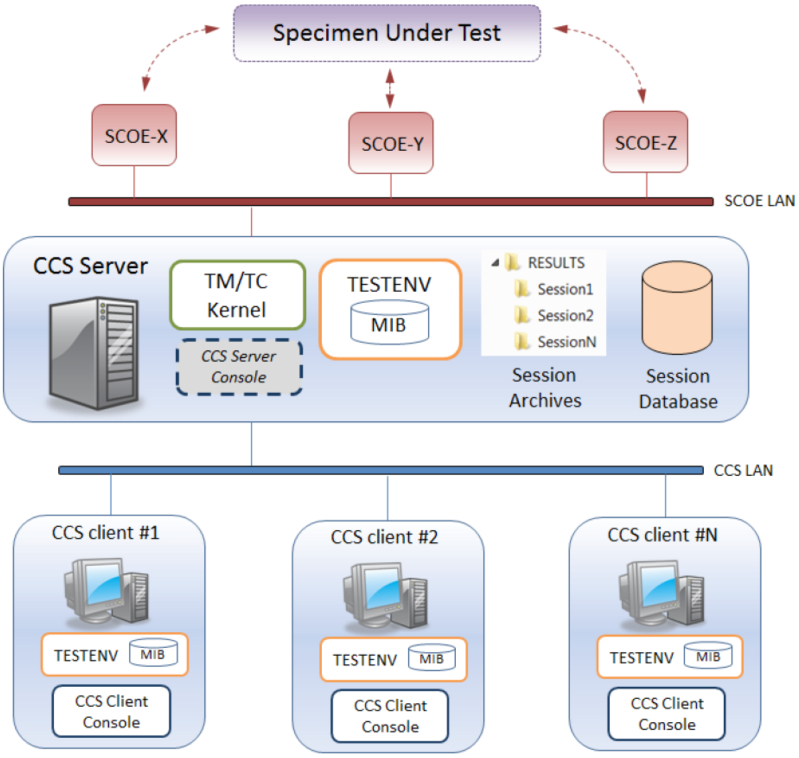


Figure 5.10 General CCS configuration.

It is very similar, in the user interface, to the TSC to which stands as a major multi user version. It comes as a rack containing two servers and a NAS with three separated LANs: the CCS LAN, the SCOE LAN and one more spare LAN. It also has the possibility to mount a GPS antenna to get precision timing on the scale of microseconds. Up to fifteen workstations can be connected to the CCS LAN and can issue commands, run test sequences and receive all the telemetries.

The CCS LAN is protected by a firewall from the outside; the firewall lets in connections coming from other, authorized, CCS stations, in this way an operator can participate to a test session from another location.

A dedicated MIB is developed for NISP AVM test phase in accordance with ICU and DPU communication protocol. Dedicated test scripts were also prepared.

5.2.2 The NISP SCOE

We have been endowed by ESA, with the NISP SCOE, supplied by SIEMENS, to provide all the interfaces necessary to the test the NISP. The SCOE is equipped with a power supply, a Spacewire interface and a MIL-STD-1553B programmable device, controlled by two servers. One of these servers runs the TSC application that controls all the interfaces and connects as SCOE to the CCS.

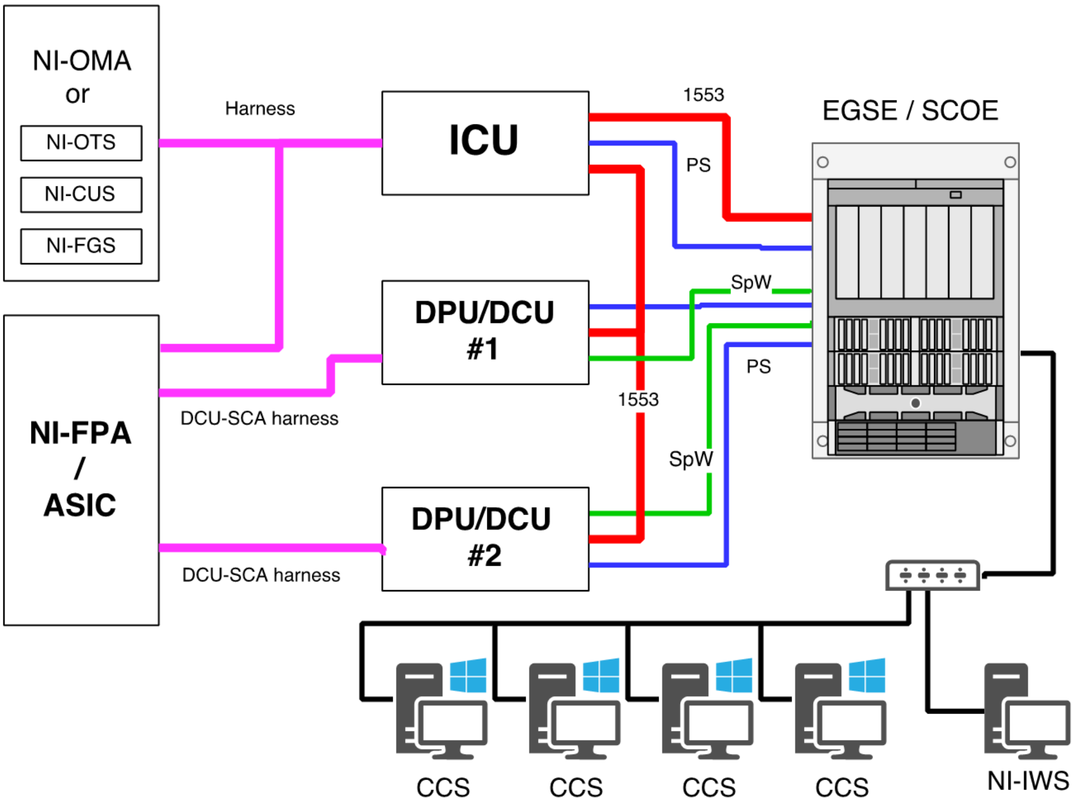


Figure 5.11 Configuration for testing with CCS, NISP SCOE and NI-IWS.

The NISP-SCOE has three power outputs connected through dedicated cables to the ICU and to the DPUs, both nominal and redundant units. The Spacewire interface has eight ports, two for each of the four DPUs that will be part of the FM model. The MIL-STD-1553B device can be programmed in all the possible configurations: bus controller, remote terminal and bus monitor.

For NISP AVM tests the NISP-SCOE is used as bus controller in place of the CDMU to exchange with the ICU TCs and TMs. All the SCOE equipment can be controlled from the CCS through dedicated TCs. Commands directed to the ICU are also sent from the CCS through a dedicated MIB developed by INAF-OAS Bologna group. The science data collected by the Spacewire logger is stored in a dedicated archive accessible through Ethernet connection by the CCS.

5.2.3 The NISP Instrument Workstation

The NI-IWS is connected to the CCS and receives from this all the telemetries from the NI-WE, it also receives a copy of the science data from the SCOE. It can be used as a monitor that collects process stores and analyses the NISP data. NI-IWS can be used in two modes:

- *Live mode*: live visualization of housekeeping TM and science data, file by file. Live data are automatically made available by the CCS to the NI-IWS displays as soon as they arrive from the instrument. This is the nominal mode during AIV/AIT activities.
- *Deferred mode*: In deferred mode the NI-IWS will display the TM and science data stored by the CCS relative to a time chosen by the operator. The loading of deferred data is performed by the NI-IWS on the files selected by user from a directory buffer.

The local data storage is organized by data run identified by a *Run Identifier.* The RunID is generated in live mode when user requests to the main application to start the delivery of real time HK packets.

The system automatically associates to the data run:

- the HK TM file created by the NI-IWS to store the received packets
- all the Science Data files retrieved from the CCS in that time period.

The NI-IWS reads the TMs and the science data in raw format but stores them in. fits *files* format, which is suitable for on-line and off-line analysis.

One of the tools of the NI-IWS is the *Quick Look Software*, it provides to the user the monitoring and analysis functions to verify the correctness of the test results versus expected values.

5.3 NISP AVM Integration

The NISP AVM hardware components were integrated in the NISP AVM model and mated with the EGSE hardware at Padua laboratory. The laboratory is hosted in the Physics Department; it is composed by two rooms as shown in the map in Figure 5.12.

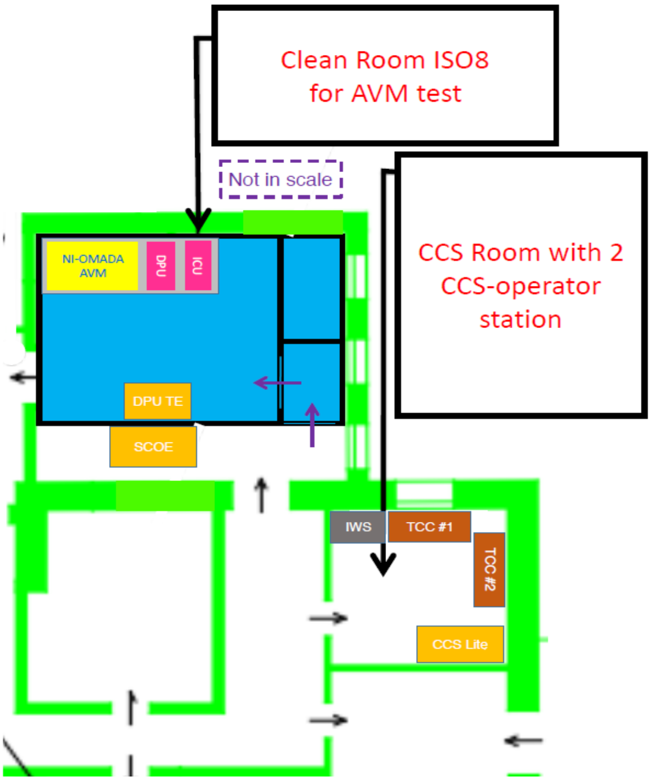


Figure 5.12: Map of the test facility prepared by Padua University and INFN. The blue area is the ISO-8 clean environment.

In the first room, highlighted in blue, there is the ISO-8 environment; it is composed by an entrance small area and by a clean room that hosts the NISP AVM. The temperature and humidity of the clean room are continuously checked and regulated. For the assembly of the NI-WE and the execution of the functional tests the requirement is to have controlled temperature (15 ÷ 30) °C and humidity (50% ± 10%) RH.

Next to the clean area, in the same room, there is the SCOE which is connected directly to the ICU and DPU for 28 V power distribution, 1553 Bus and Spacewire links. All such harness is provided by TAS-I and is installed under the floating floor of the room.

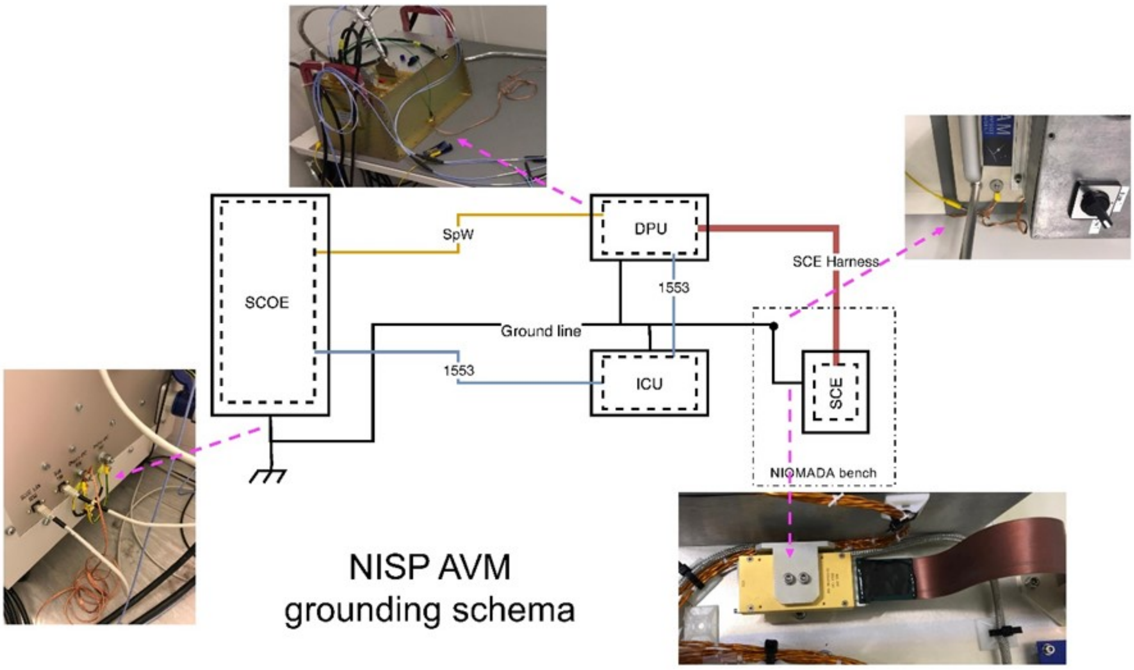


Figure 5.13: Grounding connections are shown with black lines; SCOE acts as star-point and ICU, DPU, NI-OMADA bench and the SCE are connected to it. MIL1553 bus are shown with blue lines, Spacewire link between DPU and SCOE is shown with a yellow line and finally the harness between DCU and SCE is indicated with a red solid line.

The SCOE is then connected to the CCS main rack that is placed in a second room, next to the first one. CCS operators run the Test Sequences from the two available CCS Station located in the Control Room, the NI-IWS is installed in the Control Room as well, next to the CCS stations. Special care was given to the grounding configuration in the NISP AVM integration (see Figure 5.13).

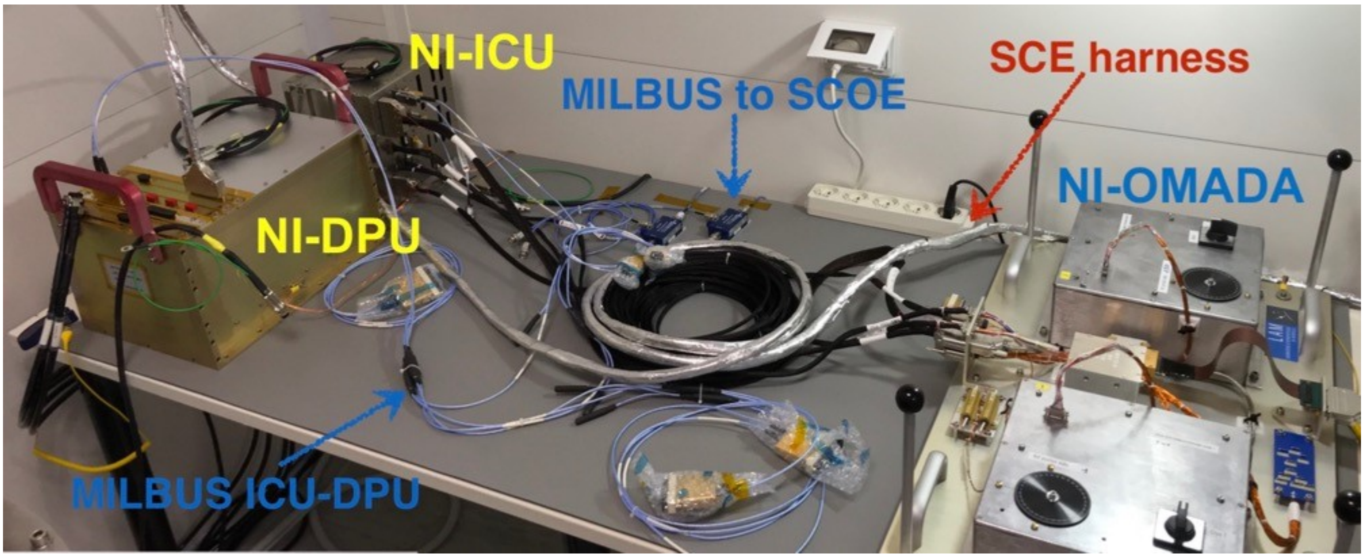


Figure 5.14: Picture of the NISP AVM at the time of the first integration.

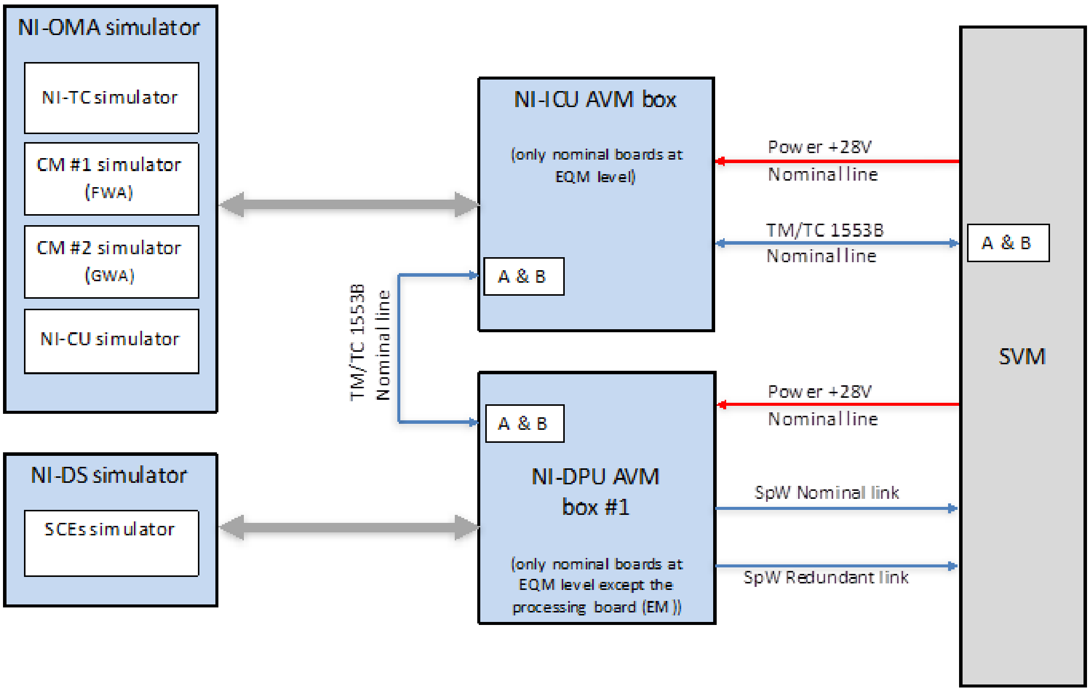


Figure 5.15: Diagram of the test setup used for NISP AVM functional tests.

The AVM is fully representative for what concerns:

- primary electrical interfaces
- science data format
- mechanical interface of the DPU and ICU
- electrical performances.

The main differences with regard to the NISP FM behaviour are the following:

- it can only work at room temperature and it cannot work in vacuum.
- FWA/GWA CM AVM do not rotate. Consequently, the home sensor search and check commands cannot be tested.
- only one DPU unit is present and only one DCU board is mounted in this unit.
- DPU EM has only the nominal Maxwell board, no redundancy can be tested.
- Only the ICU nominal is present, no redundancy can be tested.
- the amount of science data is 1/16 of what expected from NISP FM nominal survey. By means of dedicated image acquisition sequence, the daily production of data of the NISP-FM can be emulated.

5.3.1 NI-WE AVM Software configuration

The main purpose of the NI-WE AVM is to demonstrate the validity of the design of the NISP and of the corresponding pieces of software.

The restrictions due to the limitations of the testing environment, the temperature, the pressure, the missing components and the status of development of the two application software are taken into account.

The Software components are all in advanced status of development, close to CDR completion, they are reported in Table 5.1.

On-board software	Version	Supplier
ICU BSW	Flight version	UPCT (Spain)
ICU ASW	v0.5	INAF/OATO
DPU BSW	Flight version	OHB-I
DPU ASW	V0.6	INAF/OAPD

Table 5.1: Versioning of the pieces of Software installed on NISP AVM.

The ASWs were tested soon after the AVM hardware integration by means of the dedicated EGSE.

The integration of them required some tuning and all the modifications are traced in their own repositories.

5.4 NISP AVM functional tests

The purpose of NISP AVM functional tests is the following:

- verify the NI-WE commands and functions for all the NI-WE possible configurations in flight; nominal and contingency case are included
- verify that the NI-WE is able to follow all NISP operational modes and sequences
- verify TC and TM flow
- verify the science data flow
- verify, as much as possible at room temperature, the good health of the NI-WE subsystem and the correct connection of the NI-WE with the S/C and NI-OMADA.

The tests are divided in Short Functional Test (SFT), Full Functional Test (FFT) and Robustness tests. Several atomic Test Procedures were prepared in order to test: the interface between SVM and ICU, NI-OMA commanding and telemetry acquisition through the ICU, TC/TM interface between ICU and DPU and finally DPU to MMU interface. All these interfaces follow different levels and they are managed by ICU ASW and DPU ASW that should operate in a coherent way. Each test procedure is coded into TCL scripts that are prepared following the TAS-I framework already described in Chapter 4.

5.4.1 ICU to SVM Interface

The NISP instrument interface with the CDMU is realized by the ICU ASW; it is implemented via the SCOE dual-redundant MIL-STD-1553B link. All the TM/TC packets related to the NISP instrument are routed through this link by the SCOE. The packets are compliant to Euclid Space to Ground Interface Document issued by TAS-I [49].

ICU ASW manages to forward DPU commands and retrieve DPU telemetries by means of a dedicated internal interface. Such additional interface bus is a dual-redundant MIL-STD-1553B bus independent from the one used in the communications between ICU and the SVM. Telecommands destined to the DPU/DCU system are sent as ordinary TCs from the SCOE to the ICU ASW, it analyses the command ID and, if the recipient is a DPU, it prepares the proper message in the secondary internal MILBUS. The ICU collects its own and DPU housekeeping parameters and transmits them to ground via the S/C interface. It is expected from the ICU an amount of 2 *kbit/s* for the housekeeping. The ASW is able to manage 1 command per second per DPU and to generate two telemetry blocks, each block can contain up to 4 event packets (5,x) and one housekeeping packet.

The communication between both ICU BSW and ICU ASW and CDMU is realized by the PUS Services detailed in Table A.5 in the Appendix and a specific 1553 bus profile is fixed.

5.4.1.1 Mass Memory Unit Spacewire interface

The MMU interface between SCOE and DPU is implemented via one Spacewire link (Nominal and Redundant) for each DPU section. The link rate is 40Mbps; it is independently started by the SCOE and activated by the DPU ASW in the initialization phase.

The overall process of data transmission to the MMU after processing of a single detector is accomplished by the DPU ASW processing task in three steps:

- insertion of the header to the compressed image files
- DMA data transmission on the Spacewire memory
- start of physical Spacewire transmission in chunks of 64 Kb.

For each exposure frame, before compression, the DPU ASW generates the following data set:

- set of exposure telemetry parameters

- a programmable number of raw lines
- science signal data
- science χ^2 data
- SCE telemetry and SCA temperatures.

The integrity of the data transferred on the MMU is checked by the NI-IWS software.

5.4.2 NISP Operation modes

The NISP operation modes are identical to the ones defined in Euclid NISP Instrument Operation Concept Document (IOCD) [40] as shown in Figure 5.16. Each transition between NISP operating modes is triggered by ground TC, simulated by the EGSE, and consequently implemented by NI-ICU ASW and NI-DPU ASW functions.

