POLITECNICO DI TORINO

Master's Degree Course in Mechatronics Engineering

Master's Degree Thesis

Integrated Subsystem Test on Fine Guidance Sensor (FGS) unit of ESA's EUCLID mission

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Abstract

EUCLID is an ESA mission intended to investigate dark energy by measuring the redshift of distant galaxies with an unprecedented accuracy. This will help physicists and astronomers to better understand the origin of our universe. One of the main characteristics of EUCLID spacecraft is its attitude control capabilities, as they need to be very precise to perform the scientific measurements. The units that give EUCLID this characteristic are part of the AOCS (Attitude and Orbital Control Systems), being one of them the Fine Guidance Sensor (FGS). FGS is composed of two main elements: Electronic Unit (EU) and two PEMs (Proximity Electronics Module). FGS Electronic Unit is intended to communicate with the spacecraft onboard computer (CDMU), execute procedures of image processing, manage the internal modes by use of the Application Software (ASW) and Startup Software (SUSW), manage the power supplies for PEMs and compute attitude of the spacecraft given the data coming from detectors. As part of the final stage of development and construction of this satellite, a set of test campaigns need to be done in order to validate and guarantee the correct functioning of the units, subsystems and systems. The ISST (Integrated Sub System Test) is a test that allows a broad but deep verification of the functionalities offered by the unit. The main scope of the thesis is to develop and perform an entire ISST on FGS EU to verify that a set of representative functionalities fulfill the requirements set at the design stage of the EUCLID project. The required specifications are given by Engineering Department of Thales Alenia Space Italy and are the basis of the test procedure developed in this thesis.

Acknowledgements

Es increíble cómo va pasando el tiempo y cómo cambia el entorno esos diferentes períodos. A pesar de esta gran variabilidad, la constante ha sido siempre el apoyo y cariño de la gente en cada etapa.

Quiero expresar mi profundo agradecimiento a todos aquellos que han formado parte de este largo pero divertido camino: a mis padres, a mi hermana Leslie, mis abuelas Clara y Haydee, a mi familia en general. A mis amigos de la UC, de la Escuela Popular, a los internacionales, a los profesores en Chile, en Rusia e Italia y a los no amigos. Todos ustedes han sido indispensables para poder crecer como persona, como profesional y para llegar a este punto.

Una parte importante para mí también es reconocer y agradecer la confianza que los colegas de Thales Alenia Space han depositado en mí para hacerme cargo de esta unidad (FGS, Sensor de Guía Fina) prácticamente en su totalidad. No sólo me cedieron esas responsabilidades, también se encargaron amablemente de responder todas mis preguntas. Me han dado la oportunidad de crecer como ingeniero y como persona en un proyecto de ciencias de gran escala de la Age ncia Espacial Europea: EUCLID. Poco a poco el sueño de convertirme en astronauta en el futuro parece ser más real, y definitivamente enfrentarme a este tipo de responsabilidades me da herramientas que podrán ser útiles en el espacio.

Con esta tesis culmina mi camino a convertirme oficialmente en Ingeniero en Chile e Italia. Desafíos seguirán apareciendo en el futuro, y sé que puedo contar con el apoyo de quienes aparezcan en en el camino y de los que ya han estado conmigo anteriormente.

Son unos grandes, ¡gracias!
Sebasthian Alejandro Ogalde Castro

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1 Introduction

1.1 EUCLID Program Overview

The universe as we understand it found its origins on the Big Bang. In the first instants the mass distribution was homogeneous. The big question is how the Universe ended up having the structure it has in our epoch: a complex assembly of galaxies, clusters and superclusters. By now, the theory that supports these conditions consists in two assumptions: two dominant components that form nearly the 96% of the energy density of the universe. The first one is the **dark energy** (76%), causing the accelerated expansion of the universe; and **dark matter** (20%), which has the same effects in gravity as normal matter, but does not emit or absorb light.

EUCLID is an ESA mission intended to measure with an unprecedented accuracy the redshift of distant galaxies. This will help physicists and astronomers to investigate dark energy.

One of the main characteristics of EUCLID spacecraft is its attitude control capabilities, as they need to be very precise to perform the mission scientific measurement.

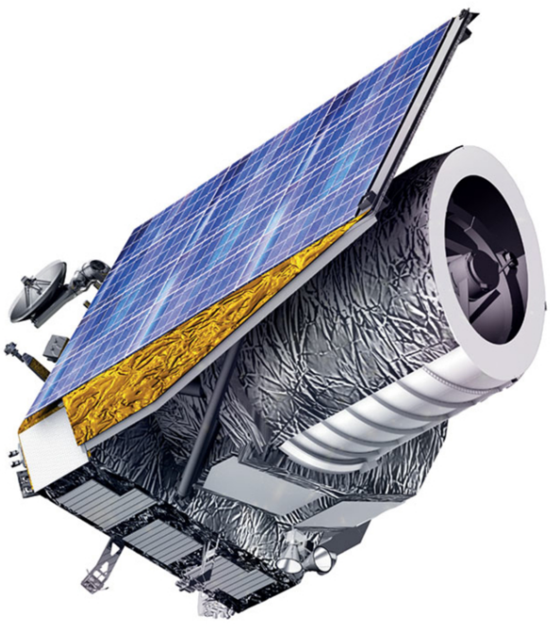

Figure 1: Euclid Spacecraft. 3D Model

As per the Definition Study Report, we find the following Scientific Objectives to **understand the nature of Dark Energy and Dark Matter**

1. Reach a dark energy Figure of Merit >400 using only weak lensing and galaxy

clusteing; this roughly corresponds to 1 sigma errors on w_p and w_a of 0.02 and 0.1, respectively.

2. Measure γ, the exponent of the growth factor, with a 1 sigma precision of <0.02, sufficient to distinguish General Relativity and a wide range of modified-gravity theories.

3. Test the Cold Dark Matter paradigm for hierarchical structure formation, and measure the sum of the neutrino masses with a 1 sigma precision better than 0.03eV.

4. Constrain n_s, the spectral index of primordial power spectrum, to percent accuracy when combined with Planck, and to probe inflation models by masuring the non-Gaussianity of initial conditions parametrised by f_{NL} to a 1 sigma precision of ≈ 2.

The surveys that are going to be performed by Euclid are divided into two different approaches: Wide Survey and Deep Survey. The first one covers an area of 15000 deg^2 and consists in a step and stare with 4 dither pointings per step. On the other hand, the Deep Survey covers tinier area (40deg^2), divided in at least 2 patches of >10deg^2 and 2 magnitudes deeper than the wide survey.

Euclid will have a payload with instruments that allows it to survey the universe in visible and near infrared spectrum:

- Telescope: 1.2m Korsch, 3 mirror anastigmat, f=24.5m
- Visual Instrument (VIS): Visual Imaging, 550-900nm. Sensitivity 24.5 mag. Detector: 36 arrats 4k x 4k CCD. Pixel Size: 0.1 arcsec.
- Near Infrared Photometry (NISP): 16 arrays of 2k $\times$ 2k NIR sensitive HgCdTe detectors.
  - NIR Imaging Photometry. Wavelength ranges: Y (920-1146 nm), J (1146-1372 nm) and H (1372-2000nm). Sensitivity 24 mag.
  - NIR Spectroscopy. Wavelength range: 1100-2000 nm. Sensitivity $3 \cdot 10^{-16}$ erg cm-2 s-1.

Euclid's mission will have a nominal duration of 7 years, and it is planned to be launched on 2022 from Kourou (French Guiana) mounted on a Soyuz ST-2.1 B rocket.

1.2 Testing and Integration

The main objective of this thesis is to perform a full **Integrated Sub-system Test (ISST)** of FGS EU, which corresponds to a complete verification of the functionalities of the unit. Since a good knowledge about the operations of the unit under testing, a detailed description of all the relevant functions will be given in the next chapters.

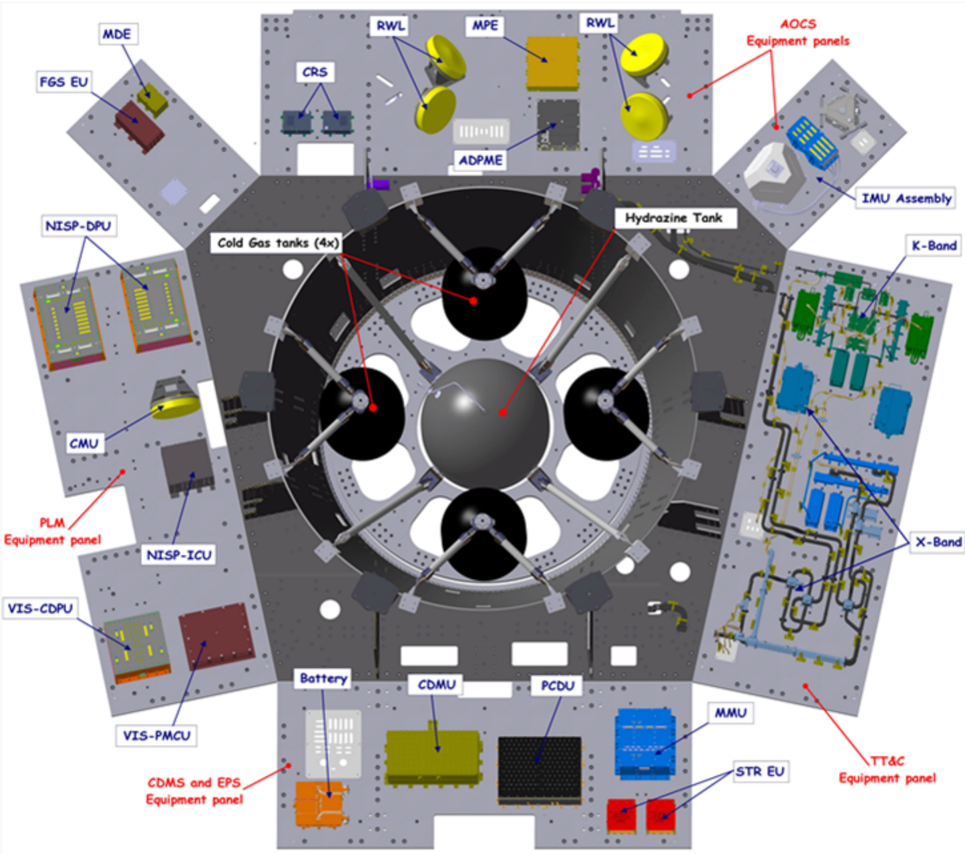

Figure 2: Euclid Overview

2 Unit Description

2.1 Fine Guidance Sensor (FGS)

The Fine Guidance Sensor is a unit that belongs to the AOCS Subsystem, and manufactured by Leonardo Airborne & Space Systems (LDO) and CRISA. It is composed by two main parts: **FGS Electronic Unit (EU)** and **FGS Proximity Electronics Module (PEM)**.

FGS is an "hybrid" unit because it belongs to the PLM (Payload Module), where the Electronic Unit (EU) and the warm electronics are; and to the SVM (Service Module), where the PEM is located together with the CCDs (FPA) (cold electronics).

2.1.1 FGS Electronic Unit (EU)

FGS EU is intended to communicate with the spacecraft onboard computer (CDMU), execute procedures of image processing, manage the internal modes by use of the Application Software (ASW) and Startup Software (SUSW), manage the power supplies for PEMs (Proximity Electronics Modules) and compute attitude of the spacecraft given the data coming from detectors.

It is composed by two identical sections: EU Nominal (FGS EU Section A) and EU Redundant (FGS EU Section B). This redundancy is to maintain reliability in both processing and power sections.

FGS EU has four modules in total inside connected between them:

- **PM (Processing Module) A & B**: offers processing power to analyze and reduce the images captured by PECs and performs control of the unit itself. It is based on a SoC device with a LEON-2 FT processor @ 80MHz.
- **PDM (Power Distribution Module) A & B**: offers proper power supplies for the two PECs of both of PEMs. PDM can operate in any redundancy scheme: off, cold and hot depending of the commanding of the PM. This means that it can the powered and controlled from each of both FGS sections independently, assuring the complete commandability.

In figure 3 the electrical architecture of FGS is depicted.

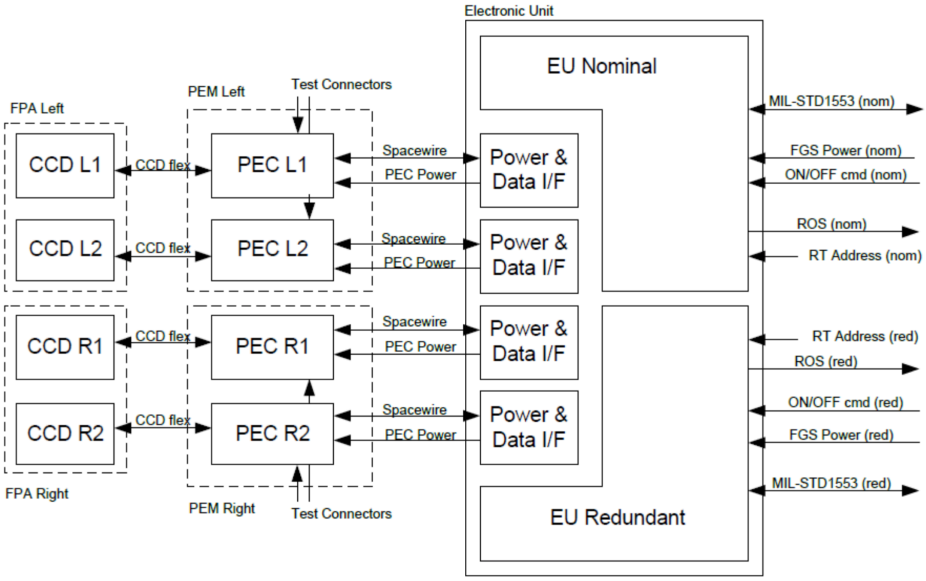

Figure 3: FGS Electronic Architecture (from [6])

2.1.2 FGS Proximity Electronics Module (PEM)

PEM (Proximity Electronics Unit) is a device that integrates the processing part and the CCD detectors. FGS System includes two PEMs. Each PEM includes two channels (PEC - Proximity Electronics Channel), each one interfacing a CCD. The PEMs also includes the mount and the harness of the CCDs, which is called Focal Plane Assembly (FPA)

PEMs are powered from the Electronic Unit. The data link between them follows the SpaceWire standard. In Figure 4 one of the PEMs is depicted with FPA mounted.

