HERSCHEL / PLANCK

System Design Report for CDR

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1. SCOPE

1.1 Objectives

This document presents a technical, system-level presentation and justification of the Herschel and Planck satellites, design, interfaces and performances to support the Critical Design Review (CDR).

The Herschel and Planck satellites are built in a modular way with 2 modules per satellite:

– Service Module (SVM) which houses the platform equipment and the instrument warm units. The SVM's for Herschel and Planck shares strong similarities. They are both under ALENIA responsibility and their design is described in the "SVM Design Report" (RD01.1)

– Payload Module (PLM) which provides the cold environment for the Herschel and Planck payloads. Each PLM is very specific due to the different requirements of the payloads. The Heschel PLM (H-EPLM), under Astrium responsibility, is decribed in the "H-EPLM Design Description" (RD01.2) while the Planck PLM (P-PLM), under Alcatel responsibility is described "P-PLM Design Report" (RD01.3). In the frame of the overall CDR process, the Payload Module CDR have been successfully conducted before the System and SVM CDR.

The present document focuses on overall system design and architecture and does not aim at detailing the module design. The reader is invited to refer to the Module design reports for detailed module description.

1.2 Organisation of the document

Section 2 gives the list of reference and applicable and reference documents used to build the design. It also shows the relationship between the various documents.

Section 3 details the most salient requirements for Herschel and Planck which are important design drivers.

Section 4 details the mission analysis aspects.

Section 5 details the requirements from the instruments and their implementation.

Section 6 presents the overall system design of the Herschal and Planck satellites.

Section 7 presents a summary of the analyses performed on Herschel satellite to justify the design.

Section 8 presents a summary of the analyses performed on Planck satellite to justify the design.

The budget for Herschel and Planck are presented in a separate document, the "System Budget Report" (RD02.3).

1.3 Overall program status summary

1.3.1 Overview

The Kick off of industrial Phase B took place in April 2001. The first program review i.e., the System Requirements Review was successfully completed in October 2001. The Preliminary Design Review was kicked-off on 02/07/02. Close out of the PDR took place on 12/12/2002.

The present Critical Design Review will start with the Kick-Off on 17/08/04, collocation is planned in week 40 of 2004 (from 28/09/04 to 1/10/04) and the ESA Board Meeting is planned on 12/10/2004.

Further formal reviews are planned as follows:

- Qualification Review (QR) beginning of 2006
- Acceptance Review (AR) beginning of 2007

The Launch date is nominally scheduled on 3/08/2007.

1.3.2 Main achievements since PDR

The design process from PDR to CDR follows a "V" cycle in which PDR is first performed at system level then at lower levels while for CDR a bottom-up approach is followed, lower level CDR's being conducted before modules (H-PLM and PPLM) and system CDR (combined with the SVM CDR).

So, following the system PDR, the PDR's at subsystem and equipment levels were conducted. At SVM level, the ones which are not finalised are:

- Reaction Wheels for which a close-out is planned, combined with the CDR, in September 2004
- The PDR for the harness, which has been combined with the CDR, is still open. Close-out of the major actions from the PDR is planned for beginning of September 2004. This will allow to re-initiate the CDR process with a review planned for beginning of October 2004.

At H-PLM levels, the updated inputs from the launcher related to the Barbecue and Hot Spot modes has delayed the review process for the external MLI's. The PDR, combined with the CDR is planned for beginning of September 2004.

At system level, the PDR for the SVF was not successful and a delta-PDR is planned for end August 2004 (cw 36).

The CDR's have been completed for most equipments and subsystem with some still remaining open:

- H-PLM: the status of the lower level CDR's is decribed in the document "Herschel Subcontractors Review Synthesis Report", HP-2-ASED-RP-0115. Since the issue of this document, the status of the PDR's has evolved as described here above. For the CDR's, only the HSS CDR remains open.
- SVM: the status of the lower level CDR's is described in the document "Lower level CDR summary report"
- System: the status of the lower CDR's is described in the document " Lower level CDR synthesis", H-P-1-ASP-RP-0786.

Concerning the external interfaces, consolidation of the instruments and launcher interfaces occurred since PDR. For the instruments, all the IHDR's were conducted between 9/7/2003 and 13/05/2004 which allowed a stabilisation of the interfaces. In addition, the WIH routing was performed by ASP and is now frozen.

The main issues which were settled with Arianespace are:

- Launcher attitude during launch: the discussions initiated during Phase B have been finalised and a baseline has been defined. This led to the definition of roll transients at EAP and EPC separations. The impacts on the design (mainly external MLI's of the H-PLM and SVM top) have been analysed and introduced in the design
- Definition of the launch window and launcher capacity: several iteration took place to find the best optimum between system and launcher design. By allowing opening of the fairing at a lower SAA, a solution has been found maximising the launcher capacity while meeting the requirements in terms of launch window (6 months per year, 45 minutes per day) and minimising the impacts on spacecraft design.

The DCI's for Herschel and Planck have been issued (see AD03.4 and AD03.5).

Following PDR, an Avionics Consolidation Plan was conducted with the following objectives:

- Review of the avionics baseline, in particular FDIR mechanisms
- Compatibility of requirements with baseline and proper flow down to lower levels
- Review of internal and external interfaces
- Review of development plans and AIT plans.

All companies involved in the Avionics design (CDMS, ACMS, Software) participated to this plan which was successfully concluded by an "Avionics Review" on 23-24/04/03.

Several iterations took plance on the development plan to contain schedule and cost. In particular, the STM of Planck has been deleted. This has been justified by a risk analysis and is presented in the updated Design and Development Plan (RD03.28).

1.3.3 Critical areas

The following sections highlight critical areas on which special attention has been given during the Phase C. Each of these points will be further detailed as part of the relevant documents included in the CDR data package.

1.3.3.1 Design aspects

Satellite Mass

The Launch Mass has remained an issue during all phase C. Due to the change of launcher baseline to an A5 ECA, the launch specification to the satellite was increased from 5310 to 6269 kg including adapters, thus leaving a total mass of 5299 kg in the case of a launch with SPELTRA and the current requirement of 5349 kg for a launch with a SYLDA 5.

This allowed an evolution of the modules mass requirements, taking into account other important aspects:

- Structural sizing of the SVM: this was one limiting factor for the H-PLM mass
- Planck balancing: Planck being a spinner, the inertia ratio is a critical value for the ACMS sizing. This was limiting the mass increase of the Planck PLM.
- Overall Planck mass increase is limited by the tanks filling capacity.

The launcher capacity increase was used to increase the H-PLM Helium capacity in order to regain margins in the lifetime budget. Consequently, the H-PLM mass allocation was changed from 1653 kg to 1825 kg. The H-PLM mass budget initially went over this requirement but the latest trend shows a good stabilisation below the requirement. The trend is expected to improve with large elements (CVV, He tanks) which should be weighed during the summer.

On PPLM, the development phase showed a mass increase of the cryo-structure and telescope. Beginning of 2003 the mass requirement was updated to 272 kg. The PPLM has remained below this requirement. The QM hardware has now been weighed with a mass of 254 kg.

On SVM the main critical item was the structure. A mass reduction exercise was conducted when it appeared at the MRR2 close-out/MRR3 Input Review Board that a strong mass increase was announced by CASA. By conducting an audit on the way the structure was sized and revisiting the structure load cases, a mass reduction of around 50 kg was obtained.

The current launch mass budget is over the specification of SRS 3.2. However, taking into account the increased launcher capacity, an agreement was reached at the System PM#23 on updated mass requirements to which the spacecraft are compliant. The updated requirement will be reflected in the SRS 3.3 and the system mass budget has been based on this agreement.

Instruments interfaces

Numerous interface changes by the instruments still occurred during phase. They were mainly due to HIFI on Herschel and LFI on Planck. Due to the fact that all instruments have passed their IHDR the changes have stabilised and the latest evolutions tend more to formalise existing design features than to introduce design changes.

Some thermal interfaces with instruments are slightly out of specifications. This concerns Planck for which some 4K coolers elements (CRU, CCU) and the PAU are slightly out of specification (by 1-2 °C). These out of specification are obtained when all margins are included. It is expected that when, following testing, the margins can be reduced, the non compliance will disappear. ALS will submit a RFD. In addition, discussions are still ongoing on the thermal stability of the SCC.

Attitude transients during launch

During phase C, it appeared that the launcher attitude control could not ensure that, after fairing jettison, Herschel remains Sun pointed. Two transients were defined, one due to booster separation, one due to EPC separation leading potentially to a complete rotation of the launcher in roll. The main impact is on the H-PLM external MLI's. A first study was conducted to redefine MLI's able to withstand high temperature and tests were conducted at ESA to confirm the chosen design. Subsequently it appeared that Sun reflections on the telescope was leading to local hot spots on the Sunshade MLI. A design coping with this effect has just been defined by ASED and needs to be iterated with Austrian Aerospace, the MLI manufacturer.

Software

On software, the consolidation of requirements took longer than anticipated. In addition, the software complexity (autonomy, mission continuation, mandatory attitude control for cryogenic payload, FDIR) led to longer than planned software development. The situation at CDR is that the DDR has been performed for Basic SW and CDMS Application SW. QR/CDR of ACMS Application SW is planned in September 2004. Mitigation of risks and reduction of planning slippage impact has been performed via staggered delivery approach adjusting development effort to AIT needs. Collocation/resident from ALS at SFF premises (CDMS ASW contractor) is planned.

Data Base

The development for Herschel/Planck of a new Data Base starting from scratch took longer than anticipated. Indeed, the need to support 2 spacecraft in parallel and potentially 5 system AIT will, combined with operation commonality (SCOS 2000), lead to a complex but flexible and performing tool. Several iterations were also needed with ALS and its subcontractor to define an input format allowing to efficiency populate the database. The main issues are now solved and ALS is now using the data base to start the AVM testing.

ACMS

Great progress on ACMS was achieved since PDR related to both subsystem and SCOE design. The remaining areas of risk are related to Software Development and validation. Close monitoring is performed by ASP and ALS and collocation of ALENIA staff at DS/Sener is planned.

Solar array

The novelty of both high temperature substrate developed in Kongsberg as well as the use of triple junction GaAs solar cells is a risk element identified at the start of the programme. While the development is on-going (coupon in tes, Planck STM in assembly), numerous NCR's were raised. The main NCR's are related to the shunt diode integrated to the cell. Question have been raised about the qualification of the cell in lifetime. A working group will be organised by ASP, in coordination with ALS and ASED to cover these issues.

Propulsion

Several difficulties have occurred during the tank membrane development. The difficulties were increased by the fact that the subcontractor was a US one which induced lack of visibility and difficulty to get full traceability. The QM membrane presents small cracks but has successfully gone through life testing (equivalent to 4 times the lifetime). Further verification that the cracks do not induce contamination will be performed during QM testing of the tank, while ESA will check that the cracks do not propagate. Go-ahead has been given for FM membrane manufacturing.

The schedule impact of late tank delivery is mitigated by the possibility to have late integration of the tanks into the satellites.

1.3.3.2 Performance aspects

Herschel cryogenic lifetime

Taking the opportunity of the launcher capacity increase provided by the baselining of the Ariane 5 ECA upper stage, it was decided by beginning of 2003 to increase by 100 mm the height of the He II tank. At this opportunity, agreement was reached by all parties on the definition of lifetime and associated margins. Since then ASED has always be compliant with the 3.5 years cryogenic lifetime including all dispersions and margins.

Pointing

To meet the stringent pointing requirements of Herschel, the STR is now accommodated on a platform directly linked to the CVV lower bulkhead. This allows to have a very stable thermal interface leading to high thermo-elastic stability. The Herschel pointing budgets are fully compliant to requirements, except for SRPE which is linked to the intrisic performance of the STR (see discussion in RD02.3).

Cleanliness

Following a detailed analysis of the CVV windows in-orbit cleanliness, it appears that the levels of particulate and molecular contamination on the CVV windows were above HIFI expectations. After iteration with HIFI, it was clarified that the requirement of 80 % transmission was the driving requirement for the instrument. The cleanliness analysis of the LOU windows has been further refined (see RD04.6) taking into account in particular rediffusion from adjacent surfaces. This allowed to consolidate the molecular contamination figure. Using this updated figure the transmission budgets are well within specification (see RD03.21) and it is proven that the molecular contamination can be increased by more than an order of magnitude while still meeting the transmission specification.

1.3.3.3 Verification aspects

Instruments verification

An open issue remains on the level of instrument testing before delivery to the satellite level AIT. Since PDR, the schedule pressure on the instruments have further increased and there is the risk that the instrument teams reduce testing to meet the agreed delivery dates. Considering instrument testing at satellite level, iterations will have to be performed with instruments to consolidate the implementation of the existing Test Requirement Sheets into Satellite/Module Test Specifications. This activity is already running for the H-PLM EQM and Planck CQM models.

Planck telescope verification

Verification of the FM telescope is an open issue, linked to the out of specification of the FM reflectors. Several actions involving Alcatel and Contraves Space were undertaken with the following conclusions:

- Nominal OGSE is technically feasible but remains a complex operation. It is additionally only compatible with Reflectors within or very close to their specification (in particular for quilting)
- Interferometry simply does not work as the combination of the defects on the 2 reflectors combine in such a way as making the interferograms impossible to exploit.
- Alternative approach for Telescope verification based upon a focus-only control is under study. It might also be combined with videogrametry for reflectors shape control at operational temperature.

Planck cryogenic testing

The test configuration for Planck cryogenic testing in CSL has been consolidated. The facility CDR has been successful and a blank test is planned for October 2004. In coordination with the Cryo Chain Study, a model of the whole cryo chain is available and running. It has run at Alcatel to simulate the cool-down phase up to 0.1 K. This has been used to consolidated the cool-down sequence, defining with the instruments the various steps and criteria to start-up and operate the cryo-chain. Issue 1 of the Test Specification for the Planck CQM test is available and the test is planned beginning of 2005.

AVM

Considering the key objective within the verification process of the AVM, the test bed development in terms of technical performance and schedule has been closely monitored. The first tests involving the CDMU are now running. The overall logic has been established including links between hardware and software. The next major step will be the integration of the ACMS EM units which represent an important part of the bench. The AVM will also be used to accommodate instrument warm units for satellite testing.

2. DOCUMENTS

2.1 ESA documents

2.1.1 Technical Specifications

AD01.1 Herschel/Planck System Requirements Specification (SRS)
SCI-PT-RS-05991, Issue 3.2

AD01.2 Planck telescope Optical & RF System Specification
H-P-3-ASPI-SP-0274, Issue 2.0

2.1.2 ESA Undertakings

AD02.1 Herschel Telescope Specification
SCI-PT-RS-04671, Issue 7.0

AD02.2 Planck Telescope - Primary Reflector/Secondary Reflector Specification
SCI-PT-RS-07422, Issue 5.4

2.1.3 Satellite System Interface Specification

AD03.1 Herschel/Planck Operations Interface Requirement Documentation (OIRD)
SCI-PT-RS-07360, Issue 2.2

AD03.2 Herschel/Planck Space/Ground Interface Requirement Document (SGICD)
SCI-PT-RS-07418, Issue 3.1

AD03.3 Herschel/Planck Packet Structure ICD
SCI-PT-RS-07527, Issue 5.0

AD03.4 Herschel DCI
DCI-10-501-31, Issue 0.0

AD03.5 Planck DCI
DCI-10-501-32, Issue 0.0

2.1.4 Instrument Interface Specifications

AD04.1 Herschel/Planck IID Part A
SCI-PT-IIDA-04624, Issue 3.3

AD04.2 IID Part B: SPIRE
SCI-PT-IIDB/SPIRE-02124, Issue 3.2

AD04.3 IID Part B: HIFI
SCI-PT-IIDB/HIFI-02125, Issue 3.2

AD04.4 IID Part B: PACS
SCI-PT-IIDB/PACS-02126, Issue 3.2

AD04.5 IID Part B: HFI
SCI-PT-IIDB/HFI-04141, Issue 3.2

AD04.6 IID Part B: LFI (including Sorption Cooler ICD 3.0 draft3)
SCI-PT-IIDB/LFI-04142, Issue 3.1

2.2 Prime Documentation

2.2.1 Satellite System Specifications

AD05.1 General Design and Interface Requirements
H-P-1-ASPI-SP-0027, Issue 4.2

AD05.2 Environment and Test Requirements
H-P-1-ASPI-SP-0030, Issue 4.2

AD05.3 Cleanliness Requirement Specification
H-P-1-ASPI-SP-0035, Issue 2.2

AD05.4 EMC Specification
H-P-1-ASPI-SP-0037, Issue 4.0

AD05.5 Software Design Requirement Specification
H-P-1-ASPI-SP-0046, Issue 3.0

AD05.6 SVM Requirements Specification
H-P-4-ASPI-SP-0019, Issue 4.1

AD05.7 H-EPLM Requirements Specification
H-P-2-ASPI-SP-0250, Issue 3.2

2.2.2 Product Assurance Requirements

AD06.1 Radiation Requirements
H-P-1-ASPI-SP-0017, Issue 1.0

AD06.2 Safety Requirements for Subcontractors
H-P-1-ASPI-SP-0029, Issue 2.1

2.2.3 Interfaces Requirements

AD07.1 SVM Interface Specification
H-P-4-ASPI-IS-0042, Issue 5.0

AD07.2 H-EPLM Interface Specification
H-P-2-ASPI-IS-0039, Issue 5.0

AD07.3 P-PLM Interface and Applicability Specification
H-P-3-ASPI-IS-0070, Issue 3.0

AD07.4 Herschel MTICD
H-P-2-ASPI-ID-0258, Issue 2.0

AD07.5 Planck MTICD
H-P-3-ASPI-ID-0257, Issue 2.0

AD07.6 Herschel System Electrical ICD
H-P-2-ASPI-ID-0260, Issue 2.0

AD07.7 Planck System Electrical ICD
H-P-3-ASPI-ID-0259, Issue 2.0

AD07.8 MGSE Interfaces Specification
H-P-1-ASPI-IS-0120, Issue 4.0

AD07.9 EGSE Interfaces Requirements Specification
H-P-1-ASPI-IS-0121, Issue 4.0

2.3 Reference Documents

2.3.1 Design Reports

RD01.1 SVM Design Report
H-P-RP-AI-0005, Issue 3.0

RD01.2 H-EPLM Design Description
H-P-2-ASEP-RP-0003, Issue 3.0

RD01.3 P-PLM Design Report
H-P-3-ASPI-RP-0313, Issue 2.0

2.3.2 Budget Reports

RD02.1 SVM Budget Report
H-P-BD-AI-0001, Issue 3.0

RD02.2 H-EPLM Budget Report
H-P-2-ASED-RP-0004, Issue 3.0

RD02.3 System Budget Report
H-P-1-ASPI-BT-0264, Issue 7.0

2.3.3 Trade-offs, Technical Notes, Plans

RD03.2 Planck Cleanliness Control Plan
H-P-1-ASPI-PL-0253, Issue.3.0

RD03.3 EMC/ESD Control Plan
H-P-1-ASPI-PL-0038, Issue 3.1

RD03.4 Herschel System Alignment Plan
H-P-1-ASPI-PL-0276, Issue 3.0

RD03.5 Planck System Alignment Plan
H-P-3-ASPI-PL-0078, Issue 4.0

RD03.7 Herschel/Planck Pointing Budget Module Allocation
H-P-1-ASPI-BT-0176, Issue 3.0