Figure 5.16 shows the different ICU operational modes and the possible transitions among them. Black arrows indicate transition due to TCs while red arrows indicate state transitions triggered by abnormal or error recovery situations (FDIR).

In nominal operation each transition between DPU/DCU/SCS different modes is driven by sequences of ICU TCs forwarded to the subsystems. The DCU and SCS operating modes are managed internally by the DPU (see Figure 5.17).

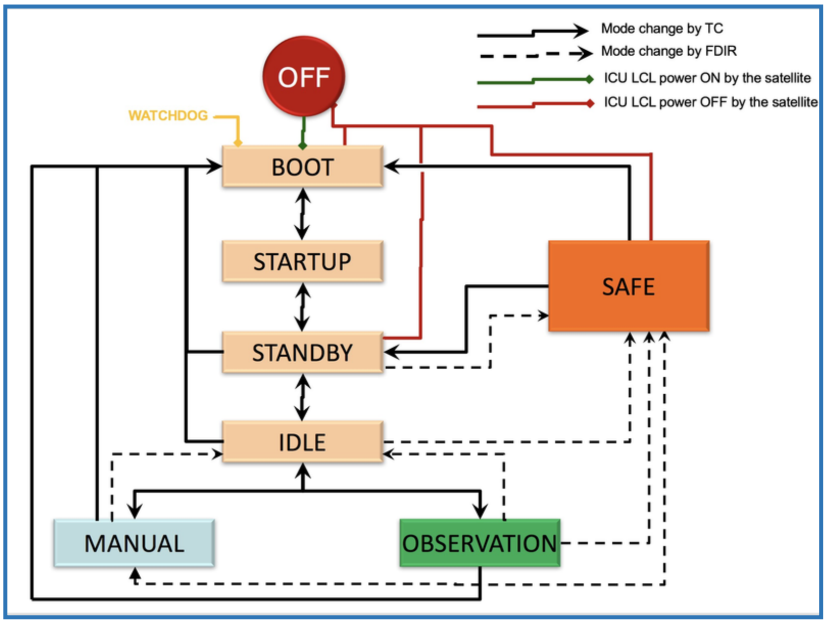


Figure 5.16: NISP operation modes, anomalous or error conditions cause the transition of the Instrument to the SAFE mode, it can be leaved only by TC issued from ground.

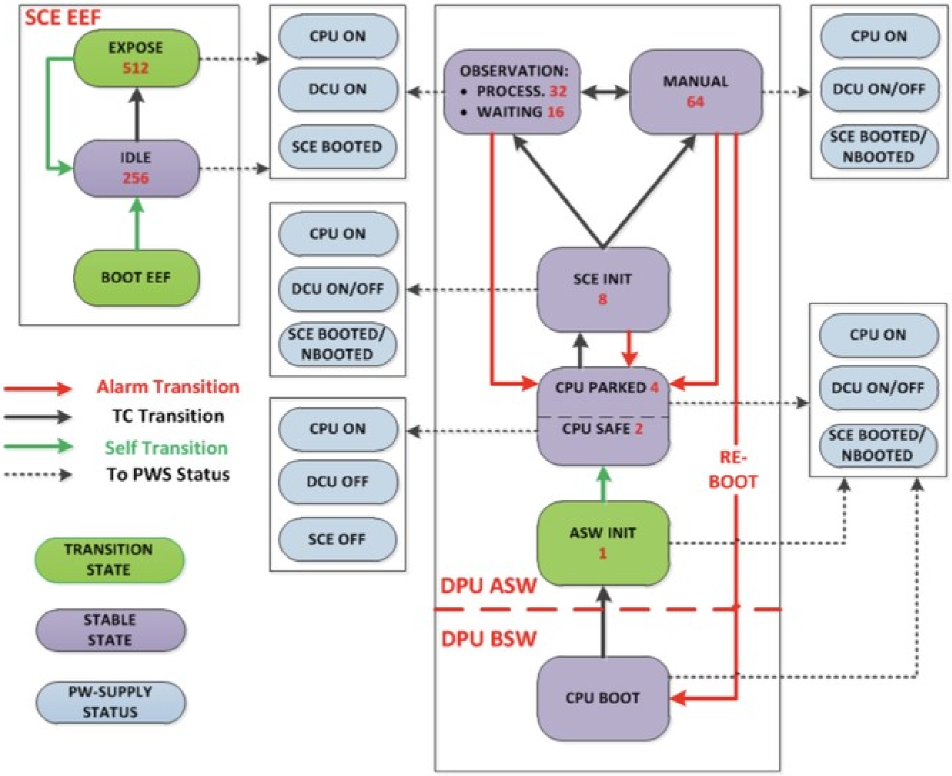


Figure 5.17:DPU ASW modes. The transition between ASW INIT to CPU SAFE is governed by the DPU ASW and implies the initialization of all DPU devices and DBB memory scrubbing. The transition between SCE IDLE to SCE EXPOSE is governed by the DPU ASW and it is provoked by the command that starts data acquisition.

5.4.3 NISP Synoptic display

According to ECSS an important characteristic of space software is ***Observability*** that means that its internal status can be fully determined through the observation of the output variables. The observability can be implemented at different levels and this level should be well-regulated from outside since, in principle, could affect performances. The observability can ease the system integration and failure investigation.

The only information available from outside are those coming through the telemetries. While it is possible to perform a detailed analysis on the flux of telemetries saved in the sessions, it is useful sometimes to have some information accessible at glance and in real time when operating the equipment. To this purpose I have developed a synoptic display showing the leading information about NISP status to assist the testing operations.

The Synoptic display is built in the CCS/TSC framework and receives constantly updates on the telemetry parameters used by the view (Figure 5.20); there are many controls that simplify the visualization of incoming parameters, and many more can be created by means of the graphics primitives, an example are the two filter wheels with grism and bandpass filters present in the Top right of the display.

The CCS/TSC has an editor to develop synoptic displays that are saved as XML script in files with extension. sxl. The display is editable also from a text editor simplifying some operations. There is also a tool that performs checks on the consistency of the synoptic file and the connection between the different parts and the telemetry parameters used.

It is also possible to associate actions, such as opening web pages or launching TCL scripts; these functionalities are not implemented in the NISP Status synoptic.

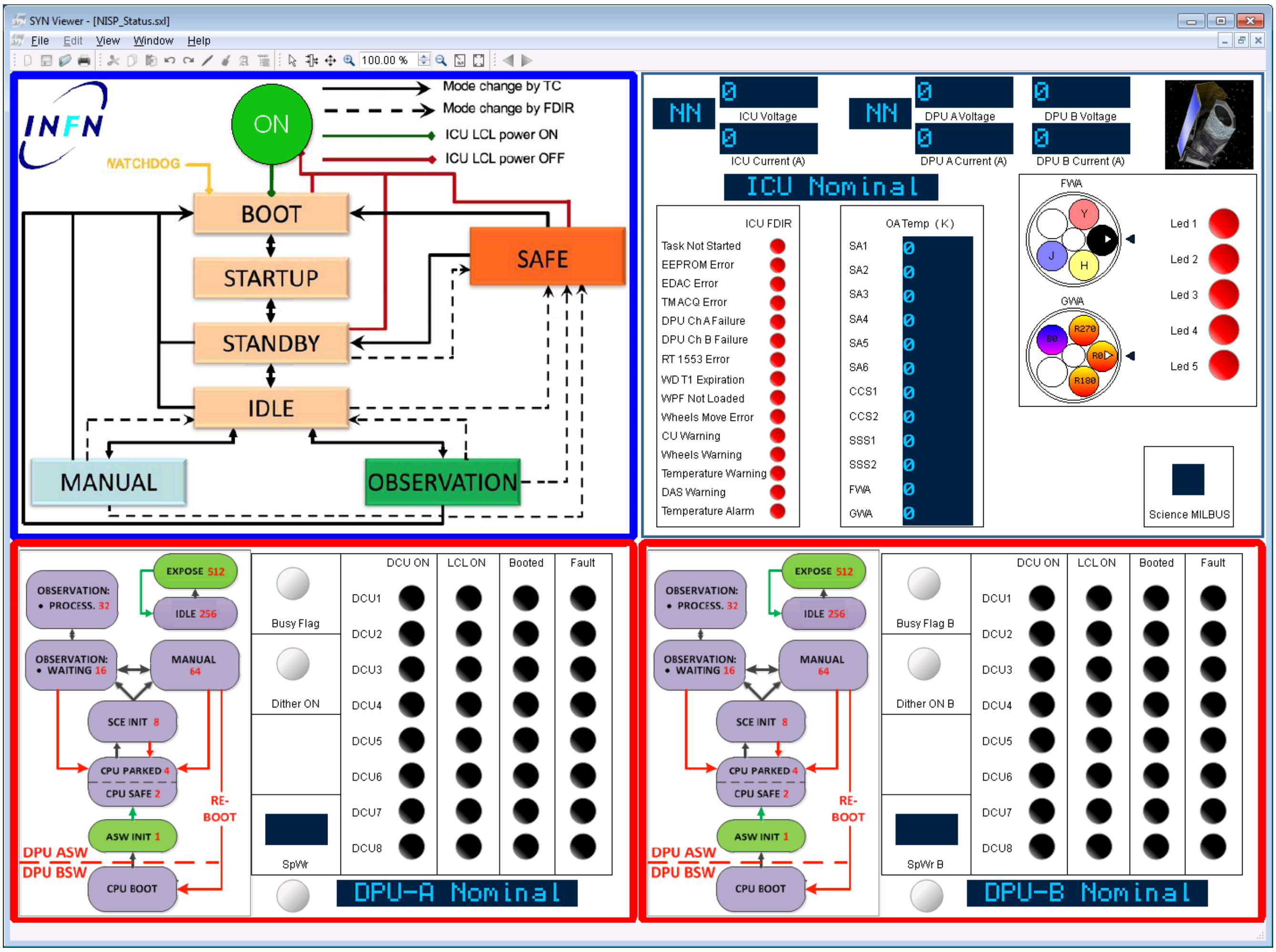


Figure 5.18 NISP Status Synoptic Display View.

The NISP Status Synoptic is made by one window divided in four quadrants. In the upper left quadrants, the ICU status is showed. On top we find the power status, deducted from TM arriving from the SCOE. When the application software is running and is periodically sending telemetries the Synoptic shows the internal status of the ASW highlighting the corresponding rectangle. If this value is marked as expired by the framework, (the time interval indicating the validity of an incoming telemetry packet is specified in the MIB), and a valid telemetry from ICU BSW is arriving the *BOOT Status* is highlighted.

On the upper right quadrant there are information on the NISP and the power supply:

- Current and Voltage values for ICU and DPU A-B, both nominal or redundant
- ICU FDIR bitmask status
- Optical Assembly temperature, cryogenic or nominal sensors
- Filter Wheels position, both FWA and GWA
- Calibration Unit Led status
- Currently selected MIL-STD-1553B bus for communication with DPUs (Channel A or B).

It is possible to read constantly the tension applied to the ICU and to the DPU_A and DPU_B. It is also specified which one between the nominal and redundant unit is powered. In the same quadrant a LED-bank indicating the status of the ICU FDIR mask is placed. On the left of the FDIR leds the Optical Assembly temperatures are shown. Depending on the value of the temperature there are showed values from normal sensors or cryo-sensors. If the value is below a threshold the latter are displayed.

The positions of the two wheels are displayed graphically with a turning picture of the wheels. There are five LEDs that follow the status of the parameters for the CU leds in the telemetries.

In the lower part of the Synoptic display there is a detailed representation of the status the two DPUs. It is clearly specified which unit is displayed, nominal or redundant, then the internal status of the application software is displayed in a hierarchical tree guiding the user in the logical transitions between different statuses. On top of the DPU status tree there is the status of the SCEs. When the SCE is booted the banner corresponding to his status, between the two possibilities: Idle and Exposing, is highlighted. Among the other information the busy *flag,* the *dither-on flag* of the DPU ASW internal status and the selected Spacewire Channel are indicated on the panel.

High relevance is given to the status of the electronics controlling the focal plane. The power status of each DCU and the status of the Sidecar are reported.

The NISP status synoptic has proven to be useful and reliable during tests, it is currently configured to be launched automatically when a new CCS session is created and when a workstation joins the session.

5.4.4 Short Functional Test (SFT)

SFT is the first step of the NISP AVM test plan. It aims at verifying NI-WE functions related to NISP nominal operation. The test is divided in 11 TCL atomic scripts. It is organized as a nominal power ON and Start-Up sequence followed by a nominal exposure with the verification, at each step, of the proper behaviour of the system. The test is designed to verify also ICU to NI-OMA interface and NISP operational modes including nominal transition among them. All TCs that will be used during the nominal operations will be checked. SFT has to be executed in a fully automated mode, no user intervention is foreseen and the logical order of the eleven scripts is shown in Figure 5.19.

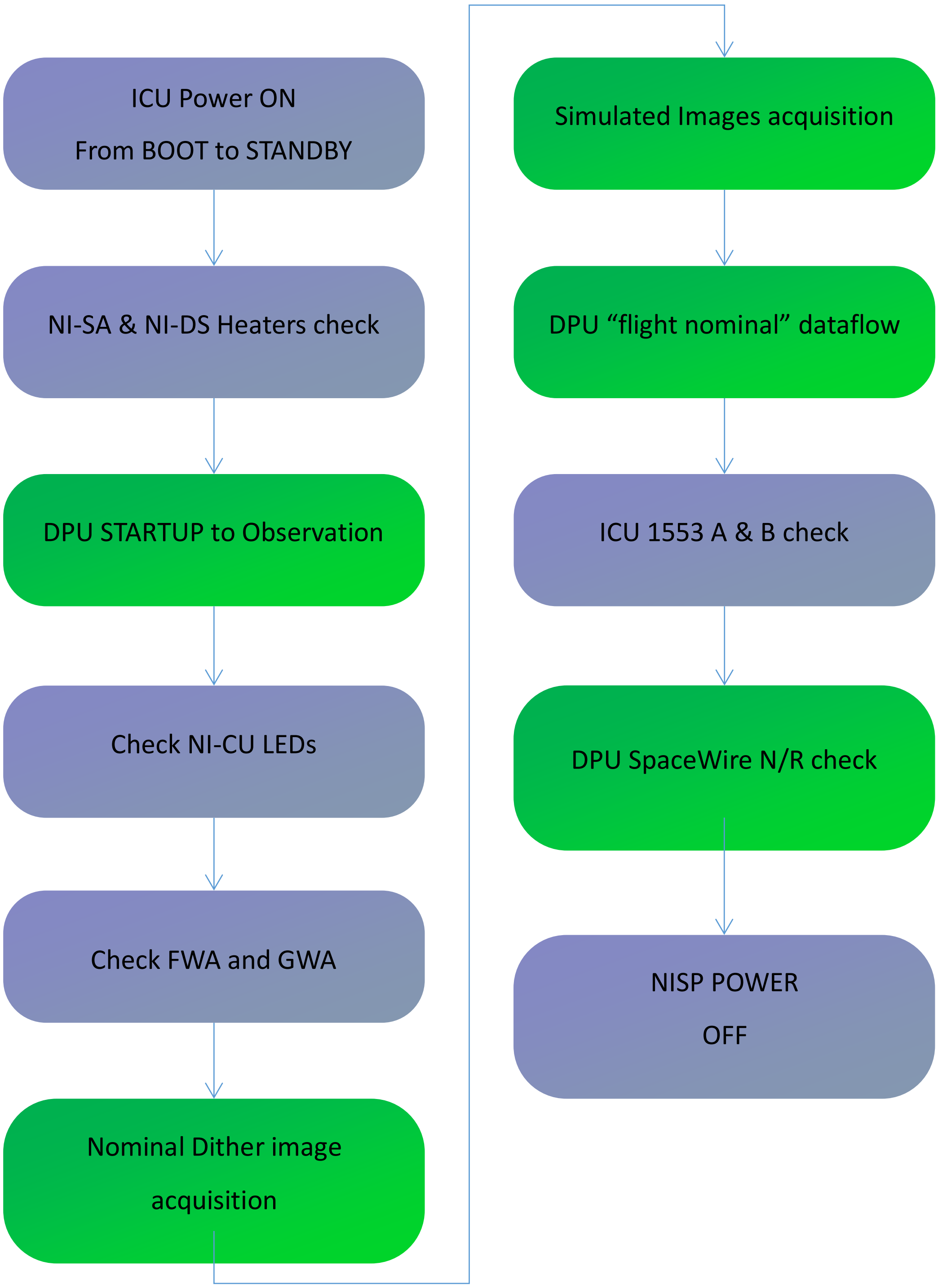


Figure 5.19: Summary of the SFT. Violet boxes represents test cases involving the ICU and the NI-OMA simulator, green boxes are for test cases involving ICU and DPU.

5.4.5 Full Functional Test (FFT)

The purpose of the FFT is to test NISP non nominal TCs including DPU re-boot and patch and dump of all the possible memories managed by the ICU ASW. One FDIR will be tested and PUS Service 3 for Housekeeping and Diagnostic packet reports generation will be used. The test is divided in 23 TCL atomic scripts and it has to be executed in a fully automated mode. The order of different scripts is shown in Figure 5.20; it is defined in such a way to group the functions in the same NISP mode.

Figure 5.20: FFT Sequence. Violet boxes represents test cases involving the ICU and the NI-OMA simulator, green boxes are for test cases involving ICU and DPU. NISP status is given in each box. Some scripts which include FDIR testing were not included in the NISP AVM delivery in June 2018, they will be part of a second delivery in Fall 2018.

5.4.6 Robustness Test (RbT)

The NISP AVM run two robustness test for more than 24 hours each.

The first one is achieved with the execution of 960 dithers composed by 4 MACC (2,2,2).

The goal of this test is reproducing the NISP daily data flow. Data are acquired from SCE configured with pins to ground. The processed images transferred to IWS are compared with the first one, that is assumed to be the reference one. When the two images are subtracted null result is expected.

The second-long run is a sequence of 20 nominal Euclid Observation Cycles, each composed by 4 nominal dithers, MACCs are configured as follows:

- 1st dither: Spectro, photo Y, photo J, photo H
- 2nd dither: Spectro, photo Y, photo J, photo H
- 3rd dither: Spectro, photo Y, photo J, photo H
- 4th dither: Spectro, photo Y, photo J, photo H, dark.

In this sequence the simulation of FWA and GWA rotation using the NI-OMA interface is included. The duration of this long test is expected to be about 24 hours.

RbT long runs have to be executed in a fully automated mode, no user intervention is foreseen.

5.4.7 Success Criteria

The following success criteria have to be verified after the execution of SFT, FFT and RbT [50].

- **Telecommand History:** the complete telecommand history and their parameters must be analysed at the end of each test. They should be in agreement with codified SFT and FFT sequence of telecommands
- **Packet amount:** different housekeeping packets collected during SFT and FFT have to be counted. At the end of SFT, the number of TM(1,2),TM (1,8), TM(5,3) and TM(5,4) must be equal to zero
- **Analogue Telemetry:** all the HK analogue telemetries must be plotted and analysed for the whole duration of each test. The monitoring limits must never be exceeded during the whole duration of the test
- **Digital Telemetry:** all the HK digital telemetries must be analysed for the whole duration of each test. They must be compared to the expected ones
- **Science Data:** one image acquired in simulated mode (Pixel by Pixel) and one

image acquired in simulated mode (Frame by Frame) must be compared to the expected ones

- **Data Production:** the amount of science data and HK data production shall be determined for each test.

5.5 NISP AVM Test Report

The preparation of NISP AVM functional test took several weeks to be completed from February to May 2017; ICU ASW and DPU ASW were fully integrated in the hardware components and their interface is now consolidated and robustly checked.

The NISP AVM TRR was held on May 23rd involving NISP Team, TAS-I and ESA delegates. SFT, FFT and RbT were formally run from May 25th up to May 29th, they were all completed with positive results and only minor problems emerged.

FFT scripts dealing with FDIR procedure implementation were excluded from the formal test because the ICU and DPU ASW do not support them yet, they will be performed during the next NISP EM tests.

NISP AVM hardware, MIB and Test Sequences were delivered to TAS-I in June 2018 for SVM integration tests.

In the following sections there is a detailed description of each script used in the SFT, FFT and RbT and some plots showing the results obtained. The TM/TC and scientific data are retrieved off-line from CCS and IWS archives.

5.5.1 SFT-01: EUC_NISP_ICU_Start_Up

This script implements the ICU Power ON and Start-up procedure. The initial NISP MODE is OFF and all NISP subsystems are not powered, the operations to be performed are the following (note that for each TC the presence of acceptance and execution TM report is automatically checked, if they are not present the script automatically stops and requires user intervention):

- send the TC to Power ON the ICU (Nominal unit), the ICU BSW starts automatically

- check the presence of the Boot Report Event
- check BSW Housekeeping periodic packets
- perform a Connection Test with BSW using the PUS Service (17,1)
- send the two TCs to load ICU ASW versions stored in the EEPROM and then start it. During the Start-Up the ASW performs an internal diagnostic of the ICU, initializes the DAS board and at the end starts to send the HK1 packets. Such periodic packet is generated every two seconds and includes: all the ICU digital and analogue telemetry, NI-OMA subsystems housekeeping and DPU digital telemetry. Finally, the ASW automatically moves to the STARTUP mode
- check that STARTUP mode is reported in the TMs
- move the ICU to STANDBY mode.

At the end of SFT01 the NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode.

ICU power consumption is monitored trough the SCOE telemetries; it is shown in Figure 5.21, digital and analogue TMs are as expected, ICU ASW is launched without error reports. The test is completed successfully.

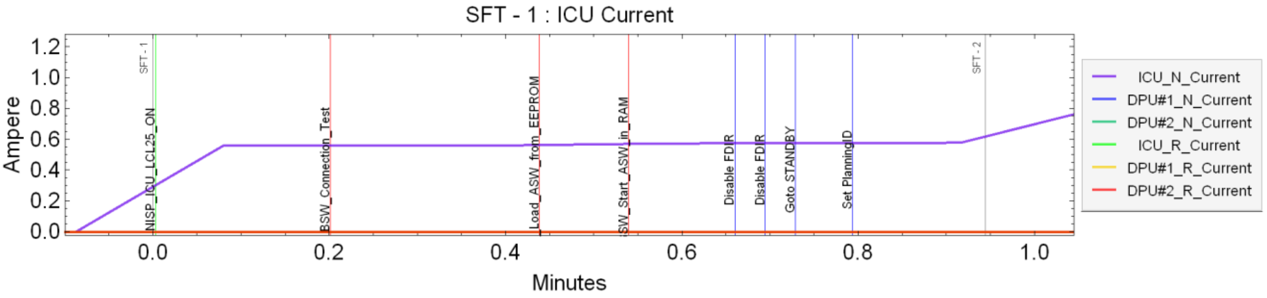


Figure 5.21: ICU Power consumption ad seen by SCOE telemetry. The ICU Nominal current is represented along the violet curve; the vertical lines represents all the TC issued during the SFT-01. Green lines are SCOE TC, red lines are ICU BSW TC and blue lines are ICU ASW TCs.