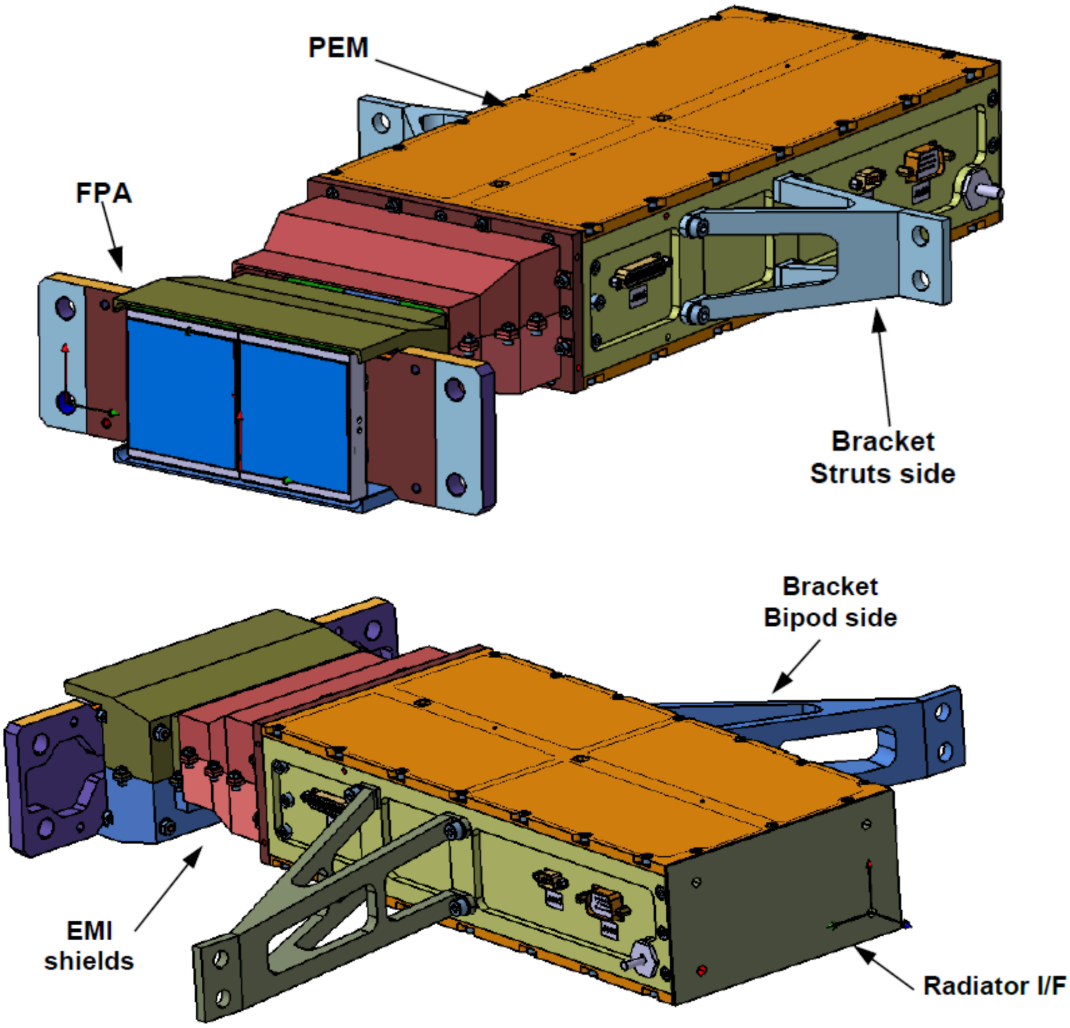

Figure 4: PEM Assembly

2.2 FGS Startup Software (SUSW or BSW)

The FGS Startup Software (or Basic Software), developed by CRISA, corresponds to the initial software that is entered to by FGS EU at power on or at a hard reset from SUSW itself or ASW. It is designed to perform basic functions, for example: perform memory checks and reads, load the Application Software at the unit's RAM and jumping to it. It has two modes: Init Mode and Maintenance Mode. The checks performed by the unit before entering Init Mode are:

1. At startup FGS will try to start with the first SUSW Image available in the memory bank. If this fails, the default reset by watchdog will be triggered and the unit will try autonomously to start from the redundant copy of SUSW.

2. If the execution is successful, communication through Milbus 1553 will be available and a Boot Report telemetry packet will be send to troubleshoot the failure.

3. In case of a second reset by watchdog triggered by the redundant copy, FGS EU will set the RoS (Report of Startup) pin to a logical HIGH to signal this event to the onboard computer.
4. Further attempts will be done with the redundant copy of the SUSW, while the RoS is maintained in HIGH state. This state will be kept until the power is shut down.

2.2.1 Init Mode (INI)

Init Mode is the first mode that is entered to, immediately after powering on the unit and having performed the general Health Check. Allows to Load and Jump to the Application Software (ASW) and change to Maintenance Mode to perform memory operations and checks.

2.2.2 Maintenance Mode (MNM)

Maintenance mode can be entered from Init Mode. It allows to perform operations in ASW Memory Sections and the unit's RAM. This includes also the possibility to re-write entire ASW Images, settable parameters and table of Hot Pixels / Bad Columns (HP/BC) found in the CCDs while PECs are in StandBy.

2.3 FGS Application Software (ASW)

FGS Application Software is the program that FGS EU runs when performing all the operations FGS was designed for. Among them are: relative and absolute tracking, image capturing and health check capabilities. Figure 5 depicts the complete state machine of FGS SUSW and ASW.

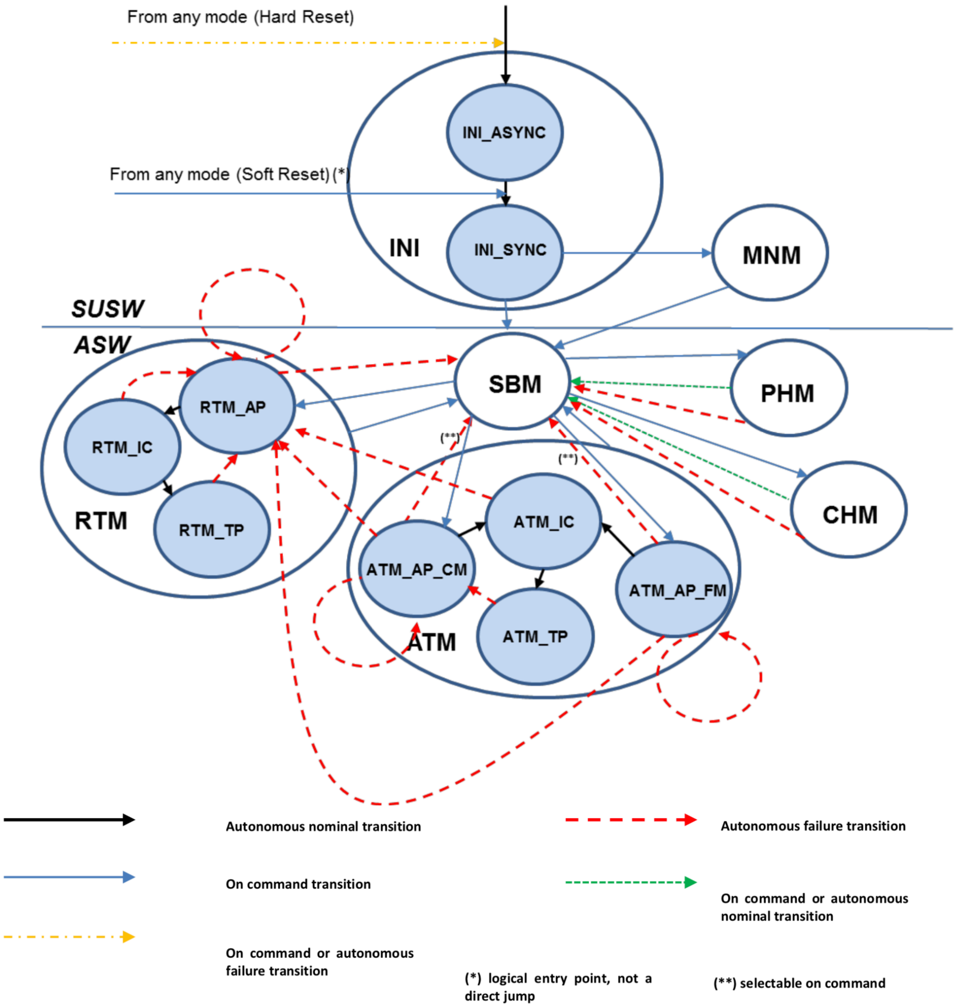

Figure 5: FGS SUSW and ASW states and transitions (from [5])

- **SBM (Standby Mode)**: it is the initial mode after jumping and loading the ASW. It allows to jump onto other states and to perform general health check operations on the electronic unit and the PECs.
- **PHM (Photo Mode)**: FGS EU has the functionality of capturing pictures using PEMs CCDs with variable gain, integration time, and windowing options.
- **CHM (Checkout Mode)**: in order to verify the proper functioning of the entire chain of data of FGS, there are special modes that allow to generate dummy data

from different parts of the unit. Since this data is known beforehand, it is possible to determine where an error is by cross-checking the received information on Ground.

- **RTM (Relative Tracking Mode)**: to perform tracking relative to the first locked position/pattern of stars. The quaternion is given as a delta of angular position with respect of the first quaternion.
- **ATM (Absolute Tracking Mode)**: to perform tracking in absolute coordinates. For this mode to work correctly, it is necessary to have a previously loaded catalog in FGS EU. This is the main functionality of FGS. The quaternion determined by the unit is then given to AOCS to perform the corresponding actuation as a closed-loop system to stabilize the satellite. Stabilization is crucial when capturing science data.

2.3.1 PHM (Photo Mode)

The PECs can be used to perform acquisitions of the sky. A complete capture is composed of two steps: acquisition and download; and they need to be performed separately.

The acquisition phase is entered by sending a TC 180,3 to FGS EU with `PHM_SUBMODE=0`. The PEC to be used is also selectable in the TC 180,3. Regarding the CCD data, it can be acquired in Raw Format (direct pixels from the FPGA) or in RLE format, which is an option that allows the FPGA to compress the image by grouping adjacent pixels with the same value and reporting them only once and the quantity grouped. The CCD can also be readout in Window Mode (Raw or RLE pixel) and in Full Frame mode, which allows to download the entire CCD Image. Due to limitations on the memory of FGS EU, a Full Frame capture can be only done in RLE. The Application software will return autonomously to Standby Mode after finishing the acquisition.

The download phase is entered by sending a TC 180,3 to FGS EU with `PHM_SUBMODE=1`. When the FGS EU receives the TC, the download of the acquired image is done by sending the entire image and all its parameters inside telemetry packets 180,10 `Window Download`. Nominally (in flight conditions) the On-board Computer of the spacecraft (CDMU) will be listening to these telemetries before sending FGS to Download Mode by sending a TC 8,1 `Acquire Image`. The telemetries are going to be parsed and saved as a file in the Mass Memory Unit (MMU) of the spacecraft, ready to be sent to ground control when requested. In testing environment, the PLM SCOE is going to be used. In this case, the telemetries are received directly in CCS. The pixels can then be extracted from the TM history directly using CADET utility and parsing functions. The Application software will return autonomously to Standby Mode after the download of the image is finished.

2.3.2 RTM (Relative Tracking Mode)

In Relative Tracking Mode, FGS performs tracking relative to the first locked star pattern in acquisition phase. The received quaternion will be the delta of angular position with respect to the first valid calculated attitude. If the process goes well within the first try of every phase, a locked tracking will be available in less than 10s.

RTM is entered by sending a TC 180,1 to FGS EU, indicating the PECs that are going to be used. FGS ASW will enter first to RTM Acquisition Phase (RTM-AP). In RTM-AP the first attitude calculation is attempted by making an acquisition with the selected PECs. The corresponding CCDs are commanded to shot mode, full frame capture and default time exposure set to 1.5s (or INT_TIME_PEC_A[1|2] = time given in TC 180,1). This capture is to acquire an enough amount of stars for attitude calculation. If this condition is achieved, FGS ASW will generate a TM 3,26 SID=4 giving information about RTM phase, and enter to RTM Intermediate Phase (RTM-IC).

RTM-IC is entered automatically after successfully acquiring a minimum amount of stars for attitude calculation. Intermediate Phase is intended to validate the detected stars. This time CCDs are commanded to shot mode, but acquisitions are done in Window Mode (up to 10 windows of 100x100 pixels around detected stars). If the stars detected in RTM-AP are actually valid, FGS will enter to RTM Tracking Phase (RTM-TP). Otherwise, FGS will come back to RTM-AP to reattempt to get valid stars. As in RTM-AP a TM 3,26 SID=4 is generated with information about the RTM phase.

RTM-TP is the phase where FGS is actually performing tracking with locked stars, giving a relative attitude measurement every 2s (tracking cycle duration). CCDs are commanded to TV mode and acquisitions are made in Window Mode (up to 10 windows of 13x13 around detected stars). In every tracking cycle, a TM 3,26 SID=4 is generated with information about the RTM phase, including the determined relative quaternion. At the first tracking cycle, also a TM 3,26 SID=6 is generated with information about the position of the valid detected targets. If the amount of valid stars decay to less than the minimum needed, FGS automatically goes to RTM Acquisition Phase to retry to get valid targets.

2.3.3 ATM (Absolute Tracking Mode)

Since ATM mode is still not functional in FGS ASW, the description of it will be omitted.

2.3.4 CHM (Checkout Mode)

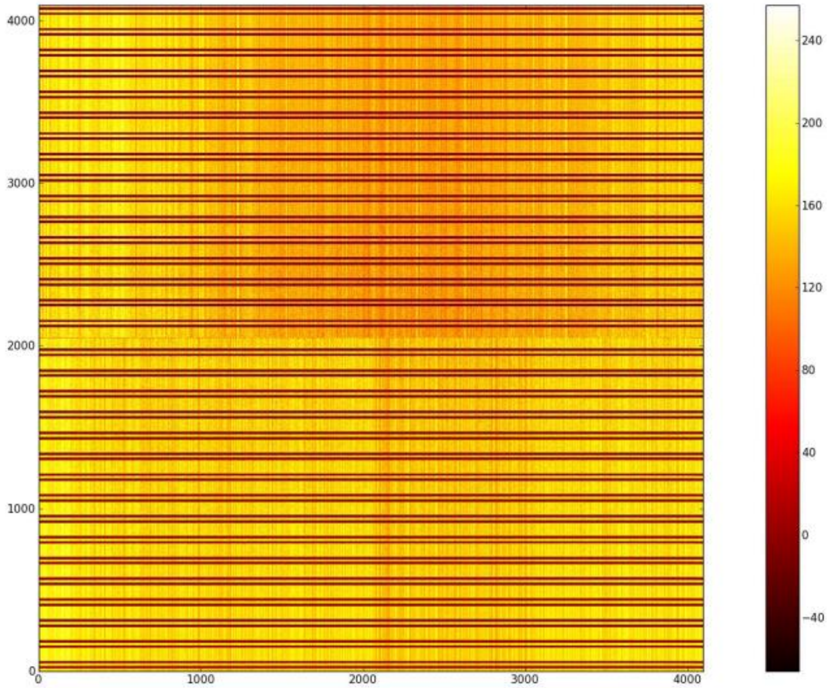

Figure 6: Charge Injection lines are present on every CCD of the PEMs to perform this test.

- **CHM-FT (Fixed Telemetry Mode)**: this mode allows to verify the interface between FGS EU and the onboard spacecraft computer (CDMU) in "stand-alone" configuration. When sent to CHM-FT, FGS EU generated a set of known, dummy telemetries (described in [5]) that serve to verify the correct transmission of data towards the on-board computer.

- **CHM-FS (Fixed Telemetry Mode, FPGA)**: this mode generates simulated patterns using the internal FPGA of the unit. The purpose is to verify the correct execution of the RLE algorithm and segment transmission through SpW. This is used to test the data interface between the PEC and FGS EU. The PEC used for this mode shall be turned on at the time of execution.

- **CHM-CI (Charge Injection Mode)**: charge injection lines are present on each CCD of the PEMs to inject charges at the center of the detectors. This generates a predefined pattern that can be downloaded and analyzed a posteriori. The pattern obtained is depicted on Figure 6.

3 Test Environment

In this section, a general overview of the test environment will be given. This is to understand how the test will take place, which instruments, hardware and software will be used.

3.1 Hardware

3.1.1 PLM SCOE

SCOE means **Special Check-out Equipment**. In general terms, it allows to simulate the whole environment with which a specific unit needs to function nominally. The PLM SCOE (Payload Module SCOE) offers the possibility to simulate the spacecraft communication and power interfaces. Therefore, it serves as a tester for all the units from the Payload Module: **VIS**, **NISP** and **FGS**.

Among all the capabilities of the PLM SCOE, the most important are

1. **Power:** 28V 10A. LCL interfaces and HV-HPC (high-voltage high-power commands), compliant with the design of the PCDU.
2. **Communication:** Milbus STD-1553B compliant communication interface, which is also compliant with Euclid specifications for the communication protocol. SpaceWire (SpW) communication interface towards simulated CDMU (not used for FGS EU).

3.1.2 ESG (Electrical Stimuli Generator)

ESG stands for **Electrical Stimuli Generator**. It is aimed to generate simulated skies according to the needs of the test. In our tests will be used to generate portions of the sky in real time to check the tracking capabilities of FGS. It can work as:

1. **Stimulator:** ESG can be connected directly the test connectors on PECs. By doing so, ESG will act as the CCD, overriding the data coming from the real sensor. In this mode, ESG sends all the data in the same format as the real sensor would.
2. **Simulator:** In this case, ESG acts as an entire PEC and it is connected to the Electronic Unit. By doing so, ESG sends data corresponding not only to the image generated but also telemetry data, as the real PEC would. When using ESG in simulator mode

3.2 Physical Environment

The premises used to perform these tests for FGS EU are TAS-I Turin clean room. The Spacecraft shall be maintained within the following environmental controlled conditions:

- Temperature: 19° to 25°C.
- Relative Humidity: 45% ± 65%.
- Delta Pressure: ≥1.2 mmH2O
- Cleanliness: class 8 as per STD ISO 14544-1 (ex. FED-STD-209E; i.e less than 100000 dust particles of 0.3 micron diameter per cubic foot).