RD03.8 Inhibits/Separation Functions
H-P-1-ASPI-TN-0195, Issue 3.0

RD03.9 Data Flow
H-P-1-ASPI-TN-0154, Issue 1.0

RD03.10 Time Adjustment
H-P-1-ASPI-TN-0153, Issue 1.0

RD03.11 Data Rates and Downlink Rates
H-P-1-ASPI-TN-0130, Issue 3.0

RD03.12 Effect of Attitude Control on Herschel and Planck Operational Orbit
H-P-1-ASPI-TN-0131, Issue 1.0

RD03.13 Calculation of Herschel Solar Forces and Torques
H-P-1-ASPI-TN-0088, Issue 2.0

RD03.14 OBSW Documentation and Reviews
H-P-1-ASPI-TN-0219, Issue 1.0

RD03.15 System Impact of the Increase of the Planck Orbit Size Angle
H-P-1-ASPI-TN-0235, Issue 1.0

RD03.16 Cleanliness EOL Needs
H-P-1-ASPI-TN-0197, Issue 2.0

RD03.18 Impact of propellant tank temperatures on wobble angles
H-P-1-ASPI-TN-0132, Issue 2.0

RD03.20 Mission TimeLine Management
H-P-1-ASPI-TN-0316, Issue 1.1

RD03.21 Herschel optical performances
H-P-2-ASPI-TN-0344, Issue 3.0

RD03.22 Herschel safety analysis
H-P-2-ASP-AN-0609, Issue 1.1

RD03.23 Planck safety analysis
H-P-3-ASP-AN-0610, Issue 1.1

RD03.24 Time Synchronisation
H-P-1-ASPI-TN-0391, Issue 1.1

RD03.25 Herschel Telescope Heater Connections
H-P-2-ASP-TN-0531, Issue 1

RD03.26 On the Use of the Herschel/Planck Mission Time Line
SCI-PT-16783, Issue 1

RD03.27 Intended Operational Usage of Sub-schedules
ESA/ESOC OPS-OGH draft document, author M Schmidt, dated 31/03/2004

RD03.28 Design and Development Plan
H-P-1-ASPI-PL-0009, Issue 4.0

2.3.4 Analyses

RD04.1 CDR Planck dynamical analysis & sine prediction report
H-P-1-ASP-AN-0718, Issue 1.0

RD04.2 CDR Thermal analysis report
H-P-1-ASPI-RP-0692, Issue 1.0

RD04.3 Herschel-Planck EMC analysis
H-P-1-ASPI-AN-0202, Issue 2.0

RD04.4 Radiation shielding analysis of Herschel and Planck satellites
H-P-1-ASPI-RP-0321, Issue 1.0

RD04.5 Herschel-Planck ESD analysis
H-P-1-ASPI-RP-0268, Issue 2.0

RD04.6 End of Life Cleanliness analysis
H-P-1-ASPI-AN-0269, Issue 4.0

RD04.7 Herschel Random Environment Analysis
H-P-2-ASPI-AN-0112, Issue 3.0

RD04.8 Planck Random Environment Analysis
H-P-2-ASPI-AN-0113, Issue 3.0

RD04.9 Shock Evaluation Results, Launcher Shock
H-P-1-ASPI-TN-0214, Issue 1.0

RD04.10 CDR Herschel dynamical analysis & sine prediction report
H-P-1-ASP-AN-0719, Issue 1.0

RD04.12 CDR Herschel microvibration analysis report
H-P-2-ASP-AN-0773, Issue 1.0

RD04.13 CDR Herschel microvibration analysis report
H-P-2-ASP-AN-0774, Issue 1.0

RD04.14 Herschel vibro-acoustic analyses
H-P-2-ASPI-AN-0354, Issue 1.0

RD04.15 Planck vibro-acoustic analyses
H-P-3-ASPI-AN-0353, Issue 1.0

RD04.18 Planck PLM RF performance analysis
H-P-3-ASPI-AN-323, Issue 2.0

RD04.19 LGA PATTERN with Herschel RF mock-up
H-P-1-ASP-TN-0617, Issue 1.0

RD04.20 Ariane V ECA/PLANCK preliminary coupled load analysis evaluation
H-P-3-ASP-TN-0493, issue 1.0

RD04.21 Ariane V ECA/HERSCHEL preliminary coupled load analysis evaluation
H-P-2-ASP-TN-0494, issue 1.0

RD04.22 PLANCK PLM Mechanical and Thermoelastic Analyses
H-P-3-ASP-AN-0329, issue 2.0

RD04.23 Risk Analysis Critical Item List And Control Plan
H-P-1-ASPI-LI-0212, Issue 4.0

2.3.5 Drawings

RD05.1 Herschel Grounding Diagram
H-P-2-ASPI-TN-0199, Issue 2.0

RD05.2 Planck Grounding Diagram
H-P-3-ASPI-TN-0200, Issue 2.0

RD05.3 Herschel Configuration and Interface Drawing File
H-P-2-ASPI-PL-0191, Issue 2.0

RD05.4 Planck Configuration and Interface Drawing File
H-P-3-ASPI-PL-0192, Issue 2.0

2.3.6 Subcontractors documentation

RD06.1 Herschel SVM CD Phase FEM Description
H-P-4-CASA-RP-0032, Issue 2.0

RD06.2 Planck SVM CD Phase FEM Description
H-P-4-CASA-RP-0033, Issue 3.0

RD06.4 H-EPLM FE Model Description – CDR Status
HP-2-ASED-TN-0025, Issue 4.0

RD06.5 H-EPLM Thermal Distortion Analysis – CDR Status
HP-2-ASED-TN-0046, Issue 2.0

RD06.6 Herschel Telescope
Finite Element Model Checks, CDR Status – Hexapod modification
HER.NT.00425.T.ASTR, Issue 1.0

RD06.7 Herschel E-PLM Structural Analysis Report
HP-2-ASED-TN-0049, Issue 2.0

RD06.8 Herschel H-EPLM Alignment Methods, Plan and Results
HP-2-ASED-TN-0097, Issue 1.0

RD06.9 SVM Structure Specification
H-P-SP-AI-0001, Issue 7.0

RD06.10 PLANCK PLM thermal analysis
H-P-3-ASPI-AN-0330, Issue 2.0

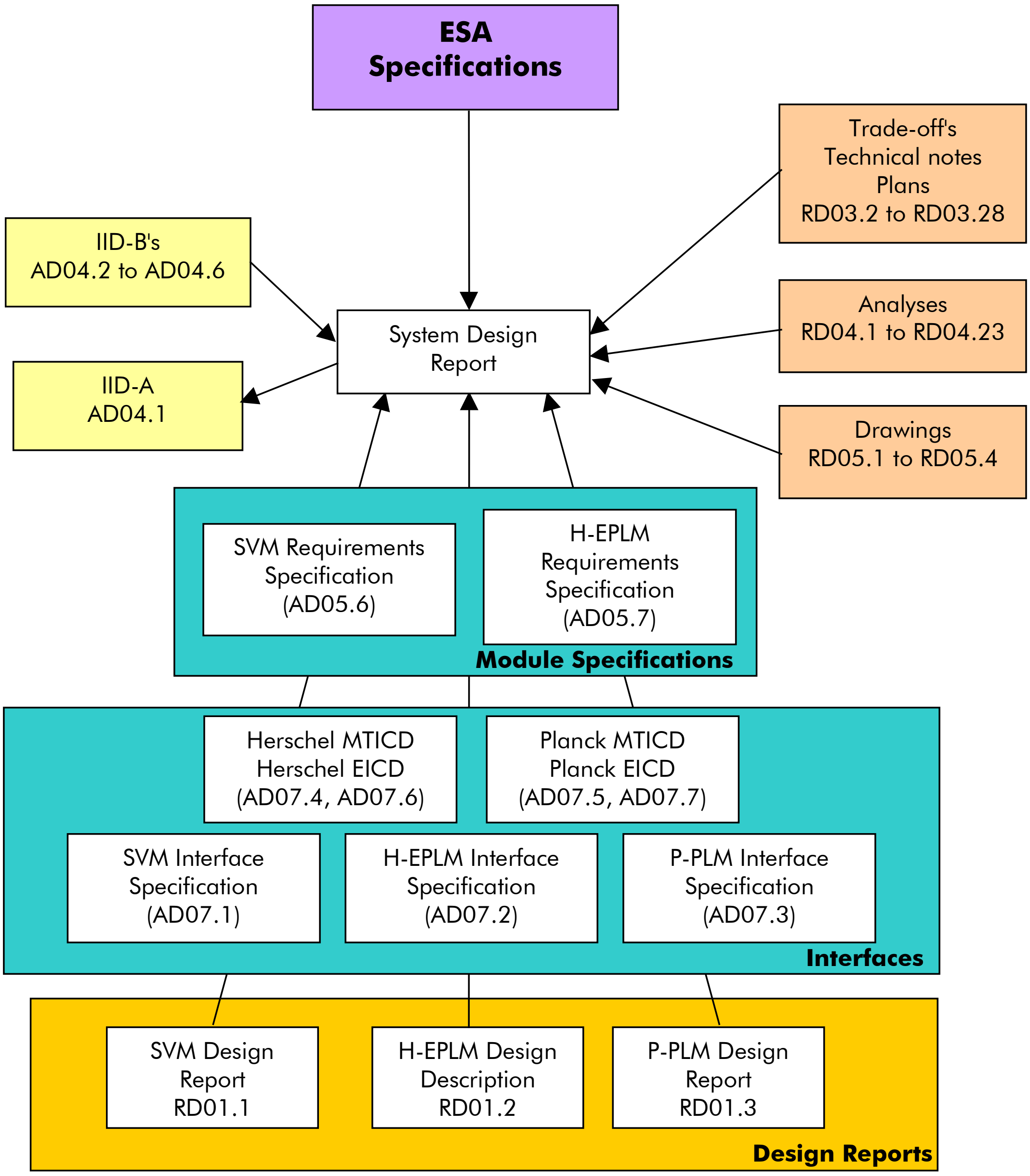
RD06.11 H-EPLM thermal model and analysis
HP-2-ASED-RP-0011, issue 4.0

RD06.12 SVM TCS thermal analysis report
H-P-AI-RP-0040, Issue 3.0

RD06.13 SVM Mechanical Environment and Test Specification
H-P-SP-AI-0033, Issue 2.0

2.4 Relationship between documents

The System Design Report provides the top level description of the Herschel and Planck satellite design. However, full description and justification is given by the whole engineering documentation as defined in Sections 2.1, 2.2 and 2.3. The following diagram shows the relationship between the various documents and provides a road map through the data package.



3. KEY SYSTEM REQUIREMENTS AND DESIGN DRIVERS

3.1 Main driving requirements

The driving requirements for Herschel and Planck are quite heterogeneous but they are basically identical for both satellites which is one of the reason to have merged the two missions in one single programme.

The main driving requirements are:

Cryogenic payload: both spacecraft have stringent temperature requirements for their focal plane units: down to 0.3 K on Herschel and 0.1 on Planck. The solutions, at payload module level, to reach these low temperatures are different between Herschel and Planck:

- Passive radiator at 60 K on Planck, plus accommodation of the active cooling chain provided by the experiments
- Superfluid Helium cryostat for Herschel, plus instrument sorption cooler on PACS and SPIRE.

Even if the payload modules are different, the satellite architecture derived from this requirement is similar on both spacecraft. It is based on the separation into 2 modules:

- PLM (PayLoad Module) housing the cold Focal Plane Units (FPU) and providing the cryogenic environment
- SerVice Module (SVM) housing the warm equipment: payload warm units and platform equipments.

In addition, efficient thermal decoupling has to be provided between the 2 modules:

- The SVM and PLM have to be linked by a conductively insulating link which impose the use of a Glass Fiber truss between the two modules
- Conductive heat loss has to be minimised through the harness linking the FPU to the warm boxes. This imposes the use of cryo harness which is particularly critical on Herschel
- Radiative decoupling between modules lead to the use of radiative shield which is the basics of Planck PLM thermal insulation but is also used on Herschel.

Finally, on both satellites, a Sunshield/Sunshade has to be implemented in order to protect the PLM from Sun illumination and to provide thermal insulation from Solar heat flux.

Operation from L2: both spacecraft will orbit the L2 Lagrange point of the Sun/Earth system. This allows to have optimum conditions for cryogenic spacecraft but constrains the launcher capacity, imposes long distances for telecommunications and drives system autonomy as visibility to ground for each satellite is only possible 3 hours per day with one ground station.

Interfaces: several type of interfaces drives the satellite design. The most important is the interface with the scientific instruments. Both spacecraft houses a complex payload. Even if the number of instrument is small (3 instruments on Herschel, 2 instruments on Planck) they are each composed of a large number of equipment boxes (total of around 20 on each spacecraft). Further more, on Planck, the presence of cooling chain leads to implementation of a complex tubing. In addition to FPU having cryogenic requirements, warm equipment boxes have specific thermal requirements in terms of reduced temperature range and thermal stability.

In the phase between PDR and CDR, the instrument interfaces have been frozen. The instruments held their IHDR (Instrument Hardware Design Review), the accommodation of instruments have been frozen and the instrument harness has been defined. Updated version of the IID-B's and of the IID-A have been produced for the CDR and this updated definition is reflected in the design.

The launcher interfaces are also driving requirements. It imposes a limited volume under the fairing both for Herschel in upper position and for Planck under SYLDA 5. The baseline launcher is the ARIANE 5 ECA with a specified launch capacity to L2 of 5349 kg: this is the allocation to the satellites to which the mass of adaptors (SYLDA 5 (440 kg), 2624 adaptors (120 kg each)) have to be added. An overall ESA reserve of 169 kg has to be kept inside the allocation to satellites. Further optimisation of the launch sequence (see section 4) allows to increase the launcher capacity by around 200 kg.

Autonomy: during operational orbit, the satellites will be operated by one ground station, meaning that the daily schedule consists of 3 hours of ground contact and 21 hours of autonomous operations. In order to cope with a ground station failure, the autonomy requirements are, for both spacecraft, to operate nominally during 48 hours and to survive during 7 days without ground contact. In order to ensure scientific mission continuity, the main driving requirement for autonomy is that no single failure should lead to entering the survival mode.

Attitude control: due to the presence of the cryogenic payload module, the attitude has to be controlled to avoid lighting of PLM's by Sun radiation. This imposes autonomous detection capability and recovery at ACMS level. In addition Herschel instruments requires accurate pointing in scientific mode: this drives the ACMS design by imposing high accuracy sensors. On Planck, the mission imposes a slow spinning spacecraft which leads to an ACMS concept which is intermediate between a true spinner and a 3-axis controlled spacecraft.

Commonality: given the similarity of both mission, the spacecraft can have a significant level of commonality. This is of course limited to the Service Module as the two payload modules are basically different. Commonality applies to the following items:

- SVM structure: similar design of both structure as well as simplification of mechanical testing
- Power: similar power needs and distribution requirements
- Telecommunication: identical requirements, only the antenna layout is different
- Data handling and ACMS: a similar avionics architecture can be used, allowing to have identical computers for Herschel and Planck, even if the ACMS requirements are different
- Propulsion: the delta-V requirements are in the same range for both spacecraft, allowing to use the same concept (hydrazine) and to have identical components on both spacecraft.

Lifetime: the nominal lifetime requirements for Herschel and Planck are the following:

- 3.5 years for Herschel
- 21 months for Planck.

Full spacecraft performance, including margin shall be achieved at the end of this nominal lifetime. Extended lifetime is also envisaged:

- 6 years for Herschel
- 2.5 years for Planck.

This imposes to size the Fuel for attitude and orbit control for this duration. The items which degrade with time or usage shall be compatible with this extended duration. However, at the end of the extended duration, performance has to be met under nominal conditions, not taking into account margins.

The lifetime is also a design driver for the H-EPLM cryostat for which the lifetime of 3.5 years has to be achieved with a margin of 15 % on cryogen.

Temperature fluctuation: on Planck, the payload is extremely sensitive to temperature variations. In order not to disturb the scientific measurement, the thermal design must ensure that all temperature fluctuation inside the SVM are damped. This leads to have a satellite mode of operation with as much as possible a fixed configuration with constant dissipation. Compensation heating has to be provided for all loads which are switched OFF. However, the main source of temperature fluctuation is coming from the cycling operation of the 20 K sorption cooler provided by the instruments.

On Herschel, temperature stability requirement are expressed by the HIFI instrument which, for its scientific performance, requires stability for units located inside the cryostat as well as for warm instrument units. This imposes an active thermal control of the HIFI warm units inside SVM. The additional power induced by this active thermal control (55 W) has been removed from the ESA margin on power.

3.2 Evolution of system requirements since PDR

3.2.1 System Requirement Specification

Since PDR, two updates of the System Requirements Specification (AD01.1) where issued following discussions between ASP and ESA:

- SRS 3.1 dated 22/11/2002
- SRS 3.2 dated 01/12/2003.

The main updates of requirements are discussed in the following sections. In addition, since the last issue of the SRS 3.2, some evolution of the design have occurred which are not formally introduced in the SRS. This is discussed in Section 3.3.1.3.

3.2.1.1 Evolution from SRS 3.0 to SRS 3.1

A first set of updated spec is related to the change of launcher baseline from ES/V to EC/A:

- Update of the launch sequence in MISS-015
- Update of the launch mass requirement in SGEN-050. The mass requirement was still including the adapters in this Issue. The mass margin policy of SCMD-080 has been updated, linking the mass margin to the successful completion of PDR or CDR review (10% margin after PDR, 5% after CDR)
- Update of delta-V in SGEN-060.

The extended lifetime requirement for Herschel has been relaxed to 4.5 years (was 6 years). This concerns lifetime requirement for units which degrade with time (SPER-025) as well as propellant sizing for orbit maintenance and orbit control (SPER-030).

The alignment requirements of SCMD-088 have been updated to put them in line with the values agreed with instruments. Final agreed values is reflected is SRS 3.2.