5.5.2 SFT-02: EUC_NISP_SA_DS_Heaters

This script implements the control of Heaters; Structure Assembly (SA) and Detector System (DS) heaters can be controlled separately. The initial NISP MODE is STANDBY and only the ICU is powered, the operations to be performed are the following:

- send a TC to power ON SA Heaters
- send a TC to power ON DS Heaters
- check telemetry after one minute
- send a TC to Power OFF both Heaters.

At the end of SFT02 the NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries and is shown in Figure 5.22 and Figure 5.21, digital and analogue TMs are as expected, the Heaters are operated without error reports. The test is completed successfully.

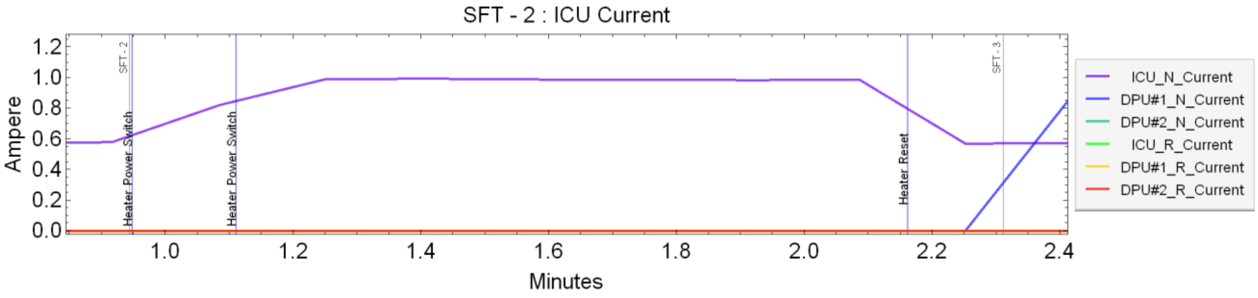


Figure 5.22: ICU power consumption. In the plot it is possible to see that before the Heaters activation the ICU current has a value of 0.6 A, during the activation the current drain is increased to 1.0 A.

5.5.3 SFT-03: EUC_NISP_DPU_Startup

This script implements the Power ON of DPU/DCU unit, including the Sidecar Boot. The initial NISP MODE is STANDBY and only the ICU is powered, the operations to be performed are the following:

- send a TC to the SCOE to Power ON the DPU
- send a TC to ICU ASW to configure the internal MIL1553 bus, in our case only DPU_A Nominal is selected as active
- wait 50 s to get the DPU BSW periodic telemetry reported by ICU ASW in the HK7 telemetry packet

- send two TCs to DPU BSW (note that commands to DPU BSW/ASW are always sent to the ICU ASW that internally forwards them to the DPU) to load the DPU ASW from EEPROM to RAM and to start ASW. After those two commands NISP switches to a transient state in which the DPU ASW is initializing the internal communication with DBB and DRB and clearing the DBB memory. This procedure takes about 3 minutes and no TM is transmitted to the ICU, in the end the DPU moves to the SAFE State. This is a stable state in which the DPU ASW provides to the ICU the main set of TM/HK from which the correct start-up of the DPU can be verified
- send a TC to load the DPU main configuration via System Configuration Table, the parameters are defined by the user in a *.ini* configuration file that is read by the TCL script
- send a TC to copy the SCE EEF from EEPROM to RAM
- send a TC to set NISP to IDLE mode
- send a TC to assign master RT between the DPU, in our case master is RT1
- send a TC to configure the bit-mask of active DCU, in our case only DCU1 is declared active in the mask
- send a TC to move the DPU ASW to SCE_INIT mode
- send a TC to apply voltage supply to the DCU1. The communication with the DCU is established and the DCU analogue and digital telemetry is generated.
- send a TC to activate the transmission of the DCU telemetry on the MIL1553, every 15 seconds it is refreshed by ICU in the HK2 telemetry packets
- send a TC to Boot the SCE EEF
- send a TC to activate the transmission of the SCE Housekeeping on the MIL1553, every 60 seconds it is refreshed by ICU in the HK4, HK5 and HK6 telemetry packets
- send a TC to activate synchronization between DCU and SCE
- send a TC to move NISP to MANUAL mode, this is necessary to configure via TC the SCE. The configuration is loaded from the *.ini* file and the SCE pins are shorted to ground
- send a TC to move NISP to OBSERVATION mode.

At the end of SFT-03 the NISP is in OBSERVATION mode and ICU, DPU, DCU and SCE are powered ON and ready for scientific data acquisition. NI-WE power consumption is monitored trough the SCOE telemetries. It is shown in the following pages, digital and analogue TMs are as expected, no error reports are received. The test is completed successfully.

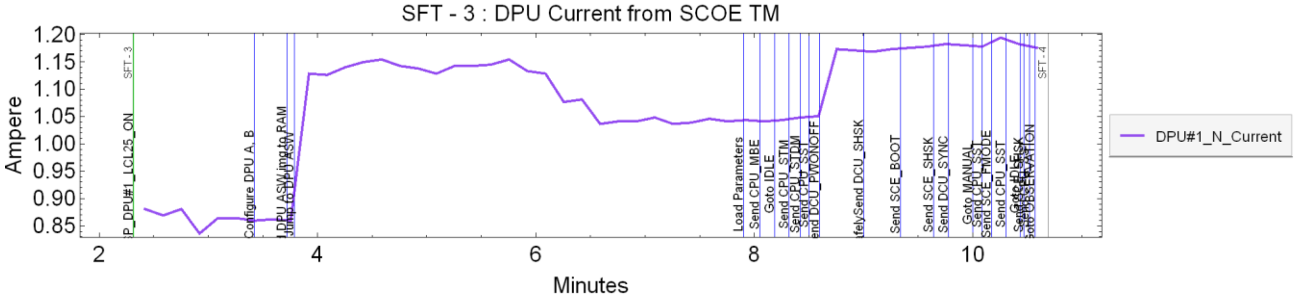


Figure 5.23: DPU current as seen by the SCOE power supply. At DPU power ON the BSW drained current is less than 0.9 A, after the transition to ASW there is an increase up to 1.15 A. During the DBB memory clear and scrubbing operations the current drain is constant for about 2.5 minutes. The sole DPU current is around 1.05 A, after DCU power on and SCE boot commands execution the DPU/DCU current drain increases up to 1.2 A.

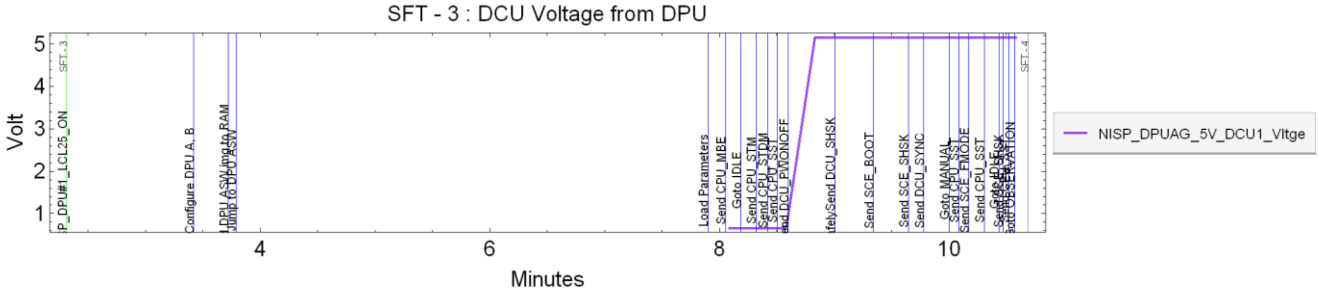


Figure 5.24: DCU Voltage as read by the PSB of the DPU, the voltage applied to the DCU follows the TC, it takes about 10 seconds to complete the DCU power ON sequence.

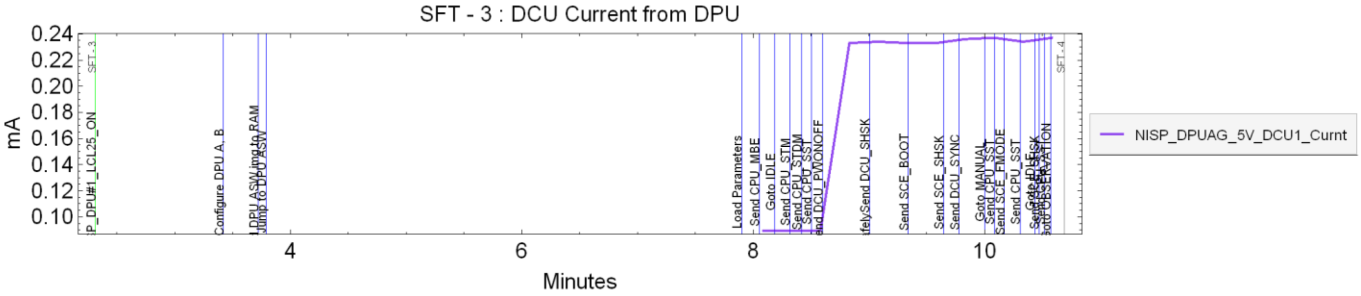


Figure 5.25: DCU current drain as measured by the PSB of the DPU.

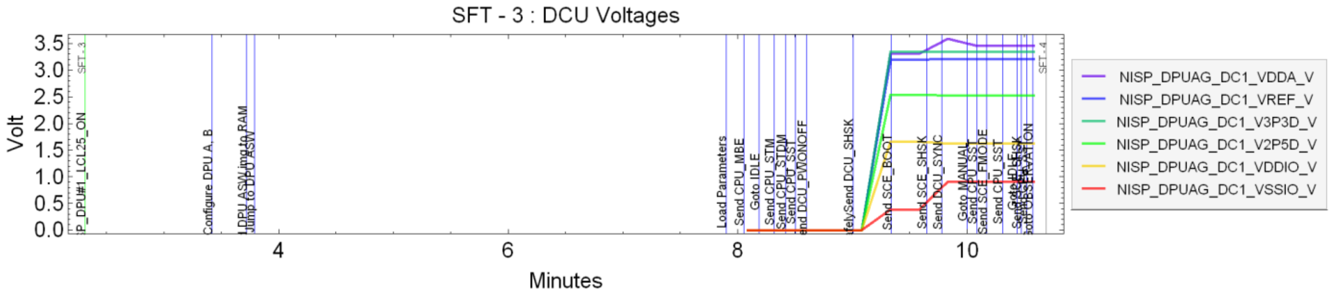


Figure 5.26: Voltages provided by the DCU to the SCE. The analogue VREF is shown in violet and it keeps stable as required.

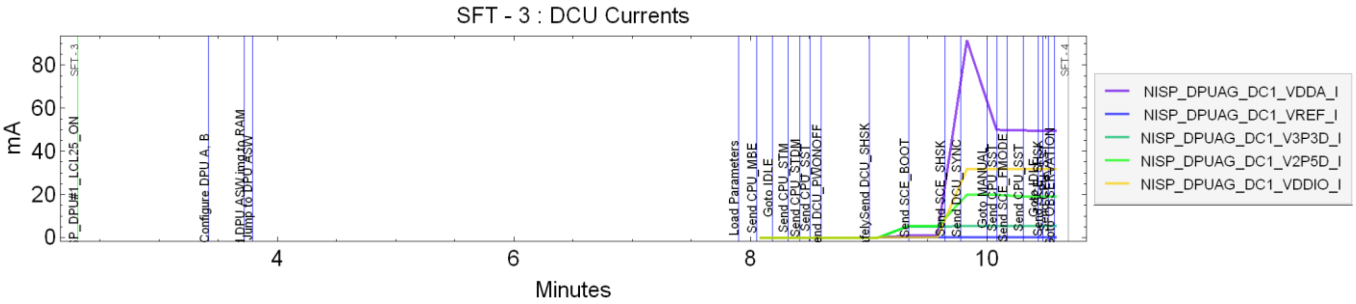


Figure 5.27: SCE current drains as seen by the DCU analogue and digital power lines. Currents are always inside the allowed limits.

5.5.4 SFT-04: EUC_NISP_Check_NI_CU

This scripts tests the NI-ICU operation and commanding by ICU ASW. The initial NISP MODE is OBSERVATION, NI-WE is powered, the operations to be performed are the following:

- send a TC to activated one LED for 30 seconds, this time is adequate to verify that the current drain is changed
- send a TC to switch off the LED
- loop the operations on the five LEDs, they can be activated only one by one.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. LED voltage is monitored in the HK1 telemetry packets. It is shown in Figure 5.28 and Figure 5.29, digital and analogue TMs are as expected, no error reports is received. The test is completed successfully.

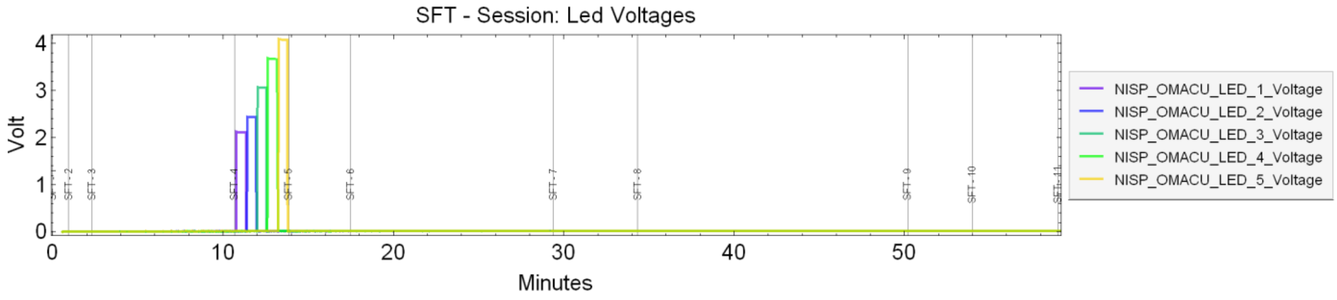


Figure 5.28: LED voltages along the full SFT, their value is different from zero only during SFT-04, when they are activated one by one. The voltage of each LED is shown with different colour code.

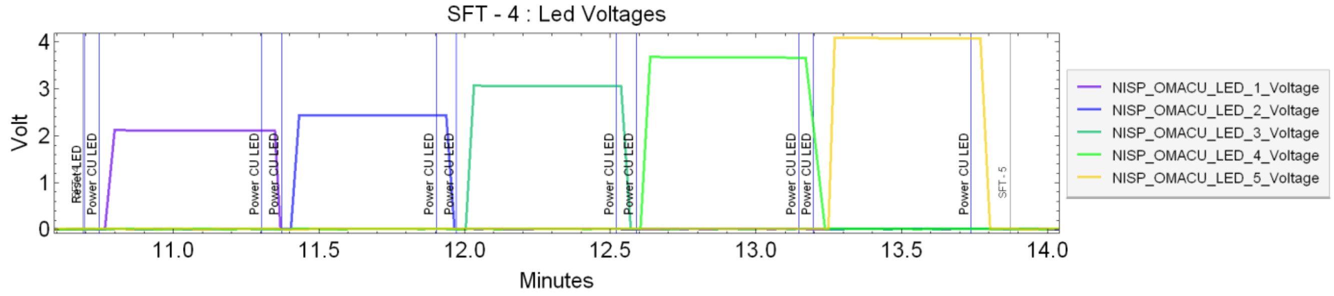


Figure 5.29: Zoom of , the SFT-04 time interval is selected in this plot.

5.5.5 SFT-05: EUC_NISP_check_FWA_GWA

This scripts tests the FWA and GWA CM AVM operation and commanding by ICU ASW. The initial NISP MODE is OBSERVATION, NI-WE is powered, the operations to be performed are the following:

- send a TC move ICU to MANUAL mode
- send a TC to activate trough the PUS Service 3 a Diagnostic packet for FWA and GWA current monitoring
- send a TC to move ICU to OBSERVATION mode
- check that the FWA rotation angle reported in HK1 telemetry packet is 0° (home position)
- send a TC to move FWA wheel to +144°, when the FWA driver starts the wheel movement an event is reported by ICU ASW, when the movement is completed the one more event is reported. If some error occurs an error report is generated
- send a TC to move FWA wheel to initial position (-144° rotation)
- send a TC to move FWA wheel to +72°
- send a TC to move FWA wheel to initial position (-72° rotation)
- check that the GWA rotation angle reported in HK1 telemetry packet is 0° (home position)
- send a TC to move GWA wheel to +144°, when the FWA driver starts the wheel movement an event is reported by ICU ASW, when the movement is completed the one more event is reported. If some error occurs an error report is generated
- send a TC to move GWA wheel to initial position (-144° rotation)
- send a TC to move GWA wheel to +72°
- send a TC to move GWA wheel to initial position (-72° rotation)
- send a TC move ICU to MANUAL mode
- send a TC to deactivate trough the PUS Service 3 a Diagnostic packet for FWA and GWA current monitoring
- send a TC move ICU to OBSERVATION mode.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. FWA and GWA currents are monitored in the HK1 telemetry packets, they are shown in Figure 5.30 and Figure 5.31, digital and analogue TMs are as expected, no error reports is received. The test is completed successfully.

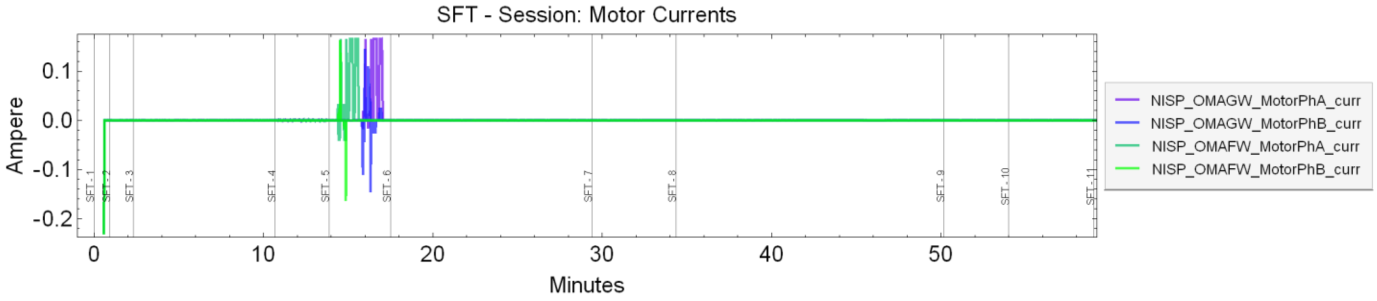


Figure 5.30: FWA/GWA motor currents along the full SFT, their value is different from zero only during SFT-05, when they are activated one by one. The FWA currents are shown in the green curves, GWA currents are shown in the Violet curves. Each step motor has two phase that have complementary values for current drains.

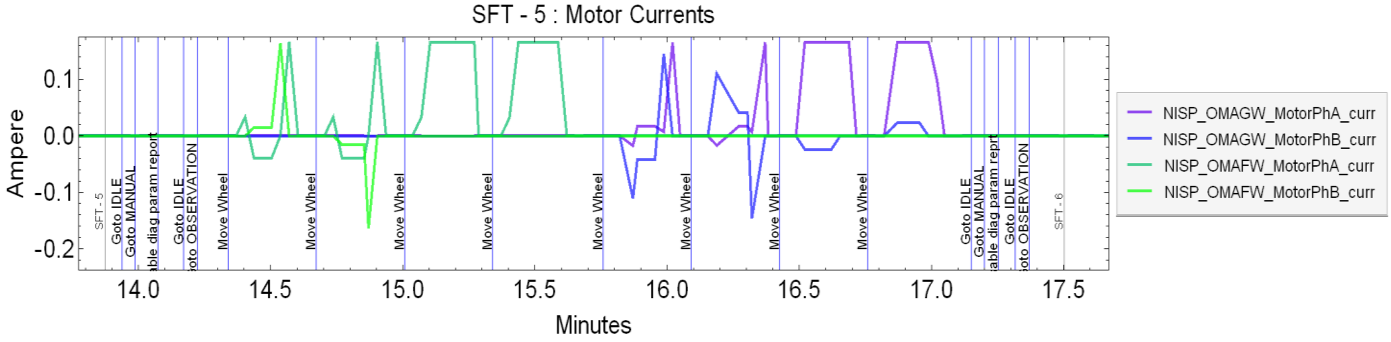


Figure 5.31: Zoom of Figure 5.30, the SFT-05 time interval is selected in this plot.

5.5.6 SFT-06: EUC_NISP_DPU_Nominal_Exposure

This script is used to perform two exposures with a set of parameters loaded to the ICU from a user defined configuration *.ini* file. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode. Image data is generated by the SCE clamping the inputs to ground and reading the noise, the operations to be performed are the following:

- send a TC to move ICU to IDLE mode
- send the Processing Parameter Configuration Table to the DPU, parameters are set by the user in the *.ini* file and forwarded to the DPU Processing Task
- send a TC to mode ICU to OBSERVATION mode

- send to the DPU the DITHER CONFIGURATION TABLE, this command contains the number of MACC in a dither, the type of MACC and the exposure mode, in this script the dither is configured with two MACCs, the first one is a (15,16,11) in Spectroscopic Mode and the second one is a (3,16,4) in Photometric Y Mode.
- send to the DPU one command to start each exposure; after the SCE data production the DCU performs the frames co-adding and data are transferred to the DBB board. The data are processed, compressed, packed with NI-SCEs HK and sent to MMU via Spacewire link. During the exposure the SCE is in EXPOSING MODE, in the end it returns back to IDLE state. During the data acquisition and co-adding the DPU ASW is in OBSERVATION WAITING mode, it moves to OBSERVATION PROCESSING during data processing and transmission to MMU.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. The test is completed successfully.

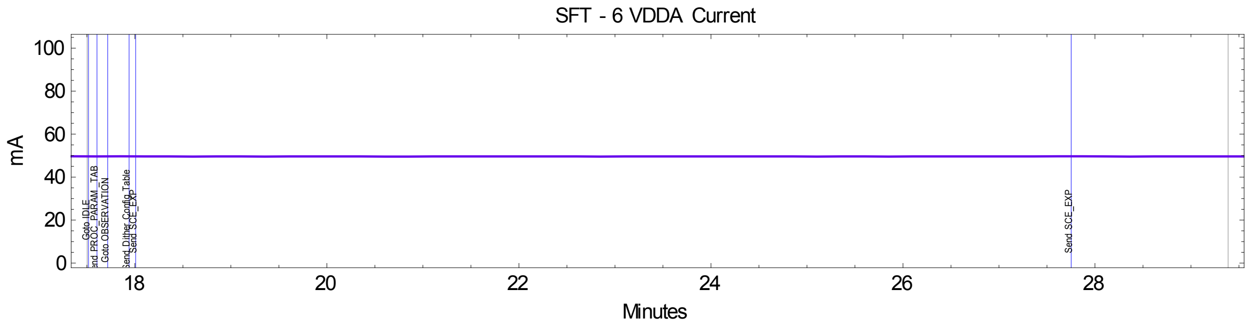


Figure 5.32: Current drained by the SCE during the exposure. It is inside allowed ranges.