All these parameters are monitored and recorded. In case of any anomaly found on these conditions, it must be reported and the test shall be stopped.

Some tests were performed in Airbus clean room in Toulouse, France. FGS EU had the same conditions as requested for TAS-I Turin, with the difference that the Flight Models of the PEMs were put on a separate place under more restrictive cleanliness conditions, equivalent to class 5.

3.3 Software

3.3.1 Tcl

The programming language used to write the Test Sequences is Tcl (Tool Command Language). Tcl is a scripting language and it was chosen by the CCS environment designers. It allows fast development of scripts and test sequences while keeping a simple syntax and a bundle of integrated functions. The integration with CCS also includes proprietary commands which allow to interact with the environment natively, for example: send telecommands to units, fetch telemetries in engineering or raw format value, etc.

3.3.2 Synoptics

Synoptics is a utility created by Euclid AIT Team, which allows the test executor to visualize relevant information of the unit in real time while testing it. It works essentially by reading the telemetries coming from the unit and refreshing onscreen widgets with this information.

For testing FGS EU and as part of the thesis work, two Synoptics were created that reflects the status of the unit in both ASW (same for both sections) and SUSW (FGS Section A and Section B). While both Synoptics show the same information for the FGS EU, they differ only in the Spacecraft interface used: SVM or PLM SCOE.

3.3.3 CADET

CADET is an utility created by Stefano Marchisio (TAS-I) in order to extract telemetries and telecommands of a given session received on ground. It allows to filter according to TMs or TCs, APID, SPID, services and subservices.

3.4 Communication Protocols

To understand how the communication goes in the satellite, we must first understand how the units are structured on it and how they are managed. The CDMS is “the core Service Module sub-system supporting data communication:

- with Ground, via TT&C
- among on-board, equipments, via MIL-STD-1553 and discrete lines;
- between Platform and Instruments, via MIL-STD-1553B and SpaceWire bus (SpW)” [4].

FGS EU uses Milbus STD1553-B protocol to communicate with the on-board computer, and SpaceWire protocol for the communication between the PEMs and FGS EU.

3.4.1 Milbus STD1553-B

Milbus STD1553-B is a military standard for the physical layer and protocol characteristics of a data bus. Its main characteristics are (as per [7]):

- Data rate: 1MHz
- Word length: 20 bits
- Data bits/word: 16 bits
- Message length: Maximum of 32 data words
- Transmission Technique: Half-duplex
- Operation: Asynchronous
- Encoding: Manchester II bi-phase
- Number of remote terminals: Maximum of 31.
- Terminal types: remote terminal, bus controller, bus monitor.
- Coupling: transformer and direct.
- Voltage Levels: 18.0-27.0V

In Euclid, there are two buses Milbus STD-1553B available [4]:

1. **Platform (PLF):** this bus is intended to handle all the communication between the CDMU and units or subsystems from Platform

- TT&C
- AOCS: from which also FGS EU is part. FGS EU performs all its communications under the PLF Bus as remote terminal 21 (for FGS Section A) and remote terminal 22 (for FGS Section B).
- Power

2. **Science (SCI):** this bus is dedicated to the handling of the communication between the scientific instruments and CDMU plus MMU.

    - MMU
    - VIS-CDPU
    - NISP-ICU

3.4.2 SpaceWire (SpW)

SpaceWire is a communication standard designed for use in space applications. Among its characteristics we can find "low-error rate, low-footprint, low-cost, low-latency, full-duplex, point-to-point serial links and wormhole switches" [8].

4 Tests description

As said in the beginning of this document, the main scope of the thesis is to perform functional tests on FGS EU to verify that a set of representative functionalities fulfill the requirements set at the design stage of the Euclid project. In this chapter, every test case will be described in general terms as per the required specifications given by Engineering Department of Thales Alenia Space Torino (as per [2]) for the unit, and then a description of the step-by-step implementation of the test is given, which corresponds to the scope of the work of this thesis. This procedure is written by me also as internal document of Thales Alenia Space in [3].

For all tests cases, a set of general success criteria apply. Those are:

- Expected FGS configurations: this means that FGS is found with the expected internal states that are described in the ICD of the SUSW/ASW for a certain mode or functionality.
- No TCs Rejection (except the expected ones): in general a TC rejection represent a wrong behavior of the software, but there are some cases that FGS must be able to restrict some functions or to detect when a wrong TC is passed. In those cases, a TM 1,8 must notify the rejection of the TC.
- No unexpected 5,x event: recalling that service 5 is in general used to let the unit notify events. Those can be merely informative about nominal functioning, or can be a sign of an internal problem or wrong configuration.

For the particular success criteria for a given test case, they will be indicated if applicable.

In tests cases where a PEC needs to be selected, the correspondence is: R1 = 1, R2 = 2, L1 = 3, L2 = 4.

If a problem is detected, an internal process to trace it is initiated. This is called Non-Conformity Report (NCR) and describes the problem detected and under which conditions was found. An NCR can be closed only after discussing it with the unit manufacturer and arriving to an agreement about how to solve it.

4.1 PFM_SST_FGS_01 - FGS Switch on and Connection Test

This test verifies the correct FGS Power On, and also the Service 17 TC connection test.

Success Criteria

- Reception of BOOT_REPORT and content as expected
- Reception of ASW_STARTUP_REPORT and content as expected
- FGS HK reception at expected rate
- FGS HK content as expected (all TEMP, and VOLT TM inside limit, all HC as expected)

Implementation

1. Power on FGS A
   (a) Closing FGS_NOM LCL
   (b) PLM SCOE: Set 'FGS_NOM' to ON/ONLINE
   (c) Trap SUSW Boot Report
   (d) Report Boot SUSW Telemetry
   (e) Check FGSA status (BSM)
   (f) Check FGSA INI mode
   (g) Check FGSA current consumption
   (h) Check FGSA ASM,BDM Nominal (A)
   (i) Check FGSA ASM,BDM Redundant (B)
   (j) FGSA performing SUSW connection test
2. Jump to ASW using Image 0, no PEC turned on.
   (a) Setting Milbus routing for FGSA to APID 1910, RT21
   (b) FGSA performing jump to ASW
3. FGS performing ASW connection test
4. Trap primary HK packet (3,25), report TM values, and check against DB limits
5. Trap secondary HK packet (3,25), report TM values, and check against DB limits
6. Repeat all steps for FGS B.

4.2 PFM_SST_FGS_02 - FGS Time Synchronization Management

This test verifies the correct synchronisation of the FGS EU with the onboard time given by the spacecraft. The test can be executed both on SVM or on PLM SCOE.

Success Criteria

- OBT inside FGS time packets increasing correctly also in case FGS is not synchronized with SVM

Implementation

This simple test will take the timestamp from a telemetry packet of PLM SCOE or a broadcast message from SVM (depending on the spacecraft interface used). Then the same will be done with a TM 3,25 SID=2 of the FGS EU. Finally, both timestamps will be compared. The status of the synchronisation will be also checked in the FGS HK telemetries received on Ground.

1. Configure FGS in SBM Mode.
2. Check FGS is synched with OBT
3. Deactivate Time Synch
4. Verify FGS internal time management: FGS_OBT_SYNC "Not synchronized"
5. Enable User Time Sync
6. Verify FGS internal time management: FGS_OBT_SYNC "Synchronized"

4.3 PFM_SST_FGS_03,4 - FGS PEMs Switch On

This test verifies the correct PECs switch on.

Success Criteria

- Reception of TM 5,1 PEC ON event
- FGS HK content relevant to PEC switched on as expected (PEC_XX_VOLT, PECXX_TEMP1/2, and PECR1_CCD* inside limit, PEC_XX_MODE and PECXX_HP_BC_STATUS according to configuration, PEC_XX_CHECKOUT as expected, PECXX_HC = 255, PECR1_ERR_STAT = 0).
- SpaceWire status relevant to PEC switched on as expected (SPWIRE_STATUS according to configuration, SPWIRE_LINK_STATUS_XX = 0)

Implementation

1. Configure FGS in SBM Mode as per 8.3.1
2. Power on one by one the 4 PECs (R1, R2, L1, L2) performing the following actions:
3. Record the PEC mode and voltage
4. Check the reception of PEC_ON event
5. Check FGS HK content relevant to PEC switched on are as expected (inside DB limits):
   - PEC_XX_VOLT
   - PECXX_TEMP1/2
   - PECRx_CCD
   - PEC_XX_MODE
   - PECXX_HP_BC_STATUS according to configuration
   - PEC_XX_CHECKOUT as expected
   - PECXX_HC = 255
   - PECR1_ERR_STAT = 0
6. Spacewire status relevant to PEC switched on as expected:
   - SPWIRE_STATUS according to configuration
   - SPWIRE_LINK_STATUS_XX = 0

4.4 PFM_SST_FGS_04 - FGS PEMs Switch Off

As the name of the test indicates, this test case is to verify FGS EU performs the switch off of each PEC correctly.

Success Criteria

- Reception of TM 5,1 PEC OFF event
- FGS HK content relevant to PEC switched off as expected (PEC_XX_VOLT near zero, PEC_XX_MODE according to configuration)
- SpaceWire status relevant to PEC switched on as expected (SPWIRE_STATUS according to configuration)

Implementation

Power off one by one the 4 PECs (R1, R2, L1, L2) performing the following actions:

1. Check the reception of PEC_OFF event
2. Check FGS HK content relevant to PEC switched off are as expected (inside DB limits):
   - PEC_XX_VOLT near zero
   - PEC_XX_MODE according to configuration
3. SpaceWire status relevant to PEC switched off as expected
4. SPWIRE_STATUS according to configuration

4.5 PFM_SST_FGS_06 – FGS Redundancy Verification

This test sequence verifies the cross redundancy of the unit: ensures that both FGS sections work with both SUSW and ASW, and are capable of driving the PECs indistinctly.

Implementation

1. Configure FGS in SBM Mode.
2. Turn on FGS B (FGS_RED LCL) to INI Mode
   - Enable 1553 interrogation for FGS B RT 22
   - Trap SUSW Boot Report
   - Check FGS B status (BSM)
   - Check FGS B INI mode
   - Check FGS B current consumption
   - Check FGS B ASM,BDM Nominal (A)
   - Perform FGS B SUSW connection test
3. Turn on FGS A (FGS_NOM LCL) to ASW Mode, Image 1
   - Enable 1553 interrogation for FGS A RT 21
   - Trap SUSW Boot Report
   - Check FGS A status (BSM)
   - Check FGS A INI mode

- Check FGS A current consumption
- Check FGS A ASM,BDM Nominal (A)
- Perform FGS A SUSW connection test

4. FGS A Jump to ASW Mode, Image 1
    - Setting Milbus routing for FGS A to APID 1910, RT 21
    - FGS A perform jump to ASW
    - Trap ASW Boot Report
    - Perform ASW connection test
    - Trap primary HK packet (3,25), report TM values, and check against DB limits
    - Trap secondary HK packet (3,25), report TM values, and check against DB limits
    - Turn on PEC R1 using FGS A in ASW Mode
    - Checking PEC_R1 mode = On
    - Turn off FGS A
5. FGS B Jump to ASW
    - Setting Milbus routing for FGS B to APID 1910, RT 22
    - FGSB perform jump to ASW
    - Trap ASW Boot Report
    - Disabling events 32585 and 32606 (To be removed after EUCL-TAST-NCR-1-507 closure)
    - Perform ASW connection test
    - Trap primary HK packet (3,25), report TM values, and check against DB limits
    - Trap secondary HK packet (3,25), report TM values, and check against DB limits
    - Check PEC R1 status using FGS B
    - Check of TM packets content
    - Trap primary HK packet (3,25) and report TM values for PEC
    - Turn off PEC R1 using FGS B
6. Turn off FGS B

4.6 PFM_SST_FGS_07 – FGS Patch and Dump Test

This test is to verify the correct behavior of all possible memory operations available in FGS SUSW and FGS ASW.

Success Criteria

- Successful patch and dump of 4 bytes in RAM (both PM).
- Successful dump of 8 bytes from SUSW EEPROM (both PM).
- Successful dump of 8 bytes from ASW EEPROM (both PM).

Implementation

This test is divided in three subtests:

1. **Test 1 ASW Service 6**: tests the patch and dump functionalities of the Application Software.
   (a) **RAM Patch and Dump**: 8 bytes arbitrarily chosen (`0xAAAABBBB`) are to be written in the RAM section of the FGS memory at address `0x405AB330`, and the re-read by dumping the written data.
   (b) **SUSW EEPROM Dump**: 8 bytes from the address `0x00030000` (SUSW EEPROM) are going to be dumped using Application Software TC.
   (c) **ASW EEPROM Dump**: 8 bytes from the address `0x10300000` (ASW EEPROM) are going to be dumped using Application Software TC. This address corresponds to the first bytes of the ASW installed in the second bank.
2. **Test 2 SUSW Service 6**: tests the patch and dump functionalities of the Startup Software. Essentially the tests are the same as the ones done using the ASW.

Test 1: ASW Service 6

1. Check FGS is in Standby Mode
2. Dump 4 bytes from address 0x405AB330 (HEX) from Memory RAM
3. Trap Memory Dump Report
4. Dump 8 bytes from address 0x00030000 (HEX) from Memory Boot EEPROM
5. Trap Memory Dump Report
6. Dump 8 bytes from address 0x10300000 (HEX) from Memory ASW EEPROM

7. Trap Memory Dump Report

Test 2: SUSW Service 6

1. FGS ASW Soft Reset and go to MNM Mode
   - Soft reset FGS ASW
   - Trap boot report
   - Trap SUSW Reset Report TM(5,4) EID 32257
   - Report Boot SUSW Telemetry
   - Check FGSA status (BSM)
   - Check FGSA INI mode
   - Check FGSA current consumption
   - Check FGSA ASM,BDM Nominal (A)
   - Perform connection test
   - FGSA performing SUSW connection test
   - Check INI Mode configuration
   - FGSA going into MNM mode
   - Check FGS is in Management Mode
2. **Dump 4 bytes** from address 1079685936 (DEC) in Memory RAM
   - Check Memory Dump Report
3. **Dump 8 bytes** from address 196608 (DEC) in **Memory Boot_EEPROM**
   - Check Memory Dump Report
4. **Dump 8 bytes** from address 271581184 (DEC) in **Memory ASW_EEPROM**
   - Check Memory Dump Report

4.7 PFM_SST_FGS_08 – CDMS/FGS Onboard Traffic Management

This test verifies the correct HK and DIAG telemetries according to commanded configuration: generation frequency, enable/disable.

Success Criteria

- Reception of HK and Diag TM packets according to commanded configuration
- Frequency of HK and Diag TM packets according to commanded configuration
- Reception of Event MODE_TRANSITION according to configuration

Implementation

1. Change HK/DIAG generation rate
2. Measure time gap between consecutive TM
3. Disable TM
4. Check that the disabled TM is not generated anymore
5. Re-enable TM
6. Check that the re-enabled TM is properly generated
7. Report HK/DIAG
8. Report Enabled HK packets
9. Perform a mode transition after having disabled/re-enabled the "MODE_TRANSITION event"

4.8 PFM_SST_FGS_09 - FGS Health Check - PHM

This test verifies the correct acquisition and download in PHM. Different acquisitions and download conditions are going to be done in order to cover all of them.

Success Criteria

- **TM 5,1 MODE_TRANSITION** is received when sending FGS to PHM Acquisition Mode and PHM Download Mode.
- Autonomous transition to SBM is performed after acquisition and after download.