The way to handle loss of ground contact has been clarified: action has to be initiated after 60 hours without ground contact (MOOM-180). It will consist in performing transponder/antenna toggling to test all possible combination, each combination being tested for 1 hour (MOOM-185). This requirement has been further updated in SRS 3.2 to reduce the duration for each combination to 10 minutes.

Some requirements linked to H-EPLM were updated:

- Clarification that the impact of Helium content determination has to be included in lifetime calculation (SPLM-030)
- Update of maximum temperature maximum He bath temperature after 6 days from 2.15 K to 2.1 K (SPLM-060)
- New concept for Helium exhaust torque which shall compensate for the solar torque (i.e. main component around Y axis) (SPLM-090).

New requirement SCMD-217 about accuracy of time adjustment: this is not a driving requirement.

Update of requirement related to link budgets; reference is made to SGICD and the details which were present in the SRS are deleted (SMTT-115, SMTT-120, SMTT-125, SMTT-130).

3.2.1.2 Evolution from SRS 3.1 to SRS 3.2

The mass requirement (SGEN-050) has been updated to specify only the mass allocated to the spacecraft. The adapters are not anymore part of the mass requirement. The allocation of 5349 kg for spacecraft was derived for a configuration with SPELTRA. Further evolution of the launcher performance have shown that this performance was corresponding to the 7.5 deg perigee shift. With the latest evolution of the launch window definition in which optimum trajectory is used thanks to fairing opening at SAA = 20 deg, this allocation can be increased. The ESA reserve (SCM-085) has been updated to the 169 kg which are considered in the budgets.

Following discussions at the System PM#23, new mass requirements are expected to be formalised in SRS 3.3:

- Updating the allocations for the CFE's (instruments, Herschel telescope, Planck reflectors)
- Allocating 5593 kg to the satellites (from updated launcher capacity defined by ARIANESPACE at RAMP)
- Keeping an ESA margin of 100 kg.

These new data are considered to build the mass budget in RD02.3.

The delta-V requirements were updated. They are still considering the old launch window cases with 7.5 or 15 deg perigee shift. With the new baseline with optimum trajectory, a delta-V of 225 m/s is sufficient for Planck injection (see Section 4). This is the value used in the delta-V budget. It can also be noted that the Crema 2.2 is giving more accurate values for the manoeuvre SAA and that the fact to consider "any" SAA is conservative for some manoeuvres. This is discussed in Section 4.

A Crema 2.3 has been edited mid-July 2004. It gives updated delta-V for Herschel and Planck. The main noticeable differences are:

- Increase of the "Removal of launcher dispersion" from 40 m/s to 50 m/s
- Decrease of the Planck injection manoeuvre from 225 m/s to 215 m/s.

These values have been considered to build the fuel budget (see RD02.3). It leads to an increase of the total fuel mass:

- The total delta-V on Herschel is increased by 10 m/s
- On Planck, the additional 10 m/s of the "Removal of launcher dispersion" are performed with less efficiency than the 10 m/s removed from the injection manoeuvre.

The cleanliness requirements have been updated:

- the contribution of 2300 ppm from launcher during ascent has been clarified. As specified in the SRS, the contribution for the phase under fairing after encapsulation (class 10 000 conditions) is not included in the 2300 ppm and has to be added in the contamination budget, further reducing the margins.
- Requirements on sensitive surfaces have been introduced. Requirement on LOU windows has been discussed with HIFI and it has been agreed that the transmission requirement was the driving requirement, not the cleanliness. The requirement on 1st mirror inside the LOU is a new requirement.
- For Planck, 900 ppm particulate contamination is indicated for the reflectors "at delivery to the prime". It should be clear that this value includes the integration activities of the mirrors on the telescope performed at Contraves. 900 ppm is the contamination level of the reflectors at the beginning of satellite integration activities at ASP.

Following increase of CVV height and He tank capacity, the margin on cryogen for lifetime calculation has been increased to 15 % (SPLM-035).

Requirement for conductivity of external surfaces has been deleted for HSS OSR's (SENV-145).

Annex 1 on Scientific Pointing Modes has been updated and TBC and TBD removed. MOOM-105 has clarified that peak-up applies to all scientific pointing modes, except link scanning.

It should be noted that the requirement to implement a VMC on Planck is still present (MOGE-035) while it has been agreed to delete it at project level. A RFD will be issued to formally cover this point.

3.2.2 Space to Ground ICD (SGICD)

Since the PDR, 2 versions of the SCICD were released:

- Issue 3.0 on 29/11/2002
- Issue 3.1 on 1/12/2003.

The main evolutions of issues 3.0 and 3.1 w.r.t. issue 2.1 are:

- PSS 04 105 replaced by ECSS E 50. The main impacts identified are:
  - Need at SVM and System level to measure out-of band spurious up to 40.5 GHz instead of 10 GHz previously specified. This imposes the use for the TTC SIT of a non conventional spectrum analyser in place of the standard one foreseen in the TTC SCOE.
  - Need for a vector analyser to check the GMSK modulation (IQ pattern) at SVM level.

  In both cases, rental solution would have to be envisaged to be fully compliant.
- Emission bandwidth reduced from 7 MHz down to 4.2 MHz. It was not possible to meet this requirement for the medium bit rate case. The emission bandwidth requirement has been updated in SGICD Iss. 3.1 and is now acceptable.
- New section on frame synchronisation included with no impact: introduced in CDMU baseline.
- Bit randomiser is formally specified. This was already included in the CDMU baseline as well as in the TM/TC DFE.
- The ranging tone frequency was defined but with an error which has been corrected in SGICD Iss. 3.1.
- New section on up-link sweep range and phase discontinuity: no impact as the SCOEs are not supposed to reflect the ground stations performance.
- Addition of Villafranca for LEOP: the characteristics of Villafranca station are generally identical to Kourou, except for the G/T of 35.2 dB/T instead of 37.5 dB/T for Kourou. If Villafranca is used for TM at 5 Kbps during LEOP, the maximum distance will be 550 000 km for Villafranca instead of 750 000 km for Kourou. It should be noted that values for antenna gain in downlink and uplink have been updated in Iss. 3.1 without modification of EIRP and G/T.
- Used of Kourou for TC at 4 kbps up to 450 000 km and for TM at 5 kpbs up to 750 000 km: this additional cases have been considered in the link budgets.

RF suitcase delivery at L-24 months: at the RF Suitcase kick-off, it was agreed with ESA to have a delivery of the RF Suitcase on 31/05/04. The RF Suitcase uses equipment from the AVM (TTC transponder, TWTA, RF switch and diplexer). Due to the advanced date of the RF compatibility testing the AVM testing will not be finished at that time. This means that these equipment will have to be returned to AVM at the end of the RF compatibility testing.

4. HERSCHEL/PLANCK MISSION OVERVIEW

The scope of this section is to present an overview of Herschel/Planck mission and to assess the mission constraints on operations and spacecraft design.

The section includes:

- A general overview of Lissajous orbits around second Lagrange point (L2)
- A presentation of mission trade-offs (in particular launch scenario and launch window optimisation)
- Launch phase description and analysis
- Transfer phase description and analysis
- Operational phase description and analysis.

4.1 Introduction

4.1.1 Reference operational orbits

Both Herschel and Planck spacecraft are planned to operate from Lissajous orbits around the L2 Lagrange point of the Sun + Earth system. As shown in Figure 4.1-1, this point is aligned with the Earth and the Sun and located at 1500000 km from the Earth, away from the Sun.

Such orbits present the following advantages for the satellite operations:

- thanks to the Earth and Sun almost constant distances, the thermal environment is very stable. The thermal radiation from the Earth are reduced and induces a cold environment which is favourable for operating cryogenic satellites such as Herschel and Planck
- the radiation environment is very low compared to an eccentric orbit such as ISO or XMM, or even compared to GEO orbits
- as the Sun and the Earth remain close together from the spacecraft, the shielding of the Sun thermal radiation will also prevent straylight effects from the Earth. The satellite communication with the Earth is facilitated as the satellite remains Sun pointed.

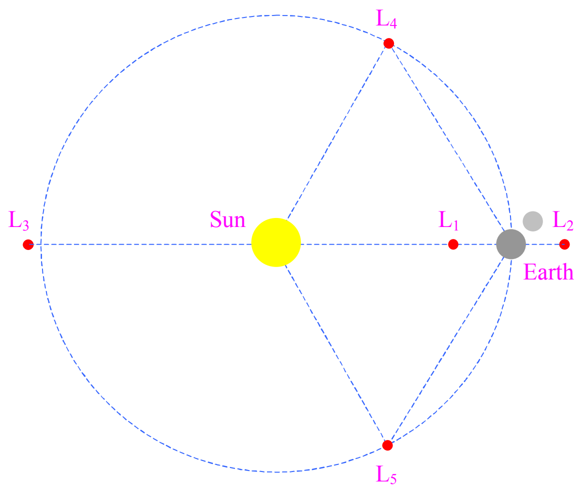


Figure 4.1-1 Lissajous orbit at L2 Lagrange point

Both spacecraft are not located at L2 Lagrange point, but orbiting around that point. The Herschel and Planck orbits are described in next sections, in the Earth rotating frame and also in the Inertial frame. Note that the three planar projections of Herschel and Planck trajectories use the same spatial scale.

Table 4.1-1 details the operational lifetime requirements for Herschel and Planck mission.

Operational Lifetime	Herschel	Planck
Required Standard Lifetime	3.5 years	1.75 years (21 months)
Required Extended Lifetime	4.5 years	2.5 years

Table 4.1-1 Required operational lifetime for Herschel and Planck missions

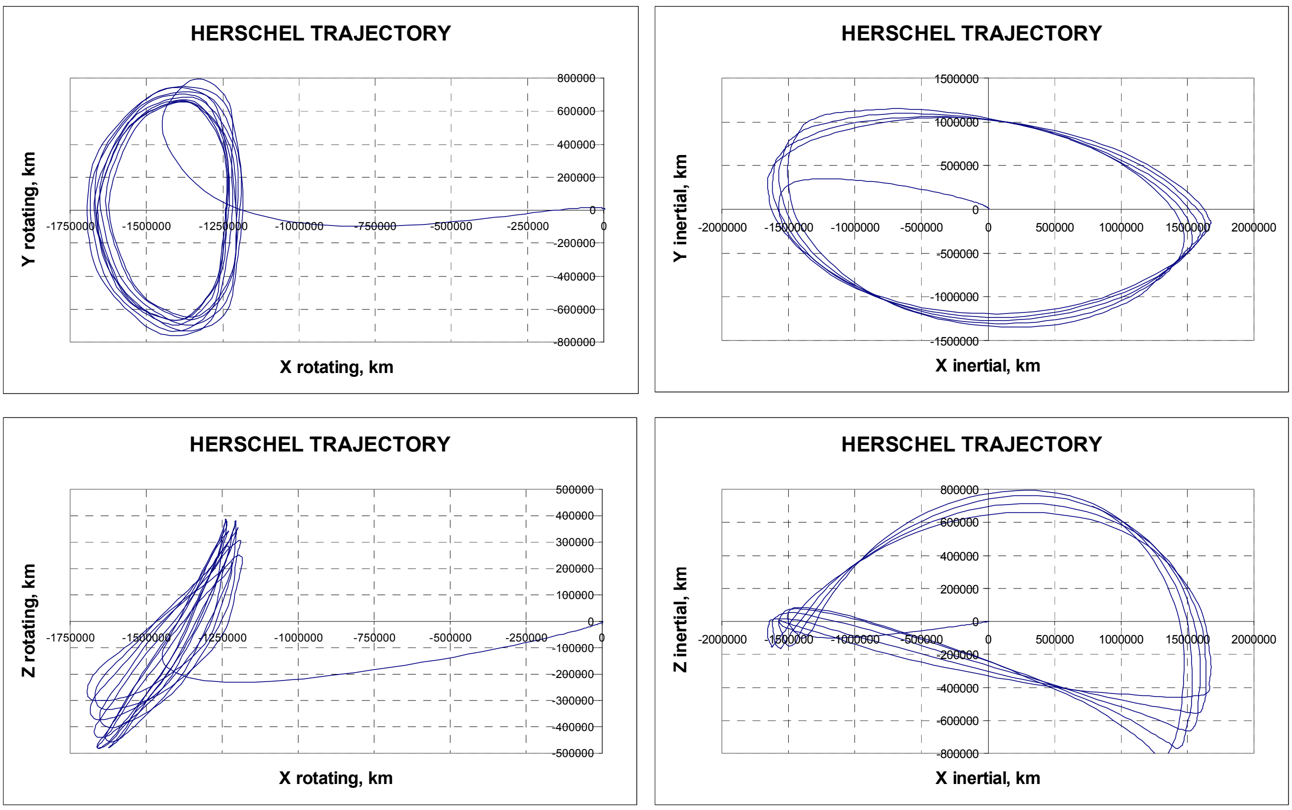
4.1.1.1 Herschel operational orbit

A large Lissajous orbit has been selected for Herschel. This orbit is characterised by large amplitudes along X,Y and Z axes depending on the launch date/hour: typical Herschel Lissajous dimensions will be around 800000 km in Y direction and around 500000 km in out of ecliptic plane (Z direction).

Figure 4.1-2 shows an example of orbit evolution of Herschel from launch to 4.75 years of propagation in Earth centred rotating frame and in Earth centred inertial frame. The large amplitudes implies that the maximum Sun-Satellite-Earth angle can reach values above 30 deg (MISS-081 from the SRS specifies 40 deg) and that the declination to Earth can be up to 40-50 deg.

This orbit can be reached without insertion manoeuvre.

Earth rotating coordinate system **Inertial coordinate system**



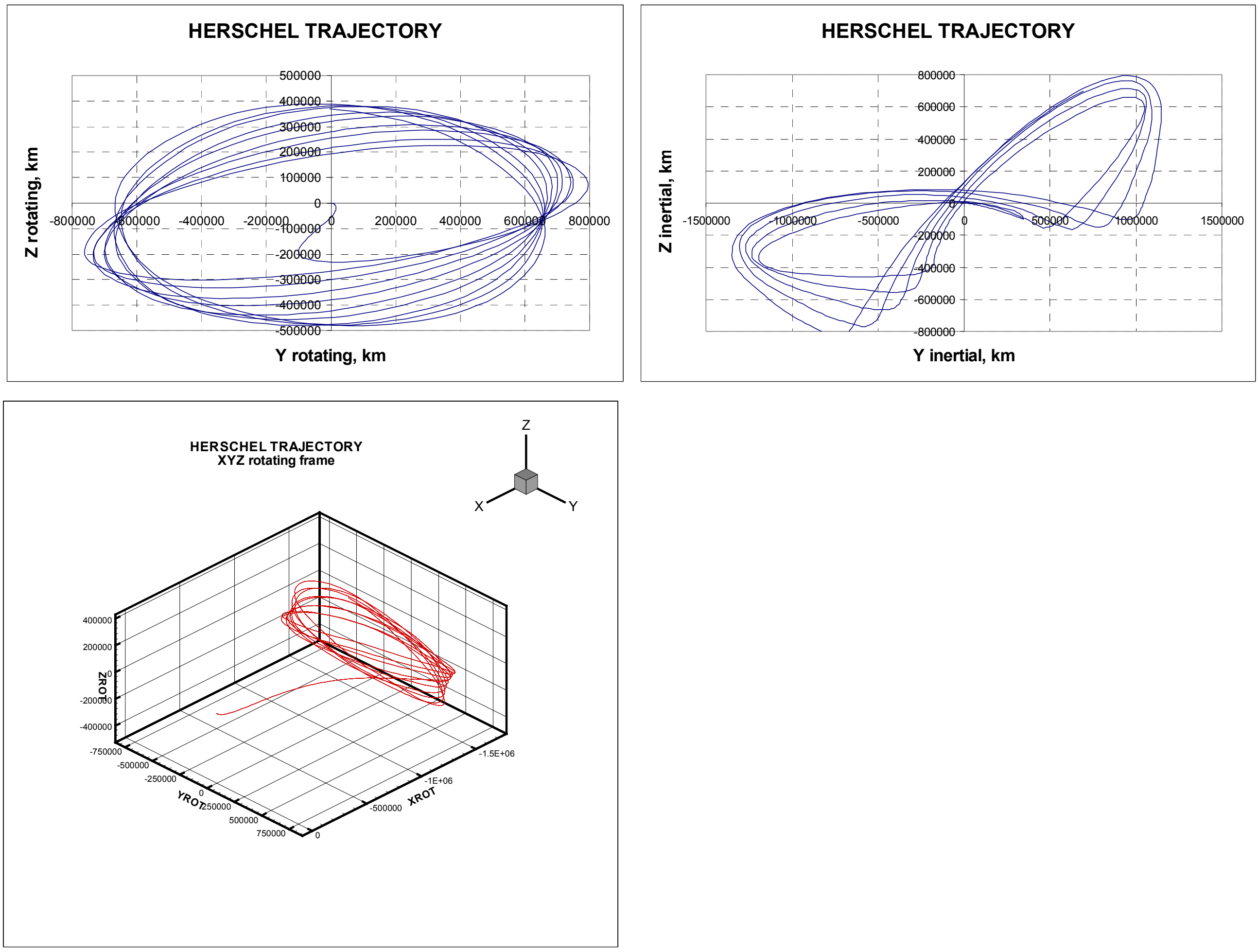


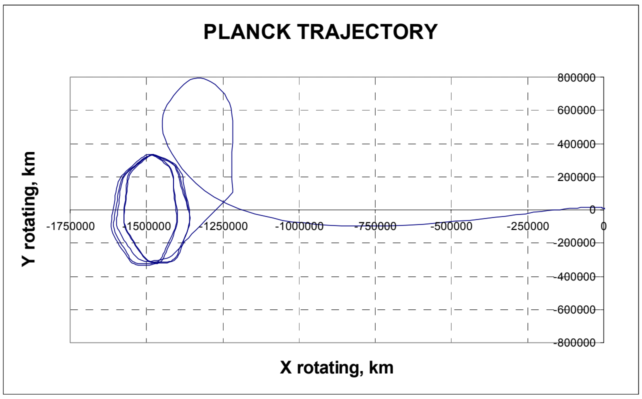
Figure 4.1-2 Herschel large Lissajous orbit around L2

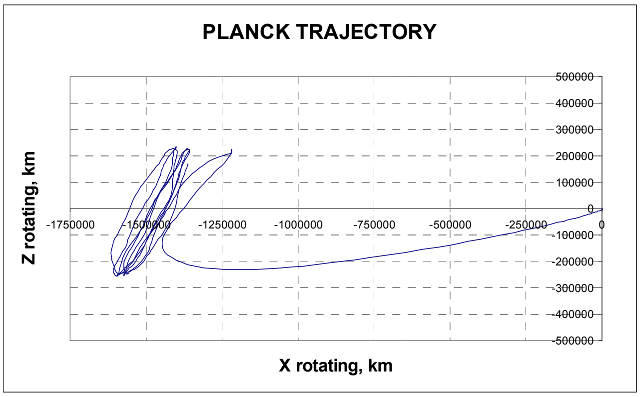
4.1.1.2 Planck operational orbit

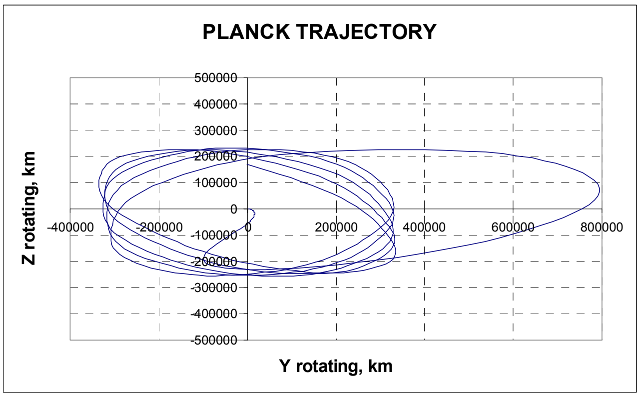
Planck is a Sun-pointed spacecraft with little manoeuvrability. In order to prevent the Earth to enter the Planck field of view and generate unacceptable straylight, the chosen baseline is a Small Lissajous orbit with a Sun-Satellite-Earth angle limited to 15 deg. This imposes an insertion manoeuvre at the arrival at L2 to reduce orbit amplitude. An allocation of 225 m/s is considered for this Planck insertion manœuvre: this constraint is taken into account in the launch window determination.