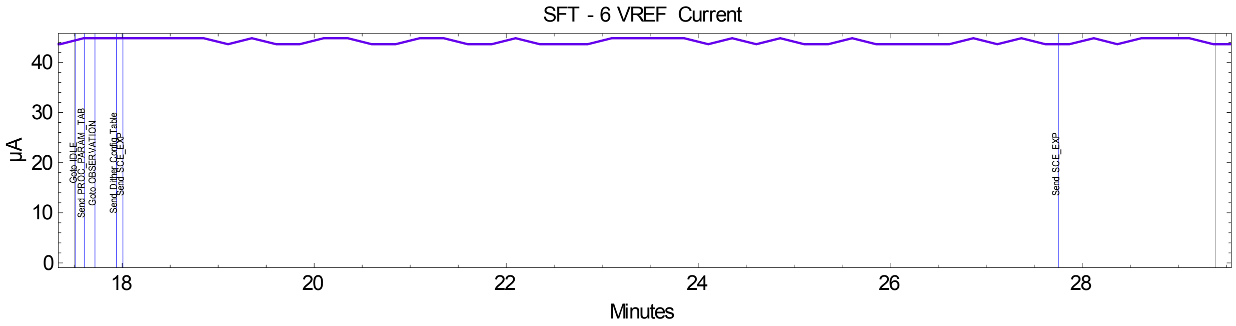


Figure 5.33: Current drained by the SCE during the exposure. It is inside allowed ranges.

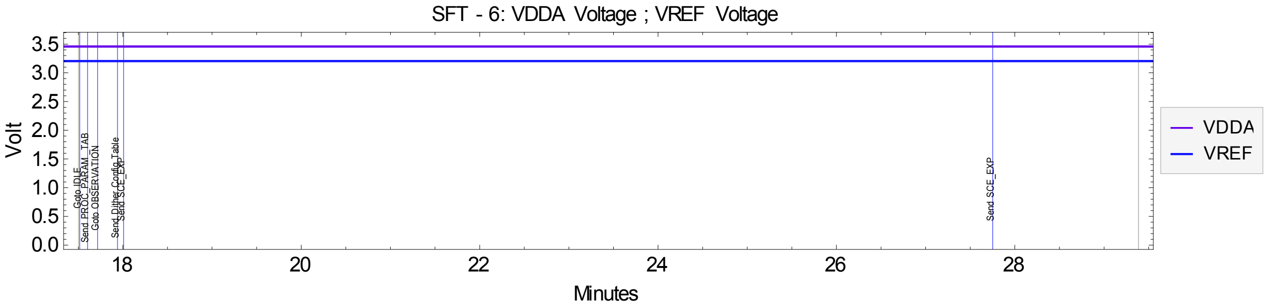
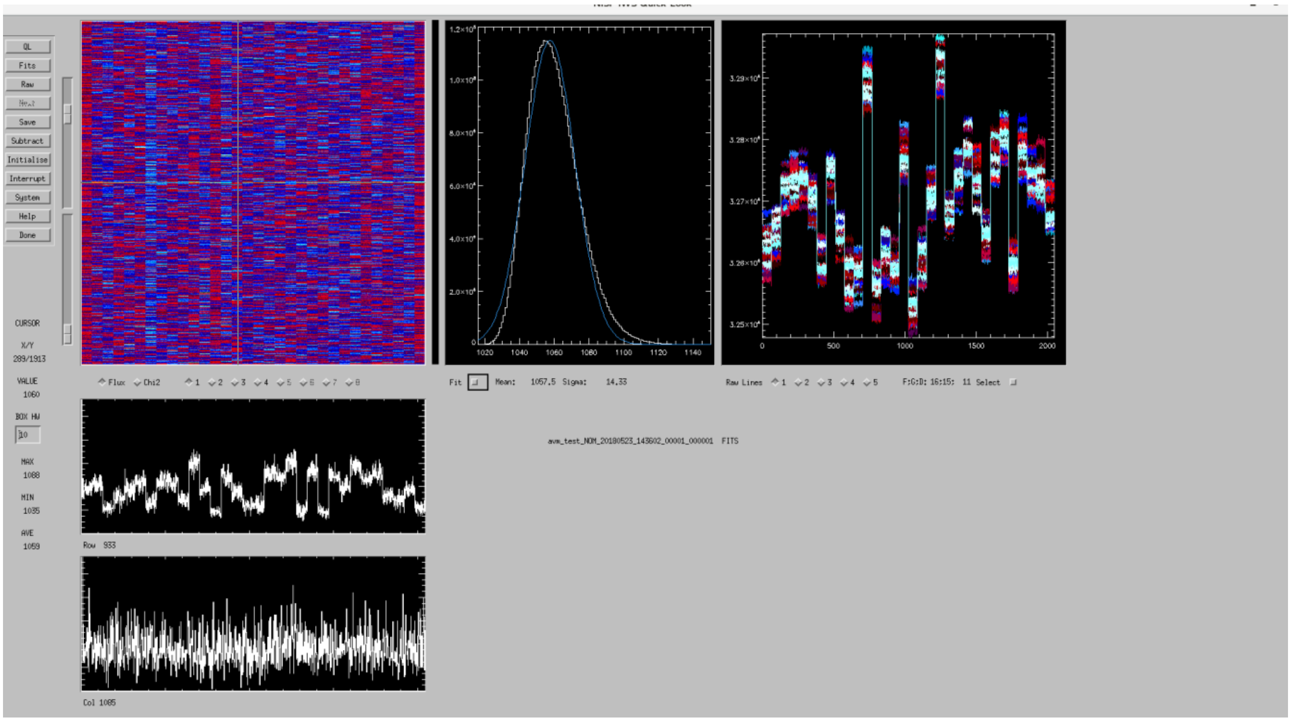


Figure 5.34: Analogue power supply lines provided by the DCU to the SCE, they are required to be stable in 5% range by design.



CURSOR
X/Y
289/1913
VALUE
1060
BOX HW
10
MAX
1088
MIN
1035
AVE
1059

Mean: 1057.5 Sigma: 14.33

F:G:D: 16:15: 11

avm_test_NOM_20180523_143602_00001_000001 FITS

Row 933

Col 1085

Figure 5.35: In the plot there is reported the nominal spectro exposure MACC (15, 16, 11), , as analysed by the IWS software; SCE is set with input to ground. The top panes report, from left to right: image (down-sampled to be displayed on the screen), image statistics and Gaussian fit and finally the five raw lines added to the compressed image.

5.5.7 SFT-07: EUC_NISP_DPU_Simulated_Exposure

This script is used to perform one exposure with a set of parameters loaded to the ICU from a user defined configuration file. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode.

Image data is generated by the SCE simulating a pre-defined pattern; the operations to be performed are the following:

- send a TC to move ICU to IDLE mode
- send the Processing Parameter Configuration Table to the DPU, parameters are set by the user in the *.ini* file and forwarded to the DPU Processing Task
- send TCs to put NISP in MANUAL mode
- send a TC to configure the SCE to produce simulated images with a pre-defined Pixel by Pixel patter
- send TCs to put NISP in OBSERVATION mode
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with one MACC (3,16,4)
- send the SCE exposure command
- send TCs to put NISP in MANUAL mode
- send a TC to configure the SCE to produce simulated images with a pre-defined Frame by Frame pattern
- send TCs to put NISP in OBSERVATION mode
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with one MACC (3,16,4)
- send the SCE exposure command.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. In particular, one of the Success Criteria of the test is that one image acquired in simulated mode (Pixel by Pixel) and one image acquired in simulated mode (Frame by Frame) must be compared to the expected ones. The test is completed successfully.

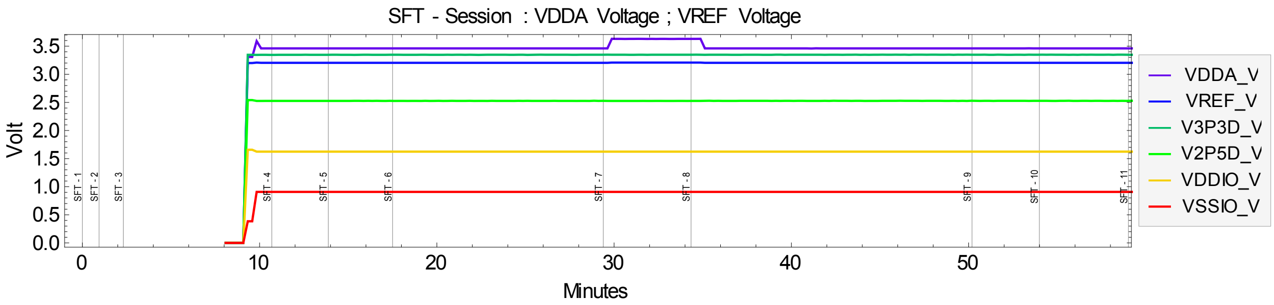
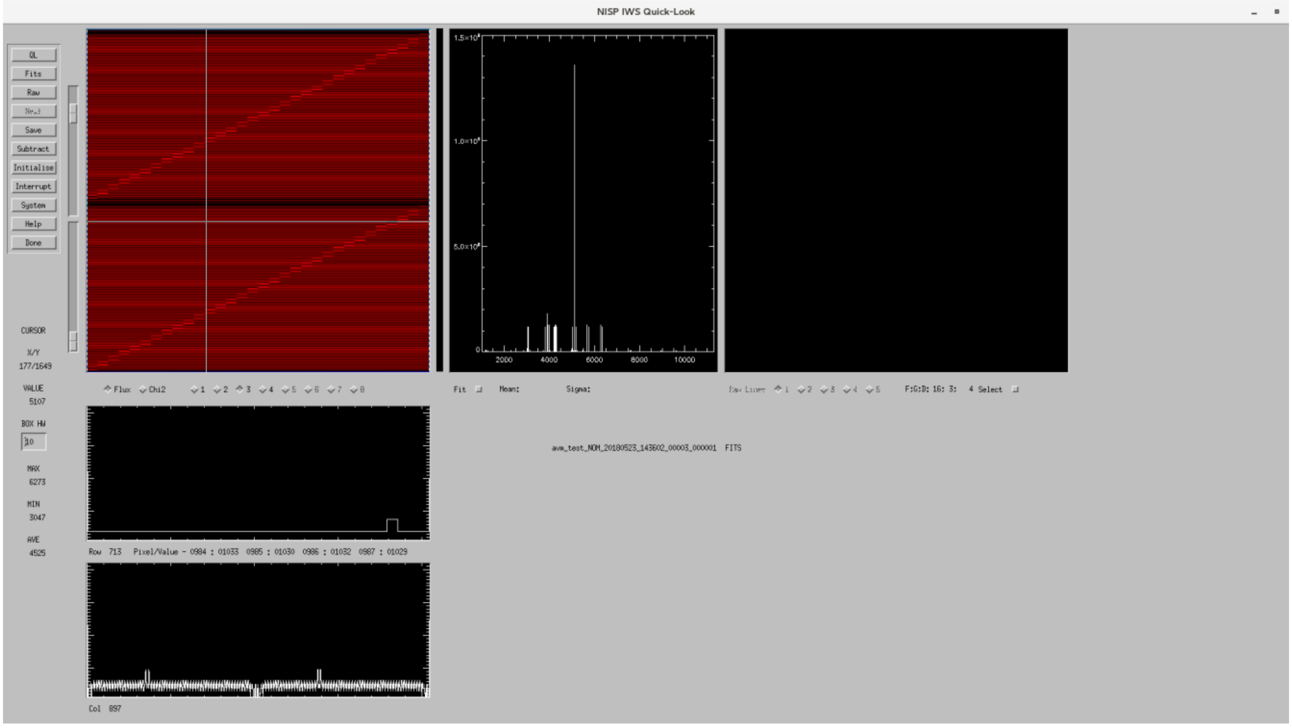


Figure 5.36: Power lines supplied by the DCU to the SCE, the plot spans all the SFT. During SFT-07 there is a higher value of the VDDA analogue supply, this is due to the operation mode of the SCE that has to provide simulated images with pre-defined patterns to the DCU. The increase and decrease of VDDA are related to the SCE_FMODE command that sets the SCE read out mode configuration.



CURSOR
X/Y
177/1649
VALUE
5107
BOX HW
10
MAX
6273
MIN
3047
AVE
4525

F:G:D: 16: 3: 4

avm_test_NOM_20180523_143602_00003_000001 FITS

Row 713 Pixel/Value - 0984 : 01033 0985 : 01030 0986 : 01032 0987 : 01029

Col 897

Figure 5.37: Display of the processed image for the Pixel by Pixel simulated mode. The left panel shows the processing result on the full sensor. It is consistent with what expected.

5.5.8 SFT-08: EUC_NISP_DPU_Nominal_Flight_Data_Flow

The purpose of the test is to simulate data flow similar to the one expected during NISP operation with eight SCEs. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode.

Image data is generated by the SCE clamping the inputs of the ASIC to ground and reading the noise, the operations to be performed are the following:

- send a TC to move ICU to IDLE mode
- send the Processing Parameter Configuration Table to the DPU
- send TCs to put NISP in MANUAL mode
- send a TC to configure the SCE with pins shorted to ground
- send TCs to put NISP in OBSERVATION mode
- repeat eight times the two following steps
    - send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with 4 MACC (2,2,2)
    - send the four SCE exposure commands.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. Image produced are expected to be identical since the SFT was run with SCE pins set to ground. 32 files were file produced and they have been compared in statistical sense: the difference between two files is expected to be a Gaussian distribution with 0 as mean value. The test is completed successfully.

5.5.9 SFT-09: EUC_NISP_ICU_1553_bus_B_check

This script is used to check the possibility to switch by TC between the Nominal and Redundant MIL1553 channel in the ICU to DPU communication. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode. The operations to be performed are the following:

- set 1553 communication BUS to B
- check that all periodic telemetry is produced by the ICU ASW
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured

with 4 MACC (2,2,2)

- send the four SCE exposure commands
- set 1553 communication BUS to A
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with 4 MACC (2,2,2)
- send the four SCE exposure commands.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. Image produced are expected to be identical since the SFT was run with SCE pins set to ground. Files produced while the 1553 Bus B was selected are compared with files produces while the 1553 BUS A was selected. The difference between couple of files is expected to be a Gaussian distribution with 0 as mean value. The test is completed successfully

5.5.10 SFT-10: EUC_NISP_SPW_Redundant_check

This script is used to check the possibility to switch by TC between the Nominal and Redundant Spacewire channel in the DPU to SCOE interface. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode. The operations to be performed are the following:

- send TCs to put NISP in MANUAL mode
- send TC to the DPU to select the Spacewire Redundant channel
- send TCs to put NISP in OBSERVATION mode
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with 4 MACC (2,2,2)
- send the four SCE exposure commands
- check the amount of data transferred to the SCOE Spacewire logger
- send TCs to put NISP in MANUAL mode

- send TC to the DPU to select the Spacewire Nominal channel
- send TCs to put NISP in OBSERVATION mode
- send the DITHER CONFIGURATION TABLE to the DPU, the dither is configured with 4 MACC (2,2,2)
- send the four SCE exposure commands
- check the amount of data transferred to the SCOE Spacewire logger.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. Image produced are expected to be identical since the SFT was run with SCE pins set to ground. Files produced while the Nominal Spacewire channel was used are compared with files produces while the Redundant Spacewire channel was used. The difference between couple of files is expected to be a Gaussian distribution with 0 as mean value. The test is completed successfully.

5.5.11 SFT-14: EUC_NISP_Power_OFF

This script is used to Power OFF the NISP AVM. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode. The operations to be performed are the following:

- send a TC move the DPU to SAFE mode, in this mode the DCU/SCE are powered OFF
- wait 30 seconds and check the DCU power
- send a TC to move the ICU to IDLE mode
- send a TC to move the ICU to STANDBY mode
- send a TC to the SCOE to Power OFF the DPU
- send a TC to the SCOE to Power OFF the ICU.

The final NISP MODE is OFF; the NI-WE and all the sub-systems are powered OFF. Digital and analogue TMs are as expected; no error report is received. The test is completed successfully.

5.5.12 SFT report

The SFT was completed successfully and only minor problems were detected. With respect to the Success Criteria defined in the Test Plan, results are as follows:

- **Telecommand History:** the acceptance and execution of all the TC issued during the SFT were verified using TM(1,x). The verification of the TC is done automatically using the *.tcl* command ::L2TCOPS::sendTCack. For the TCs issued to move the FWA/GWA wheels it is not possible to perform TM(1,x) check, anyway the *.tcl* script can catch the events associated to the start and end of the wheel rotation.

- **Packet amount:** during nominal operation of the DPU EM sporadic errors leading to (5,2) events were observed, they are generated during the access to the 485 DCU serial bus to acquire the SCE HK. For this behaviour a NCR has been open to OHB-I. In addition to these errors it emerged also a problem in the periodic reading of the DCU analogue TMs. During normal operation, the DCU analogue TM is not any more updated by the DPU ASW. For this behaviour also a NCR has been opened to OHB-I. Recently this problem was fixed updating the DCU FPGA firmware.

  One TM(5,4,326) is generated when a parity error is detected during the transmission of the analogue telemetry from the DAS board to the CDPU of the ICU. This type of error triggers an FDIR which commands the transition of the ICU to SAFE mode. The origin of the error is still unclear. In order to avoid this problem, the SFT was run with the Telemetry Acquisition Error FDIR disabled.

  TM(5,2,305) are produced during the movement of the FWA/GWA. In normal operation these errors trigger the corresponding FDIR which commands the ICU to move to SAFE mode. Using an oscilloscope, we checked that there is no overcurrent on the commanded wheel and so Wheels Warning FDIR was disabled during SFT.

After the NISP AVM validation test it was understood that the overcurrent is triggered by the wheel which is not commanded. Raising that threshold from 20 to 30 ADU no TM(5,2,305) is generated during the rotation of FWA and GWA.

- **<u>Analogue/Digital Telemetry</u>:** all the telemetries were plotted and found inside allowed ranges, as an example Figure 5.38 and Figure 5.39 are reported

- **<u>Science Data</u>:** one image was acquired in simulated mode (Pixel by Pixel) and one image was acquired in simulated mode (Frame by Frame), they are as expected must be compared to the expected ones

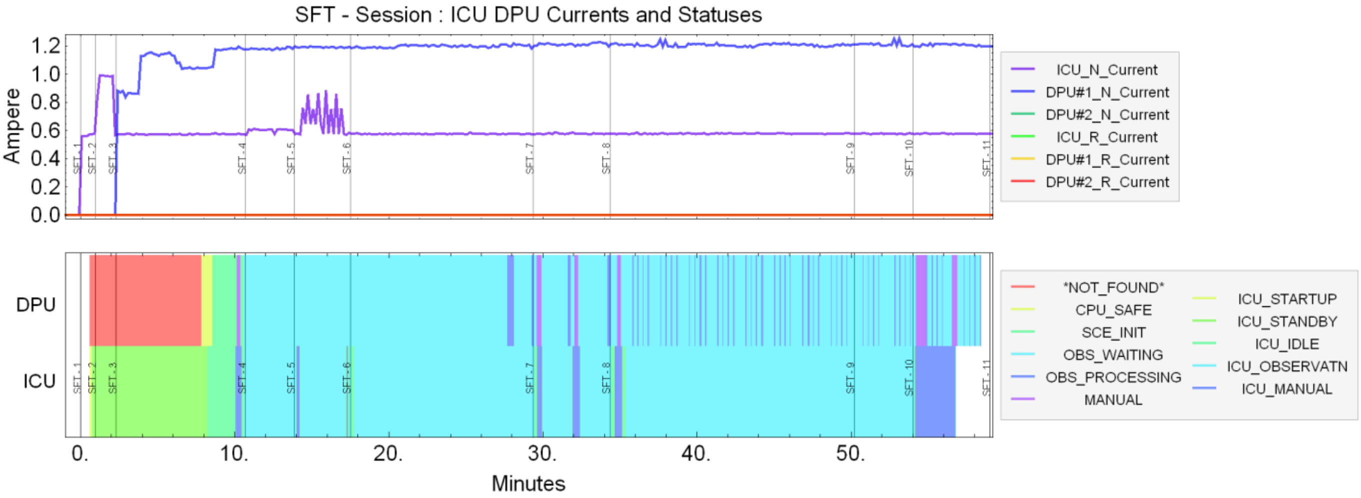


Figure 5.38: In the top plot there are the ICU and DPU currents as measured by the SCOE power supply, no anomalous values are reported. DPU current is shown with the blue line; it is stable after the SCE boot at the end of SFT-03, small increases are visible during SFT-08 and SFT-09, they are probably related to the processing task. ICU current is stable. There is only one increase during the FWA/GWA motor movements. In the bottom plot the ICU and DPU modes are reported, they are always as commanded and expected. The DPU mode before ASW transition to SAFE mode is not valid.

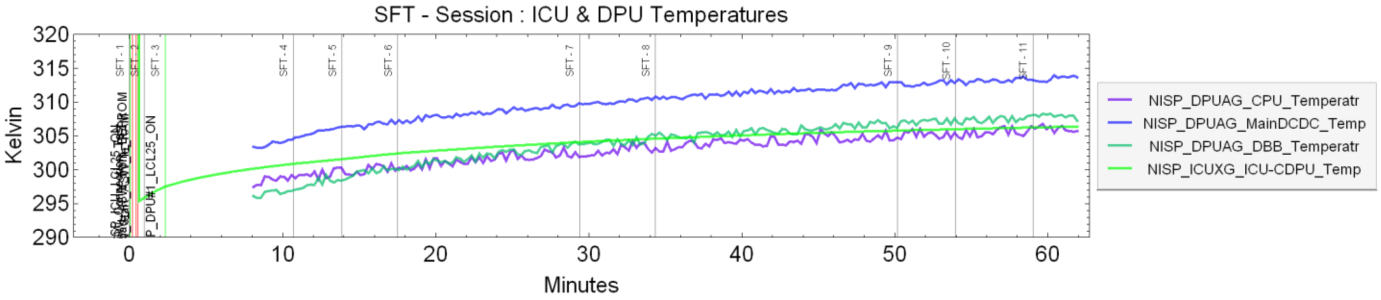


Figure 5.39: Temperatures of NISP sub-systems during SFT test. No anomalous values are detected, the trend is slightly increasing, more data are available after the long duration Robustness Test.

5.5.13 FFT-01: EUC_NISP_ICU_startup_FDIR_offon

This script implements the ICU Power ON and Start-up procedure, the FDIR functions are disabled and enabled by TC. The initial NISP MODE is OFF and all NISP subsystems are not powered, the operations to be performed are the following:

- send the TC to Power ON the ICU (Nominal unit), the ICU BSW starts automatically
- check the presence of the Boot Report Event
- check the presence of BSW Housekeeping periodic packets
- perform a Connection Test with BSW using the PUS Service (17,1)
- send the two TCs to load ICU ASW versions stored in the EEPROM and then start it. ASW automatically moves to the STARTUP mode
- check that STARTUP mode is reported in the TMs
- send a TC to Disable all FDIR functions
- send a TC to Enable all FDIR functions
- disable TM_ACQ_ERROR_FDIR (see paragraph 5.5.12)
- disable WHEELS_WARNING FDIR (see paragraph 5.5.12)
- send a TC to move ICU to STANDBY mode
- perform connection test with ICU ASW.

The final NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected, ICU ASW is launched without error reports and FDIR are ENABLED. The test is completed successfully.