Implementation

This test case is divided in 8 sub tests:

1. RLE, PEC R1, Window 20x20. No ESG needed, real CCD in Darkness condition.

2. Raw pix, PEC R1 Q0, Window 70x70. No ESG needed, real CCD in Darkness condition.
3. Raw pix, PEC R1, Window 70x70 with nominal charge injection
4. RLE acquisition of Full Frame
5. RLE acquisition of Full Frame binning 2x1 (RTM AP-like)
6. RawPix, PEC R1 Q0, Window 70x70, download via TM(180,10) nominal with thumbnails
7. RawPix, PEC R1 Q1, Window 70x70, download via TM(180,10) - window not multiple of 7
8. Only with SVM RawPix, PEC R1 Q2, Window 1000x1000, download via MMU
9. Only with SVM RLE, PEC R1 Q3, Window 1000x1000, download via MMU
10. RawPixel, PEC R2 Q0, Window 70x70, download via TM(180,10), binning 2x1
11. RawPixel, PEC R2 Q1, Window 70x70, download via TM(180,10), binning 1x2
12. RawPixel, PEC R2 Q2, Window 70x70, download via TM(180,10), binning 2x2
13. RLE, PEC R2, Full Frame, download via MMU
14. PHM interrupted by TC(180,5)

The parameters used are indicated in the following tables. For the Download part, only the different arguments are written, as the same TC is used to go to both modes.

Acquisition	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6a	6b	6c
PHM_SUBMODE	0	0	0	0	0	0		
FULL_FRAME	0	0	0	1	1	0		
ACQ_TYPE	1	0	0	1	1	0		
AREA_SEL	1	0	0	0	0	1		
PEC	1	1	1	1	1	1		
W_START_X	3720	0	0	0	0	680		
W_START_Y	2020	0	0	0	0	610		
W_END_X	3740	69	69	0	0	749		
W_END_Y	2040	69	69	0	0	679		
INT_TIME_PEC	100	10	10	250	250	100		
GAIN	1	1	1	1	1	1		
RLE_THRESHOLD	15000	0	0	1000	1000	0		
PIXEL_BINNING	0	0	0	0	1	0		
WIN_DWNLD_TYPE	0	0	0	0	0	0		
RLE_START_ID	0	0	0	0	0	0		
RLE_END_ID	0	0	0	0	0	0		
Download								
PHM_SUBMODE	1	1	1	1	1	1	1	1
WIN_DWNLD_TYPE	0	0	0	0	0	0	1	2
RLE_END_ID	N-1	0	0	N-1	N-1	0	0	0

Table 1: PHM Test Cases 1 to 6. TC parameters.

Acquisition	Test 7	Test 8	Test 9	Test 10	Test 11	Test 12	Test 13	Test 14
PHM_SUBMODE	0	0	0	0	0	0	0	0
FULL_FRAME	0	0	0	0	0	0	1	0
ACQ_TYPE	0	0	1	0	0	0	1	0
AREA_SEL	2	0	0	2	1	1	0	1
PEC	1	1	1	2	2	2	2	1
W_START_X	3030	604	2100	440	2839	858	0	2652
W_START_Y	1530	2842	2100	1708	1380	3300	0	1794
W_END_X	3095	1604	3100	509	2908	927	0	3652
W_END_Y	1599	3842	3100	1777	1449	3369	0	2794
INT_TIME_PEC	100	10	150	150	150	100	250	150
GAIN	1	1	1	1	1	1	1	1
RLE_THRESHOLD	0	0	1000	0	0	0	1000	0
PIXEL_BINNING	0	0	0	1	2	3	0	0
WIN_DWNLD_TYPE	0	0	0	0	0	0	0	0
RLE_START_ID	0	0	0	0	0	0	0	0
RLE_END_ID	0	0	0	0	0	0	0	0
Download								
PHM_SUBMODE	1	1	1	1	1	1	1	1
WIN_DWNLD_TYPE	0	0	0	0	0	0	0	0
RLE_END_ID	0	0	N-1	0	0	0	N-1	0

Table 2: PHM Test Cases 7 to 14. TC parameters.

For all sub test cases, the implementation follows the same steps:

1. Send TC 180,2 Enter PHM Mode with `ACQ_TYPE`=0 in order to start PHM Acquisition Mode.

2. Capture **TM 5,1 PHM_ACQUIRED_SEGMENTS**. This is an event sent by FGS after it finished the acquisition. In case of RLE acquisition mode, extract the number of acquired segments to give it as an argument to **TC 180,2 Enter PHM Download Mode**.

3. Only if S/C Interface is SVM Send **TC 8,1 Acquire Image** to CDMU Application Software (CASW) in order to make it listen for FGS's **TM 180,10 Window Download** packets.

4. After returning autonomously to SBM, send TC 180,2 Enter PHM Mode with `ACQ_TYPE`=1 in order to start PHM Download Mode.

5. FGS will start sending **TM 180,10 Window Download** with all the captured data. Detect autonomous mode change to SBM.

1. Configure FGS in SBM Mode as per 8.3.1
2. Switching on PEC_XX
3. Checking PEC_XX mode = On
4. Turn Off others PEC
5. Check FGS is in SBM mode
6. Send TC: goto PHM mode for Data Acquisition
   - Check reception of RLE acquisition end event (EID 32601)
   - Check reception of Mode change event
7. Check FGS is in SBM mode
8. Send TC: goto PHM mode for Data Download
9. Check reception of Mode change event
10. Check FGS is in SBM mode
11. Execute post-processing using Ground Tool
12. Reconstructing image from TM(180,10).

The next steps depend on the spacecraft interface: SVM or PLM SCOE. The Test Sequence detects automatically the interface used by reading a parameter in environment configuration file.

PLM SCOE

5. Extract **TM 180,10 Window Download** with CADET utility and save it locally or on FTP server to a tsv file.
6. Use `fgs_image_analizer` tool to extract pixels from raw telemetry packets read from tsv file.

SVM

5. Detect reception of **TM 5,1 EVT_IMAGE_ACQUISITION_SUCCESSFULL** from CASW.

6. Perform file download from MMU to ground.

7. Extract pixels from downloaded MMU file and generate image.

Up to this date, a Non-conformity Report was released to the **TC 8,1 Acquire Image**, which does not capture the FGS packets with image data. Due to this, the SVM part of this test case cannot be performed.

4.9 PFM_SST_FGS_10 – FGS Functional Performance (using ESG) - RTM

By using ESG, a portion of the sky is simulated and transmitted to the FGS EU. The test is to verify the correct generation of events and the relative tracking capabilities of FGS ASW.

Success Criteria

- TM 5,1 indicating mode change (from SBM to RTM-AP) is properly generated
- TM 5,1 indicating mode change (from RTM-AP to RTM-IC) is properly generated
- TM 5,1 indicating mode change (from RTM-IC to RTM-TP) is properly generated
- Attitude lock within 14s from TC Enter RTM
- TM 3,26 SID=5 is transmitted in 8th Communication Frame each 2 seconds
- TM 3,26 SID=6 is received at first tracking cycle
- TM 3,26 reports valid attitude relative and the attitude value is coherent with simulated dynamics evolution
- FGS Relative Measurement Error is inside FGS requirement (when dynamic conditions are below 0.05arcsec/s around X/Y and below 2.5arcsec/s around boresight).

Implementation

This test will be divided in 5 tests which represent different conditions for RTM Mode:

1. RTM R1-L1, static
2. RTM R2-L2, dynamic [0.05 0.05 2.5]"/s nominal case
3. RTM R1-L2, dynamic [0.3 -0.3 15]"/s
4. RTM R2-L1, dynamic [-0.3 0.3 15]"/s, angular rate provided

5. RTM R1-L1, dynamic [-0.05 0.05 -1]"/s, optical distortion

Test1 (RTM static LDO's scenario)

1. Configure ESG as per icf file.
2. Configure FGS in SBM Mode
3. Check FGS is in Standby Mode
4. Check correct PEC configuration, otherwise change it
5. Enable continuous transmission of SID=6
6. Send TC: Enter RTM mode configured as per Table 3
7. Check entrance in RTM-AP mode with PEC R1 L1 and mode execution
8. Check entrance in RTM-IC and execution
9. Check entrance in RTM-TP and execution
10. Check CCD R1: 10 stars are detected at each valid tracking cycle.
11. Check CCD L1: at least 1 star is detected at each valid tracking cycle.
12. Tracking is maintained for at least 20 cycles. Then, the attitude is propagated for 3 cycles. At fourth, tracking is recovered and maintained again for 20 cycles.
13. Send TC(180,5) Enter SBM
14. Check FGS is in SBM
15. Execute post-processing using Ground Tool
16. Computed quaternion is in line with dynamic input with tolerance of 1E-8.
17. Computed angular rate in line with dynamic inputs with tolerance of 1E-6 rad/s.

	Test 1	Test 2	Test 3	Test 4	Test 5
PEC_A1	1	2	1	2	1
INT_TIME_PEC_A1 (in seconds)	0	100	0	0	0
RLE_THR_PEC_A1	0	0	0	0	0
PEC_A2	3	4	4	3	3
INT_TIME_PEC_A2	0	100	0	0	0
RLE_THR_PEC_A2	0	0	0	0	0
PEC_SB	2	0	0	0	0
ANG_RATE_X	0	0	0	-1969	-328
ANG_RATE_Y	0	0	0	1969	328
ANG_RATE_Z	0	0	0	98466	-6564
ANG_RATE_VALIDITY	0	0	0	1	1
ACQ_REP_DISABLE	1	0	0	0	0
ADAPTIVE_TH_DISABLE	1	1	1	1	1
OPT_DISTORTION_ENABLE	0	1	0	0	1

Table 3: RTM Test Cases. TC parameters.

4.10 PFM_SST_FGS_11 - FGS Functional Performance (using ESG) - ATM

By using ESG, a portion of the sky is simulated and transmitted to the FGS EU. The test is to verify the correct generation of events and the absolute tracking capabilities of FGS ASW.

Success Criteria

- TM 5,1 indicating mode change (from SBM to ATM-AP) is properly generated
- TM 5,1 indicating mode change (from ATM-AP to ATM-IC) is properly generated
- TM 5,1 indicating mode change (from ATM-IC to ATM-TP) is properly generated
- Attitude lock within 14s from TC Enter ATM with Coarse acquisition or within 11s with Fine Acquisition
- TM 3,26 SID=5 is transmitted in 8th Communication Frame each 2 seconds
- TM 3,26 SID=6 is received at first tracking cycle
- TM 3,26 reports attitude relative valid and the value is coherent with simulated dynamics)

- FGS Relative Measurement Error is inside FGS requirement (when dynamic conditions are below 0.05arcsec/s around X/Y and below 2.5arcsec/s around boresight).
- FGS Absolute Measurement Error is inside FGS requirement (when dynamic conditions are below 0.05arcsec/s around X/Y and below 2.5arcsec/s around boresight).

Implementation

This test will be divided in 3 tests which represent different conditions for ATM Mode:

1. ATM Coarse Acquisition, using PECs R1-L2, static simulated image, 50" pointing error, optical distortion enabled and relativistic aberration compensation enabled
2. ATM Coarse Acquisition, using PECs R2-L1, dynamic simulated image with [0.25 -0.25 0.25]"/s
3. ATM Fine Acquisition, R2-L2, dynamic simulated image with [0.05 0.05 1]"/s, 3" pointing error

Test1 (ATM static, coarse acquisition, 50" error, opt.distortion and aberration LDO's scenario)

Pointing01 0.210516872 -0.409395158 0.405960534 0.789477229

1. Configure ESG as per icf file.
2. Configure FGS in SBM Mode
3. Check FGS is in Standby Mode
4. Check correct PEC configuration, otherwise change it
5. Enable continuous transmission of SID=6
6. Upload the star catalogue 65535_Point00001_OBCF.bin through service8 FID=110
7. Check correct catalogue upload verifying OBSERVATION_ID and Last catalog updated correctly parameter in HK TM
8. Send TC: Enter ATM mode configured as per Table 4
9. Check entrance in ATM-AP mode with PEC R1 L2 and mode execution
10. Check entrance in ATM-IC and execution
11. Check entrance in ATM-TP and execution
12. Check CCD R1: at least 8 stars are detected at each valid tracking cycle.

13. Check CCD L2: at least 8 stars are detected at each valid tracking cycle.
14. Tracking is maintained for at least 50 cycles. Then, the attitude is propagated for 3 cycles. At fourth, tracking is recovered and maintained again for 20 cycles.
15. Send TC(180,5) Enter SBM
16. Check FGS is in SBM
17. Execute post-processing using Ground Tool

Test3 (ATM dynamic, fine acquisition with angular rate, 3" pointing error – LDO's scenario)

Pointing_01 0.210516872 -0.409395158 0.405960534 0.789477229

1. Configure ESG as per icf.
2. Configure FGS in SBM Mode
3. Check FGS is in Standby Mode
4. Check correct PEC configuration, otherwise change it
5. Enable continuous transmission of SID=6
6. Upload the star catalogue 65535_Point00001_OBCF.bin through service8 FID=110
7. Check correct catalogue upload verifying OBSERVATION_ID and Last catalog updated correctly parameter in HK TM
8. Send TC: Enter ATM mode configured as per Table 4
9. Check entrance in ATM-AP mode with PEC R2 L2 and mode execution
10. Check entrance in ATM-IC and execution
11. Check entrance in ATM-TP and execution
12. Check CCD R2: at least 8 stars are detected at each valid tracking cycle.
13. Check CCD L2: at least 8 stars are detected at each valid tracking cycle.
14. Tracking is maintained for at least 50 cycles. Then, the attitude is propagated for 3 cycles. At fourth, tracking is recovered and maintained again for 20 cycles.
15. Then FGS loose tracking due to very high angular rate.
16. Check falls back in ATM-AP and RTM-AP and then in SBM.

17. Check FGS is in SBM
18. Execute post-processing using Ground Tool

	Test 1	Test 2	Test 3
Real dynamic condition			
quat_1		0,210516873	
quat_2		-0,409395159	
quat_3		0,405960534	
quat_4		0,789477229	
ang_rate_x [rad/s]	0	1,21203E-06	2,42407E-07
ang_rate_y [rad/s]	0	-1,21203E-06	2,42407E-07
ang_rate_z [rad/s]	0	1,21203E-06	4,84814E-06
OBSERVATION_ID	65535	65535	65535
PEC_A1	1	2	2
INT_TIME_PEC_A1	0	0	0
RLE_THR_PEC_A1	0	0	0
PEC_A2	4	3	4
INT_TIME_PEC_A2	0	0	0
RLE_THR_PEC_A2	0	0	0
PEC_SB	3	4	1
ANG_RATE_X	0	0	0
ANG_RATE_Y	0	0	0
ANG_RATE_Z	0	0	0
ANG_RATE_VALIDITY	0	0	0
ORBITAL_SPEED_X	500	0	0
ORBITAL_SPEED_Y	0	0	0
ORBITAL_SPEED_Z	0	0	0
INITIAL_ATTITUDE_1	210516872	210516872	210516872
INITIAL_ATTITUDE_2	-409395158	-409395158	-409395158
INITIAL_ATTITUDE_3	405960534	405960534	405960534
INITIAL_ATTITUDE_4	789477229	789477229	789477229
ACQ_MODE	0	0	1
RTM_DISABLE	0	1	1
ACQ_REP_DISABLE	1	1	1
RELATIV_ABERR_COMP	1	0	0
ADAPTIVE_TH_DISABLE	1	1	1
OPT_DISTORTION_ENABLE	1	0	0

Table 4: ATM Test Cases. Simulated conditions and TC parameters

4.11 PFM_SST_FGS_12 - FGS Health Check with CCD Image (Charge Injection) CHM-CI

This test verifies the correct telemetries sent by FGS EU to CDMU when entering to Checkout Mode, Charge Injection.