Figure 4.1-3 shows an example of a 15 deg Lissajous orbit from launch to 2.75 years of propagation in Earth centred rotating frame and in Earth centred inertial frame. In this case, the Y amplitude is 330000 km, and the Z amplitude is 250000 km.

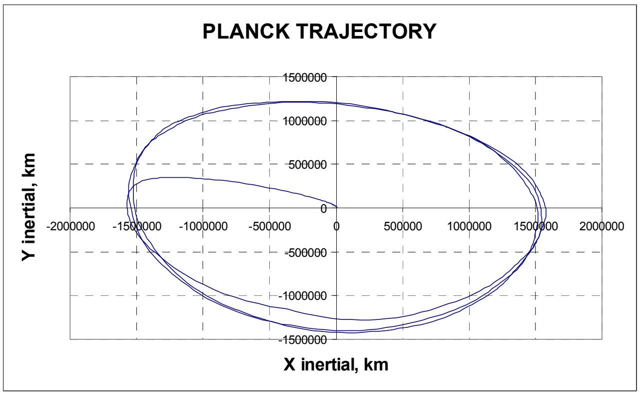
Earth rotating coordinate system

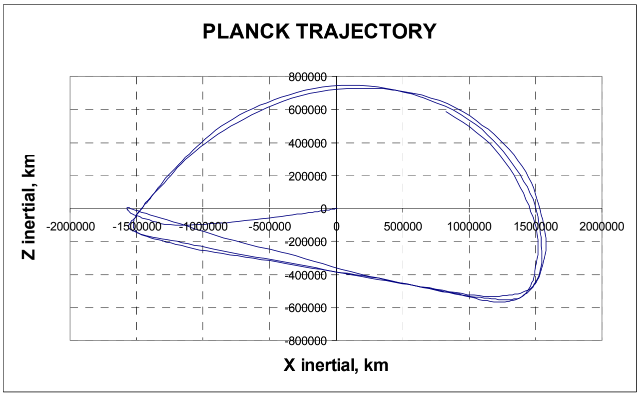


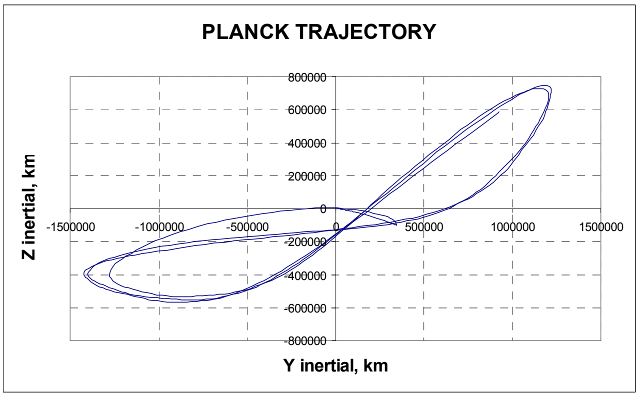




Inertial coordinate system







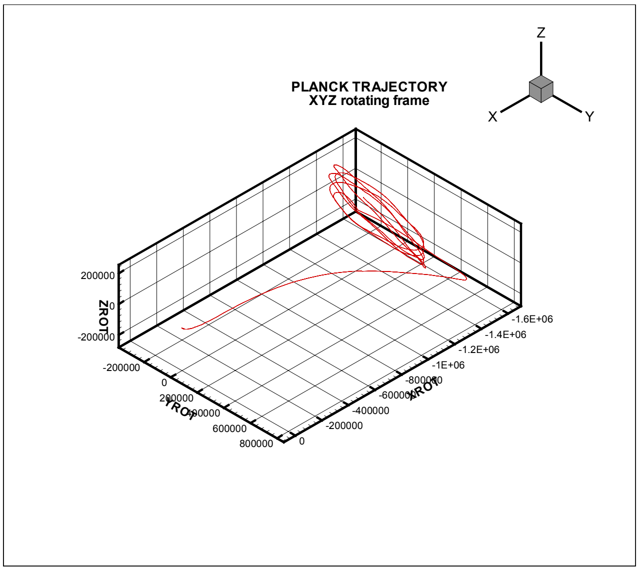


Figure 4.1-3 Planck small Lissajous orbit around L2

The Sun-Satellite-Earth angle is limited to 15 deg for Planck

4.1.2 Attitude constraints

Herschel and Planck being cryogenic satellites, their payload modules are nominally planned to be always in shadow. In addition, for increased thermal performance, coating materials with low emissivity are used in the PLM's; these materials will reach high temperature when exposed to Sun.

During phase C/D, inputs from Arianespace has shown that the launcher cannot guarantee that the PLM's are alwoys maintained in the shadow. This is especially true for the Herschel PLM which can be exposed to Sun after fairing jettison. On the opposite, the Planck PLM remains shadowed under SYLDA for the whole flight: only conditions at separation from launcher can lead to Sun illumination of the PLM.

The following sections detail the attitude constraints for each satellite. Two main phases are considered:

– Launch

– In-orbit phase.

4.1.2.1 Herschel attitude constraints

Launch phase

Two type of constraints have to be considered during the launch phase:

– Steady state attitude constraints

– Transient attitude variations.

In Roll, the steady state attitude excursions are due to:

– Launcher Roll attitude control

– Variation of the Sun direction over a day in the launch window

– Variation of the Sun direction with the launch date.

A value of ± 26 deg has been allocated to cover these effects.

In Pitch, the attitude constraints are set by to events:

- Sun Aspect Angle at fairing opening: a value of 20 deg is considered as the baseline for CDR. Considering a 5.5 deg launcher inaccuracy for this event, it means that a value of 25.5 deg SAA at fairing opening has to be considered for launch window determination. The SAA of 20 deg at fairing opening has been imposed by the need to increase launcher performance. The previous value was 50 deg.
- Sun Aspect Angle at H3: a maximum value of 140 deg SAA is considered. Considering a 3 deg launcher inaccuracy for this event, it means that the launch window has to be compliant with a maximum SAA at H3 of 137 deg.

The resulting allowed Sun directions are shown in the following figure. They are also applicable during the SCAR phase, from EPC shutdown to Herschel separation from launcher.

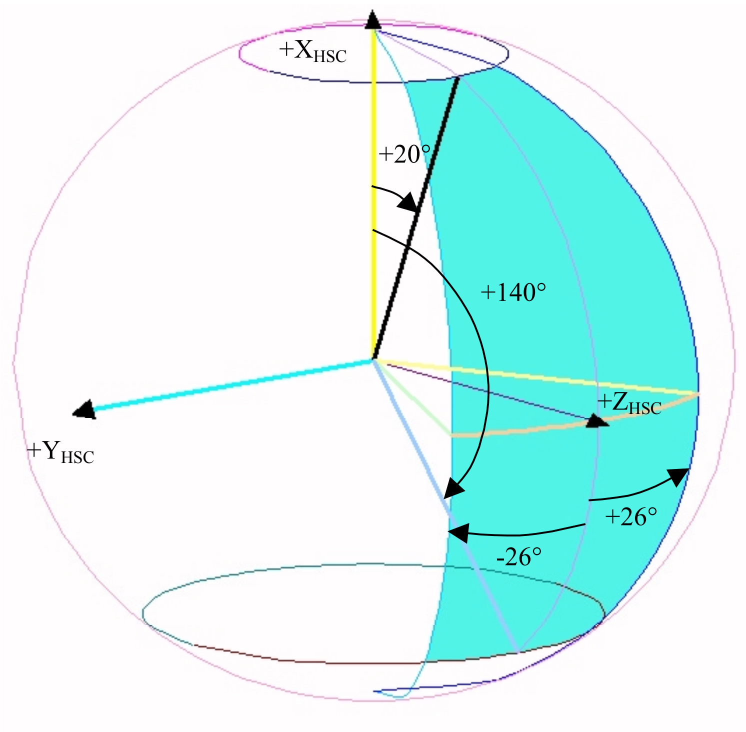


Figure 4.1-4 SAA constraints during launch

The transient attitude behavious is due to the fact that during transient events (EAP separation, EPC separation) the roll attitude control is not strong enough to counteract the parasitic toraues. This can lead to a complete rotation in roll of the spacecraft. This is shown in the following figure:

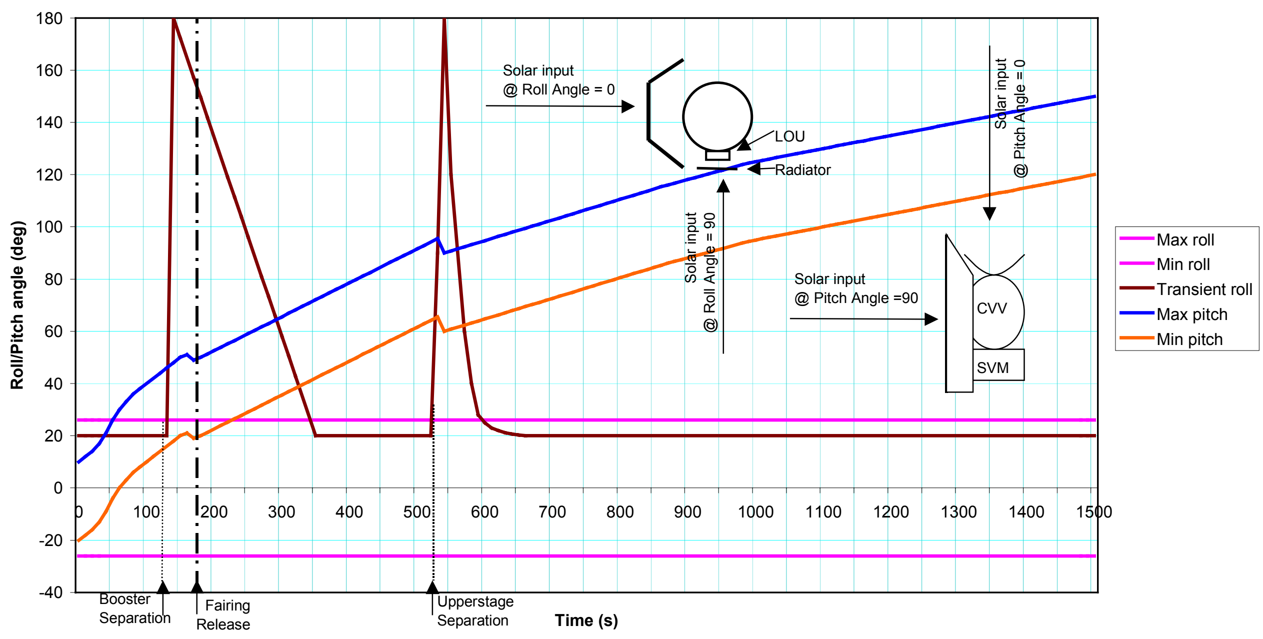


Figure 4.1-5 Roll and Pitch attitude during launch

The figure clearly shows the 2 transients:

– Booster separation: the transient begins before faring separation but launcher is not yet back in its nominal attitude at the time of fairing jettison. The roll rate to consider during this phase is low: 0.5 deg/s

– EPC separation: for this case, a higher roll rate of 3 deg/s can be considered.

In-orbit phase

Herschel is a three-axis stabilised, observatory type satellite. Its typical scientific mission consists in pointing successively at various targets in the sky according to a predefined schedule.

At any time in the mission, the whole sky is not accessible. This is due to the fact that the cold payload has to be protected from the Sun to remain operational. Any rotation around the Sun direction is allowed as it does not change the lighting conditions. Rotations around the perpendicular to the Sun direction are constrained in order to limit the size of the shield protecting the payload. The constraints are shown in Figure 4.1-6:

– between -1° and +1° from the (XHSC , ZHSC) plane

– between +60° and +120° from the +XHSC axis.

Full scientific performance has to be reached within this operational zone.

To allow flexibility for ACMS around this operational zone, it has been specified that no illumination of the H-EPLM shall occur for:

– between -5° and +5° from the (XHSC , ZHSC) plane

– between +58.5° and +121.5° from the +XHSC axis.

In addition, to take into account failures of the ACMS close to the operational zone limits, a contingency zone for transient shorter than 1 min has been defined/:

– between -10° and +10° from the (XHSC , ZHSC) plane

– between +55° and +125° from the +XHSC axis.

These zones are shown in the following figure:

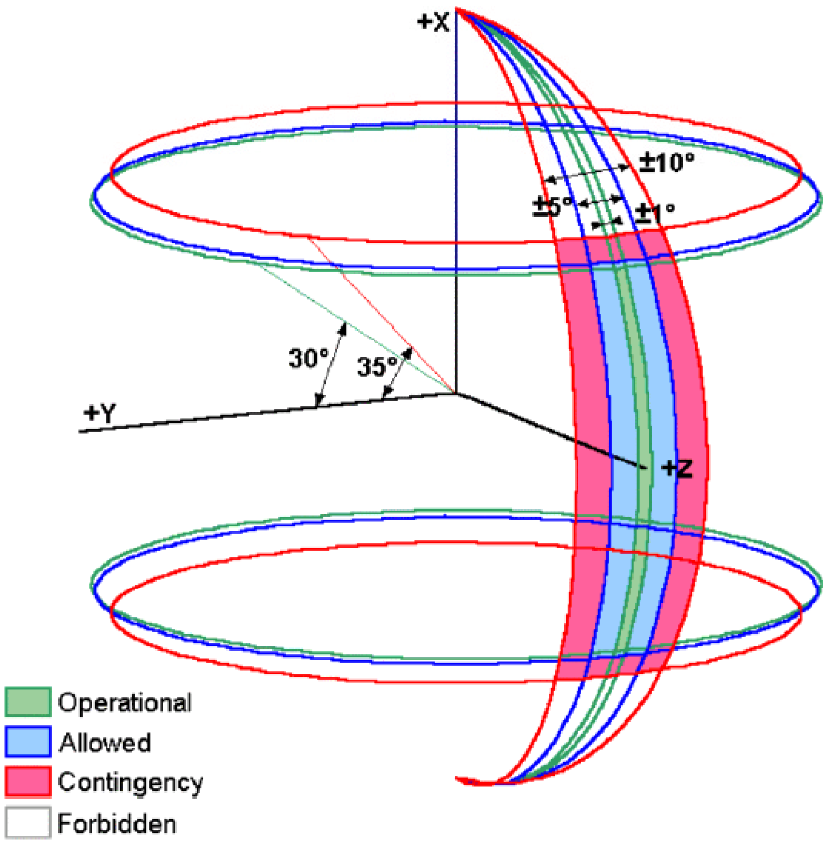


Figure 4.1-6 Herschel Sun pointing zones

The Herschel sunshield/sunshade protecting the payload has thus to be designed such that no part of the cryostat or telescope are hit by the Sun light for any Sun direction within the allowed one.

4.1.2.2 Planck attitude constraints

Launch phase

Planck is protected by the SYLDA up to Herschel separation. At that time, the hole at the top of SYLDA 5 will be open with a risk of illumination of the PPLM top. The angle between the Sun and the launcher (Y_L, Z_L) plane shall be maintained below 10 deg.

In-orbit phase

The Planck attitude profile is very different from the one from Herschel. Planck is a spinner which systematically scans the celestial sphere to produce a sky map. As shown inFigure 4.1-7, the Planck spin axis is normally opposite to the Sun, with the telescope line of sight at 85 deg from the spin axis. During one rotation, the instruments scan a sector of the celestial sphere with an angular diameter of 85 deg.

In order to view the celestial poles, it is thus mandatory to be able to depoint the spin axis by from the Sun direction. A scanning law which depoints the spin axis at 10 deg maximum from the Sun will be defined, in order to achieve scientific objectives. This means that the spacecraft has to be compatible with a maximum angle of 10 deg between the spin axis and the Sun. This is shown inFigure 4.1-8.

Due to the fact that Planck is in orbit around L2, it makes one rotation around the Sun per year. The spin axis has also to rotate at the same rate to remain Sun pointed. This is achieved by making regular precession manoeuvres which also includes out of plane motion to achieve the Planck scanning law. This scanning law is constrained by the fact that the angle between the spin negative axis (-XS) and the direction from satellite to Earth has to remain below 15 deg.