5.5.14 FFT-02: EUC_NISP_ ICU_Dump_Load_Word_ICU_memories

This script checks the Memory Load and Memory Dump command of the ICU ASW. One word is Loaded and the Dumped from all supported ICU memory locations. The initial NISP MODE is STANDBY, only ICU is powered ON, the operations to be performed are the following:

- send a TC to Load the word 0x00AA on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0x00AA
- send a TC to Load the word 0x0000 on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0x0000
- send a TC to Load the word 0xAAAA on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0xAAAA
- send a TC to Load the word 0x0000 on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0x0000
- send a TC to Load the words 0x00AA 0xAAAA on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0x00AA 0xAAAA
- send a TC to Load the word 0x00AA 0x00BB on ICU RAM at address 0x40600038
- send a TC to Dump a word in ICU RAM form address 0x40600038, the execution is successful if the data field content of the TM(6,6) is 0x00AA 0x00BB
- send a TC to check the ICU RAM address 0x40600038, the service provides a success report telemetry.

The final NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected. Service 6 is tested on the ICU RAM, which is the only memory area that can be patched by the ICU ASW, the SAU size of ICU RAM is 4, so up to two words are patched and dumped. The test is completed successfully.

5.5.15 FFT-03: EUC_NISP_ HK_Event_configuration

This script checks the PUS Service 3 commanded by the ICU ASW. The initial NISP MODE is STANDBY, only ICU is powered ON, the operations to be performed are the following:

- send a TC to define a new HK packet
- send a TC to define a new diagnostic packet, the parameters to be over-sampled in this packet has to be specified
- send a TC to enable new HK packet
- send a TC to report the content of the new HK packet
- send a TC to disable the new HK packet
- send a TC to enable new diagnostic packet
- send a TC to disable the new diagnostic packet
- send a TC to change the frequency of one HK packet
- send a TC to request one ICU ASW HK packet even if it is outside its proper generation frequency
- send a TC to delete the new HK packet
- send a TC to delete the new diagnostic packet.

The final NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected. Service 3 is tested for new HK and Diagnostic packets definition and usage. The test is completed successfully.

5.5.16 FFT-04: EUC_NISP_ ICU_Thresholds

This script checks the possibility to modify ICU ASW thresholds that trigger software FDIR intervention; one FDIR is triggered on purpose to move the ICU in SAFE mode. The initial

NISP MODE is STANDBY, only ICU is powered ON, the operations to be performed are the following:

- send a TC to deactivate all ICU ASW FDIR
- send a TC to move ICU to STARTUP mode
- read the CDPU default warning and alarm thresholds in the HK1 telemetry packet
- send a TC to set the thresholds at 99% of the default values
- read the LVPS default warning and alarm thresholds in the HK1 telemetry packet
- send a TC to set the threshold at 99% of the default values
- read the Motor Currents default warning and alarm thresholds in the HK1 telemetry packet
- send a TC to set the threshold at 99% of the default values
- read the LED voltages default warning and alarm thresholds in the HK1 telemetry packet
- send a TC to set the threshold at 99% of the default values
- read the CDPU default warning and alarm thresholds in the HK1 telemetry packet
- send a TC to set the thresholds at 10% of the default values
- send a TC to ENABLE all FDIR functions
- send a TC to move ICU to STANDBY mode
- wait for the ICU ASW transition to SAFE, this mode change is induced by the triggered FDIR
- send a TC to move ICU to STANDBY mode
- send a TC to move ICU to STARTUP mode
- send a TC to reset CDPU default warning and alarm thresholds
- send a TC to move ICU to STANDBY mode.

The final NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected. FDIR threshold modification by TC is checked, one FDIR is triggered by threshold modification. The test is completed successfully.

5.5.17 FFT-05: EUC_NISP_ ICU_Reset_in_Standby_and_Restart

This script checks the possibility to modify re-boot the ICU and re-start the ICU ASW. The initial NISP MODE is STANDBY, only ICU is powered ON, the operations to be performed are the following:

- send a TC to move ICU to BOOT mode
- check the presence of the Boot Report Event
- check the presence of BSW Housekeeping periodic packets
- perform a Connection Test with BSW using the PUS Service (17,1)
- send two TCs to load ICU ASW versions stored in the EEPROM and then start it. ASW automatically moves to the STARTUP mode
- check that STARTUP mode is reported in the TMs
- disable TM_ACQ_ERROR_FDIR (see paragraph 5.5.12)
- disable WHEELS_WARNING FDIR (see paragraph 5.5.12)
- send a TC to move ICU to STANDBY mode.

The final NISP MODE is STANDBY, all units are OFF, except the ICU which is in STANDBY mode. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected and shown in Figure 5.40. The ICU reboot is tested, BSW is started by TC and then the ASW is restarted. The test is completed successfully.

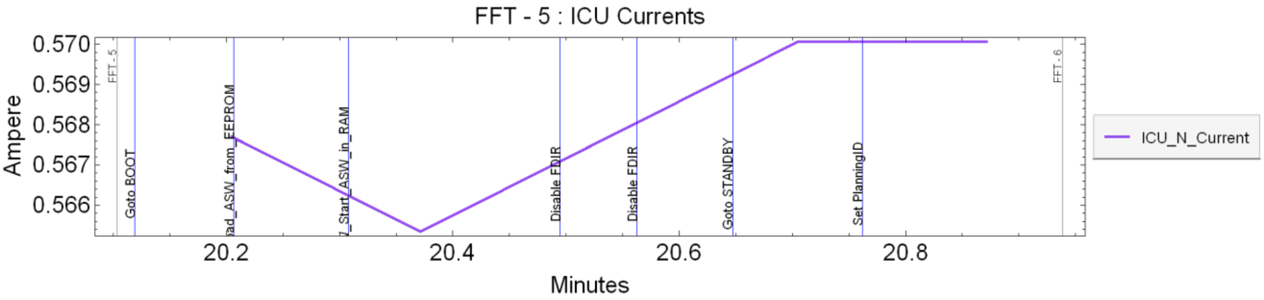


Figure 5.40: ICU current drain and ICU ASW states are shown, the ICU nominal current is reached when the STANDBY mode is reached.

5.5.18 FFT-06: EUC_NISP_ STARTUP_to_SCE_IDLE

This script permits the Power ON of the DPU/DCU and the boot of the SCE. The initial NISP MODE is STANDBY, only ICU is powered ON, the operations to be performed are the following:

- send a TC to the SCOE to Power ON the DPU
- send a TC to ICU ASW to configure the internal MIL1553 bus, in our case only DPUA Nominal is selected as active
- wait 50 s to get the DPU BSW periodic telemetry reported by ICU ASW in the HK7 telemetry packet
- send two TCs to DPU BSW to load the DPU ASW from EEPROM to RAM and to start ASW
- send a TC to load the DPU main configuration via System Configuration Table, the parameters are defined by the user in a *.ini* configuration file that is read by the *.tcl* script
- send a TC to copy the SCE EEF from EEPROM to RAM
- send a TC to set NISP to IDLE mode
- send a TC to assign master RT between the DPU, in our case master is RT1
- send a TC to configure the bit-mask of active DCU, in our case only DCU1 is declared active in the mask
- send a TC to move the DPU ASW to SCE_INIT mode
- send a TC to apply voltage supply to the DCU1. The communication with the DCU is established and the DCU analogue and digital telemetry is generated
- send a TC to activate the transmission of the DCU telemetry on the MIL1553, every 15 seconds it is refreshed by ICU in the HK2 telemetry packets
- send a TC to Boot the SCE EEF
- send a TC to activate the transmission of the SCE Housekeeping on the MIL1553, every 60 seconds it is refreshed by ICU in the HK4, HK5 and HK6 telemetry packets
- send a TC to activate synchronization between DCU and SCE
- send a TC to move NISP to MANUAL mode, this is necessary to configure via TC

the SCE. The configuration is loaded from the *.ini* file and the SCE is configured to produce images with a simulated pattern

- send a TC to move NISP to OBSERVATION mode
- send a TC to perform connection test with the ICU ASW
- send a TC to move NISP to MANUAL mode
- send a TC to perform connection test with the DPU ASW, it is the CPU_NOP command
- Send a TC to move NISP to OBSERVATION mode.

The NISP final state is in OBSERVATION and ICU, DPU, DCU and SCE are powered ON and ready for scientific data acquisition. NI-WE power consumption is monitored trough the SCOE telemetries. Digital and analogue TMs are as expected, no error reports is received. The test is completed successfully.

5.5.19 FFT-07: EUC_NISP_ SA_DS_Heaters_Reset_FPGA_Conf

This script checks the possibility to command Heaters. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to switch on the SA Heaters
- wait 1 minute
- send a TC to switch on the DS Heaters
- wait 1 minute
- send a TC to reset Heaters.

The final NISP MODE is OBSERVATION, ICU and DPU are powered ON. ICU power consumption is monitored trough the SCOE telemetries, digital and analogue TMs are as expected. The test is completed successfully.

5.5.20 FFT-08: EUC_NISP_ CU_FGWA_rejection_cmd

This script checks the possibility to operate FWA, GWA and the NI-CU, these sub-systems have to be operated one by one. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to power ON LED#1
- send a TC to power ON LED#2 and check that this command is rejected, the event (5,2,332) is received
- send a TC to move FWA wheel and check that this command is rejected, the event (5,2,332) is received
- send a TC to move GWA wheel and check that this command is rejected, the event (5,2,332) is received
- send a TC to reset LED FPGA
- send a TC to move FWA wheel and check that this command is accepted
- send a TC to move GWA wheel and check that this command is is rejected, the event (5,2,332) is received
- send a TC to power ON LED#1 and check that this command is rejected, the event (5,2,332) is received
- wait 30 seconds until the FWA movement is completed
- send a TC to power ON LED#1
- wait 1 minute
- send a TC to power OFF LED#1.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; only expected (5,2) error reports are received. The test is completed successfully.

5.5.21 FFT-09: EUC_NISP_ Dither_Abort

This script checks the possibility to abort one exposure via dedicated TC. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a DITHER CONFIGURATION TABLE to the DPU and configure a dither composed by 4 MACC(2,2,2)

- send the TC to abort the dither to the DPU, after the issue of this command the processing task is stopped, the Dither is set to OFF in the digital DPU telemetry and the SCE state is set to IDLE.
- send a DITHER CONFIGURATION TABLE to the DPU to configure a dither composed by 4 MACC(2,2,2)
- send four commands to start the SCE exposure.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. Figure 5.41 shows the ICU and DPU power consumption and the DPU and SCE states. The test is completed successfully.

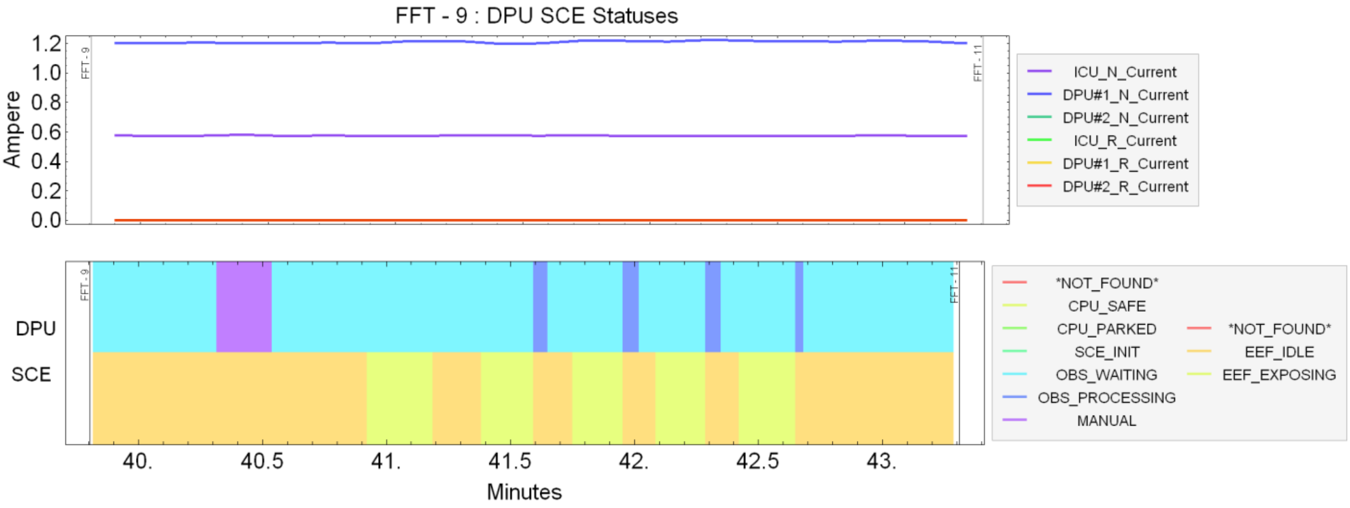


Figure 5.41: ICU and DPU power consumption are showed in the top plot. DPU and SCE status are reported in the bottom plot.

5.5.22 FFT-11: EUC_NISP_ IPC_exposure

During FFT test non nominal NISP exposure modes are also tested; such modes are referred as Engineering ones and they are designed for the calibration and performance verification phases. One of these modes is the so-called IPC exposure. This particular exposure is performed to study the electrostatic potential between neighbouring pixels;

this effect can be modelled by a parasitic capacitance.

One standard method applied to measure, and then correct such effect, consists in changing the V_{reset} value of a pixel in such a way to introduce a fake signal on the pixel. The method that will be adopted for Euclid detectors is to create a grid of pixels with a strong signal. The IPC can be measured by reconstructing the induced signal on the neighbours of a pixel. This pattern is then shifted and repeated on the other pixels to cover the whole matrix.

This script checks the possibility to perform exposures for IPC calibration using dedicated TC. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send to the DPU a DITHER CONFIGURATION TABLE configured for IPC exposure, the dither is composed by 1 MACC(2,1,1) and the exposure mode is CALIBRATION_IPC
- send to the DPU the TC to start the IPC exposure.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected for an IPC calibration exposure. The test is completed successfully.

5.5.23 FFT-12: EUC_NISP_ KTC_exposure

KTC noise is thermal noise associated with capacitors, in general the process of resetting a capacitor introduces such noise. During detector readout kTC noise is responsible for the variation of the content of the first frame after reset. kTC noise can be eliminated by UTR sampling.

This script checks the possibility to perform a kTC calibration exposure via dedicated TC. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to move NISP to MANUAL mode

- send a TC to the DPU to configure the SCE pins shorted to ground
- send a TC to move NISP to OBSERVATION mode
- send to the DPU a DITHER CONFIGURATION TABLE configured for kTC exposure, the dither is composed by 1 MACC(1,1,0) and the exposure mode is CALIBRATION_kTC
- send to the DPU the TC to start the kTC exposure.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are formally as expected for a kTC calibration exposure. The test is completed successfully.

5.5.24 FFT-13: EUC_NISP_ DCU_Reset_Check

This script checks the possibility to modify ICU ASW thresholds that trigger FDIR intervention; one FDIR is triggered on purpose to move the ICU in SAFE mode. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a DITHER CONFIGURATION TABLE to the DPU to configure a dither composed by 4 MACC(2,2,2)
- send four commands to start the SCE exposure
- send a TC to move the ICU to IDLE
- send a TC to move the DPU to MANUAL
- check in the HK2 telemetry packet the number of Goups and the number of Frames co-added by the DCU
- send a TC to the DPU to Reset the Groups and Frame counters, check that counters are set to zero
- send a TC to the DPU to Boot the SCE, in this case select the Soft boot option because
- send a TC to move the NISP to OBSERVATION
- send a DITHER CONFIGURATION TABLE to the DPU to configure a dither

composed by 4 MACC(2,2,2)

- send four commands to start the SCE exposure.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. No difference is found between the data produced before and after the DCU counters reset. The test is completed successfully.

5.5.25 FFT-15: EUC_NISP_ Manual_image_acquisition

This script checks the possibility perform exposures with the NISP in MANUAL mode. The initial NISP MODE is OBSERVATION, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to move NISP to MANUAL mode
- send a DITHER CONFIGURATION TABLE to the DPU to configure a dither composed by 4 MACC(2,2,2)
- send four commands to start the SCE exposure.

The final NISP MODE is MANUAL; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. The test is completed successfully.

5.5.26 FFT-17: EUC_NISP_ ICU_DPU_Dump_Load_One_Word

This script checks the Memory Load and Memory Dump command of the ICU ASW. One word is Loaded and the Dumped from all supported ICU and DPU memory locations. The initial NISP MODE is MANUAL, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to the DPU to disable DCU and SCE housekeeping scanners, this command is necessary because the data used by Load and Dump commands are spanned on the same sub-addresses used for HK handshaking between ICU and DPU

- run FFT-02 to Load and Dump word on ICU RAM address
- send a TC to the ICU to Load the data “abacadae” on DPU RAM at the address 0x0
- send a TC to the ICU to Dump a word form DPU RAM form address 0x0, the execution is successful if the data field content of the TM(6,6) is “abacadae”
- send a TC to the ICU to Load the data “abacadae” on DBB at the address 0x40000000
- send a TC to the ICU to Dump a word form DBB address 0x40000000, the execution is successful if the data field content of the TM(6,6) is “abacadae”
- send a TC to the ICU to Load the data “abacadae” on DRB at the address 0x20000000
- send a TC to the ICU to Dump a word form DRB address 0x20000000, the execution is successful if the data field content of the TM(6,6) is “abacadae”
- send a TC to the ICU to Load the data “abacadae” on DCU1 at the address 0x60000000
- send a TC to the ICU to Dump a word form DCU1 address 0x60000000, the execution is successful if the data field content of the TM(6,6) is “abacadae”.

The final NISP MODE is MANUAL; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received. Service 6 is tested on the ICU RAM and on the DPU CPU, DBB, DRB and DCU1 boards. The SAU size of is 4, so up to two words are patched and dumped. The test is completed successfully.

5.5.27 FFT-18: EUC_NISP_ HK_Event_configuration_manual

This script checks the PUS Service 3 commanded by the ICU ASW in MANUAL mode. The initial NISP MODE is MANUAL, ICU and DPU are powered ON, the operations to be performed are the same described in FFT-03.

The final NISP MODE is MANUAL; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received. The test is completed successfully.

5.5.28 FFT-19: EUC_NISP_ SCE_command_check_manual

This script checks the possibility of the DPU ASW to modify SCE registers. The initial NISP MODE is MANUAL, ICU and DPU are powered ON, the operations to be performed are the following:

- send a TC to the DPU to perform connection test
- send a TC to the DPU to check the aliveness of the SCE
- send a TC to the DPU ASW to dump the value of SCE register 0x6002, in this case the value is the default one 0X8119
- send a TC to the DPU ASW to modify the value of the SCE register to 0x8110
- send a TC to the DPU to Power OFF the DCU
- send a TC to the DPU to Power ON the DCU
- send a TC to the DPU to Boot the SCE microcode
- send a TC to the DPU ASW to dump the value of SCE register 0x6002 and check that the default value is applied again
- send a TC to the DPU to synchronize DCU and SCE.

The final NISP MODE is MANUAL; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received. The SCE register is modified via dedicated TC; the execution of the command is check using the Memory Dump command on the modified SCE register. The test is completed successfully.

5.5.29 FFT-22: EUC_NISP_ DPU_CPU_reset

This script checks the possibility to re-boot of the DPU CPU main board without affecting the focal plane power status. The initial NISP MODE is MANUAL, ICU and DPU are powered ON, the operations to be performed are the following:

- send to the DPU the CPU REBOOT command, this command should restart the DPU BSW
- wait 50 s to get the DPU BSW periodic telemetry reported by ICU ASW in the HK7 telemetry packet

- send two TCs to DPU BSW to load the DPU ASW from EEPROM to RAM and to start ASW
- check that at start-up the DPU mode is CPU_PARKED
- send a TC to set NISP to IDLE mode
- send a TC to assign master RT between the DPU, in our case master is RT1
- send a TC to configure the bit-mask of active DCU, in our case only DCU1 is declared active in the mask
- send a TC to move the DPU ASW to SCE_INIT mode
- send a TC to apply voltage supply to the DCU1. The communication with the DCU is established and the DCU analogue and digital telemetry is generated.
- send a TC to activate the transmission of the DCU telemetry on the MIL1553, every 15 seconds it is refreshed by ICU in the HK2 telemetry packets
- send a TC to Boot the SCE EEF
- send a TC to activate the transmission of the SCE Housekeeping on the MIL1553, every 60 seconds it is refreshed by ICU in the HK4, HK5 and HK6 telemetry packets
- send a TC to activate synchronization between DCU and SCE
- send a TC to move NISP to MANUAL mode, this is necessary to configure via TC the SCE. The configuration is loaded from the *.ini* file and the SCE is configured to produce images with a simulated pattern
- send a TC to move NISP to OBSERVATION mode
- check in the HK2 telemetry packet that DCU is powered ON and that SCE is Booted
- send a DITHER CONFIGURATION TABLE to the DPU to configure a dither composed by 4 MACC(2,2,2)
- send four commands to start the SCE exposure.

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software, they are as expected. The test is completed successfully.

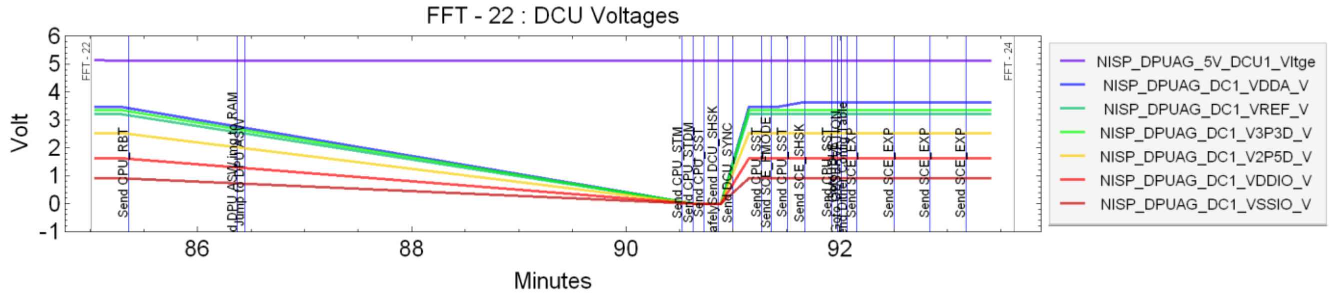


Figure 5.42: DCU power is shown in the upper violet line, the power to DCU/SCE is never excluded during the transitions between ASW and BSW and viceversa. The voltages supplied to the SCE are not stopped during the reboot but the telemetry is not present when the DPU ASW is not running and/or it is restarting.

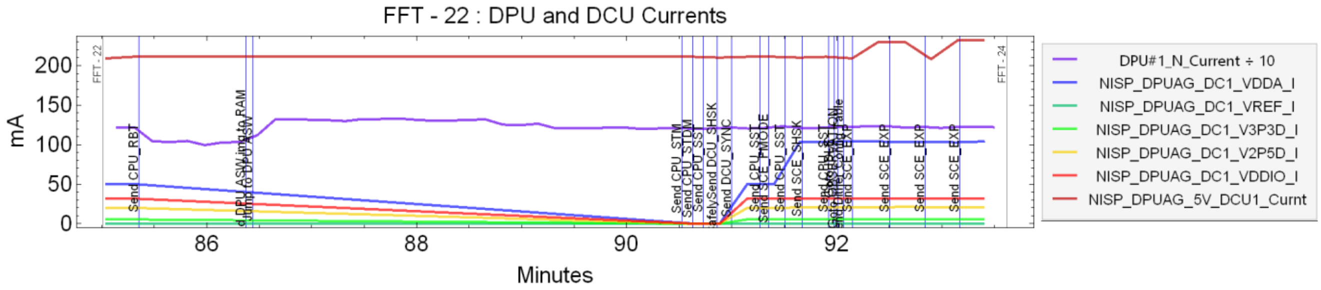


Figure 5.43: DCU current is shown in the upper red line, it never goes to zero. DPU current drained from the SCOE lowers during the BSW execution.