Success Criteria

- TM 5,1 indicating mode change (from SBM to CHM-CI) is properly generated
- The TEST_RESULTS parameter of TM 180,11 is = 1 (OK)
- If CHM-CI is executed at ambient condition the TEST_RESULTS can provide negative results also if the entire chain is healthy. Therefore it is suggested to request download of pixels data.
- Pass/fail criteria related to the acquired data is the following:
  - The received "pixel row data" from the CCD, using a window dump is comparable with the expected pattern (see Figure 8 3 and ref to ASW ICD section 14.6.1), i.e. for what concerns position of high and low rows
  - No unexpected /new Hot Pixels or Bad Column pixels appears
  - No unexpected/new pixels with zero signal appears

Implementation

1. Check correct PEC configuration, otherwise change it (i.e. if the CHM is with PEC1 only)
   - Turn ON PEC R1
   - Turn Off PEC R2
   - Turn Off PEC L1
   - Turn Off PEC L2
2. Setting parameters value in RAM for PEC R1
   - Check FGS is in Standby Mode.
   - Set parameter values in RAM through TC(8,1) FID=120
   - Get parameter values from RAM through TC(8,1) FID=120
3. Go to CHM-CI
   - Check FGS is in SBM mode

- Send TC: goto CHM mode with Charge Injection check
- Check FGS is in CHM-CI mode
- Check TEST_RESULTS parameter of TM 180,11 is = 1 (OK)

4. Check FGS is in Standby Mode
5. Go to CHM-CI for window acquisition and download
   - Check FGS is in SBM mode
   - Send TC: goto CHM mode with acquisition of a window....
   - Check FGS is in CHM-CI mode
   - Check FGS returns in SBM mode
   - Send TC: goto CHM mode for window download...
   - Check FGS is in CHM-CI mode
   - Check reception of TM(180,10) packets
   - Check FGS returns in SBM mode
6. Execute post-processing using Ground Tool

4.12 PFM_SST_FGS_13 - FGS Heath Check with Fixed Telemetry Transmission (FPGA Test) CHM-FS

This test verifies the correct telemetries sent by FGS EU to CDMU when entering to Checkout Mode, Fixed Telemetry Transmission (using FPGA).

Success Criteria

- TM 5,1 indicating mode change (from SBM to CHM-FS) is properly generated
- The TM 3,26 content is congruent with FGS ASW ICD section 14.6.2.21
- The TEST_RESULTS parameter of TM 180,12 is = 1 (OK)

Implementation

1. Check correct PEC configuration, otherwise change it (i.e. if the CHM is with PEC 1 and 4)
   - Turn ON PEC R1
   - Turn ON PEC L2

2. Go to CHM-FS
    - Check FGS is in SBM mode
    - Send TC: goto CHM mode with FPGA check.
    - Check FGS is in CHM_FS mode
    - Check Test Report
    - Check TM(3,26) SID=4 Diagnostic Parameter Report
    - Check of TM packets content
3. Check FGS is in Standby Mode
4. Repeat the same with PEC configuration R2 and L1
5. Execute post-processing using Ground Tool

4.13 PFM_SST_FGS_14 - FGS Heath Check with Fixed Telemetry Transmission (TM Mode) CHM-FT

This test verifies the correct telemetries sent by FGS EU to CDMU when entering to Checkout Mode in Fixed Telemetry Transmission.

Success Criteria

- TM 5,1 indicating mode change (from SBM to CHM-FT) is properly generated
- The number of TM 3,26 transmitted packet is equal to 50 for each SID
- The TMs 3,26 content is congruent with FGS ASW ICD section 14.6.3
- The TEST_RESULTS parameter of TM 180,13 is = 1 (OK)
- Overall duration of 100s is expected (TM 3,26 frequency is 0.5Hz).

Implementation

1. Check FGS is in Standby Mode....
2. Send TC: goto CHM mode with fixed TM check First Pattern....
    - Check FGS is in CHM_FT mode
    - Check Test Report
    - Check Fixed TM Reception
3. Check FGS is in SBM mode

4. Send TC: goto CHM mode with fixed TM check First Pattern.
    - Check FGS is in CHM_FT mode
    - Check Test Report
    - Check Fixed TM Reception
5. Check FGS is in SBM mode
6. Execute post-processing using Ground Tool

4.14 PFM_SST_FGS_15 - FGS EU ASW Loading

The test is aimed to perform a complete load of FGS EU Application Software using:

1. Directly sending a set of TCs 6,2
2. Using file from MMU
3. Also HP/BC, SP tables will be uploaded.

Success Criteria

- After reboot, the `ASW_IMGX_CHECKSUM` parameter of boot report of SUSW is correct.

Implementation

1. Soft reset FGS ASW
    - Trap boot report
    - Trap SUSW Reset Report TM(5,4) EID 32257
    - Report Boot SUSW Telemetry
    - Check FGSA status (BSM)
    - Check FGSA INI mode
    - Check FGS A current consumption
    - Check FGS A ASM,BDM Nominal (A)
2. Perform connection test
3. FGS A going into MNM mode
4. Check FGS is in Management Mode....
5. Upload in Memory ASW_EEPROM the following Files:

- Test 1: ASW and CRC Table Loading
- Test 2: SP Table Loading
- Test 3: HP/BC Table Loading

6. Check Memory Check Report

7. FGSA Jump to ASW

    - FGS performing ASW connection test
    - Trap primary HK packet (3,25), report TM values, and check against DB limits
    - Check of TM packets content
    - Trap secondary HK packet (3,25), report TM values, and
    - Check of TM packets content

4.15 PFM_SST_FGS_16 - FGS Full PEC Download

This test verifies the FGS capability to perform a download of the full CCD image. Since CDMU software still does not support direct loading of images from FGS EU to MMU, this test was performed by directly downloading the window download telemetries containing the image information from Ground.

Success Criteria

- Reconstructed CCD image is complete and coherent
- No unexpected Bad Column pixels appear
- No unexpected/new pixels with zero signal appear
- Average signal and signal spatial variation is according to the reference CCD image

Implementation

1. Prepare CCS script to capture PEC R1 Q0

2. Switching on PEC_R1

3. Checking PEC_R1 mode = On

4. Check FGS is in SBM mode

5. Loop to download the whole PEC

    - Send TC: goto PHM mode for Data Acquisition ....
    - Check reception of Raw Pixel acquisition end event (EID 32602)

- Check reception of Mode change event
- Check FGS is in SBM mode
- Send TC: goto PHM mode for Data Download....
- Check reception of Mode change event
- Check FGS is in SBM mode

4.16 PFM_SST_FGS_17 - FGS EU 1553 Health Check

This test verifies the capability to switch between both sections of FGS: A and B, in the 1553 bus on both BSW and ASW. No data loses must occur in these switches.

Implementation

1. Turn on FGS A
   - Trap SUSW Boot Report
   - Report Boot SUSW Telemetry
   - Check FGS A status (BSM)
   - Check FGS A INI mode
   - Check FGS A current consumption
   - Check FGS A ASM,BDM Nominal (A)
2. Perform connection test
3. Switch FGS A to 1553 Bus B
4. FGSA Jump to ASW
   - Trap ASW Boot Report
5. Perform connection test
   - Trap primary HK packet (3,25), report TM values, and check against DB limits
   - Check of TM packets content
   - Trap secondary HK packet (3,25), report TM values, and check against DB limits
   - Check of TM packets content
6. Switch FGS to 1553 Bus A
   - Perform connection test FGSA

- FGS performing ASW connection test

7. Repeat the test using FGS B

4.17 PFM_SST_FGS_18 - FGS Star Catalogue Generation, Upload and Use

The aim of this test is to verify three important functionalities for FGS Absolute Tracking capabilities:

1. Generation of FGS Star Catalogue using FOG tool (not yet available, therefore not tested)
2. Using TC 8,1 FID=110 to upload a star catalog directly to FGS
3. Using file from MMU to upload a star catalog to FGS (not yet available, therefore not tested)

Success Criteria

- FOG generates a binary file of size ***to be determined*** and no error in FOG log is present. (not yet available, therefore not tested)
- Successful catalogue upload

Implementation

The implementation of this test can be only partial because: FGS vendor up to date of thesis has not delivered FOG tool, and CDMU Application Software (CASW) vendor up to date of thesis has not implemented catalogue upload using MMU. The only functionality to be verified will be using TC 8,1 FID=110 to upload a star catalog directly to FGS.

1. Open binary catalogue file delivered by TAS-I Engineering Department.
2. Upload to FGS using group of TC 8,1 FID=110.
3. Verify that the event TM 5,1 `CATALOGUE_UPLOAD_COMPLETE` is received after the last TC 8,1.

4.18 PFM_SST_FGS_99 – FGS Switch Off

This test verifies the correct FGS Power Off.

Implementation

1. Check FGS is in Standby Mode
2. PEM1 Switch Off:
   - power off PEC R1
   - power off PEC R2
3. PEM2 Switch Off:
   - power off PEC L1
   - power off PEC L2
4. EU A Switch Off
5. EU B Switch Off

5 Results

In this section, the most important telecommands and telemetries are shown to demonstrate the actual capabilities, features and correct behavior of the unit under test.

5.1 PFM_SST_FGS_01 - FGS Switch on and Connection Test

Summary: SUCCESSFUL
Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **(New) NCR 623:** "FGS EU FM Section A has an invalid HP/BC Table". When the ASW in FGS EU A is started (Load&Jump to ASW), an event 320000035 TM(5,4) INVALID_HPBC_TABLE is received (as shown in Figure 7). The event was received only on FGS EU Section A.
  - After a meeting with the FGS EU manufacturer, we were instructed to reinstall the HP/BC Tables on FGS EU Section A and verify that the problem disappears. The installation was performed in a posterior session and the problem was solved. The NCR was consequently closed.
- **(Old) NCR 543:** "FGS Temperatures in ASW Housekeeping telemetry out of range". ASW HK telemetry shows that the internal temperatures in FGS are very high. The TM parameters are FAAT2032, FAAT2033, FAAT2034 and FAAT2035 (see Figure 8).
  - In general terms, the FGS EU temperatures had a wrong calibration curve in the TM database given by FGS EU manufacturer. The solution discussed in a meeting with them was to update the database according to the termistor transfer function already present in the user manual of the unit. At the time of the test a first attempt to fix the issue was done. In fact, the parameters show the actual temperature of the unit but the internal limits for them still obey the old (wrong) values. The values reported by the unit are the right ones.
- **(New) NCR 547:** "FGS ASW Tasks Health Checks failed". Some FGS ASW TM(3,25) SID=2 320000010 parameters are in an abnormal state. Those parameters are task health status: FJJT0012 (ASW Main), FJJT0014 (PEC Data Processor), FJJT0024 (Task Monitor), FJJT0025 (PPS Manager).
  - These values report the status (health check) of the main internal processes of ASW. In a discussion with FGS manufacturer, the reason for these to be read as "Not OK" is that these tasks are part of other tasks for which the health status is already reported (e.g HK data manager is part of PEC Data Processor task). FGS ASW ICD already reports them as spare fields.

```
2019-12-19T18:13:43.022 320000035  TM(5,4) INVALID_HPBC_TABLE                        VC = 0   APID = 1910 SSC = 3
         00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

 0000 | 0F 76 C0 03 00 15 10 05 04 00 00 00 00 02 C8 25
 0010 | 7F 4C 10 00 00 00 19 01 00 02 71 A8
  2019-12-19T18:13:43.022 @TM FAAT2277      FGS_EID                Unit = N/A  Status = VALID       Raw = 32588
  2019-12-19T18:13:43.022 @TM FAAT2010      FGS_OPMODE             Unit = N/A  Status = VALID       Raw = 16
  2019-12-19T18:13:43.022 @TM FAAT2011      FGS_ABSOLUTE_CYCLE     Unit = N/A  Status = VALID       Raw = 25
  2019-12-19T18:13:43.022 @TM FAAT2390      FGS_Table_ID           Unit = N/A  Status = VALID       Raw = 1
  2019-12-19T18:13:43.022 @TM FAAT2391      FGS_Bank_ID            Unit = N/A  Status = VALID       Raw = 0
  2019-12-19T18:13:43.022 @TM FAAT2284      FGS_PEC_ID             Unit = N/A  Status = VALID       Raw = 2
```

Figure 7: NCR 623. Event received at ASW startup of FGS EU A signaling a corrupt HP/BC for PEC R2. Telemetry extracted using CADET utility from the session of the test.

	FJJT0121	FGS_TM timeout	OK	0	NO TM Timeout	N/A
▼	FAAT2032	FGS_PM_TEMP	ALARM	1803	22.065560283170733	degC
	FAAT2346	FGS_PEC_L1_VOLT	OK	11	0.018182999999999998	V
	FJJT0122	FGS_TC timeout	OK	0	NO TC Timeout	N/A
▼	FAAT2033	FGS_PDM_1_2_TEMP	ALARM	1807	21.967719977857143	degC
	FAAT2347	FGS_PEC_L2_VOLT	OK	0	0	V
	FJJT0123	FGS_TM overrun	OK	0	No TM overrun	N/A
	FAAT2348	FGS_MILBUS_COMMS_STATUS	OK	0	No error	N/A
▼	FAAT2034	FGS_PDM_3_4_TEMP	ALARM	1805	22.015943454390243	degC
	FJJT0124	FGS_TC unexpected	OK	0	No TC unexpect	N/A

Figure 8: NCR 543. Log capture of FGS EU ASW HK telemetry. Only parameters that gave error during the test are shown.

5.2 PFM_SST_FGS_02 - FGS Time Synchronization Management

Summary: SUCCESSFUL. While the test was performed using PLM SCOE, FGS EU changed the internal status of the HK telemetries regarding the synchronisation with On Board Time (OBT)

Non-Conformities: No NCRs detected.

5.3 PFM_SST_FGS_03 - FGS PEMs Switch On

Summary: SUCCESSFUL

Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 510:** "FGS generated unexpected event TM(5,2) LINK_ESTABLISHED_MISSING". When PEC R1 was turned on (using ESG stimulating FGS EU via SpW) the event TM(5,2) LINK_ESTABLISHED_MISSING was generated by FGS EU. This message seems to arrive approximately 3-4 seconds after turning the PEC on.
  - This error was investigated by FGS and ESG manufacturers. The error is still not understood, but it does not impact the test in any way, since no further events are generated and the simulation runs without any problem.

5.4 PFM_SST_FGS_04 - FGS PEMS Switch Off

Summary: SUCCESSFUL
Non-Conformities: No NCRs detected.

5.5 PFM_SST_FGS_06 - FGS Redundancy Verification

Summary: SUCCESSFUL
Non-Conformities: No NCRs detected.

5.6 PFM_SST_FGS_07 - FGS Patch and Dump Test

Summary: SUCCESSFUL
Non-Conformities: No NCRs detected.

5.7 PFM_SST_FGS_08 - CDMS/FGS Onboard Traffic Management

Summary: SUCCESSFUL
Non-Conformities: No NCRs detected.

5.8 PFM_SST_FGS_09 - FGS Health Check - PHM

Summary: SUCCESSFUL
Non-Conformities: No NCRs detected.

5.9 PFM_SST_FGS_10 - FGS Functional Performance (using ESG EGSE) - RTM

Summary: PARTIALLY DONE. At the time of development of this thesis, RTM was still under internal test from FGS manufacturer. Therefore, only a fixed portion of the sky (static test) was generated using ESG to test this mode. This test is considered only partial, as it served only to gain more confidence when using ESG and to refine the test sequences used.

Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 615:** "FGS ASW Database errors in Relative Tracking Mode (RTM)". According to ICD the calibration curve for the parameter FAAT2010 (FGS_OPMODE) must contain the rag values 49, 51 and 52 for the RTM submodes. However, the values implemented in database are 49, 50 and 51. A change was manually implemented on BD as workaround to continue with the tests. Additionally, in telemetry packets TM(3,26) SID=4 the quaternion is not converted to an engineering value by the FGS database. So presumably it is either a missing calibration curve or a missing link between calibration curve and parameters of the quaternions.

  - According to ICD the values for RTM submodes must (in decimal): 49 (RTM-AP), 51 (RTM-IC) and 52 (RTM-TP). The database expected wrong values, as discussed with the FGS manufacturer. The problem was solved in the next release of the database after the opening of this NC.

5.10 PFM_SST_FGS_11 - FGS Functional Performance (using ESG EGSE) - ATM

Due to the fact that at the time of development of this thesis, the ATM mode is still under development from the FGS manufacturer, this mode could not be tested.