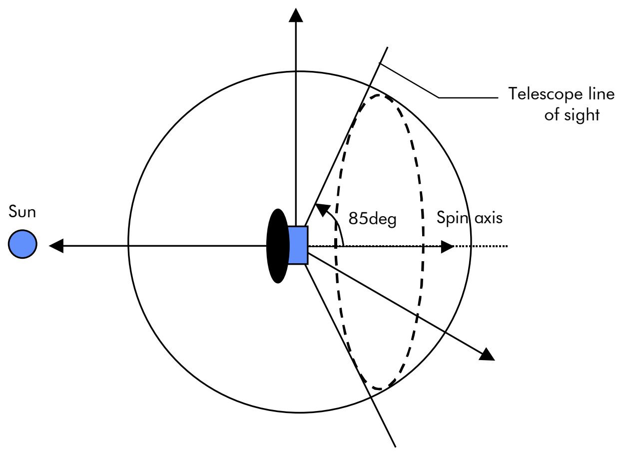


Figure 4.1-7 Planck observation strategy

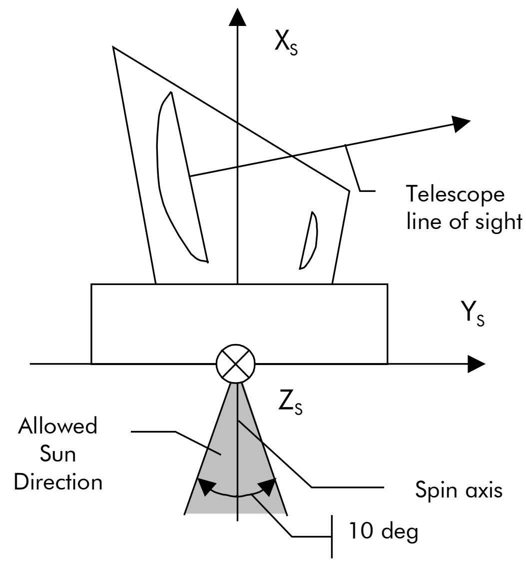


Figure 4.1-8 Planck attitude constraints: the sun in constrained to remain within 10 deg from the spin axis

4.2 Mission trade-offs

4.2.1 Introduction: history of launch scenarios

Before PDR the baseline launch option was the direct injection of Herschel and Planck to the L2 transfer orbit using the A5-ESV launcher. The ignition of EPS upper stage was delayed after a ballistic coast phase around Earth of 107 min. This solution provided two seasonal launch windows of about 3 months each (see launch window below).

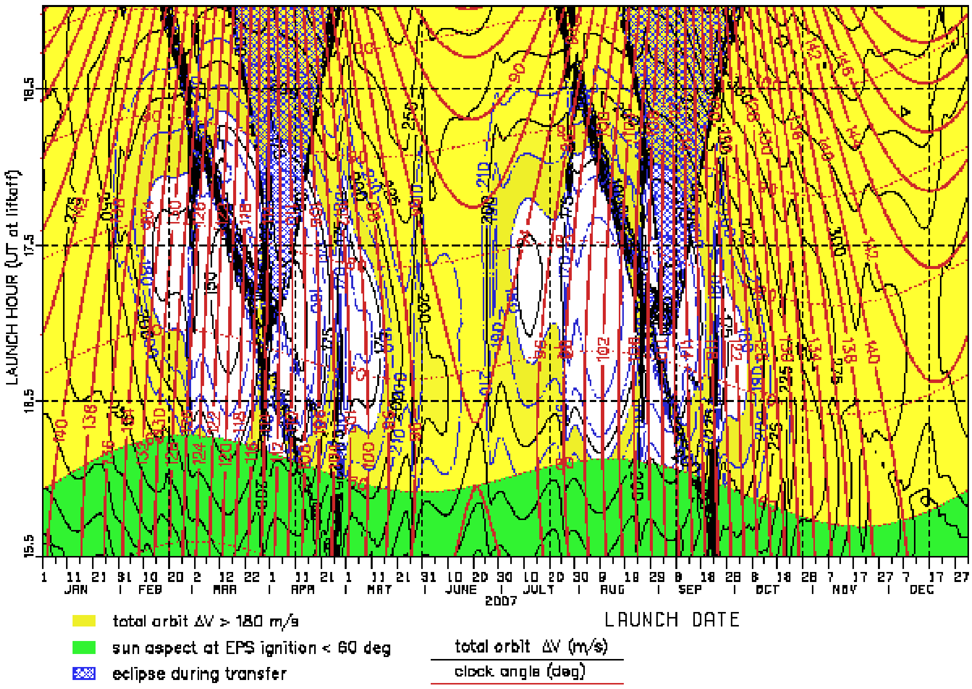


Figure 4.2-1 Year 2007 launch window for Herschel and Planck (A5-ESV, Planck 15 DEG)

It has been then decided at PDR to consider A5-ECA launcher as baseline scenario. This solution has the advantage to provide higher launch mass performances (above 6000 kg), but the main drawback of this option is that with a nominal injection strategy the Sun is along the telescope axis at fairing separation for optimal launch hours minimising Planck insertion delta-V (near 13:00 UT).

Three solutions were investigated to overcome this problem.

4.2.1.1 To use an eccentric parking orbit

Injection on a parking orbit was considered an alternative launch scenario at the time of SRR. Such a strategy consists in the injection of both spacecraft on a very elliptical orbit (called a parking orbit) with an apogee altitude from 500000 to 700000 km with a later lift-off time. The advantage is that sun/Earth/L2 line will move to the required orientation while waiting on the parking orbit. However, more detailed studies showed that an acceptable launch window duration could only be obtained with a Delta-V allocation of 425 m/s, above the capabilities of the Planck propulsion system, LEOP operations were more risky and complex, a longer transfer duration was needed, and large perigee raising manoeuvres were necessary.

Therefore this solution was discarded.

4.2.1.2 To rotate the apside line and delay launch time

The A5-ECA does not provide the facility of delayed ignition of upper stage. With the nominal A5-ECA ascent trajectory, this results in having the Herschel telescope Sun pointed at fairing separation which is not considered acceptable. The possibility to overcome this difficulty by changing the ARIANE ascent trajectory was investigated: the perigee longitude of the reached orbit is shifted Eastwards in a system fixed to the Earth. In this case, the launch hour could be delayed, maintaining the same inertial orientation of the reached orbit. The delay of the launch then leads to an increase of the Sun aspect angle (SAA) at fairing separation which can be above 50 deg.

The shift of the perigee will result in a sub-optimum ascent trajectory, and consequently in a reduction of the injected mass, but on the other hand the A5-ECA performance is higher than the one of A5-ESV, providing a priori some margin to cover the effect of the non optimality of the ascent trajectory.

Trade-off on Perigee shift angle

To analyse the perigee shift angle, it is necessary to define the right ascension of the perigee (or α angle):

$$\boxed{\alpha = \Omega + \arctan(\cos(i) \times \tan(\omega - 180°))}$$

The perigee shift corresponds to the difference between the α angle of the sub-optimum trajectory and the α angle of the optimum trajectory ($\alpha = 52.7°$ for i = 14°).

The following table compares the advantages and drawbacks of a target trajectory with small or large perigee shift.

Criterion	Small perigee shift (< ~7.5 °)	Large perigee shift (> ~7.5 °)	Comment
Launcher performance (see Figure 4.2-2)	+	-	Launch mass is maximised for small perigee shift wrt nominal apside line orientation (6273 kg at 0°).
Planck orbit insertion Delta-V	-	+	Small perigee shift leads to very large Lissajous. Therefore the available launch window respecting the 275 m/s allocation for Planck orbit insertion delta-V is narrowed, and two-manœuvre strategy is often needed for Planck insertion (in this cases the transfer duration is extended from ~4 months to 5-8 months).
Pitch angle evolution between K1 and H3	-	+	The launcher pitch evolution range from K1 to H3 is between 78° (delta-alpha 10.5°) and 100° (delta-alpha 0°). Large perigee shift is more favourable since a maximum pitch range of 76.5° (85° minus 8.5° for launcher guidance/control errors) is acceptable for Herschel illumination between K1 and H3.

Table 4.2-1 Trade-off on perigee shift angle (case with delayed launch time)

The following figure presents ECA performances versus perigee shift angle.

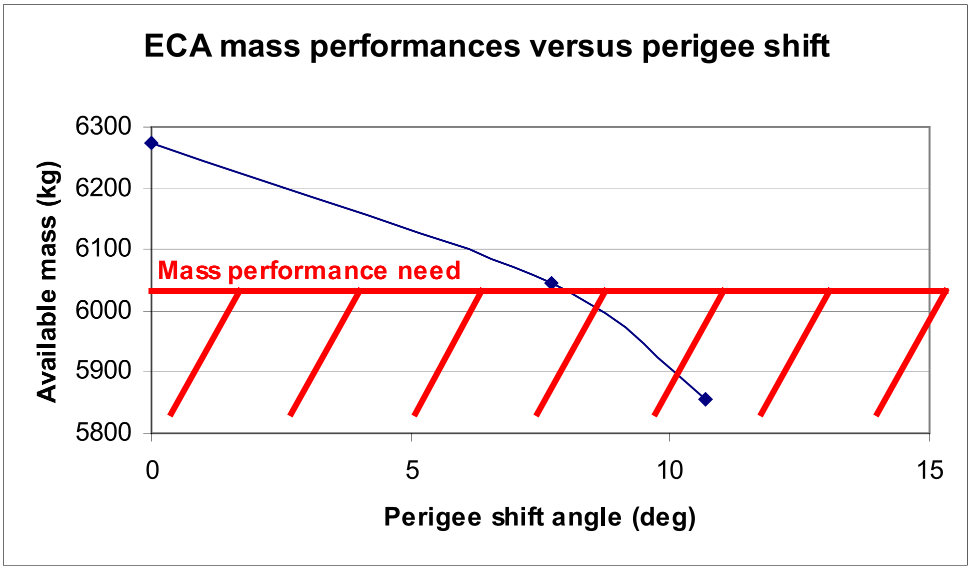


Figure 4.2-2 Evolution of A5-ECA mass performances versus Perigee shift

However this solution with sub-optimal ascent trajectory presents several critical points:

- Consolidation of A5-ECA performances showed that sub-optimum trajectories did not leave a sufficient mass margin to the mission, even with a perigee shift of 7.5 deg (see figure above).
- SAA constraint at fairing separation (> 50° +5.5° margin) + SAA constraint at ESC-A extinction (< 140° - 3° margin) led to a nearly complete closure of the launch window.

Therefore sub-optimal trajectory option with shift of perigee is also discarded.

4.2.1.3 To relax SAA constraints at fairing separation (K1)

This third solution is selected as baseline for CDR

It consists in reducing the SAA constraint at fairing opening (down to 20° + 5.5°), allowing to follow the optimal A5-ECA launch trajectory and to maximise launcher performances: 6273 kg.

This solution offers also the advantage of reducing delta-V needs for Planck insertion (down to 225 m/s).

The main parameters of the target trajectory are listed inTable 4.2-2.

Target obit	h_a, km	h_p, km	Inc, deg	ω, deg	Ω_K, deg	mass, kg
Optimum ECA ascent trajectory	1300000	319.7	14.0	207.8	-154.3	6273

Table 4.2-2 Main parameters OF A5-ECA launch orbit

4.2.2 Launch window optimisation

4.2.2.1 General approach for launch window definition

The launch window has been subject to many analyses. As both satellites are launched together, the launch window must be compatible with Herschel and Planck.

The main constraints that shall be satisfied by the launch window are the following ones:

Constraint	Comment	Impact on opening/closing of the daily launch window
Minimisation of the Planck orbit insertion Delta-V	The propellant allocation is limited to 225 m/sec assuming an injection on a Lissajous orbit with a maximum Sun-Satellite-Earth angle of 15 deg	Closing
No eclipse during transfer phase		Closing (generally) Opening (rare)
SAA at K1	Solar aspect angle at fairing jettisoning (K1) shall be higher than 20 deg (+5.5 deg of margin for launcher dispersions).	Opening
Pitch at H3	Solar aspect angle at Herschel injection (H3) shall be lower than 140 deg (-3 deg of margin for launcher dispersions). This constraint is related to the value of the perigee shift.	Closing

Besides the launch window trade-off is also related:

- to the optimisation of the launcher ascent trajectory performed by AES, since this optimisation will determine the precise A5-ECA launcher performances (available mass). The constraints impacting the launcher trajectory are for example the maximum aerothermal flux allowed for Herschel, safety rules (e.g. minimum launch azimuth is ruled by short distance safety rule), ground station coverage.
- to the perigee shift value (see Figure 4.2-2), since this parameter will also impact the launcher ascent trajectory (perigee shift de-optimises the ascent trajectory and so reduces launcher performances). As explained in 4.2.1.2, the perigee shift value was finally selected to 0°: A5-ECA optimal trajectory is considered in baseline for CDR.

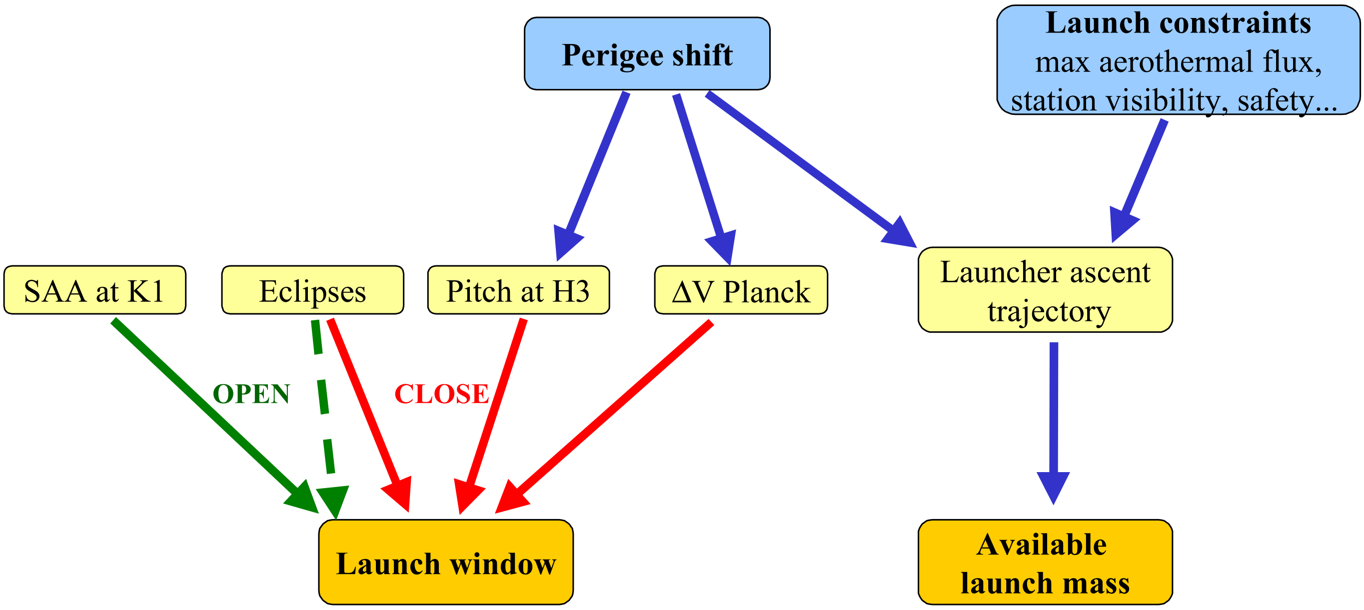


Table 4.2-3 Impact of perigee shift value on launch window and launch mass

4.2.2.2 Baseline launch window

The launch window is presented in Figure 4.2-3 and Figure 4.2-4. It has been computed for the whole year 2007 (Jan to Dec). No significant differences appear in the 2008 launch window.

Six periods are favourable:

- 07/02/15 - 07/02/28 (13 days)
- 07/03/03 - 07/03/09 (6 days)
- 07/03/29 - 07/04/04 (5 days)
- 07/07/28 - 07/09/09 (45 days)
- 07/10/04 - 08/01/20 (108 days)
- 08/01/23 – 08/01/27 (4 days)

The launch hour is between 12:30 and 15:00 UTC, which corresponds to 8:58 to 11:28 in KOUROU local solar time. The standard daily slot for ARIANE 5 launch window is 45 min: this constraint is satisfied for all the days within the selected intervals.

The total launch window covers a duration of 6 months. The launch window is closed about 1 month around each Equinox due to eclipses occurrence. The total eclipse duration during transfer can last up to 30 hours for worst launch dates.

The launch window is closed also during a large period from April to July because of Planck delta-V constraint.

Besides this launch window has been refined by taking into account some additional constraints:

- Remove points with eclipse avoidance manœuvres on Herschel
- Remove dates with eclipse during transfer within the 45-min daily slot

– Remove dates with extreme perigee velocity variation (all remaining dates lead to a perigee velocity variation < +/- 3.5 m/s): this allows to reduce the number of ARIANE flight programs and/or the delta-V allocation for correction of perigee velocity variations (manœuvre at day 1).

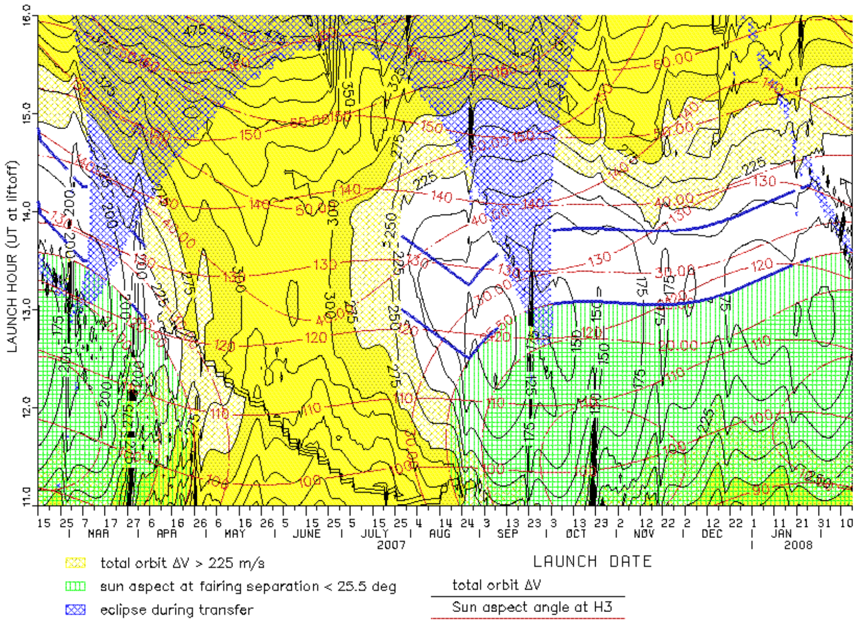


Figure 4.2-3 Year 2007 launch window for Herschel and Planck (A5-ECA, Planck 15 deg)

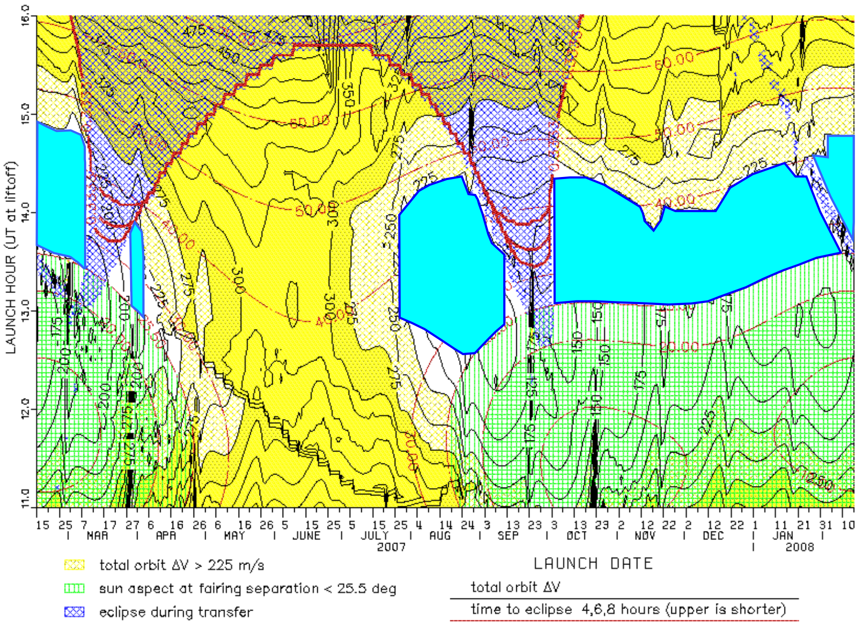


Figure 4.2-4 Launch window without refinements

4.2.3 Planck operational orbit size

The Planck maximum Sun-spacecraft-Earth angle, further called "osa" (orbit size angle), was 10° at the SRR.