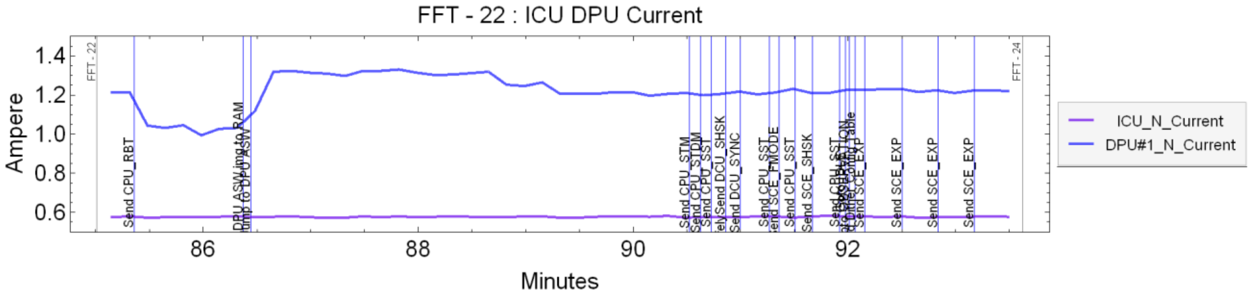


Figure 5.44: ICU and DPU power consumption as seen by the SCOE power supply.

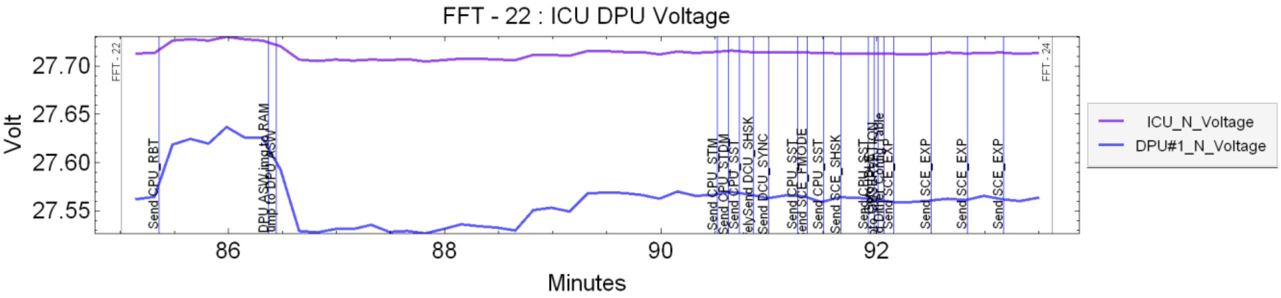


Figure 5.45: ICU and DPU Voltages as seen by the SOE power supply.

5.5.30 FFT-24: EUC_NISP_Power_OFF

This script is used to Power OFF the NISP AVM. The initial stage of NISP is OBSERVATION: all units are ON, NI-FWA and NI-GWA are not powered and in home position, NI-OMADA temperature is controlled and the SCE is in IDLE mode. The operations to be performed are the following:

- send a TC move the DPU to SAFE mode, in this mode the DCU/SCE are OFF
- wait 30 seconds and check the DCU power
- send a TC to move the ICU to IDLE mode
- send a TC to move the ICU to STANDBY mode
- send a TC to the SCOE to Power OFF the DPU
- send a TC to the SCOE to Power OFF the ICU.

The final NISP MODE is OFF; the NI-WE and all the sub-systems are powered OFF. Digital and analogue TMs are as expected; no error report is received. The test is completed successfully.

5.5.31 FFT Test report

The FFT was completed successfully and only minor problems were detected. With respect to the Success Criteria defined in the Test Plan, results are the same reported in the SFT Test Report (see paragraph 5.5.12). During the AVM validation test 63 different TCs have been send to the ICU ASW/BSW. With these tests about 80% of the total NISP TC has been verified and validated.

Analogue/Digital Telemetry: all the telemetries were plotted and found inside allowed ranges, as an example Figure 5.46, Figure 5.47 and Figure 5.48 are reported.

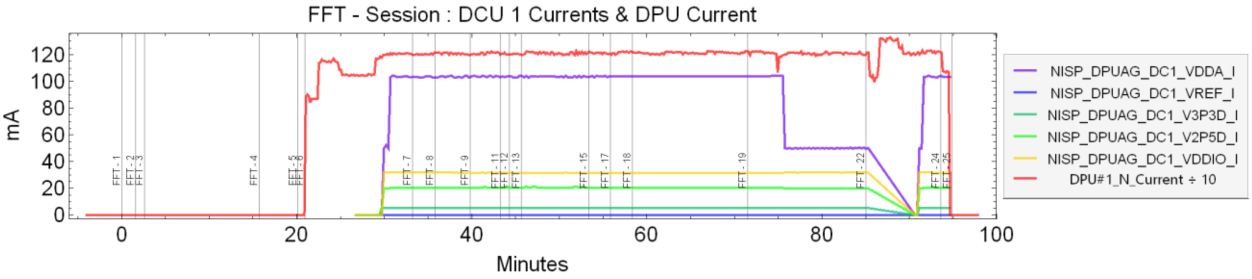


Figure 5.46: DPU Current, as seen by the SCOE power supply, is plotted in red line.

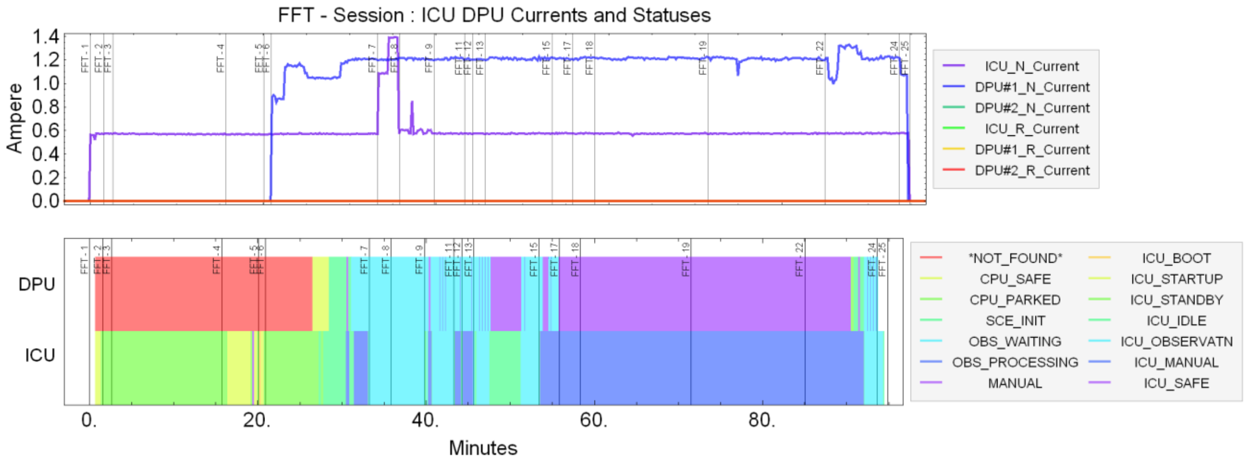


Figure 5.47: ICU and DPU power consumption and ASW states are reported, everything is consistent with issued commands.

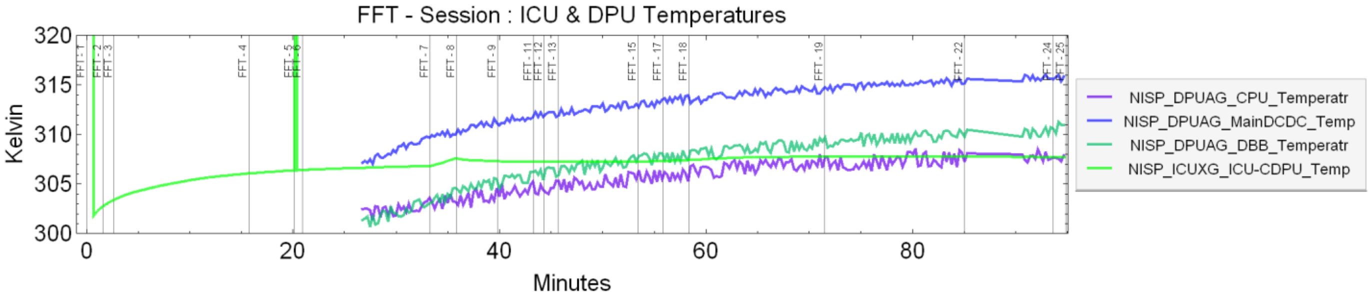


Figure 5.48: ICU and DPU temperatures are shown; there is an increasing trend for the DPU while for the ICU the temperature flattens around 307 K. The green curve has two peaks at the beginning of FFT-01 and FFT-05, the peak is at the ICU ASW start-up and the value is not valid because the DAS board is not initialized yet.

5.5.32 Robustness Test Report

The first Robustness TEST run for 29 hours; 3840 SCE exposures were commanded and executed, they are divided in 960 dithers, each of them is composed by four MACCs (2,2,2).

The final NISP MODE is OBSERVATION; the NI-WE is powered ON. Digital and analogue TMs are as expected; no error report is received during the exposures. Processed data are transmitted to the SCOE and analysed by the IWS software. The resulting 3840 images are compared to the first one; the difference between such files is expected to be a Gaussian distribution with 0 as mean value. The test is completed successfully.

The main aim of the test is to validate the TC/TM flow between ICU and DPU for a longer run.

The second Robustness test run for 24 hours, 20 Nominal Observation Cycles were performed and FWA and GWA rotation were also commanded.

The NISP Nominal Observation Cycle is composed by 17 single exposures divided in 4 Dithers. Each dither is divided in four exposures: Spectroscopy MACC(15,16,11), Photometry Y filter MACC(4,16,7), Photometry J filter MACC(4,16,6), Photometry H filter MACC(3,16,5) (see also section 2.2.4). At each dither a different red grism is used to change the orientation and one dark exposure is inserted at the end of the last dither, during the slew to a new point in the sky.

All NISP subsystems are ON, FWA and GWA are in home position, NI-OMADA temperature is controlled.

The start of the nominal observation cycle is provided by a TC to the ICU to Set the Plan ID. After each exposure the HK is retrieved from all the sub-systems and the processed images are sent by DPU to the SCOE Spacewire interface. Data integrity check is performed at the end of the long duration test by IWS software.

All commands issued to perform one Nominal Dither are reported in Figure 5.49.

I checked the time-line of each single dither to verify the repeatability over the time span of the test.

Telecommands executed and the Telemetries received are the following:

- **NISC0206** : Set Planning ID, issued 80 times

- **NISC0314** : Send Dither Configuration, issued 80 times
- **NISC0403** : Start Exposure, issued 340 times
- **NISC0801** : Move Wheel, issued 560 times
- **300101000** : TM(1,1) TC Acceptance Success, received 500 times
- **300107000** : TM(1,7) TC Execution Success, received 50 times
- **300501288** : TM(5,1) End of Wheel Rotation, received 560 times
- **300501384** : TM(5,1) End of exposure, received 340 times
- **300501385** : TM(5,1) End of MMU transmission, received 340 times

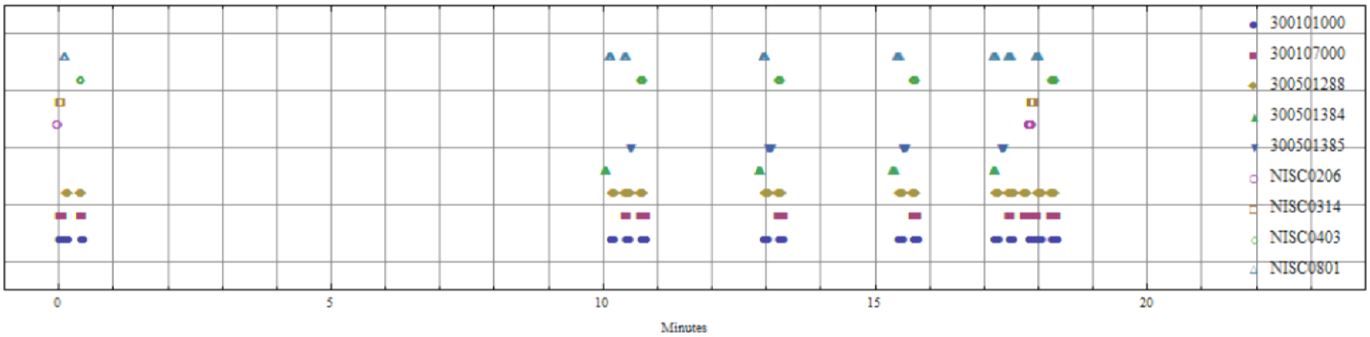


Figure 5.49: Time-line of telecommands issued and telemetries received during a single Nominal Dither.

Table 5.2 shows the time-line of telecommands issued and telemetries received during the Nominal Survey simulation. The absolute time (T) of each step in the sequence and its spread (σ) over the 20 cycles are reported. Exposure telecommands are highlighted in green, commands to the wheels are highlighted in yellow. Set Plan Id command and the completion of the last transmission to MMU are highlighted in red, they mark the beginning and the end of the Nominal Dither.

All absolute times (T) are evaluated with respect to the first command (Set Plan ID), in this way it is possible to get rid of the delay introduced by the CCS/SCOE data transfer. Each command reported in the time-line is followed by an acceptance report TM(1,1) and an execution report TM(1,7). Wheel movements, SCE exposures and data transmission to MMU are time-stamped by event reports TM(5,1). DPU ASW and SCE Status are reported and they are always coherent with event reporting telemetries.

Figure 5.50 shows the distribution of the delays between the generation of the Set Plan

ID command and the TM(1,1) prepared by the ICU ASW, the command was issued 80 times during the test and the TM(1,1) was always received.

The time spread of the entries increase from 0.3 s to 3 s along the time-line; this is related to the granularity TM/TC interface between SCOE, ICU and DPU. The 1553 interface between SCOE and ICU follows a cyclical schedule; the ICU ASW can receive one TC per second in a fixed communication frame while telemetries can be sent back in two communication frames per second. The 1553 interface between ICU and DPU follows a cyclical schedule as well and the DPU ASW can receive and process one TC per second in a fixed communication frame.

Table 5.2– Nominal Dither Timeline

Idx	DPU Status	SCE Status	T (s)	σ (s)	Description
1	OBS_WAITING	EEF_IDLE	0.	0.	Set Plan ID
2	OBS_WAITING	EEF_IDLE	1.65	0.259	Telemetry (1,1)
3	OBS_WAITING	EEF_IDLE	1.66	0.258	Telemetry (1,7)
4	OBS_WAITING	EEF_IDLE	3.27	0.467	Dither Configuration Table
5	OBS_WAITING	EEF_IDLE	5.14	0.663	Telemetry (1,1)
6	OBS_WAITING	EEF_IDLE	6.14	0.689	Telemetry (1,7)
7	OBS_WAITING	EEF_IDLE	8.16	0.735	Move FWA_ProfileID_2 (+ 144°)
8	OBS_WAITING	EEF_IDLE	9.98	0.813	Telemetry (1,1)
9	OBS_WAITING	EEF_IDLE	11.00	0.862	Wheel FWA Start_Movement
10	OBS_WAITING	EEF_IDLE	25.05	0.819	Telemetry (1,7)
11	OBS_WAITING	EEF_IDLE	25.05	0.819	Wheel FWA End_Movement
12	OBS_WAITING	EEF_IDLE	25.41	0.900	Expose_SpctrGrsmRGS__0
13	OBS_WAITING	EEF_IDLE	27.08	0.881	Telemetry (1,1)
14	OBS_WAITING	EEF_IDLE	28.08	0.836	Telemetry (1,7)
15	OBS_WAITING	EEF_EXPOSING	29.03	0.982	SCE Status -> EEF_EXPOSING
16	OBS_WAITING	EEF_EXPOSING	604.81	0.955	DPU End of Exposure
17	OBS_PROCESSING	EEF_IDLE	605.69	1.158	SCE Status -> EEF_IDLE
18	OBS_PROCESSING	EEF_IDLE	610.15	0.986	Move FWA_ProfileID_1 (-72°)
19	OBS_PROCESSING	EEF_IDLE	611.80	0.996	Telemetry (1,1)
20	OBS_PROCESSING	EEF_IDLE	612.82	0.965	Wheel FWA Start_Movement
21	OBS_PROCESSING	EEF_IDLE	626.84	0.963	Wheel FWA End_Movement
22	OBS_PROCESSING	EEF_IDLE	626.84	0.963	Telemetry (1,7)
23	OBS_PROCESSING	EEF_IDLE	627.20	0.998	Move GWA_ProfileID_19 (-144°)
24	OBS_PROCESSING	EEF_IDLE	628.84	0.965	Telemetry (1,1)
25	OBS_PROCESSING	EEF_IDLE	629.85	0.991	Wheel GWA Start_Movement
26	OBS_PROCESSING	EEF_IDLE	632.52	1.043	Tx to MMU End
27	OBS_WAITING	EEF_IDLE	643.91	1.024	Wheel GWA End_Movement
28	OBS_WAITING	EEF_IDLE	643.91	1.024	Telemetry (1,7)
29	OBS_WAITING	EEF_IDLE	644.28	1.039	Expose_Photo_Filter_Y
30	OBS_WAITING	EEF_IDLE	645.94	1.076	Telemetry (1,1)
31	OBS_WAITING	EEF_IDLE	646.94	1.075	Telemetry (1,7)
32	OBS_WAITING	EEF_EXPOSING	647.92	1.223	SCE Status -> EEF_EXPOSING
33	OBS_WAITING	EEF_EXPOSING	774.23	1.151	DPU End of Exposure
34	OBS_PROCESSING	EEF_IDLE	775.18	1.400	SCE Status -> EEF_IDLE

35	OBS_PROCESSING	EEF_IDLE	779.73	1.873	Move FWA_ProfileID_2 (+144°)
36	OBS_PROCESSING	EEF_IDLE	781.44	1.852	Telemetry (1,1)
37	OBS_PROCESSING	EEF_IDLE	782.43	1.874	Wheel FWA Start_Movement
38	OBS_PROCESSING	EEF_IDLE	786.04	1.136	Tx to MMU End
39	OBS_WAITING	EEF_IDLE	796.43	1.863	Wheel FWA End_Movement
40	OBS_WAITING	EEF_IDLE	796.43	1.863	Telemetry (1,7)
41	OBS_WAITING	EEF_IDLE	796.79	1.851	Expose_Photo_Filter_J
42	OBS_WAITING	EEF_IDLE	798.45	1.893	Telemetry (1,1)
43	OBS_WAITING	EEF_IDLE	799.45	1.858	Telemetry (1,7)
44	OBS_WAITING	EEF_EXPOSING	800.48	1.854	SCE Status -> EEF_EXPOSING
45	OBS_WAITING	EEF_EXPOSING	922.53	1.776	DPU End of Exposure
46	OBS_PROCESSING	EEF_IDLE	923.46	1.806	SCE Status -> EEF_IDLE
47	OBS_PROCESSING	EEF_IDLE	927.87	1.786	Move FWA_ProfileID_0 (+72°)
48	OBS_PROCESSING	EEF_IDLE	929.53	1.796	Telemetry (1,1)
49	OBS_PROCESSING	EEF_IDLE	930.54	1.799	Wheel FWA Start_Movement
50	OBS_PROCESSING	EEF_IDLE	934.36	1.770	Tx to MMU End
51	OBS_WAITING	EEF_IDLE	944.55	1.788	Wheel FWA End_Movement
52	OBS_WAITING	EEF_IDLE	944.55	1.788	Telemetry (1,7)
53	OBS_WAITING	EEF_IDLE	944.93	1.815	Expose_Photo_Filter_H
54	OBS_WAITING	EEF_IDLE	946.58	1.786	Telemetry (1,1)
55	OBS_WAITING	EEF_IDLE	947.55	1.844	Telemetry (1,7)
56	OBS_WAITING	EEF_EXPOSING	948.65	1.908	SCE Status -> EEF_EXPOSING
57	OBS_WAITING	EEF_EXPOSING	1033.0	1.766	DPU End of Exposure
58	OBS_WAITING	EEF_EXPOSING	1034.6	2.941	Move FWA_ProfileID_0 (+72°)
59	OBS_PROCESSING	EEF_IDLE	1033.9	1.854	SCE Status -> EEF_IDLE
60	OBS_PROCESSING	EEF_IDLE	1036.3	2.963	Telemetry (1,1)
61	OBS_PROCESSING	EEF_IDLE	1037.3	2.955	Wheel FWA Start_Movement
62	OBS_PROCESSING	EEF_IDLE	1043.0	1.817	Tx to MMU End
63	OBS_WAITING	EEF_IDLE	1051.3	2.959	Wheel FWA End_Movement
64	OBS_WAITING	EEF_IDLE	1051.3	2.959	Telemetry (1,7)
65	OBS_WAITING	EEF_IDLE	1051.6	2.968	Move GWA_ProfileID_19 (-144°)
66	OBS_WAITING	EEF_IDLE	1053.4	2.950	Telemetry (1,1)
67	OBS_WAITING	EEF_IDLE	1054.3	2.958	Wheel GWA Start_Movement
68	OBS_WAITING	EEF_IDLE	1068.3	2.927	Telemetry (1,7)
69	OBS_WAITING	EEF_IDLE	1068.3	2.946	Wheel GWA End_Movement

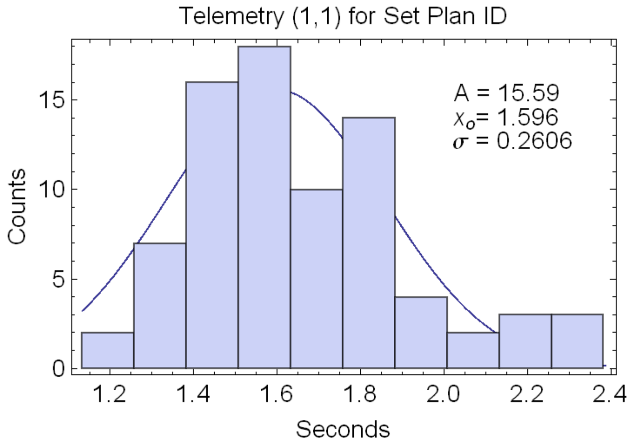


Figure 5.50: Delay between the generation time of the TC issued to Set the Planning ID of the dither and the related TM(1,1).

The second command in the time-line is the Dither Configuration; this TC is issued to the ICU ASW that produces the acceptance TM(1,1) and forwards the command to the DPU, the DPU ASW produces a positive CVT that is encapsulated in a TM(1,7) by the ICU ASW. This double-acknowledge (ICU & DPU) process requires one second by design and the spread over 20 cycles is less than one second, this result is consistent with the 1553 cycle.