5.11 PFM_SST_FGS_12 - FGS Health Check with CCD Image (Charge Injection) CHM-CI

Summary: SUCCESSFUL
Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 639:** "FGS ASW: CHM Report for Charge Injection lacks two parameters". At the end of CHM-CI Test, the packet TM(180,11) CHM Report CI Test received from FGS EU does not contain the parameters FAAT2517 and FAAT2518 as described by ASW ICD Iss 5 [5]. These parameters are contained also in the DB definition of the packet, therefore an alert was received by the test environment when the packet arrived, reporting that both parameters were impossible to extract.
  - FGS Manufacturer requested a check of the Milbus traffic to verify that the test environment was not reporting a false alarm. I performed this analysis using Wireshark software at PLM SCOE, and confirmed that the packet is truncated. LDO is still investigating a solution for this problem.

5.12 PFM_SST_FGS_13 - FGS Health Check with Fixed TM TX (FPGA Test) CHM-FS

Summary: SUCCESSFUL
Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 581:** "FGS ASW CHM-FS test gives TEST_RESULT=NOT_PERF when using only one PEC". FGS EU EQM using PEM connected as PEC1 and PEC2. At the end of CHM-FS test with only one PEC (R1), the packet TM(180,12) "CHM Test Report - FPGA Test" has the parameter FAAT2306 TEST_RESULT=NOT_PERF.
  - The two errors here are that according to the ICD, this check should return TEST_RESULT=OK. And, as per ICD, FAAT2306 should not corresponde to NOT_PERF but to FAIL_QUATERNION. In fact, the same parameter is used for the three different CHM tests, even when they do not have the same meaning for all cases. In a meeting with the manufacturer, it was agreed to perform the implementation of a dedicated parameter for every test. The repetition of the test is still pending. NCR not closed yet.

5.13 PFM_SST_FGS_14 - FGS Health Check with Fixed TM TX (TM Mode) CHM-FT

Summary: SUCCESSFUL
Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 257:** "Wrong generation of fixed TM packets during FGS CHM". The selected operative mode (CHM Fixed TM transmission) generated TM packets containing some fixed TM values. This mode produces packets with different values than the ones expected and found in the ASW ICD [5].
  - The problem was discussed with FGS manufacturer, and the ASW ICD was updated accordingly. NCR closed.

5.14 PFM_SST_FGS_15 - FGS EU ASW Loading

Summary: SUCCESSFUL. This test was performed using FGS EU EQM when an update was needed from ASW v1.05.54 to v1.05.60 (latest release to the date). The process takes approximately 15 minutes for ASW loading, other 15 minutes for HP/BC tables loading, and 1 minute for CRC tables update. The update was done successfully and it is going to be performed in the future in FGS EU FM for every new version released by FGS EU manufacturer.

Non-Conformities: No NCRs detected.

5.15 PFM_SST_FGS_16 - FGS Full PEC Download

Summary: SUCCESSFUL. This test was performed only in Airbus premises at Toulouse, France. The main objective of this test is to obtain a reference from the PEMs

Flight Model for on-ground and in-flight activities.

Non-Conformities: NCRs detected. Not blocking the continuity of the test.

- **NCR 633:** "FGS ASW: TM(180,10) Window Download arrives at 2Hz instead of 3 when HK is enabled". When downloading CCD packets TM(180,10) with HK packets enabled, ASW does not transmit 3 TM(180,10) packets per second, but only two. This occurs even if a TM(3,25) is not received in that Major Communication Frame. In order to use all the available bandwidth, a workaround had to be used: set HK frequency to "1" for TM(3,25) SID=2,3 (this means 0.5Hz) as first step, and then a loop disables TM(3,25) SID=2,3 for 20 seconds and re-enable TM(3,25) SID=2,3 for 5.
  - FGS ASW has three slots in every Major Communication Frame in the communication I/F Milbus 1553. The problem here is that one of them is not used if the HK telemetry packets are not deactivated. The expected behavior should be that FGS must send all pending information down to Ground in the first available slot. In discussion with FGS manufacturer, the problem is still to be solved and a solution is under investigation.
- **NCR 637:** "FGS ASW: Glitches seen in PEC temperature parameters FAAT2073 and FAAT2074". Glitches in the temperature telemetries of PECs appear when the HK telemetries (TM(3,25) SID=2,3) are disabled for some minutes and then re-enabled. In some cases the variation with respect to the real value (the stable one after the glitch) is almost 0.7°C. It was observed only for parameters associated with PEC L2, but it is very likely that the problem also happens with the other PEC temperature telemetries.

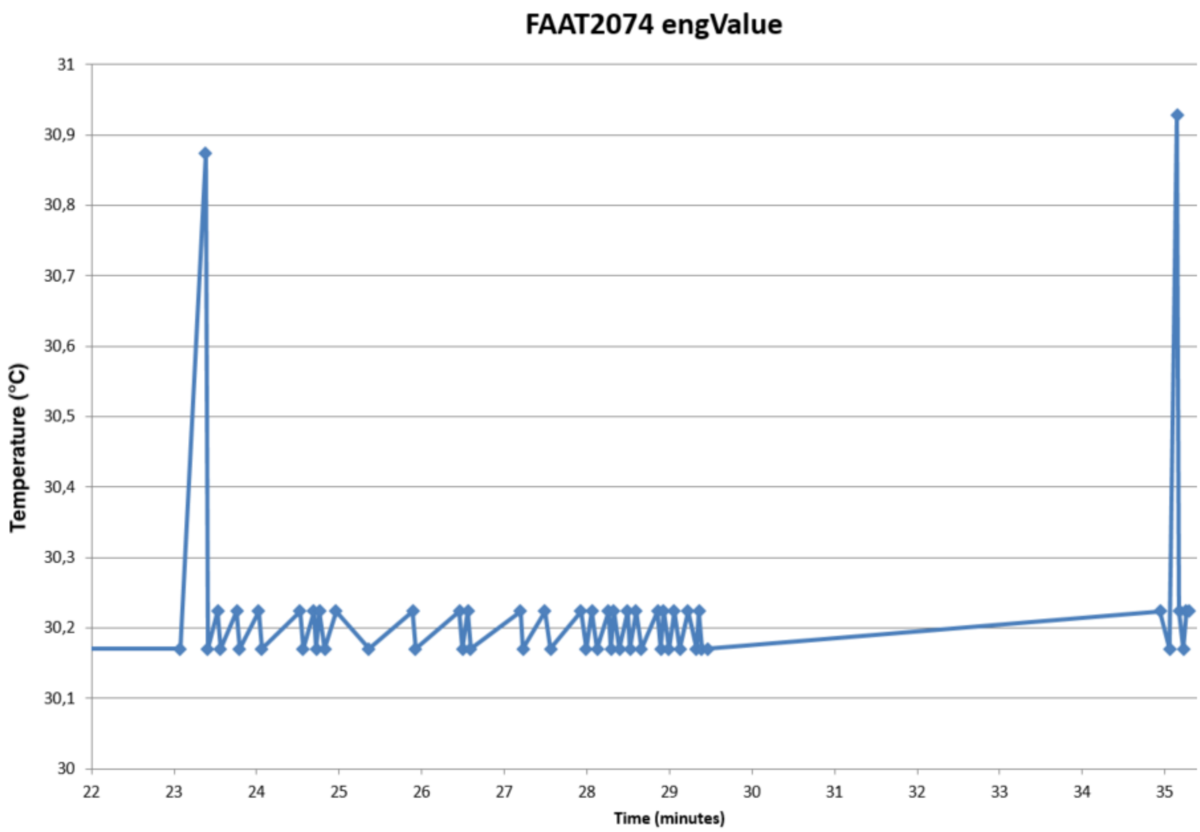

Figure 9: NCR 637: Glitches observed in parameters FAAT2073 and FAAT2074, which correspond to PEC L2 temperatures.

The following sub sections give a general description of the captured and downloaded image for each PEC flight model. The first image of each one correspond to the reconstructed image from telemetry packets TM(180,10) received from ground. As explained in the Test Description, the entire image is captured in blocks of 686x1024 pixels, 10ms of exposure time. These blocks are visible in the image obtained without detrending due to the readout process inherent to CCD technology. This introduces a linear trend in the direction of the readout because the pixels are still capturing light while waiting to be read.

In order to have a better understanding of the image captured, a detrending process was implemented in post-processing off-line phase. The second image from each subsection show the detrended image for each CCD.

Then -when applicable-, a more detailed description and analysis of the image is done: hot pixels and bad columns. As part of the Consent of Shipping of PEMs, the manufacturer informed about the known bad columns and hot pixels detected at their premises in their own tests on each CCD. Since they performed these tests in flight conditions (in thermal vacuum chambers), our tests in ambient conditions can trigger extra effects due to higher temperatures.

5.15.1 PEC R1 (PEC#1)

Image: 686x1024 pixels, 10ms exposure time.
Background: 849 DN (pix with signal >5000DN not considered)
STD: 242 DN (pix with signal >5000DN not considered)

After removing readout and windowing effect (detrended image):
Background: 0.36 DN
STD: 21.52 DN

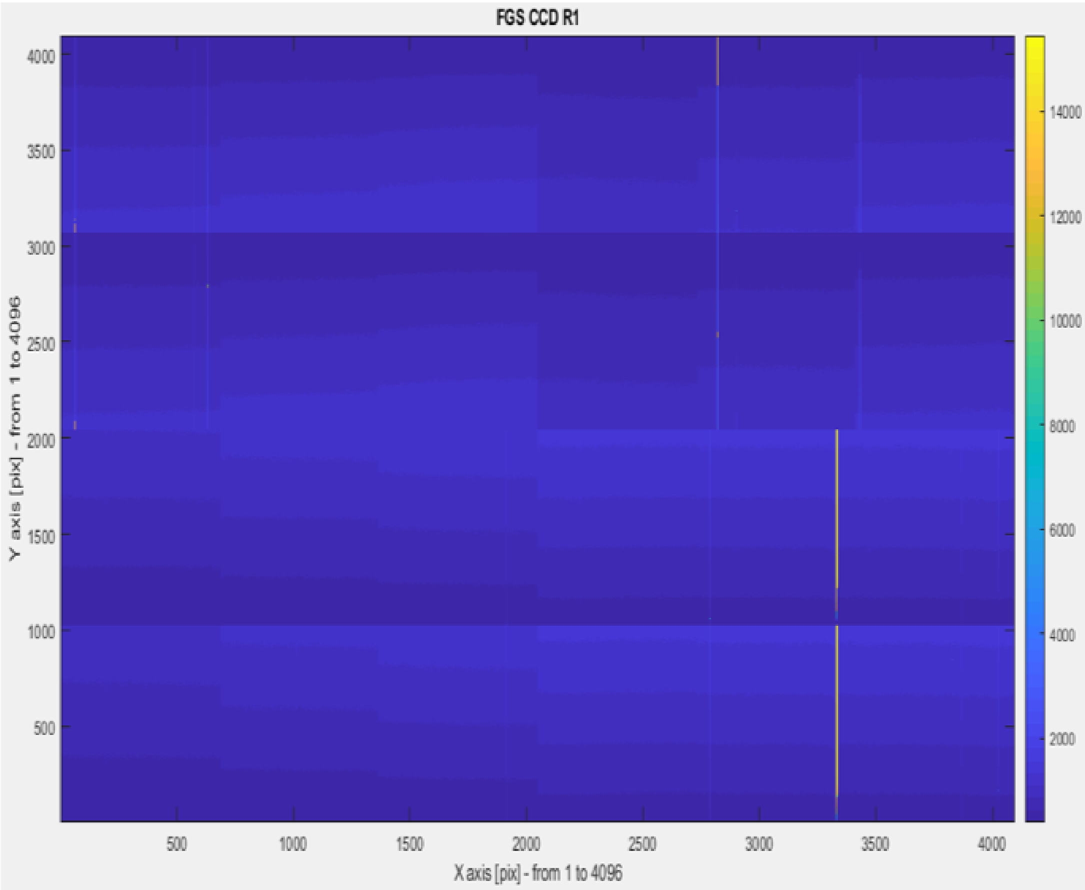

Figure 10: PEC R1 (PEC#1) obtained in dark conditions, without detrending

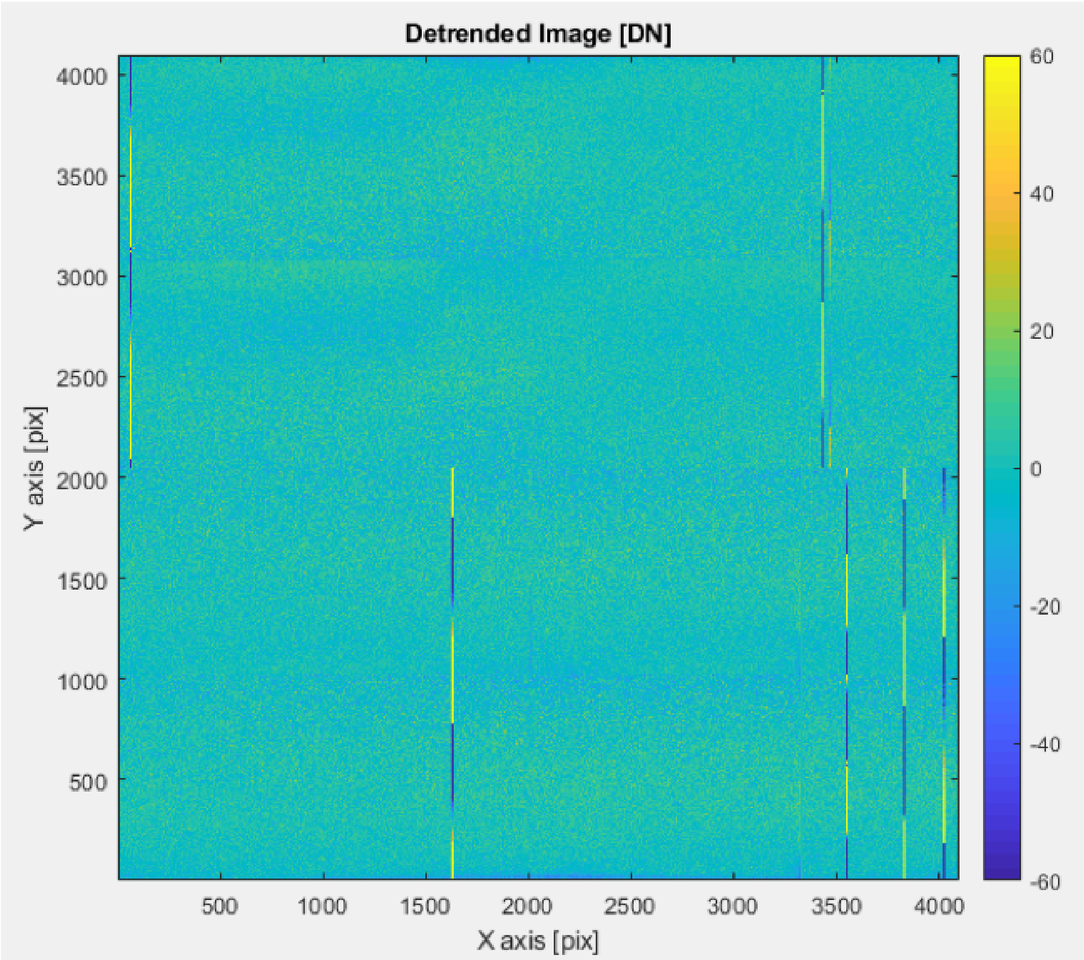

Figure 11: PEC R1 (PEC#1) obtained in dark conditions, with detrending

Known Bad Columns: only one (column 3331) which is visible in Figure 12. Due to the high temperature (in comparison to flight conditions), we observed leakage of electrons of this bad column to the adjacent ones.