But two problems appeared at the middle of Phase B:

- the mass budget has become a critical issue, therefore mass savings are researched
- the required Delta-V for an injection of Planck on a 10° orbit when launched by ARIANE 5 ECA is not compatible with the Planck tank capacity, thus making the launch scenario on A5 ECA not feasible without significant design modification on Planck.

Increasing the Planck osa allows a reduction of the injection delta-V budget and thus fuel mass savings. The system impacts of the Planck osa increase have been assessed in RD03.15. This note shows that the highest acceptable Planck osa is 15°.

The trade-off between "Planck osa = 10°" and "Planck osa = 15°" is summarised below.

PLANCK OSA = 15° INSTEAD OF 10°	ADVANTAGES	DRAWBACKS
Injection Delta V	Injection Delta-V budget is reduced of 62.5 m/s for both launch scenario (A5 ESV and A5 ECA)	None
Fuel mass	Fuel and pressurant mass savings reach 53 kg for baseline A5 ESV and 55 kg for A5 ECA.	None
Allowed propellant growth (SMRC-025 requires at least 20 %)	Allowed propellant growth increases: until 53 % for an A5 ESV launch and a baseline Planck design based on 3 tanks. Margin with a design based on 2-tanks is positive, but well below 20%. until 14 % for an A5 ECA launch and a baseline Planck design based on 3 tanks. A Planck design based on 2 tanks would not however make the A5 ECA launch a feasible option.	None
MGA constraints	None	MGA constraints (link budget margin, MGA design based on a classical horn) limit osa max to 15°.
Sun, Earth, Moon worst case locations	saa_{max} = 10° for both Planck osa	eaa_{max} = 15° (instead of 10°) maa_{max} = 31° (instead of 26°)
Rejection margin to external SIN	Rejection margin to external SIN coming from the Sun not modified.	Rejection margin to external SIN coming from the Earth is reduced, but remains still comfortable enough. Rejection margin to external SIN coming from the Moon is reduced, but remains still comfortable enough. Diffusion of moon light on primary reflector is not significant.
Rejection margin to internal sin	None	Direct illumination of the PR by the Moon occurs. Maximum computed thermal fluctuations for the PR and for the Baffle remain below the allocation from straylight budget.

The advantages of Planck osa=15° wrt 10° are fuel mass savings making the launch with A5 ECA a feasible option.

The drawbacks have a controlled impact and do not affect compliance to the concerned SRS requirements.

As a conclusion, **the Planck orbit size angle of 15° is taken as baseline**.

4.3 Launch phase

Planck and Herschel missions have been combined for a launch in year 2007. The nominal scenario consists in a dual launch with Herschel and Planck targeting an injection of both spacecraft toward L_2. Baseline launch vehicle is ARIANE 5 Evolution/CA (A5-ECA).

4.3.1 Launch Sequence

A5-ECA can inject 6273 kg on transfer orbit (with optimal ascent trajectory), including adaptators and carrying structure. After EPC separation the ESC-A upper stage is fired during 15.7 mn and raise Herschel/Planck altitude (see Figure 4.3-1). Then the objective of the SCAR sequence after H3 is to inject successively Herschel and then Planck on the transfer orbit with the adequate attitude modes (3-axes for Herschel, spinned for Planck). Table 4.3-4 gives a timetable for the whole launch sequence.

TIME	EVENT	DESCRIPTION
T_0	Lift-off (H_0)	Altitude: 0 km
T_0 + 141.8 sec	Acceleration threshold detection (H_1)	Altitude: 71 km
T_0 + 142.6 sec	Booster jettisoning (H_1 + 0.78 sec)	
T_0 + 147.9 sec	Beginning of guidance (second attitude law phase)	
T_0 + 182.6 sec	Fairing jettisoning (K1)	Herschel Sun solar aspect constraint applies. Altitude: 105 km
T_0 + 538.6 sec	End of EPC thrust phase (H_2)	
T_0 + 544.6 sec	Lower composite jettisoning (H_2 + 6 sec)	Altitude: 173 km
T_0 + 548.6 sec	Upper stage ignition (H_2 + 10 sec)	Altitude: 171 km
T_0 + 1493.9 sec	Shut down of upper stage (H_3)	Altitude: 970 km
T_0 + 1627.6 sec	Herschel separation (H4.1)	Herschel is separated in three axis mode 27 minutes after lift-off. Altitude: 1470 km Altitude rate: 3.8 km/s
T_0 + 1788.3 sec	SYLDA5-F separation (H4.2)	
T_0 + 1909.2 sec	Planck separation (H4.3)	Planck is separated in spin mode 32 minutes after lift-off. Altitude: 2700 km Altitude rate: 4.7 km/s

Table 4.3-1 A5-ECA launch sequence

The total launch sequence duration (including SCAR phase) is below 32 minutes. This duration is compatible with the battery sized for 50 minutes. Even assuming that the umbilical separation occur 8 minutes before launch, a margin of 10 minutes still remains.

During launch, TC's are sent to Herschel to open valves in the cryostat and power is provided to Planck coolers to their launch lock mode.

From launcher separation, the attitude of the spacecraft will be controlled to meet the attitude constraints described in Chapter 4.1.2.

The following figure presents the evolution of altitude versus time.

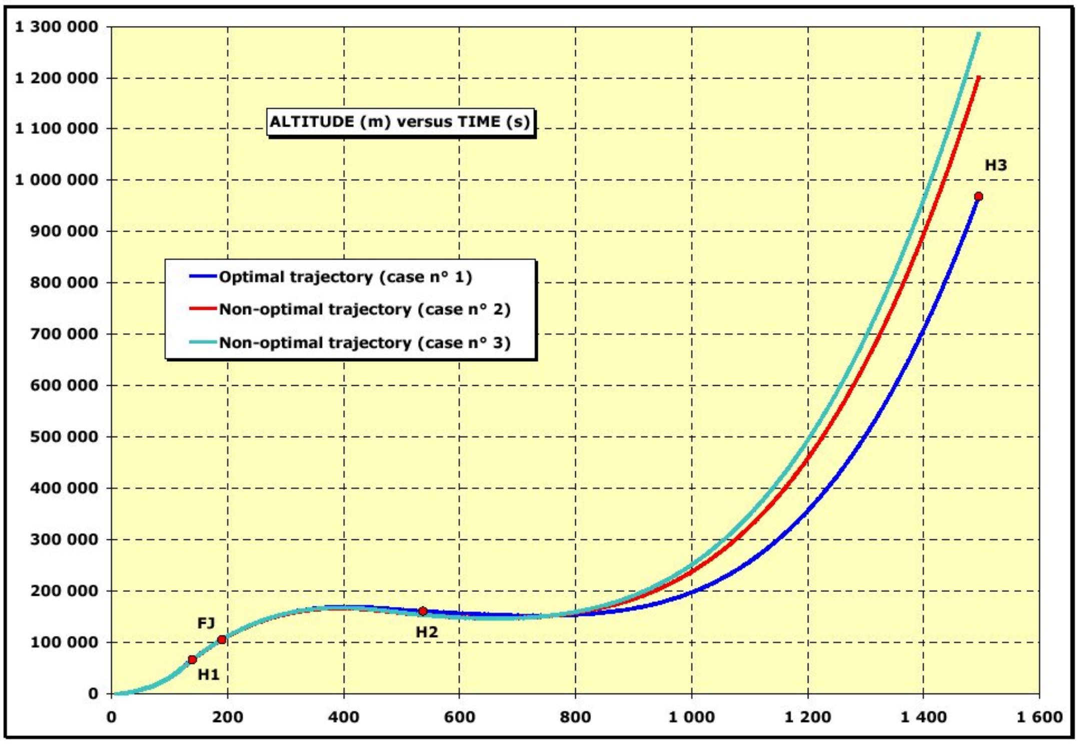


Figure 4.3-1 Altitude versus time during launch sequence

4.3.2 SCAR phase

The main events during the SCAR phase is:

- Herschel separated in three axis mode with ZS pointed to the Sun
- ARIANE 5 upper stage re-orientation to have –XS axis Sun pointed
- SYLDA 5 separation
- Planck spin-up and ejection.

A timeline is given in the following table

Type of phase	Timing	Attitude	Feared event	Attitude constraints
Launcher orientation	H3+2s to H3+133.3 s		H-EPLM illumination	-26 < Roll < +26 20 < Pitch < 140 from X axis
Herschel separation (H4.1)	H3+133.7 s	Herschel Z axis Sun pointed	H-EPLM illumination	For separation conditions see below
Stand-by	H3+133.7s to H3+143.7 s		PPLM illumination through SYLDA hole	Sun not more than 10 deg above (Y_L, Z_L)
Launcher orientation	H3+143.7 s to H3+294 s		PPLM illumination through SYLDA hole	Sun not more than 10 deg above (Y_L, Z_L)
SYLDA separation (H4.2)	H3+294.4 s	At 3 deg from Planck separation attitude		Sun at less than 10 deg from Planck –X axis
Stand-by	H3+294.4 s to H3+304.4			Sun at less than 10 deg from Planck –X axis
Launcher orientation	H3+304.4 to H3+374.7			Sun at less than 10 deg from Planck –X axis
Spin up (6°/s)	H3+374.7 to H3+415 s			Sun at less than 10 deg from Planck –X axis
Planck separation (H4.3)	H3+415.3 s	Planck –X axis Sun pointed		For separation conditions see below

Apart from the attitude constraints which have to be respected during the SCAR phase, the main requirements from system point of view are:

- Conditions at Herschel separation
- Conditions at Planck separation
- Shadowing of the AAD by the upper stage.

The conditions at Herschel separation were initially defined as:

- Herschel Z axis depointing w.r.t. Sun < 1 deg
- Longitudinal angular rate < 0.6 deg/s
- Transverse angular rate < 0.6 deg/s.

These conditions were define to ensure that, at ACMS initiation, 20 s after separation, the maximum depointing w.r.t. Sun is less than 13° with longitudinal and angular rate below 0/6 deg/s. Following the RAMP analyses, it appeared that it was not possible for A5 to be pointed at less that 1 degfrom the Sun. The problem is that the launch program computes the Sun orientation from the launch hour but not from the launch date.

On the other hand, the RAMP separation analyses showed that the longitudinal rate at separation (rotation around Xs) which is the more critical as the HSS shadowing is minimum for rotation around Xs, was well below the 0.6 deg/s. It was agreed with Arianespace that a value of 0.4 deg/s around Xs can be considered. So the updated conditions are separation have been redefined:

- Herschel Z axis depointing w.r.t. Sun < 5 deg
- Longitudinal angular rate < 0.4 deg/s
- Transverse angular rate < 0.6 deg/s.

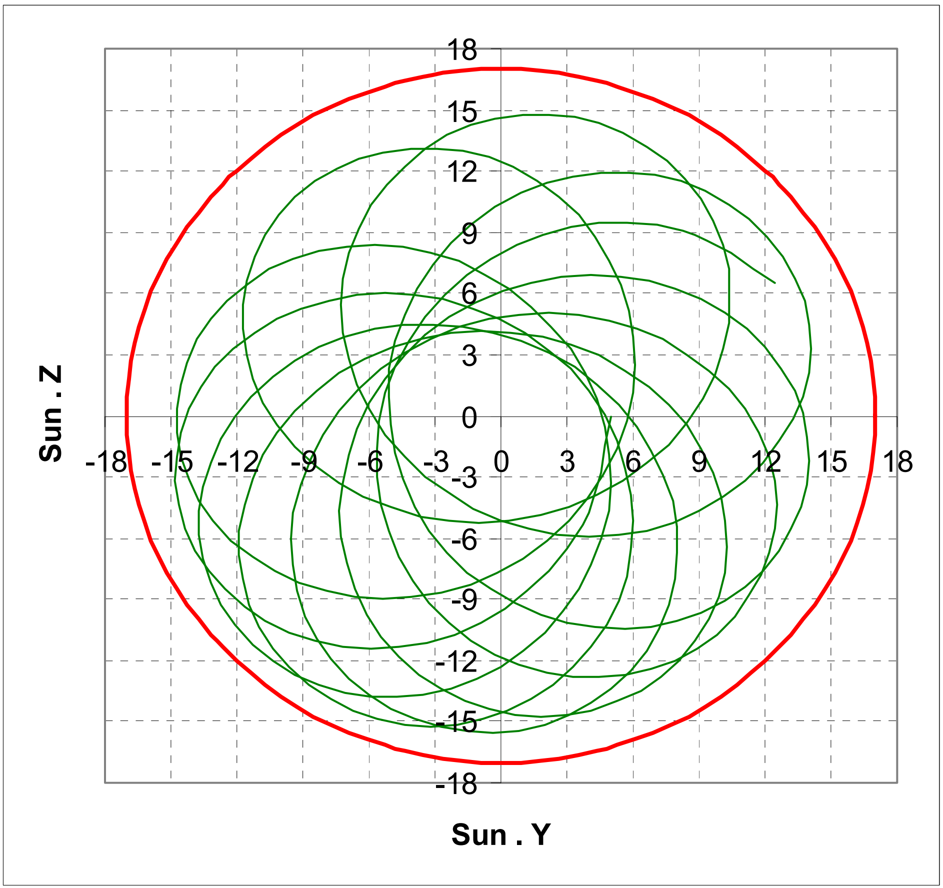
The conditions at Planck separation were initially defined as:

- Planck X axis depointing w.r.t. Sun < 1 deg
- Spin rate accuracy < 0.1 rpm
- Transverse angular rate < 0.4 deg/s.

Again, the launcher could not ensure a Sun pointing at 1 deg from Sun. In addition, the RAMP separation analysis showed that the transverse angular rate requirement could not be met and a value of 0.6 deg/s was found. The main issue was that, with such non compliances from the launcher, there was a risk of illumination of the PPLM after separation. An analysis of transient illumination of the PPLM was conducted (see RD04.2) and it was concluded that for SAA below 17 deg, the PPLM and instruments were safe with some margins. This allowed to redefine the separation conditions to:

- Planck X axis depointing w.r.t. Sun < 5 deg
- Spin rate accuracy < 0.1 rpm
- Transverse angular rate < 0.6 deg/s.

This ensures that the SAA remains below 17 deg after separation as shown in the following simulation.



The figure shows the projection on the (Y_S, Z_S) plane of the Sun vector (simulation of 5 minutes duration after separation). The red circle has a diameter of 17 deg

Figure 4.3-2 Sun direction in Planck spacecraft frame

The last item is the shadowing of the AAD, located on Planck –X side, by the launcher upper stage. The ACMS cannot be initiated if the AAD is shadowed as it will trigger a transition to survival mode. The requirement to Arianespace was to have the AAD Sun illuminated 5 minutes after separation. To meet this requirement, the upper stage is rotated by roughly 90 deg and a longitudinal thrust is activated to have a quick lateral escape. The RAMP results show that the AAD is illuminated 120 s after Planck separation which is well within requirement. Final time for ACMS activation on Planck will be decided after update of this analysis at RAMF.

<u>Collision analysis</u>

A collision analysis has been performed by Arianespace in the frame of the RAMP. Collision risk is analysed for short term and long term motions. For long term motions, the absence of collision risk is ensured by a difference in apogee altitude of the various bodies (Herschel, Planck, SYLDA-5, ESC-A). The RAMP analysis has calculated an apogee difference of around 6000 km between Herschel and Planck which ensures no risk of collision. The difference in apogee altitude with the other bodies is even higher (close to 40 000 km with SYLDA-5, above 100 000 km with ESC-A) ensuring no risk of collision. The short term analysis also shows a clean separation between the various bodies.

4.3.3 Injection Accuracy

The ARIANE 5 launcher dispersions are determinant for the navigation analysis. The first manoeuvre has the objective to correct the launcher injection error and is planned two days after lift-off. One important parameter is the accuracy of the delayed ignition of the launcher injection onto the escape orbit which is translated by a correction Delta-V allocation in the propellant budget.

Table 4.3-2synthesises the latest results provided from Arianespace . From this updated matrix, the amplitude of the first dispersion correction manœuvre has been estimated to less than 50 m/sec in CREMA 2.3 document with an updated method generating a Monte-Carlo simulation with re-optimisation of the transfer.

	a	e	i	ω	Ω	M	T
a	1	1	-0.2126	-0.009168	0.01766	0	0
e		1	-0.0174	-0.1506	0.0199	0	0
i			1	0.8996	-0.9609	0	0
ω				1	-0.9354	0	0
Ω					1	0	0
M						1	0.86614
T							1

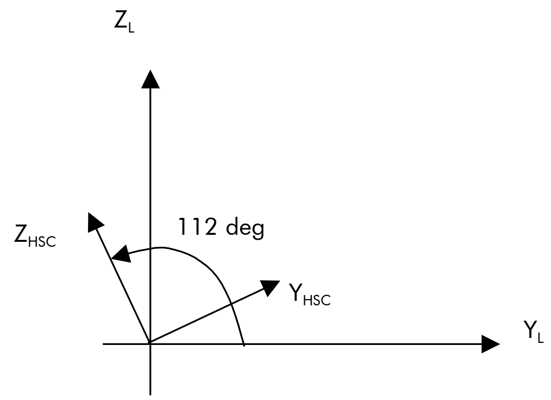
Table 4.3-2 A5-ECA dispersion correlation matrix and standard dispersions at spacecraft separation

4.3.4 Clocking

Due to the sensitivity of the Herschel spacecraft to Sun illumination, the clocking has to be determined to ensure that, during launch, the H-EPLM is not illuminated by Sun. At the beginning of phase C/D, the main identified constraint was the attitude at the EPC separation at H2 time, for which a fixed launcher attitude is imposed to ensure proper EPC re-entry in the Earth atmosphere. From this constraint, 2 clockings were defined

- A summer clocking of 96 deg (angle between Y_L and Z_{HSC})
- A winter clocking of 128 deg (angle between Y_L and Z_{HSC}).