The third command in the time-line (FWA rotation) is issued to the ICU after a delay of 2 seconds that is introduced on purpose in the script.

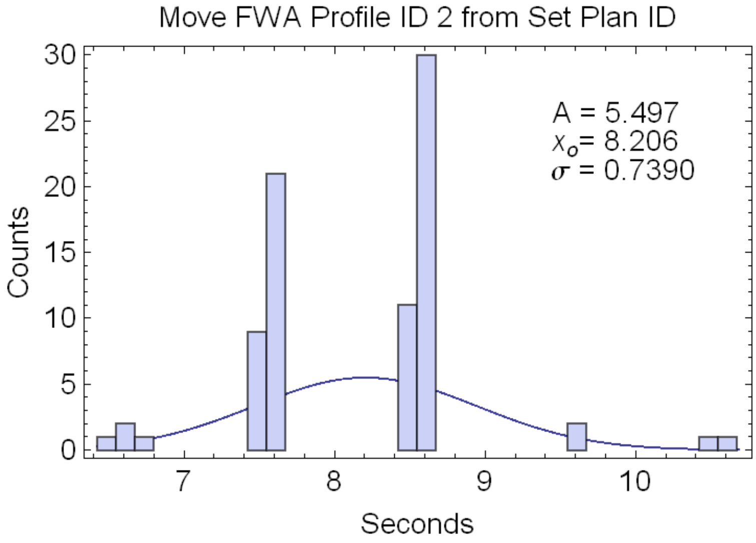


Figure 5.51: Delays between the Set Plan ID command and the first TC issued to the ICU to move the FWA wheel.

Delays reported in Figure 5.51 reproduce the granularity of the 1553 schedule; they affect also the distribution of the delays for events produced at the beginning and at the end of the FWA wheel rotation (Figure 5.52). The ICU/SCOE schedule has two slots available for telemetries and events, which is why the granularity is less evident.

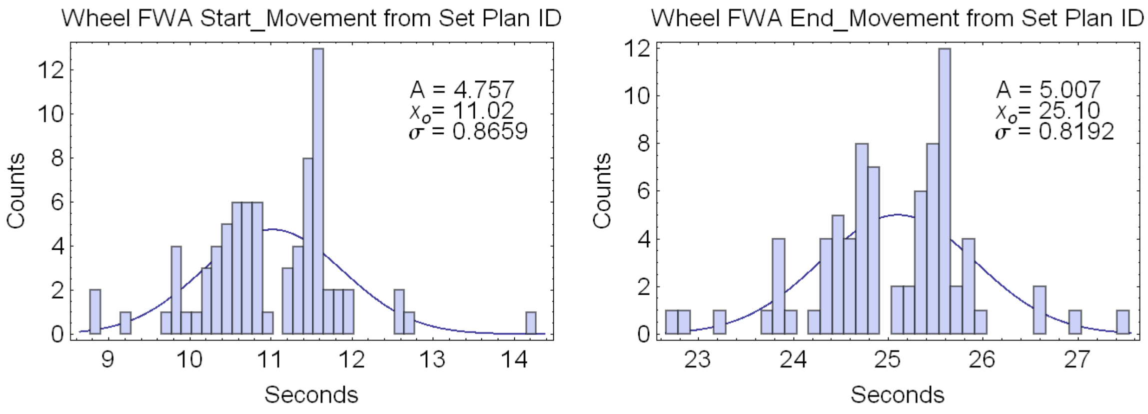


Figure 5.52: Distrubution of delays between the Set Plan ID command and the events reported at the beginning and at the end of the FWA wheel movement.

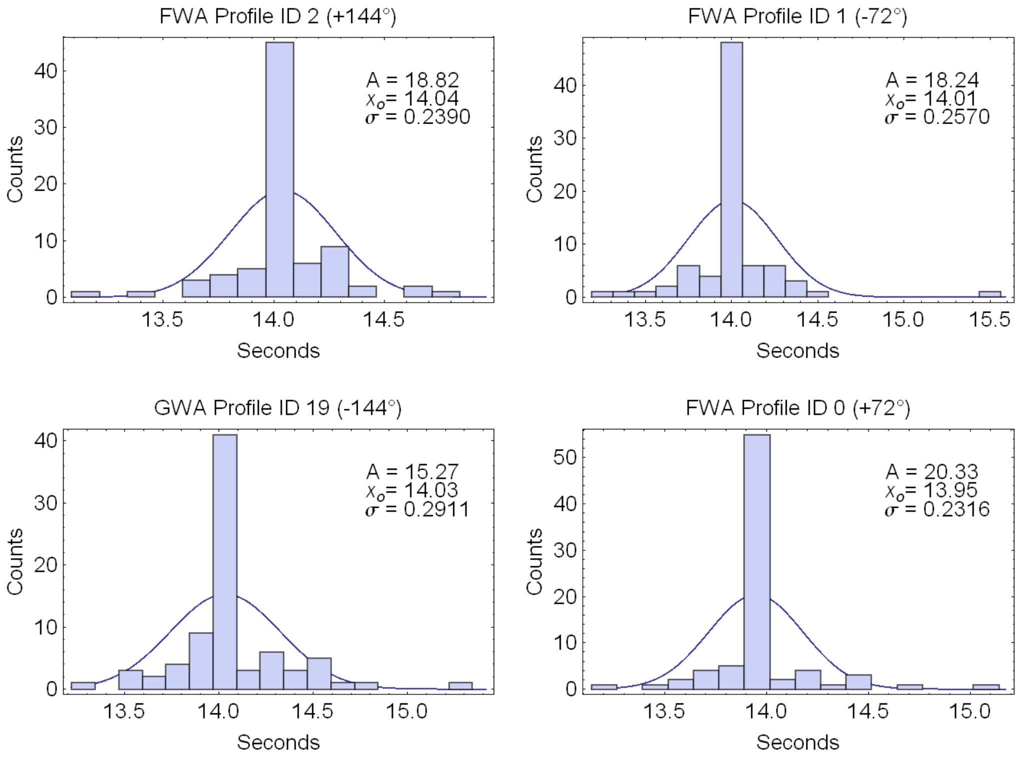


Figure 5.53: Wheel rotation time, it is evaluated as the delay between the events produced by the ICU ASW at the beginning and at the end of each movement.

The TC/TM interface timing is determined by the 1553 schedule, the wheels rotation time is driven by the ICU drivers and it should be 14 s. The rotation time distribution is shown in Figure 5.53, it is in agreement with expectations.

After FWA wheel rotation the exposure command is issued to the DPU ASW. The command is accepted and the DCU starts data acquisition from the SCE. As soon as the SCE sends data to the DCU the status of the DPU is set to Observation Waiting/EEF_Exposing. The DCU acquires data, performs the co-adding and transfers data to the DBB for processing, at this time the status of the DPU is set to Observation Processing/EEF_Idle and ICU prepares the event End of Exposure. This cycle is performed for every exposure programmed in a dither; Figure 5.54 and Figure 5.55 show the delays for all the steps in one exposure.

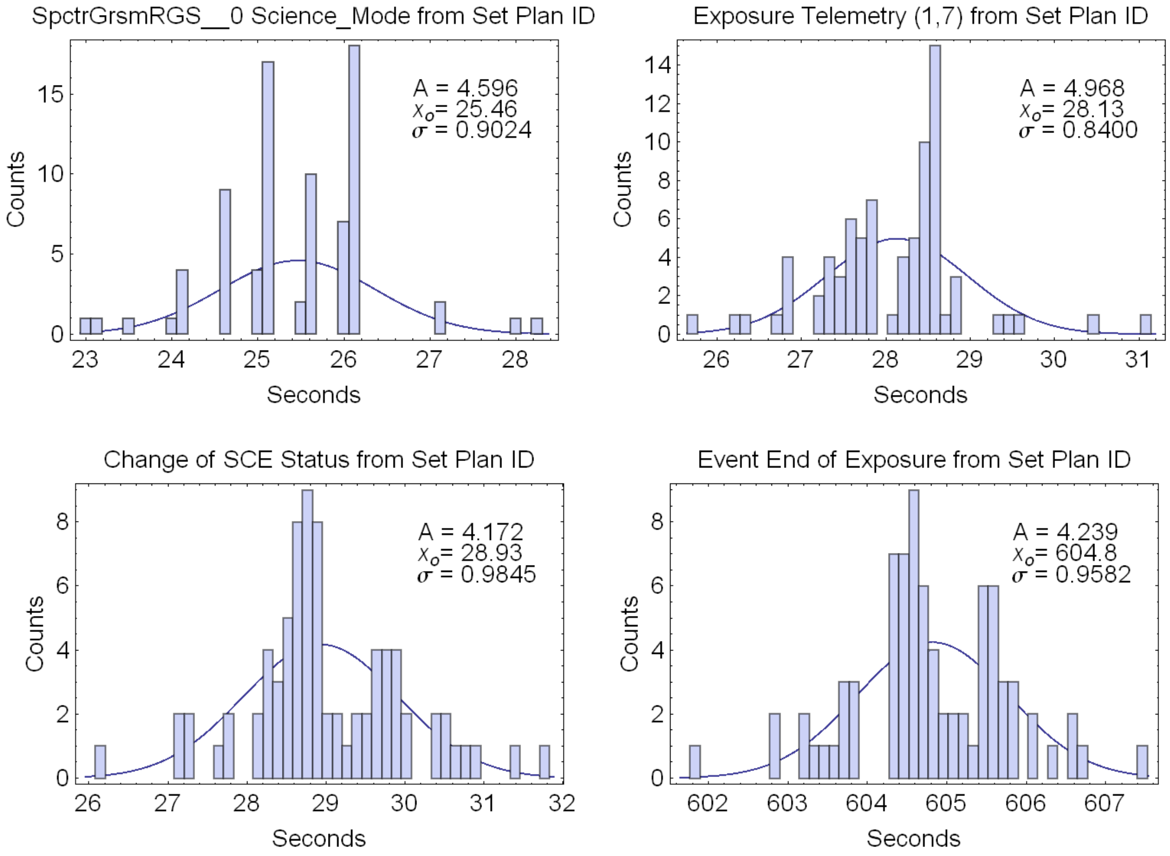


Figure 5.54: DPU exposure time-line for the Spectroscopy MACC(15,16,11), on the top left there is the TC issued by ICU, on the top right the TM(1,7) produced when the command is accepted by the DPU. As soon as the command is received the SCE is set to exposing (bottom left) and after the proper exposure time the event end of exposure is produced (bottom right).

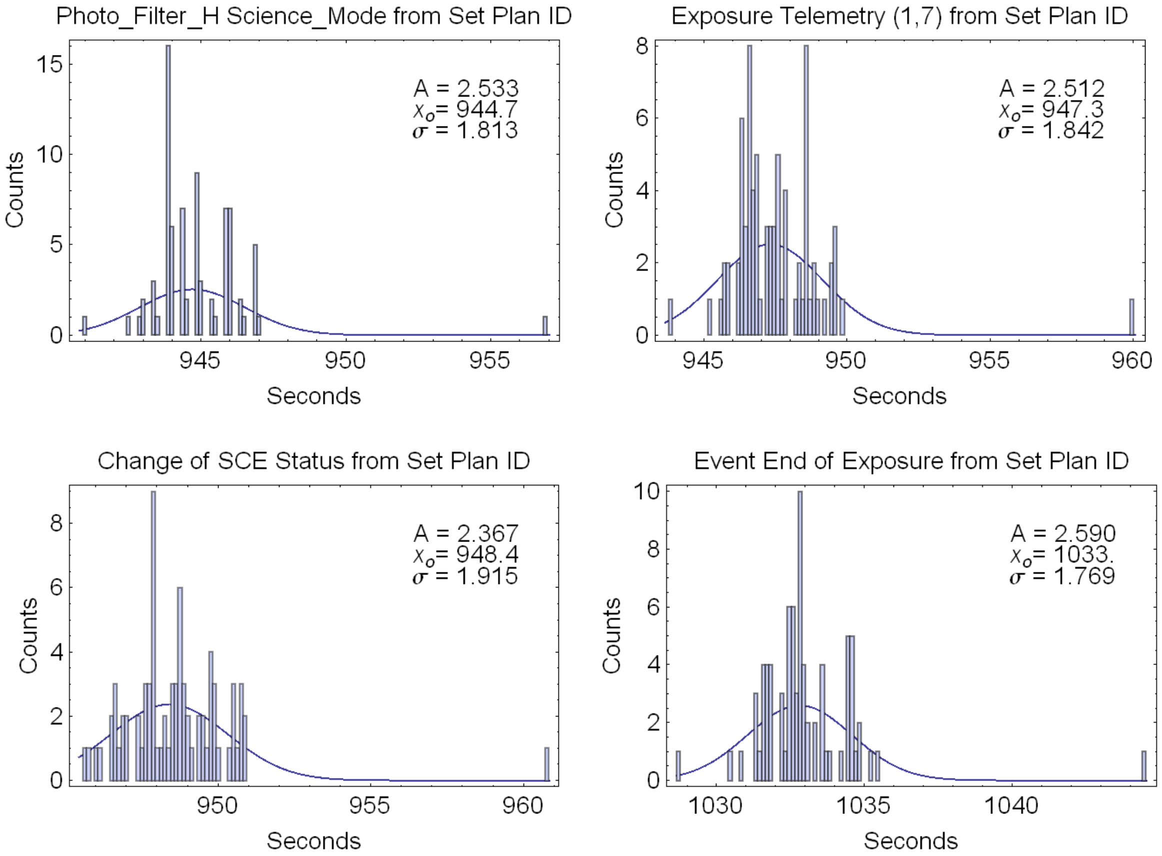


Figure 5.55: DPU exposure time-line for the Photometry H MACC(3,16,15), on the top left there is the TC issued by ICU, on the top right the TM(1,7) produced when the command is accepted by the DPU. As soon as the command is received the SCE is set to exposing (bottom left) and after the proper exposure time the event end of exposure is produced (bottom right).

The length of each exposure depends on the programmed MACC, for a Nominal Dither the expected exposure times are the following: 574 s for Spectroscopy, 124 s for Photometry Y, 120 s for Photometry J and 82 s for Photometry H.

The exposure times can be extracted from the time-line computing the difference between the change to EEF_Exposing of the SCE status and the production of the End of Exposure Event. Even if these times are extracted from the ICU HK that has a frequency of 2 s, results are compatible with expectations (see Figure 5.56).

After data processing and transfer to the SCOE via the Spacewire link the event End of Transmission to MMU is produced. The difference in time between the issue of the Set Plan ID command and the retrieval of the event End of Transmission to MMU is our best estimation of the dither time. The DPU has the requirement to achieve the processing of a nominal dither in less than 1048 s. This requirement was verified during DPU functional tests at unit level and also NISP AVM tests proved that this requirement is met. The processing time per one detector is evaluated to be 1 minute, the processing of the eight detector is done in a serial way, so the full focal plane processing can be achieved in a time compatible with the total exposure one.

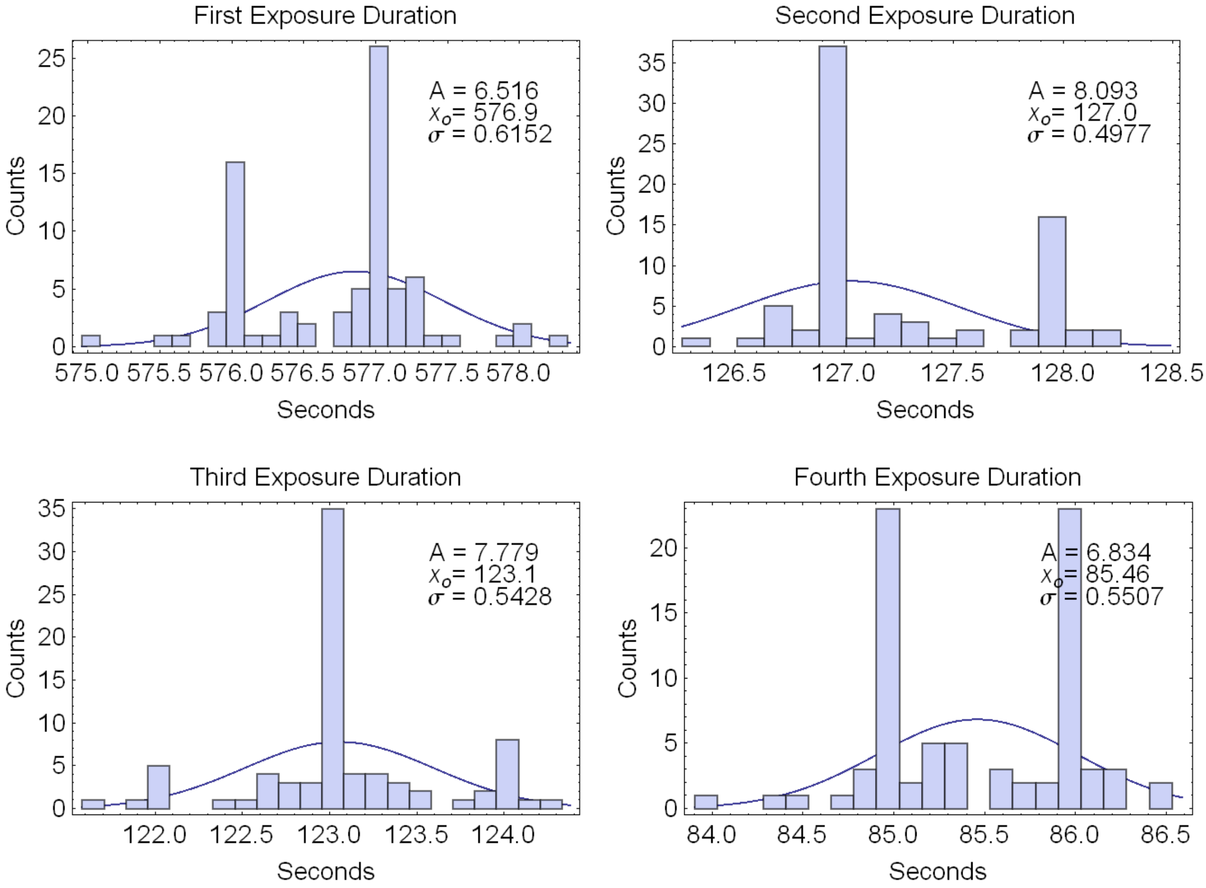
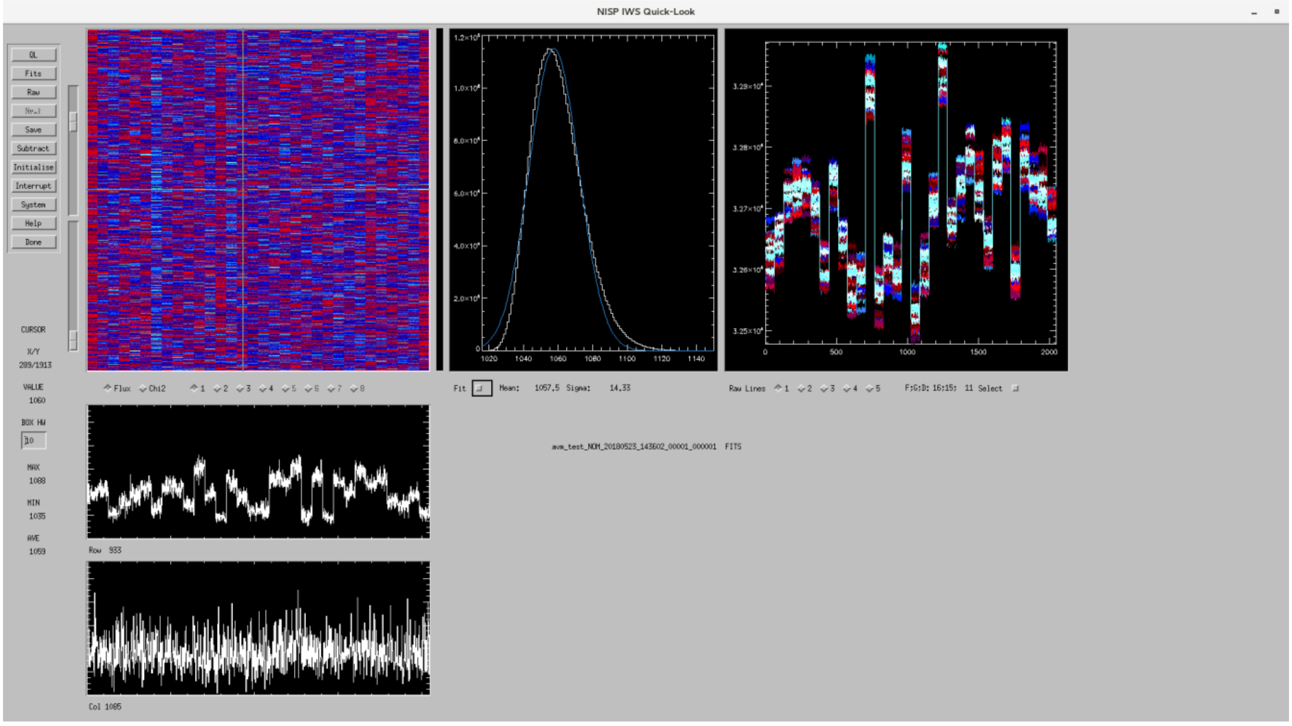


Figure 5.56 : Exposures length computed in the Nominal Survey Cycle.

The second Robustness test was useful also to verify IWS analysis tools and SCOE interfaces stability.

Figure 5.57 shows the IWS display of one Spectroscopic Image. No error is reported and the test is successful.

ICU and DPU power consumptions as seen by the SCOE power supply are reported in Figure 5.58 , no anomalies are reported. The ICU and DPU is monitored as well and no anomalies are visible in Figure 5.59. The NISP AVM is hosted in a controlled environment so very little temperature variations are foreseen.



CURSOR
X/Y
289/1913
VALUE
1060
BOX HW
10
MAX
1088
MIN
1035
AVE
1059
Row 933
Col 1085

Fit ☐ Mean: 1057.5 Sigma: 14.33

F;G;D: 16;15; 11

avm_test_NOM_20180523_143602_00001_000001 FITS

Figure 5.57: IWS Display of one Spectrocopic MACC(15,16,11). SCE pins are shorted to ground, the data acquired is random noise.

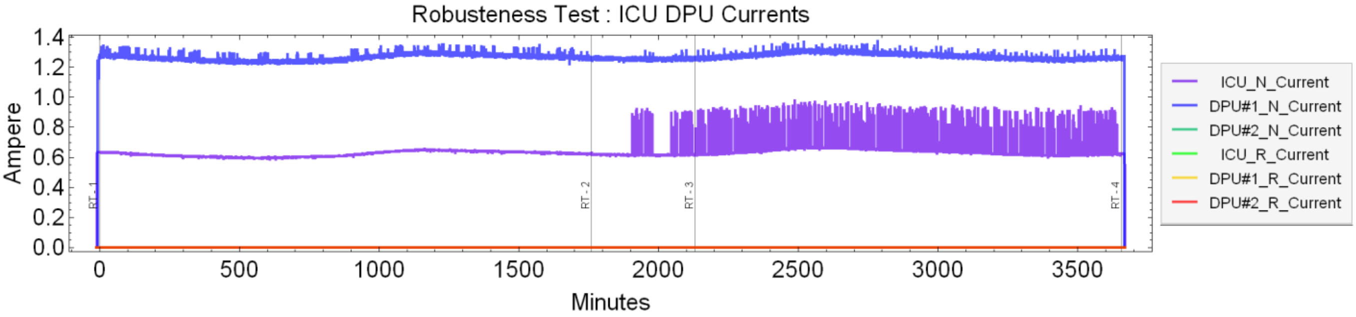


Figure 5.58: ICU and DPU currents as seen by the SCOE power supply are shown, both Robustness tests are displayed. The DPU current is stable along the test, the ICU current is substantially increased every time that a FWA/GWA rotation is issued.