Known Hot Pixels: 22. In our tests only hot pixels with high energy were observed:

Row (CCD Coordinates)	Column (CCD Coordinates)	Energy (DNs)
1400	3332	62
1401	3332	4028
1402	3332	225

Table 5: Observed hot pixels in PEC R1 (PEC#1)

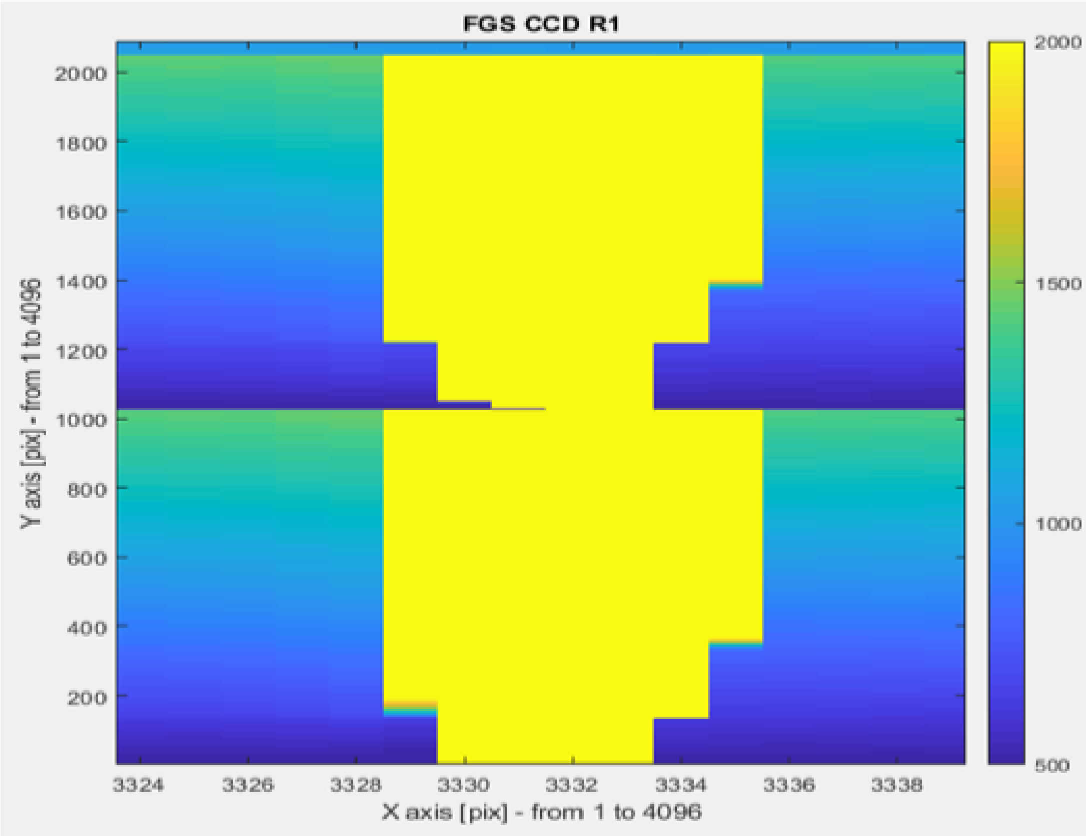

Figure 12: PEC R1 (PEC#1) bad column detected: 3331.

5.15.2 PEC R2 (PEC#2)

Image: 686x1024 pixels, 10ms exposure time.

Background: 940 DN (pix with signal >5000DN not considered)

STD: 274 DN (pix with signal >5000DN not considered)

After removing readout and windowing effect (detrended image):

Background: 0.11 DN

STD: 12.58 DN

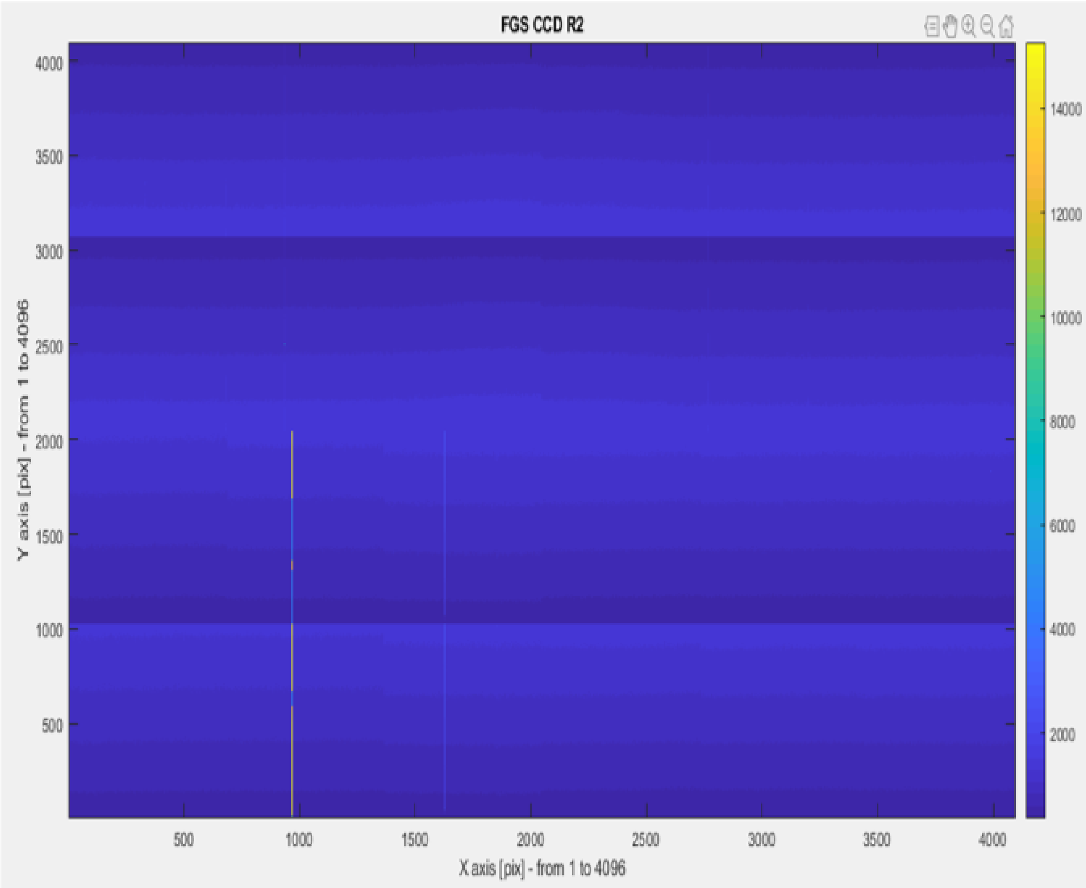

Figure 13: PEC R2 (PEC#2) obtained in dark conditions, without detrending

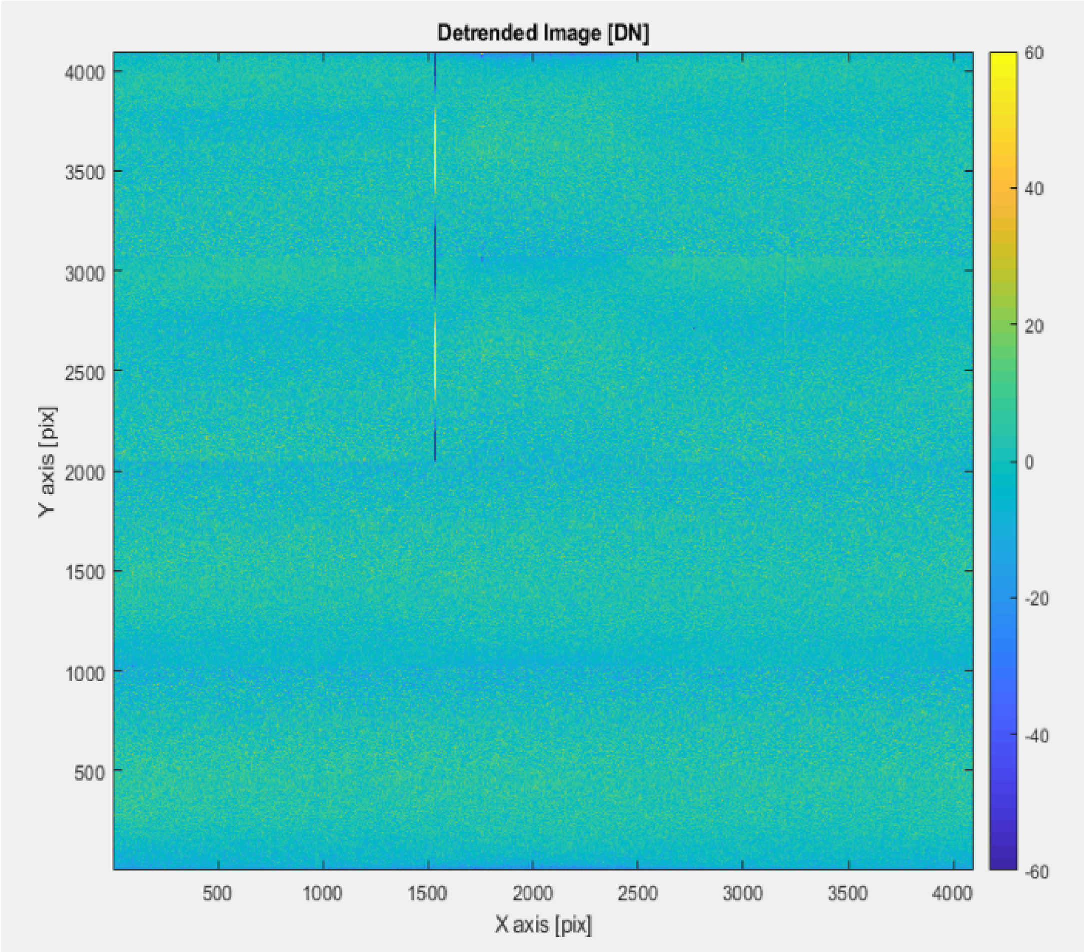

Figure 14: PEC R2 (PEC#2) obtained in dark conditions, with detrending

Known Bad Columns: only one (column 970) which is visible in Figure 15. Due to the high temperature (in comparison to flight conditions), we observed leakage of electrons of this bad column to the adjacent ones as seen in PEC#1.

Known Hot Pixels: 23. In our tests only hot pixels with high energy were observed:

Row (CCD Coordinates)	Column (CCD Coordinates)	Energy (DNs)
1336	969	28
1337	969	677
1337	970	466

Table 6: Observed hot pixels in PEC R2 (PEC#2)

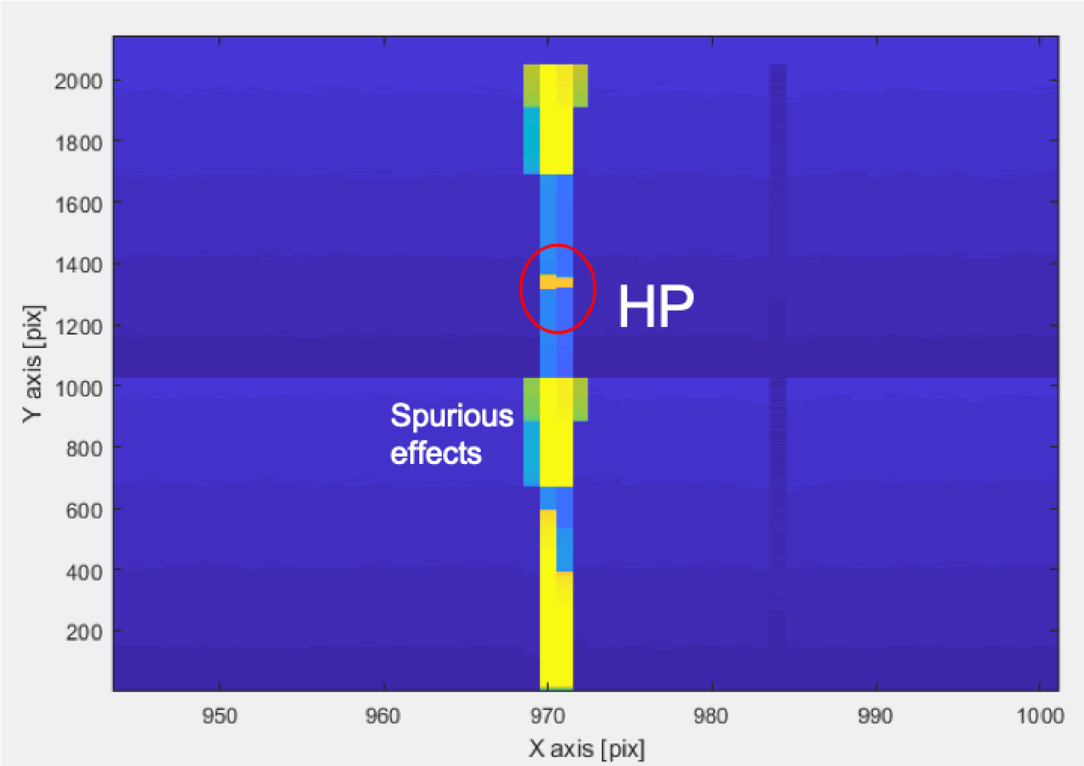

Figure 15: PEC R2 (PEC#2) bad column detected: 970.

5.15.3 PEC L1 (PEC#4)

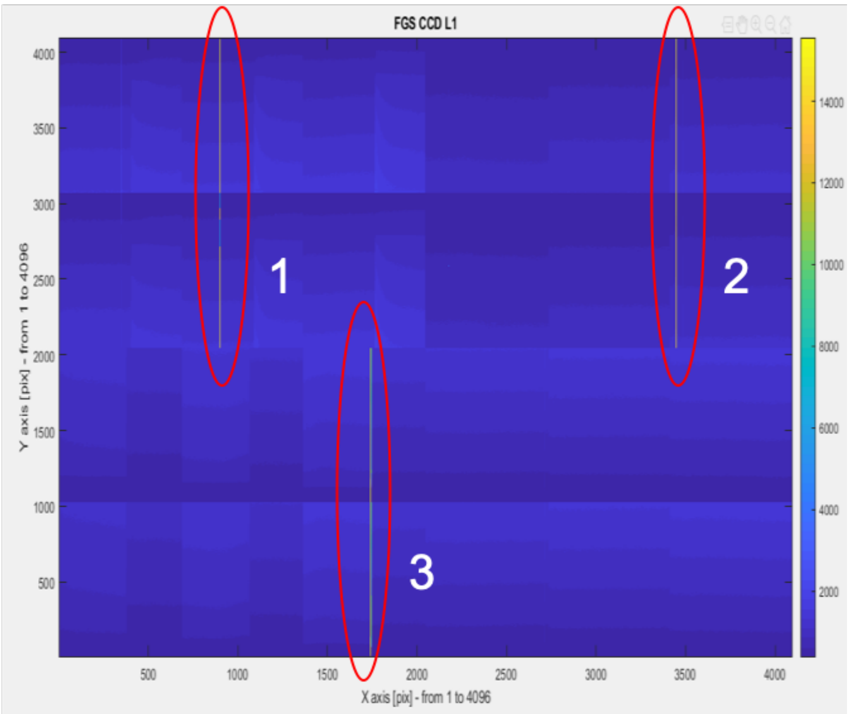

Figure 16: PEC L1 (PEC#4) obtained in dark conditions, without detrending

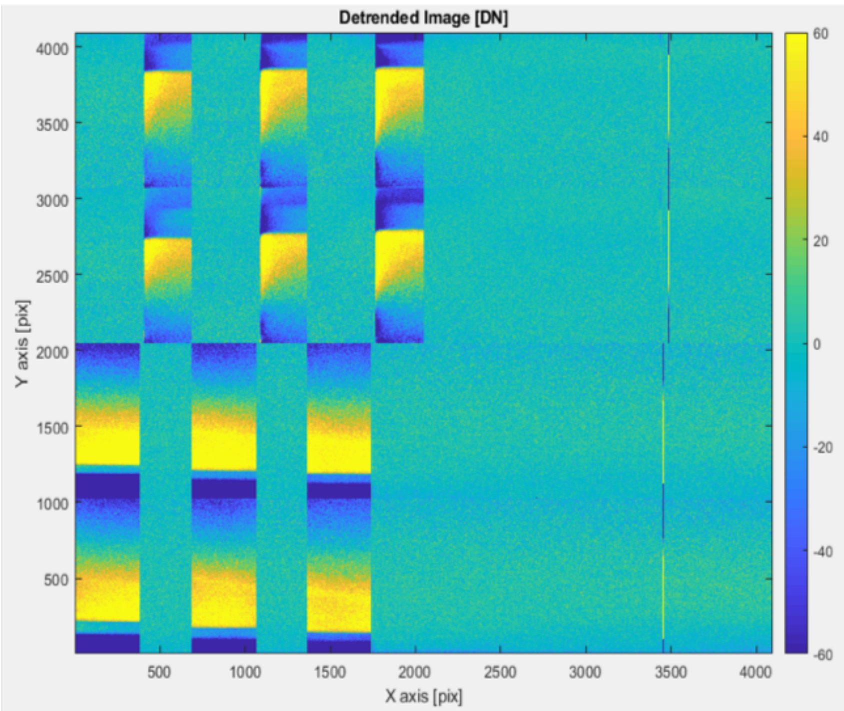

Figure 17: PEC L1 (PEC#4) obtained in dark conditions, with detrending

Known Bad Columns: no known bad columns.