Subsequent analyses has shown that the roll constraint at EPC separation was not so strong so a single, intermediate clocking was defined. The defined clocking angle for Herschel is now 112 deg as shown in the following figure.

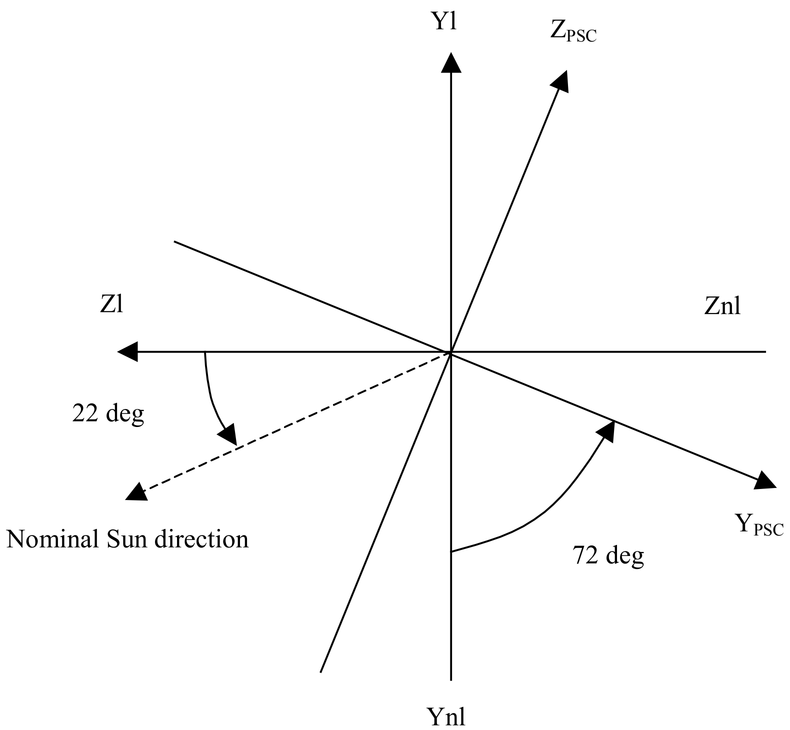


The axes Y_L and Z_L are the launcher axes, Y_{HSC} and Z_{HSC} are Herschel spacecraft axes

Figure 4.3-3 Herschel clock angle definition

For Planck, the constraints on clocking come from 3 factors:

- Holes in the conical part of the SYLDA-5 might lead to illumination of the PPLM cavity during roll transient, thus endangering the FPU's
- Holes in the cylindrical part of the SYLDA-5 might lead to illumination of the SVM: the most sensitive element is the STR
- After Herschel separation, the hole at the top of the SYLDA is open an illumination of the Planck PLM top at shallow angle can occur due to the launcher attitude control unaccuracies.



The axes Y_L and Z_L are the launcher axes, Y_{PSC} and Z_{PSC} are Planck spacecraft axes

Figure 4.3-4 Planck clock angle definition

Figure 4.3-5 is a top view of Planck inside the SYLDA-5 showing the holes in the SYLDA-5.

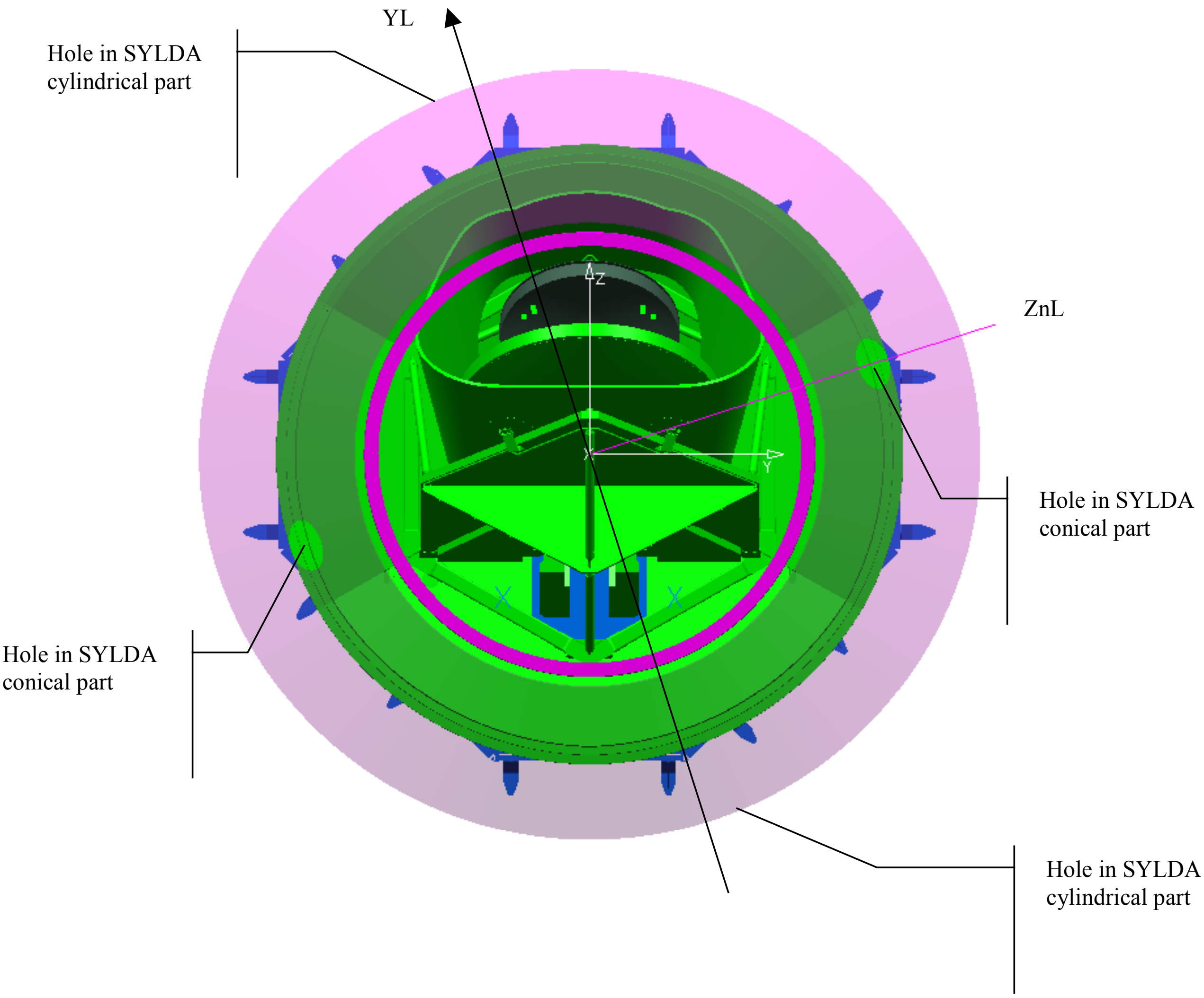


Figure 4.3-5 Planck Inside SYLDA-5, TOP view

Figure 4.3-6 shows the case for a SAA of 60 deg: when the hole projection is at the rim of the PPLM the cavity is not visible. It has been checked for SAA between 20 and 95 deg that no illumination of the cavity occurs.

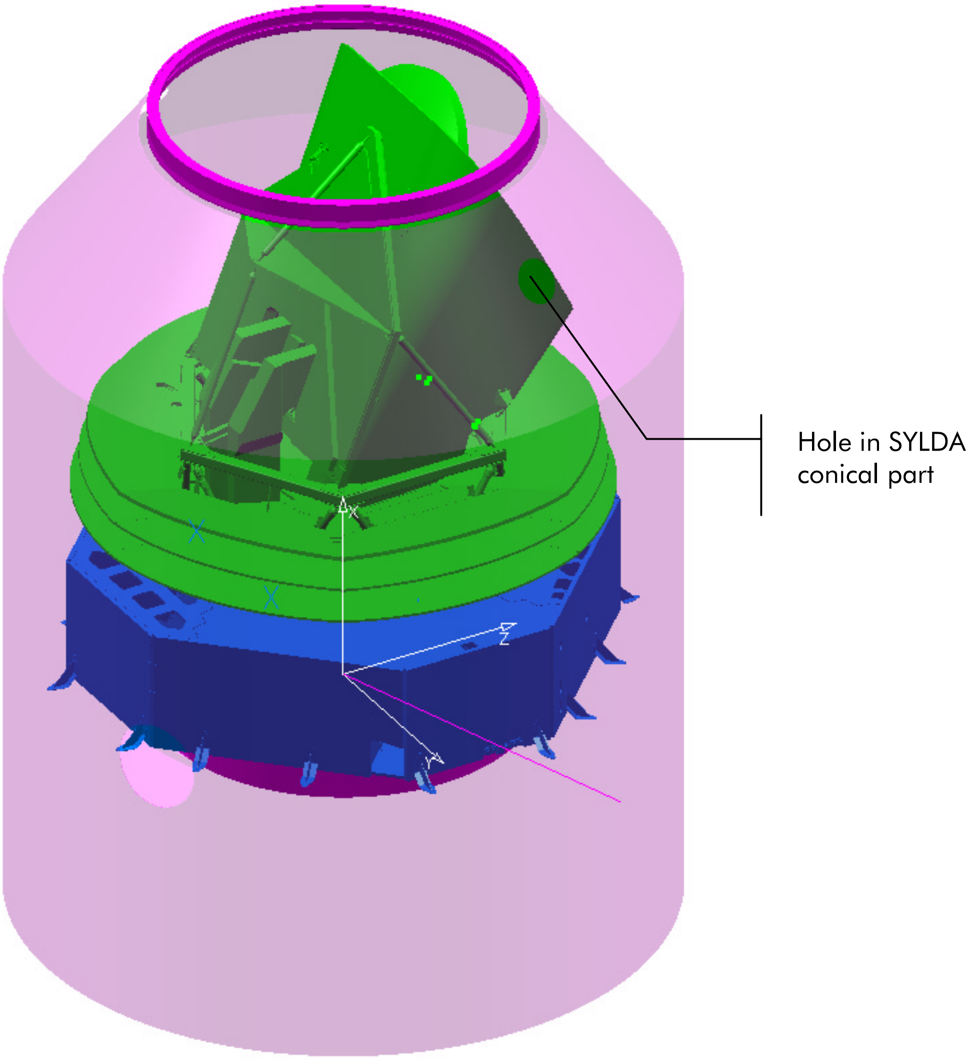


Figure 4.3-6 Avoidance of PPLM cavity illumination

With this clocking illumination of the SVM by the lower holes occurs on the following panels:

- +Z panel, max duration 22 sec, angle between Sun and STR line of sight remains above 40 deg, in line with GA requirements for STR
- +Z/-Y panel, max duration 40 s
- -Z panel, max duration 22 s
- -Z/+Y panel, max duration 40 s.

The Sun constraint w.r.t. STR is respected and the illumination of the panels is very short. No impact from illumination is expected.

After Herschel separation, the top of the PPLM can be illuminated through the hole of the adapter. It has been checked that, with this clocking, the illumination stays on the baffle top and miror back side, and no criticality has been identified.

4.4 Transfer phase

This phase begins at satellite separation from launcher and ends at the injection of the satellites on their operational orbit around L2. For Planck, this phase includes also the orbit insertion manœuvre performed to reach the small Lissajous orbit with SSCE of 15 deg.

4.4.1 Environment conditions

This section presents environment conditions of the transfer phase to L2 operational orbit: distance from Earth and Moon, Sun-satellite-Earth angle, and declination to Earth equator.

It is underlined that the following figures correspond to typical evolution of these parameters: the precise variation of these environment conditions will depend of course of the final launch date/time.

4.4.1.1 Distance to Earth and Moon

Figure 4.4-1 presents the distance to the Earth, which will drive the telecommunications and the radiation and thermal environment, and also the distance to the Moon. The left curves represents Herschel, and the right ones Planck during the transfer phase (about 6 months). Note that the distances to Earth and Moon are different for Herschel and Planck satellites after the Planck insertion manoeuvre on day 113 after separation.

As required Herschel distance to Earth remains below 1.8 Mkm and Planck distance to Earth remains below 1.6 Mkm.

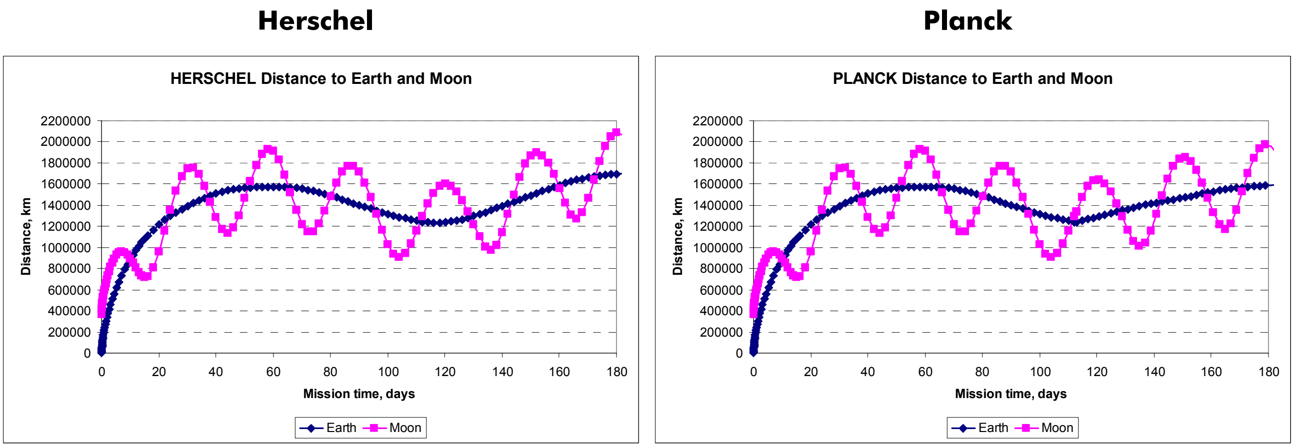


Figure 4.4-1 Herschel and Planck distance to Earth and Moon during transfer phase

4.4.1.2 Sun-Satellite-Earth angle

The Sun-Satellite-Earth aspect angle is very constrained for both spacecraft due to the nature of the mission and the on-board equipment. This angle has to be checked during all the phases of the mission and particularly during the transfer when it is submitted to large variations.

Figure 4.4-2 shows the Sun-Satellite-Earth angle for Herschel and Planck during the transfer phase.

Before Planck insertion manoeuvre, the Sun-Satellite-Earth angle reaches the maximum value of 31 deg around day 76 after separation. The Planck insertion manoeuvre reduces the Sun-Satellite-Earth angle down to a maximum value of 15 deg.

Herschel **Planck**

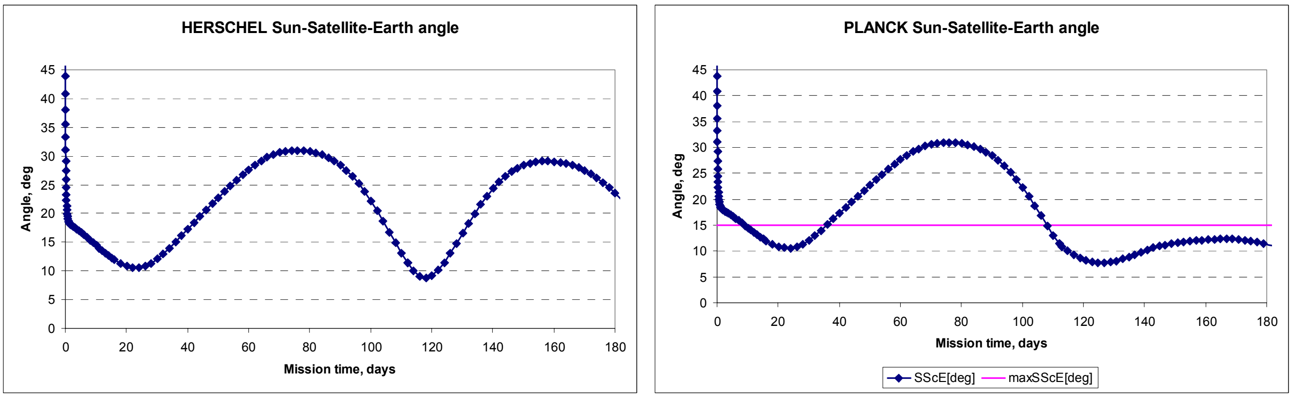


Figure 4.4-2 Herschel and Planck Sun-satellite-Earth angle during transfer phase

4.4.1.3 Declination to Earth

Figure 4.4-3 presents the declination to the Earth, which will drive the telecommunications. Dedicated analysis on station visibility analysis is presented further in Section 4.4.2.1.

Herschel **Planck**

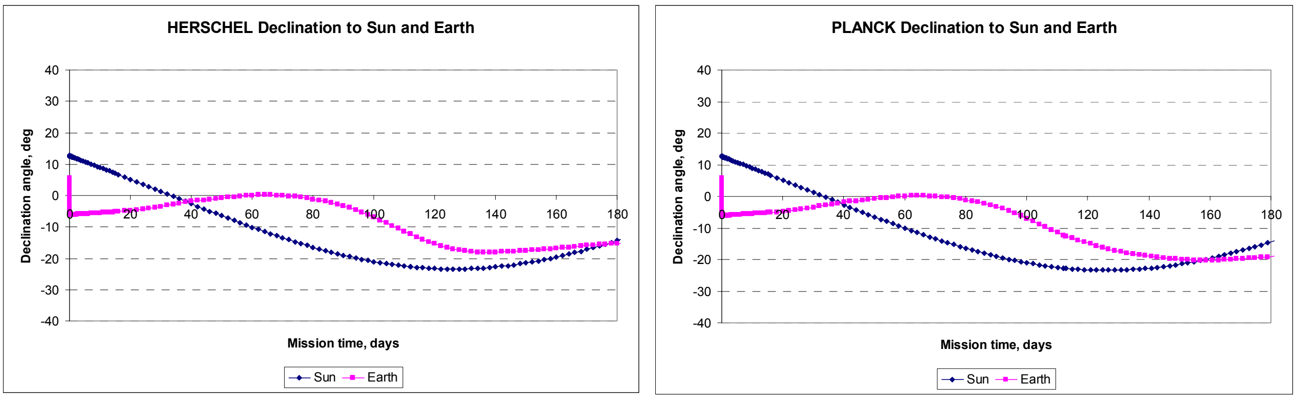


Figure 4.4-3 Herschel and Planck declination to Earth during transfer phase

4.4.2 Telecommunications during transfer phase

4.4.2.1 Station coverage analysis

4.4.2.1.1 Ground network definition

The ground station visibility during transfer is also a driving constraint for the mission. Both spacecraft will be controlled by the following ground stations: KOUROU, NEW NORCIA (baseline station in operational phase) and VILLAFRANCA. These stations belong to the ESA network and their locations is illustrated in Table 4.4-1 and Figure 4.4-6. The minimum elevation mask is taken equal to 10 deg for each station.