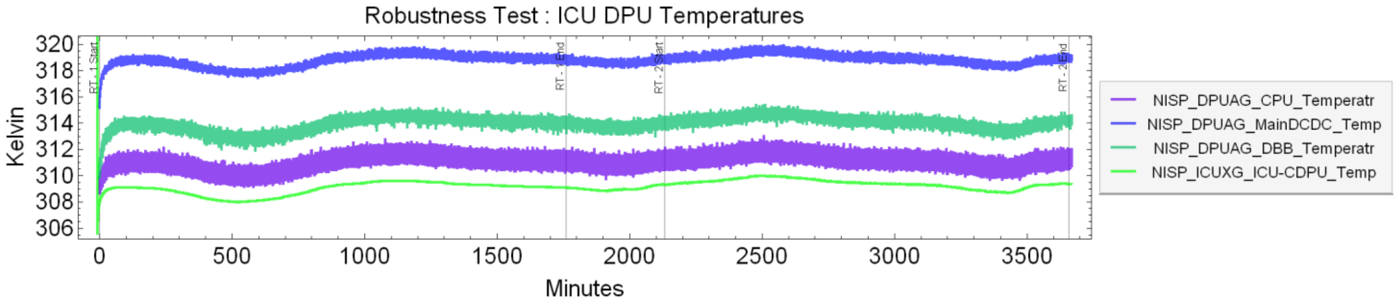


Figure 5.59: ICU and DPU temperatures in a three days operation are shown. They do not show anomalies, the DPU is 10° hotter than the ICU. A night-day cycle is visible.

The amount of science data produced during the tests and sent to the SCOE Spacewire logger is reported in Table 5.3 together with the errors detected by the SCOE on that link.

TEST	Spacewire Link	# Packets	# Bytes	ERRORS
SFT	Nominal	2398	157145736	0
SFT	Redundant	161	10550652	0
FFT	Nominal	106	7208520	1 (DPU Reboot)
RbT 1	Nominal	157440	1.0318×10^{10}	0
RbT 2	Nominal	29371	1.92486×10^{9}	0

Table 5.3: Spacewire traffic data budget. No errors were reported in the Spacewire transmission, the only one occurred during a DPU reboot operation. The reboot was commanded on purpose by TC and the Spacewire link was automatically restarted by the DPU ASW after the start-up phase.

DPU can be programmed to produce uncompressed science data and the wait time between each dither was tuned to match a target data volume. The scientific data flow produced during RbT-1 is about 1.83 GB/day which scales to 29 GB/day in case of the full focal plane (see Figure 5.60).

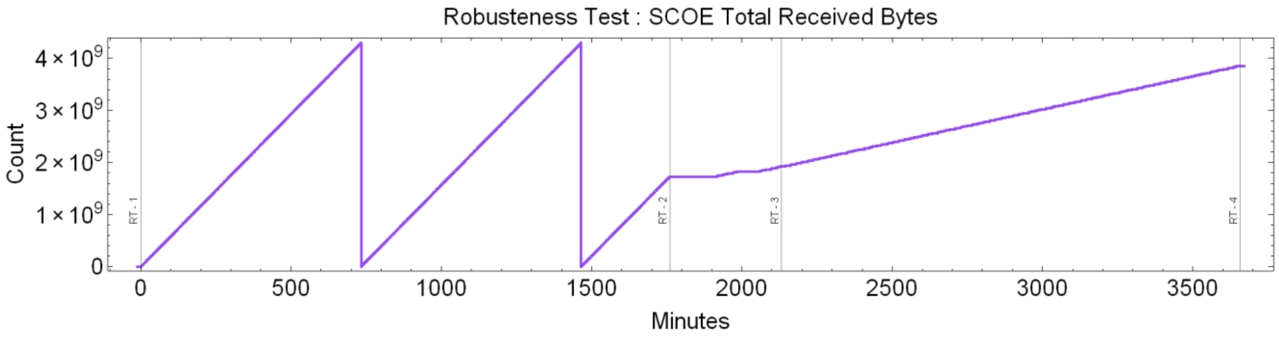


Figure 5.60: Integrated bytes transferred to the SCOE Spacewire Logger during the Robustness Test.

The NISP AVM test campaign was considered successful after the completion of SFT, FFT and Robustness Tests.

The NISP AVM model and the Test Environment composed by: ICU and DPU SWs, MIB, test sequences and related configuration files were declared compliant to the requirements and delivered to TAS-I for further integration with the Euclid satellite.

Conclusions

Warm Electronics AIV/AIT for the NISP AVM model was successfully performed. The two units, ICU and DPU, were tested at unit level and integrated in the test environment reproducing the electronic interfaces of the spacecraft.

As chapter 4 reports in detail, the DPU AIV/AIT activity at unit level ended in Fall 2017; OHB-I delivered the DPU EQM model to the NISP Italian team and launched the production of the DPU FM units.

DPU/DCU unit tests demonstrated that its performance is appropriate for the Euclid mission; all the basic functions, reported in Table 4.2 were verified; in particular, infrared detectors can be controlled effectively and on-board data processing can be completed in the allocated time with the demanding requirement concerning the DPU/DCU dither duration being met.

The software tools and simulators specifically designed for this task were appropriate and are currently in use for DPU FM models debugging and validation. The DPU ASW 1553 TM/TC interface was tested and the possibility to issue Telecommands and retrieve digital Telemetries and Housekeepings with a cyclical bus profile was fully verified and debugged.

The validation of 1553 TM/TC interface was essential to ensure the integration, of DPU and ICU units, that followed the unit tests. The integration performed in the NISP AVM model started in December 2017 at the University & INFN Padua (see all the steps in chapter 5).

The NISP AVM test campaign consists of sets of atomic tests aiming to verify all functions of ICU and DPU units. In these tests the TM/TC interface with the Euclid Service Module is tested and the nominal scientific data flow is reproduced.

Our group's task was to code the scripts, run the tests, and verify the results. Additionally, the scripts were developed according to the framework used in TAS-I to simplify their reproduction of the results.

The test campaign not only demonstrated that the instrument design is good and the on-board software is at a mature level of development, but also drove the on-board software developers, and sometimes the hardware suppliers, through the process of integration and to the fulfilment of the objectives of the NISP avionic model: it was verified that it is able to fulfil mission requirements and is ready for the integration with the spacecraft.

A Robustness Test, consisting of a Nominal Survey simulation, was performed at the end of the test campaign to verify the long-term stability of NISP AVM. The test provided a realistic simulation of the NISP operation and is the first ever completed. Chapter 5 presents several results from the data studied in great detail. Even if the NISP AVM is equipped with only one DCU, the time-line is representative of the full NISP because data taking is simultaneous for all eight detectors in the focal plane and although the data processing is performed serially the total processing time can be scaled to eight detectors.

We produced a detailed time-line of a Nominal Survey and those data will be very valuable for the Euclid Service Module test campaign. A consistent set of telemetries was gathered and the critical parameters of NISP sub-systems were saved as reference for further tests.

Figure C.1 illustrates that dither time, including the time required for on-board data processing and transmission to MMU simulator, has a repeatability of less than 2 seconds, which is in line with the 1 second granularity induced by the 1553 TM/TC interface.

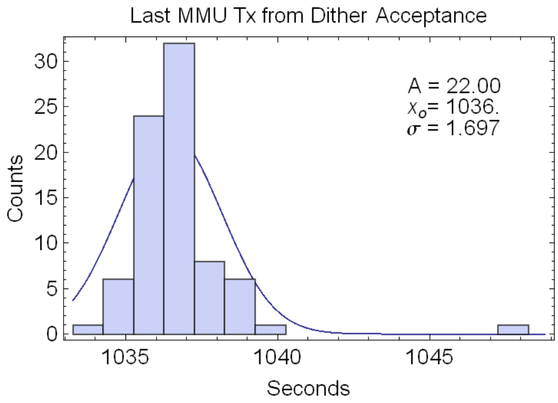


Figure C.1: Single dither duration as evaluated in the Nominal Survey Simulation.

Dither time length is consistent with expectations: scaling the data processing time to the full focal plane, results in a value below 600 s, shorter than the exposure time in one dither. This result is a strong indication that NISP can be compliant with the top level requirement on the duration of a single dither.

The AVM model proved to be adequate even with some functionalities missing. Both ICU and DPU on-board software were not fully developed at the time of the NISP AVM Tests. The procedures for Fault Detection Isolation and Recovery (FDIR) and the error handling strategy were not tested in June 2018. Completion, test, and validation took place in Fall 2018.

The NISP AIV is now moving on to the next step in the plan. The NISP EM will be tested under vacuum at cold operating temperatures. The purpose will be to verify the functional behaviour of NISP at cold operating temperatures and to prepare the full NISP performance test for the Flight Model.

Appendix A

Table A.1: APID and Services managed by pus2dpu (Telecommands section).

Managed Services			
Equipment	**APID**	**Service TYPE and SUBTYPE**	**Description**
PUS2DPU	1280	8,1 17,1	Perform Function Connection Test
DPUANOM (ASW) **DPUBNOM (ASW)** **DPUARED (ASW)** **DPUBRED (ASW)**	1281 1282 1283 1284	8,1 6,2 6,5	Perform Function Memory Load Memory Dump
DPUBROADCAST (ASW)	1285	8,1	Perform Function
DPUANOM (BSW) **DPUBNOM (BSW)** **DPUARED (BSW)** **DPUBRED (BSW)**	1391 1392 1393 1394	8,1	Perform Function
DPUBROADCAST (BSW)	1395	8,1	Perform Function

Table A.2 Managed APID and services (TM). It has to be noted that DPU ASW provides only telecommand acceptance report (1,1) while the DPU BSW provides telecommand acceptance and execution report (1,1) +(1,7).

Equipment	APID	Service TYPE, SUBTYPE	Description
PUS2DPU	1280	1,1 1,2 1,7 1,8	Acceptance Success Acceptance Failure Execution Success Execution Failure
DPUANOM (ASW) **DPUBNOM (ASW)** **DPUARED (ASW)** **DPUBRED (ASW)**	1281 1282 1283 1284	1,1 5,1 5,2	Acceptance Success Event Reporting: Progress Event Reporting: Warning
DPUBROADCAST (ASW)	1285	1,1 1,2	Acceptance Success Acceptance Failure
DPUANOM (BSW) **DPUBNOM (BSW)** **DPUARED (BSW)** **DPUBRED (BSW)**	1391 1392 1393 1394	1,1 1,2 1,7 1,8 3,25 5,1 5,2	Acceptance Success Acceptance Failure Execution Success Execution Failure Periodic Telemetries Event Reporting: Progress Event Reporting: Warning
DPUBROADCAST (BSW)	1395	1,1 1,2 1,7 1,8	Acceptance Success Acceptance Failure Execution Success Execution Failure

Table A.3: ICU DPU MILBUS1553 schedule profile

FRAME	**1st message**	**Data type**	**SubAddress**	**Comment**
0	synch without data	Sync mark		OBT obtained in the Frame 35 of the previous cycle
1	synch with data #1			
2	synch with data #2	DPU1_CPU1 ASW LMLoad	Rx 1 ÷ 16	Large memory load
3	synch with data #3	DPU1_CPU2 ASW LMLoad	Rx 1 ÷ 16	Large memory load
4	synch with data #4	DPU2_CPU3 ASW LMLoad	Rx 1 ÷ 16	Large memory load
5	synch with data #5	DPU2_CPU4 ASW LMload	Rx 1 ÷ 16	Large memory load
6	synch with data #6			
7	synch with data #7	DPU1_CPU1 ASW CMD ASW PROC_PARAM ASW SYS_CONF ASW DITH_CONF	Rx 18	Command Tables Configuration Tables
8	synch with data #8	DPU1_CPU2 ASW CMD ASW PROC_PARAM ASW SYS_CONF ASW DITH_CONF	Rx 18	Command Tables Configuration Tables
9	synch with data #9	DPU2_CPU3 ASW CMD ASW PROC_PARAM ASW SYS_CONF ASW DITH_CONF	Rx 18	Command Tables Configuration Tables
10	synch with data #10	DPU2_CPU4 ASW CMD ASW PROC_PARAM	Rx 18	Command Tables Configuration Tables

		ASW SYS_CONF ASW DITH_CONF		
11	synch with data #11			
20	synch with data #20			
21	synch with data #21	DPU1_CPU1 ASW CMD Verification	Tx 17	Command verification
22	synch with data #22	DPU1_CPU2 ASW CMD Verification	Tx 17	Command verification
23	synch with data #23	DPU2_CPU3 ASW CMD Verification	Tx 17	Command verification
24	synch with data #24	DPU2_CPU4 ASW CMD Verification	Tx 17	Command verification
25	synch with data #25			
34	synch with data #34			
35	synch with data #35	Broadcast Time Distribution to DPU#1 and DPU#2. Copy of OBT at last synchronization.	Rx 29 Tx 29	Time distribution package. Copy of time at last synchronization
36	synch with data #36			
…				
39	synch with data #39			
40	synch with data #40	DPU1_CPU1 DPU_MONITOR_TAB DPU_STATUS_TAB ASW _DPU_HSK_TAB ASW_ERROR_TAB	Tx 21 Tx 18 Tx 23 Tx 20	DPU ASW periodic digital telemetry and DPU PSB HouseKeeping
41	synch with data #41	DPU1_CPU2 DPU_MONITOR_TAB DPU_STATUS_TAB ASW _DPU_HSK_TAB	Tx 21 Tx 18 Tx 23	DPU ASW periodic digital telemetry and DPU PSB HouseKeeping

		ASW_ERROR_TAB	Tx 20	
42	synch with data #42	DPU2_CPU3 DPU_MONITOR_TAB DPU_STATUS_TAB ASW _DPU_HSK_TAB ASW_ERROR_TAB	Tx 21 Tx 18 Tx 23 Tx 20	DPU ASW periodic digital telemetry and DPU PSB HouseKeeping
43	synch with data #43	DPU2_CPU4 DPU_MONITOR_TAB DPU_STATUS_TAB ASW _DPU_HSK_TAB ASW_ERROR_TAB	Tx 21 Tx 18 Tx 23 Tx 20	DPU ASW periodic digital telemetry and DPU PSB HouseKeeping
44	synch with data #44	DPU1_CPU1 ASW_DCU_HSK_TAB ASW SCE_HSK_TAB	Tx 1 ÷ 8 Tx 9 ÷ 16	Housekeeping allocating SA from 1 to 16
45	synch with data #45	DPU1_CPU2 ASW_DCU_HSK_TAB ASW SCE_HSK_TAB	Tx 1 ÷ 8 Tx 9 ÷ 16	Housekeeping allocating SA from 1 to 16
46	synch with data #46	DPU2_CPU3 ASW_DCU_HSK_TAB ASW SCE_HSK_TAB	Tx 1 ÷ 8 Tx 9 ÷ 16	Housekeeping allocating SA from 1 to 16
47	synch with data #47	DPU2_CPU4 ASW_DCU_HSK_TAB ASW SCE_HSK_TAB	Tx 1 ÷ 8 Tx 9 ÷ 16	Housekeeping allocating SA from 1 to 16
48	synch with data #48	DPU1_CPU1 ASW MEM_DUMP_TAB	Tx 1 ÷ 16	Large memory dump
49	synch with data #49	DPU1_CPU2 ASW MEM_DUMP_TAB	Tx 1 ÷ 16	Large memory dump
50	synch with data #50	DPU2_CPU3 ASW MEM_DUMP_TAB	Tx 1 ÷ 16	Large memory dump
51	synch with data #51	DPU2_CPU4 ASW MEM_DUMP_TAB	Tx 1 ÷ 16	Large memory dump
52	synch with data #52			
55	synch with data #55			
56	synch with data	DPU1_CPU1		

	#56	DBB_DRB_STATUS_TAB	Tx 22	
57	synch with data #57	DPU1_CPU2 DBB_DRB_STATUS_TAB	Tx 22	
58	synch with data #58	DPU2_CPU3 DBB_DRB_STATUS_TAB	Tx 22	
59	synch with data #59	DPU2_CPU4 DBB_DRB_STATUS_TAB	Tx 22	

Table A.4: DPU/DCU monitored parameters and allowed ranges. The parameter name is taken as is from the EGSE MIB. Telemetries indicated with DCU# are checked for all the 8 DCUs, the MIB name in this table is the one of DCU1.

MIB Mnemonics	Monitored Parameter	Allowed ranges	Remarks
NAST0022	CPU 5.0V input Voltage	5.0V +/- 10%	
NAST0021	CPU 3.3V input Voltage	3.3V +/- 10%	
NAST0024	DRB input Voltage	5.0V +/- 10%	
NAST0023	DBB input Voltage	5.0V +/- 10%	
NAST0026	CPU 5.0V input Current	0.08A to 0.85A	
NAST0025	CPU 3.3V input Current	2.8A to 4.2A	Full range is 0 to 8.0A
NAST0028	DRB input Current	0.25A to 0.35A	Full range is 0 to 0.5A
NAST0027	DBB input Current	1.4A to 1.6A	Full range is 0 to 2.0A
NAST0029	DCU1 5.0V input Voltage	5.0V +/- 10%	
NAST0030	DCU2 5.0V input Voltage	5.0V +/- 10%	
NAST0031	DCU3 5.0V input Voltage	5.0V +/- 10%	
NAST0032	DCU4 5.0V input Voltage	5.0V +/- 10%	
NAST0033	DCU5 5.0V input Voltage	5.0V +/- 10%	
NAST0034	DCU6 5.0V input Voltage	5.0V +/- 10%	
NAST0035	DCU7 5.0V input Voltage	5.0V +/- 10%	
NAST0036	DCU8 5.0V input Voltage	5.0V +/- 10%	
NAST0037	DCU1 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0038	DCU2 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0039	DCU3 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0040	DCU4 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0041	DCU5 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0042	DCU6 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0043	DCU7 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0044	DCU8 5.0V input Current	0.2A to 0.32A	Full range is 0 to 0.5A
NAST0073	DCU# VDDA output Voltage	3.135 V to 3.465 V	
NAST0067	DCU# VDDA driver Voltage	3.135 V to 3.465 V	
NAST0069	DCU# Vref output Voltage	3.267 V to 3.333 V	
NAST0060	DCU# 3V3D output	3.135 V to 3.465 V	

	Voltage		
NAST0061	DCU# 2V5D output Voltage	2.375 V to 2.625 V	
NAST0062	DCU# VDDIO output Voltage	1.592 V to 1.708 V	
NAST0063	DCU# VSSIO output Voltage	0.852 V to 0.948 V	
NAST0068	DCU# VDDA output Current	< 80mA	Full range is 0 to 0.265A
NAST0070	DCU# Vref output Current	0.03mA to 0.3mA	Full range is 0 to 0.005A
NAST0064	DCU# 3V3D output Current	< 10mA	Full range is 0 to 0.165A
NAST1100	DCU# 2V5D output Current	< 36mA	Full range is 0 to 0.165A
NAST0065	DCU# VDDIO output Current	< 50mA	Full range is 0 to 0.165A
NAST0046	Main DC/DC temperature	19°C to 65°C	
NAST0045	CPU temperature	19°C to 65°C	
NAST0047	DBB temperature	19°C to 65°C	
NAST0066	DCU1 FPGA Temperature	19°C to 65°C	
NAST0091	DCU2 FPGA Temperature	19°C to 65°C	
NAST0116	DCU3 FPGA Temperature	19°C to 65°C	
NAST0141	DCU4 FPGA Temperature	19°C to 65°C	
NAST0166	DCU5 FPGA Temperature	19°C to 65°C	
NAST0191	DCU6 FPGA Temperature	19°C to 65°C	
NAST0216	DCU7 FPGA Temperature	19°C to 65°C	
NAST0241	DCU8 FPGA Temperature	19°C to 65°C	

Table A.5: PUS services implemented in the SVM to ICU interface for TM and TC handling. Different Services are highlighted with different colours in the Table and TMs are grouped with corresponding TCs.

Software	**TC Service**	**TM Service**
ICU BSW /ASW	All Types	TM(1,1)/TM(1,2) is generated on acceptance/rejection of a command TM(1,7)/TM(1,8) is generated on successful/unsuccessful execution of a command
ICU BSW / ASW		TM(5,1) Normal progress Report
ICU BSW / ASW		TM(5,2) Low severity error Report
ICU BSW / ASW		TM(5,3) Medium severity error Report
ICU BSW / ASW		TM(5,4) High severity error Report
ICU BSW / ASW	TC(5,5) Enable Event Report Generation	
ICU BSW /ASW	TC(5,6) Disable Event Report Generation	
ICU BSW / ASW	TC(6,2)Load Memory	
ICU BSW / ASW	TC(6,5)Dump Memory	TM(6,6) Dump packets
ICU BSW / ASW	TC(6,9)Check Memory	TM(6,10) Memory check report
ICU ASW	TC(8,1) Perform function	
ICU BSW	TC(8,201) Load ASW	
ICU BSW	TC(8,202) Start ASW	No TM(1,7)/TM(1,8) is expected
ICU BSW	TC(17,1) Connection Check	
ICU ASW	TC(3,1) Define New HK Parameter Report	
ICU ASW	TC(3,2) Define New Diagnostic Parameter Report	
ICU ASW	TC(3,3) Clear HK Parameter Report Definitions	

ICU ASW	TC(3,4) Clear Dignostic Report Definitions	
ICU ASW	TC(3,5) Enable HK Parameter Report	
ICU ASW	TC(3,6) Disable HK Parameter Report	
ICU ASW	TC(3,7) Enable Diagnostic Parameter Report Generation	
ICU ASW	TC(3,8) Disable Diagnostic Parameter Report Generation	
ICU ASW	TC(3,9) Report HK Parameter Definitions	TM(3,10) HK Parameter Definitions Report
ICU ASW	TC(3,10) Report Diagnostic Parameter Definitions	TM(3,11) Diagnostic Parameter Definitions Report
ICU ASW/BSW		TM(3,25) HK Parameter Report
ICU ASW		TM(3,26) Dignostic Parameter Report
ICU ASW	TC(3,130) Modify HK generation frequency	
ICU ASW	TC(3,131) Modify diagnostic generation frequency	
ICU ASW	TC(3,135) Report enabled HK packets	TM(3,136) Enabled HK Packets Report
ICU ASW	TC(3,137) Report enable Diagnostic packets	TM(3,138) Enabled Diagnostic Packets Report
ICU ASW	TC(3,140) One shot HK packet generation request	
ICU ASW	TC(3,141) One shot diagnostic packet generation request	

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