Known Hot Pixels: 16. In our tests only hot pixels with high energy were observed:

Row (CCD Coordinates)	Column (CCD Coordinates)	Energy (DNs)
3084	350	1443
3084	351	39
3085	350	401
2845	3447	395
2845	3448	1047
2846	3447	1122
2846	3448	1516
1227	1741	558
1227	1742	928
1227	1743	200
1228	1742	232

Table 7: Observed hot pixels in PEC L1 (PEC#4)

Since we were not working in flight conditions, the bad columns observed in Figure 16 are considered to be caused by the hot pixels which leak energy to the entire column. PEM manufacturer was informed about the phenomena found and we received confirmation of the fact that hot pixels caused this effect. Also, due to the same reason, a linear trend was observed in the "detrended" image of L1.

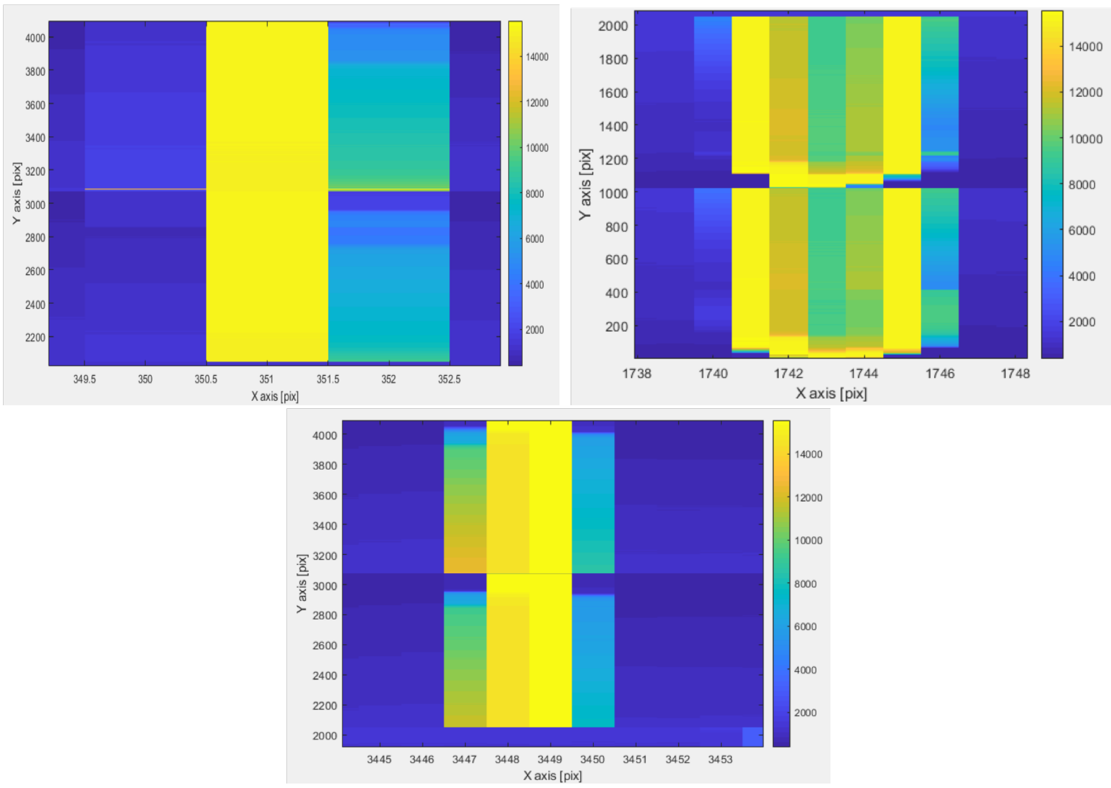

Figure 18: PEC L1 (PEC#4) bad columns detected: 351, 1743, and 3449.

5.15.4 PEC L2 (PEC#3)

Image: 686x1024 pixels, 10ms exposure time.
Background: 1004 DN (pix with signal >5000DN not considered)
STD: 296 DN (pix with signal >5000DN not considered)

After removing readout and windowing effect (detrended image):
Background: 0.07 DN
STD: 17.95 DN

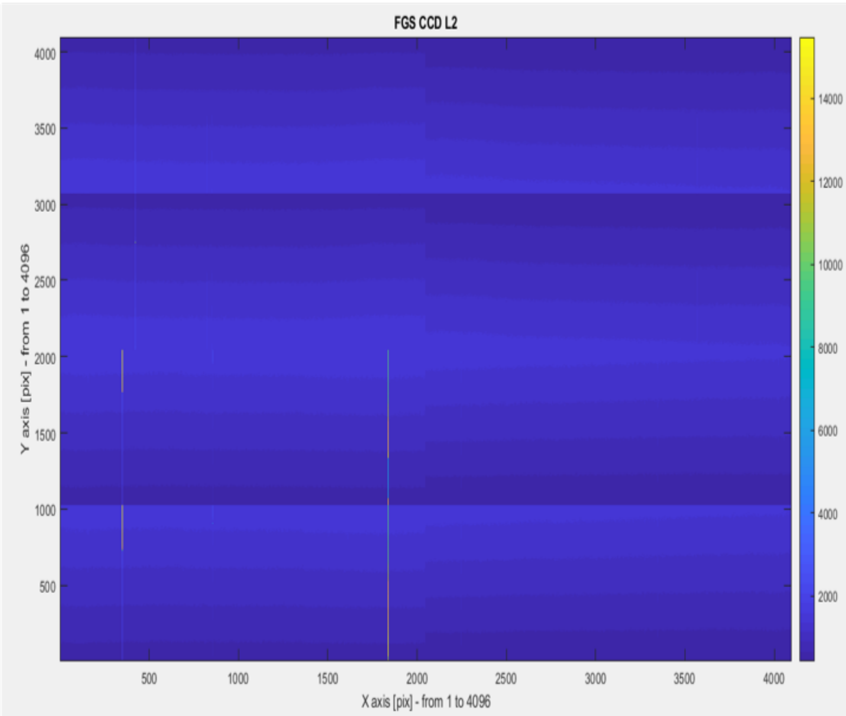

Figure 19: PEC L2 (PEC#3) obtained in dark conditions, without detrending

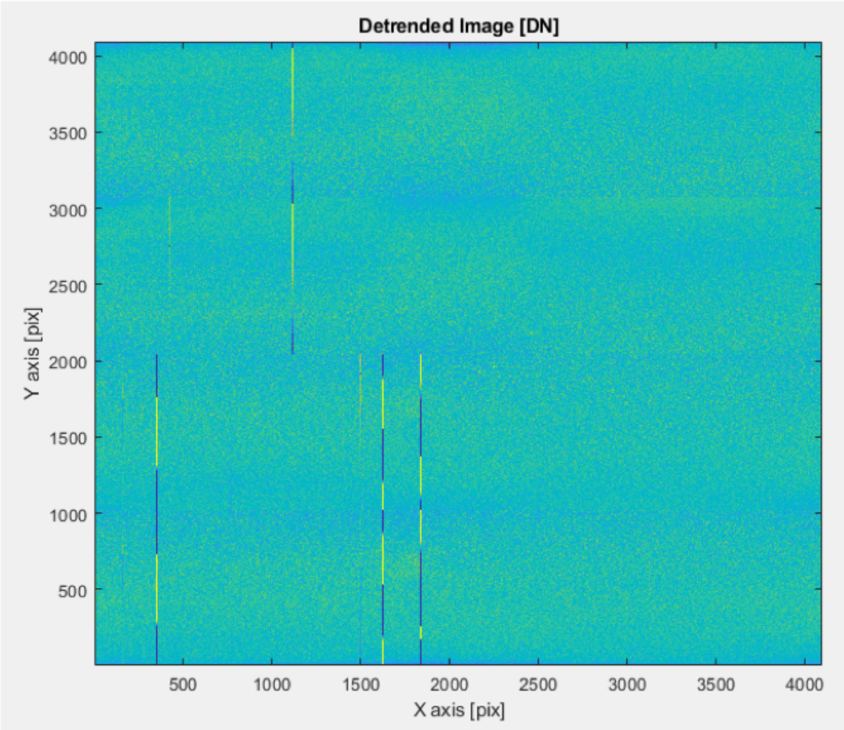

Figure 20: PEC L2 (PEC#3) obtained in dark conditions, with detrending

Known Bad Columns: only one (column 3331) which is visible in Figure 12. Due to the high temperature (in comparison to flight conditions), we observed leakage of electrons of this bad column to the adjacent ones.

Known Hot Pixels: 33. In our tests only hot pixels with high energy were observed:

Row (CCD Coordinates)	Column (CCD Coordinates)	Energy (DNs)
1022	1836	502
1022	1837	545
1023	1836	598
1023	1837	718

Table 8: Observed hot pixels in PEC L2 (PEC#3)

5.16 PFM_SST_FGS_17 - FGS EU 1553 Health Check

Summary: SUCCESSFUL Apart from the implementation defined on the Test Description, an important point of this test is to verify the absence of errors in the MILBUS-STD-1553B Platform (PLF) Bus. For this purpose, the software Wireshark comes installed in PLM SCOE to sniff the traffic in the bus. No errors were detected in this program, demonstrating the proper functioning of the communication between the Electronic Unit and the simulated SVM.

Non-Conformities: No NCRs detected.

5.17 PFM_SST_FGS_18 - FGS Star Catalogue Generation, Upload and Use

Summary: SUCCESSFUL. Only the upload of the star catalog is foreseen in this test. One catalog was made available by FGS EU manufacturer for this test. Direct telecommands containing the catalog were sent sequentially and at the end a telemetry packet (event) TM(5,1) CATALOGUE_UPLOAD_COMPLETED was trapped. Afterwards, the on board catalog was downloaded and compared offline with the uploaded one to double check the functionality of the telecommands.

Non-Conformities: NCRs detected. Not blocking the continuity of the test

- **(New) NCR 563:** "FGS ASW event TM(5,2) CATALOGUE_UPLOAD_FAIL has no parameters". When uploading an invalida catalog, FGS EU ASW gives an event TM(5,2) CATALOGUE_UPLOAD_FAIL, which according to the manufacturer must have 1 parameter (Failure reason ID 1byte). ASW sends this event without this Failure Reason. Neither raw telemetry data from ASW, nor the DB show this parameter.
  - This NC was detected in debug stage of the test sequences. Some experimentation was done when uploading the catalog. One of the failed attempts resulted in a CATALOGUE_UPLOAD_FAIL event. As shown in the Figure 21 the telemetry packet received from the Electronic Unit is not in accordance with the description of the packet in the ICD (Figure 22). After discussion with the manufacturer, we were informed that this events can only be generated due to wrong size of the uploaded catalog. That is the reason why the Failure Reason parameter was not generated anymore. The conclusion was to use-as-is, following the update of the applicable document of the FGS ASW.

```
2019-11-06T14:20:11.335 320000304  TM(5,2) CATALOGUE_UPLOAD_FAIL                    VC = 0   APID = 1910 SSC = 537
         00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
         _______________________________________________
  0000 | 0F 76 C2 19 00 12 10 05 02 00 5D C2 D6 99 F4 05
  0010 | 7F 42 10 00 00 03 8B 93 4A
  2019-11-06T14:20:11.335 @TM FAAT2277         FGS_EID              Unit = N/A  Status = VALID           Raw = 32578
  2019-11-06T14:20:11.335 @TM FAAT2010         FGS_OPMODE           Unit = N/A  Status = VALID           Raw = 16
  2019-11-06T14:20:11.335 @TM FAAT2011         FGS_ABSOLUTE_CYCLE   Unit = N/A  Status = VALID           Raw = 907
```

Figure 21: NCR 653. Log capture of FGS EU ASW TM(5,x) telemetries. The complete extraction was done using CADET utility.

32578	CATALOGUE_UPLOAD_FAIL	low	Star catalogue upload failure.	Param 1 : Failure reason ID (1Byte) 1: OUT OF RANGE 2: CCD FLAGS NOT EQUAL	EP SSW	V0.5

32578	CATALOGUE_UPLOAD_FAIL	low	Star catalogue upload failure for wrong size		EP SSW	V0.5

Figure 22: NCR 653. Capture of the Software ICD of FGS ASW. The first one is the document at the moment of NCR aperture, and the second one is the updated document (next issue) for the closure of the NCR.

5.18 PFM_SST_FGS_99 - FGS Switch Off

Summary: SUCCESSFUL. Nominal Power Off of FGS EU.

Non-Conformities: No NCRs detected.

6 Conclusions and Future Work

During this project work, a subset of the Integrated Sub System Test (ISST) described in the test procedure ([3], which was also written by me), was performed using FGS Electronic Unit in two test campaigns: one in Thales Alenia Space Italy (Turin), and the other one in Airbus France (Toulouse). The Electronic Unit and its software is already accepted from Thales Alenia Space, but some minor problems are still to be solved. These problems are internally traced using Non-conformity Reports (NCR) that are constantly revised jointly with Leonardo Airborne & Space Systems and CRISA, which are the FGS manufacturers. Within this framework, my tasks are to perform further reduced tests to verify the fixes implemented by LDO in FGS ASW and to open more Non-Conformity Reports if other problems are found. The NCRs opened until now are not blocking further tests.

The tests that are still pending are the ones to entirely validate the Relative Tracking Mode (RTM) and Absolute Tracking Mode (ATM). This modes are still under testing and verification in LDO premises, and soon these functionalities are going to be available for us to test and validate them. Once the tests are ready and performed, the ISST test campaign will be finished and the next step is to integrate FGS to its belonging system: AOCS. The tests will continue but with FGS integrated in the closed-loop control system for stabilization of the attitude of Euclid spacecraft in order to perform science acquisitions.

7 Annexes

A1 Acronym List

Abbreviation	Meaning
AOCS	Attitude and Orbital Control System
ASW	Application Software
ATM	Absolute Tracking Mode
AVM	Avionics Model
BOB	Breakout Board
BSW	Basic Software (same as SUSW on FGS)
CCD	Charge-coupled Device
CCS	Central Checkout Systems
CDMS	Control and Data Management System
CDMU	Control and Data Management Unit
CHM	Checkout Mode
DB	Demountability Bracket
DIAG	Diagnostic
EGSE	Electrical Ground Support Equipment
EQM	Engineering Qualification Model
ESG	Electrical Stimuli Ground Equipment
EU	Electronic Unit
FGS	Fine Guidance Sensor
FM	Flight Model
FUMO	Functional Model
HK	Housekeeping
HK	Housekeeping
I/F	Interface
ICD	Interface Control Document
INI	Init Mode (of SUSW)
ISST	Integrated Subsystem Test
IST	Integrated System Test
LDO	Leonardo Airborne and Space Systems
MMU	Mass-memory Unit
MNM	Maintenance Mode (of SUSW)
NCR	Non-Conformity Report
NISP	Near-Infrared Spectrometer and Photometer
NRB	Non-conformity Review Board
OBSW	On-Board Software
PCDU	Power Control and Distribution Module

Abbreviation	Meaning
PEC	Processing Electronic Channel
PEM	Power Electronic Module
PFM	Protoflight Model
PHM	Photo Mode
PLF	Platform
PLM	Payload Module
PTR	Post Test Review
RLE	Run-Length Encoding
RTM	Relative Tracking Mode
S/C	Spacecraft
SBM	Standby Mode
SCOE	Special Check-out Equipment
SpW	SpaceWire
SUSW	Startup Software (same as BSW on FGS)
SVM	Service Module
TAS	Thales Alenia Space
TC	Telecommand
TM	Telemetry
TRR	Test Review Board
VIS	VISible Imager Instrument

References

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