GROUND STATION	KOUROU	NEW NORCIA	VILLAFRANCA
Longitude, deg	-52.63	115.88	-3.95
Latitude, deg	5.10	-30.20	40.45
Min. elevation, deg	10	10	10

Table 4.4-1 Ground stations network location

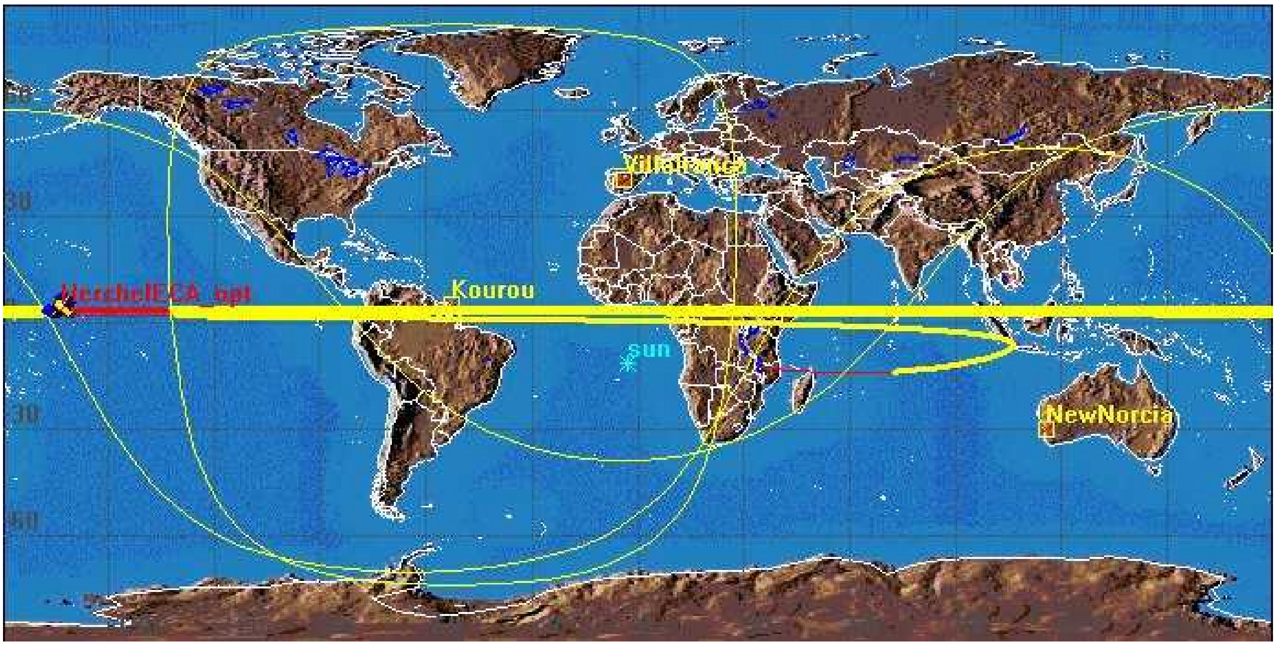


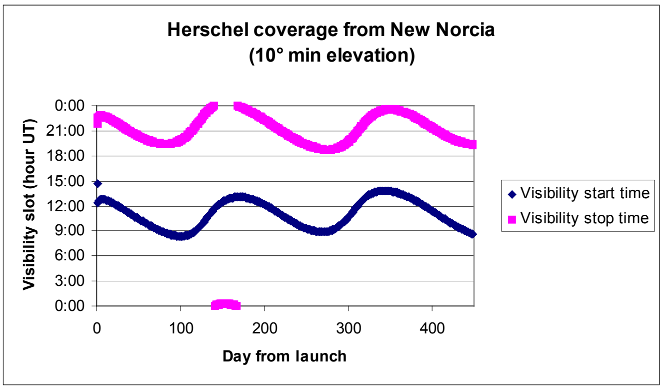
Figure 4.4-4 Ground station coverage during the first days of the transfer

Figure 4.4-4 shows that both spacecrafts are always in visibility of one station (ground track represented in bold yellow) except:

- from launcher separation above Africa to first New Norcia visibility (~12 minutes)
- everyday above Pacific Ocean.

4.4.2.1.2 Herschel and Planck visibility by NEW NORCIA

The following figure presents the evolution of the start/end times of daily visibility slots with New Norcia during the transfer phase and the first year of the operational phase. New Norcia visibility slots occur the afternoon (in UT).



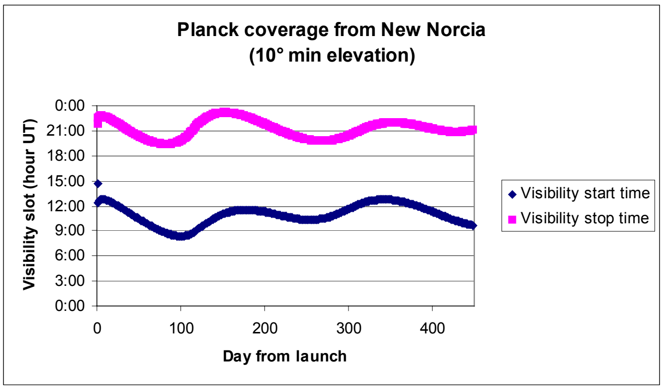
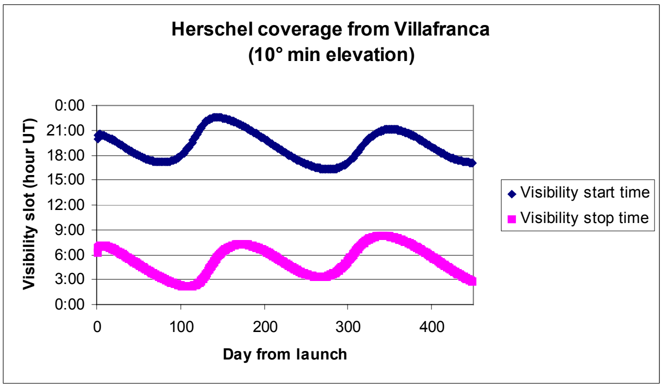


Figure 4.4-5 Herschel/Planck coverage from New Norcia

4.4.2.1.3 Herschel and Planck visibility by VILLAFRANCA

The following figure presents the evolution of the start/end times of daily visibility slots with Villafranca during the transfer phase and the first year of the operational phase. Villafranca visibility slots occur around midnight (in UT).



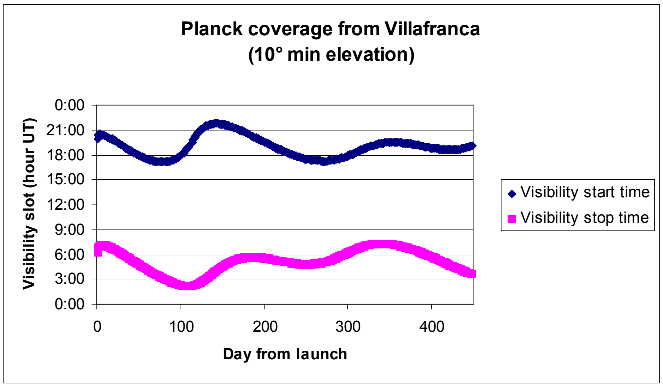


Figure 4.4-6 Herschel/Planck coverage from Villafranca

4.4.2.1.4 Herschel and Planck visibility by KOUROU

The following figure presents the evolution of the start/end times of daily visibility slots with Kourou during the transfer phase and the first year of the operational phase. Kourou visibility slots occur at the end of the night (in UT).

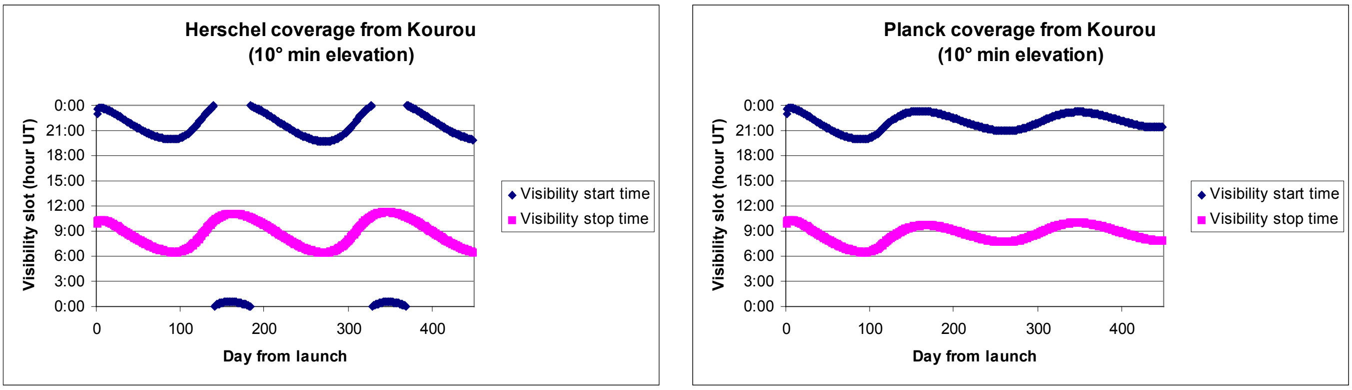


Figure 4.4-7 Herschel/Planck coverage from Kourou

4.4.2.1.5 Synthesis of the visibility analysis

As illustrated in Figure 4.4-8, the duration of each station visibility slot during the transfer phase is typically between 5 and 13 hours per day: it depends on the station latitude and on the spacecraft declination with respect to Earth equatorial plane.

There are everyday some visibility holes above Pacific Ocean without contact with any of the three stations. The typical duration of these visibility holes is between 1h30 and 3 hours per day for Planck and Herschel. The duration gets longer with high spacecraft declination: see Figure 4.4-4. These holes always happen the morning (in UT).

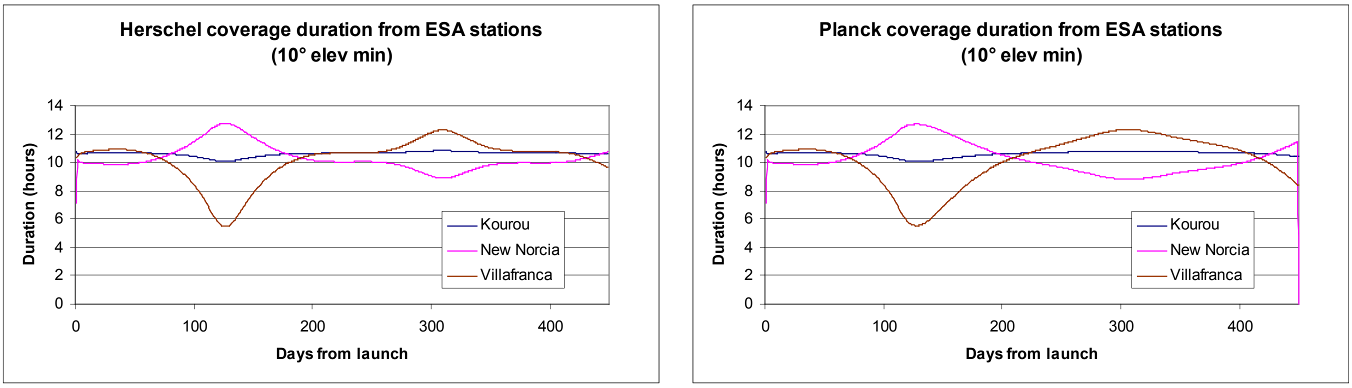


Figure 4.4-8 Herschel/Planck coverage duration from ESA stations

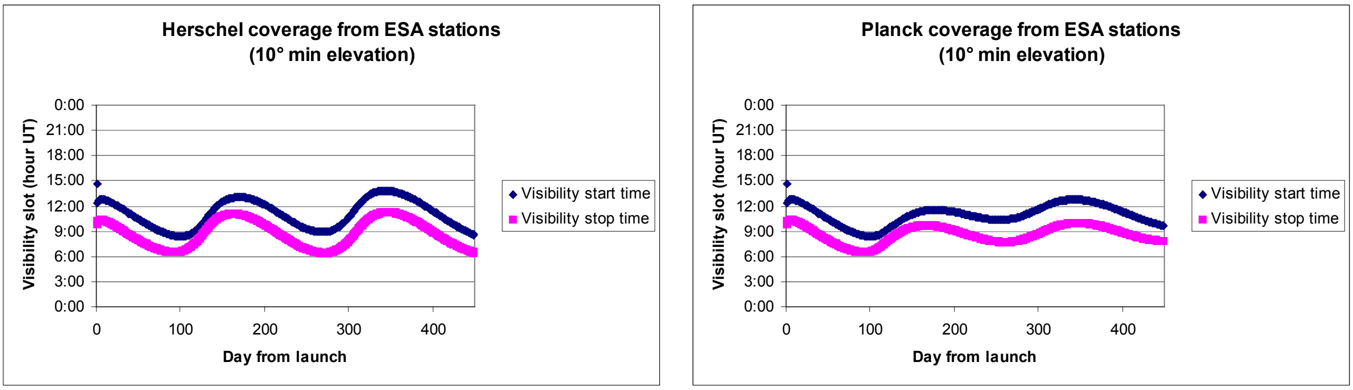


Figure 4.4-9 Herschel/Planck cumulated coverage from ESA stations

Figure 4.4-10 presents the evolution of the S/c-station distance over all the ground station coverage slots during the first week of transfer.

It shows that:

- The reception of TC at 4 kbps from Kourou or Villafranca up to 350000 km, means up to 50 hours **(~2 days)** after separation.
- The down-link of TM at 5 kbps to Kourou or Villafranca up to 750000 km, means up to 180 hours **(~7.5 days)** after separation.

Besides Figure 4.4-11 presents the evolution of the range rate for the first 10 days of the transfer. The range rate is the highest during the first New Norcia visibility (up to 5 km/s) and then sharply decreases below 1 km/s after about 10 days. The +/-0.5 km/s variation of the range rate during each slot is due to Earth rotation: it is the main contributor to the range rate after few tens of days on the transfer orbit.

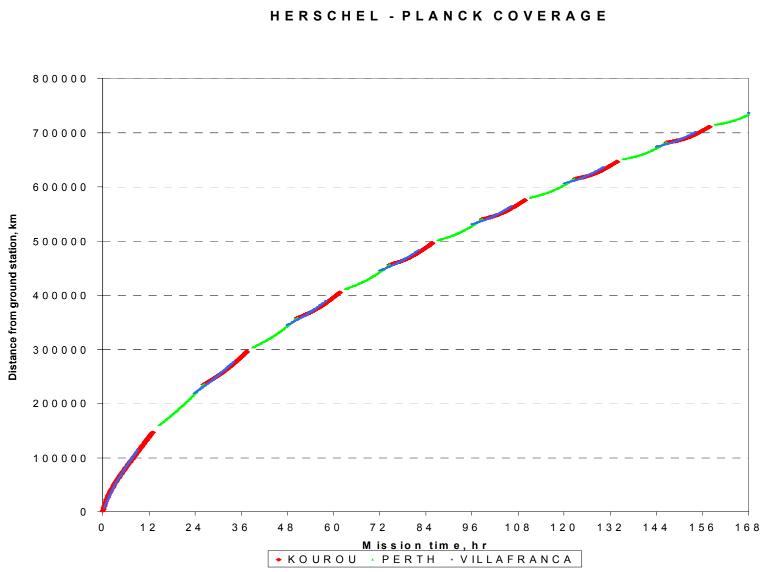


Figure 4.4-10 Ground stations visibility during first week of transfer

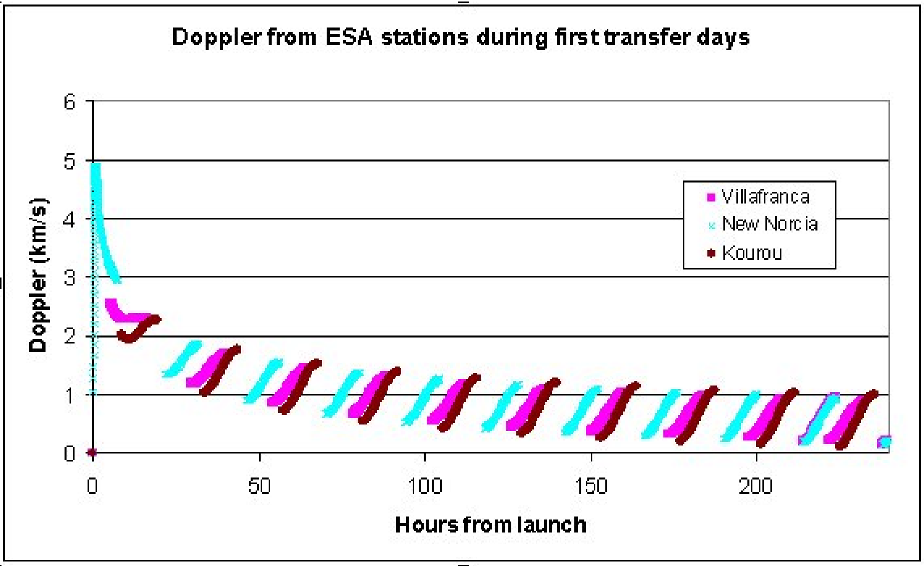


Figure 4.4-11 Doppler during first 10 days of transfer

4.4.2.2 Sun/satellite/station angle at separation

After launcher separation, Herschel and Planck sunshields are both pointed in sun direction. The antenna used for the first station acquisition with New Norcia will depend on the variation of the sun-satellite-station angle just after the separation of the 2 satellites.

Since communication antennas are pointed either in sun direction (1 antenna) or in anti-sun direction (1 antenna for Herschel, 2 antennas for Planck), a sun-satellite-station angle close to 90° is not very favourable: it means that satellite-station direction is on the edge of the antenna gain pattern or between two antennas.

The following figure presents the variation of sun-S/c-New Norcia angle during the first hour after the separation. New Norcia visibility (first station visibility slot after separation) begins about 12 minutes later. With a launch on 2007/02/15 at 14h, this angle is equal to 101° at the beginning of New Norcia visibility and then quickly decreases.

Consequently it is not possible to keep the same spacecraft antenna over the whole New Norcia pass. After separation + 18 minutes, this angle stays below 80° for the rest of the mission. Therefore the recommended strategy is to wait few minutes more and to cover the whole New Norcia visibility slot with the nominal sun-oriented antenna.

The same analysis has been performed for other launch dates/hours: it can be seen on the following figure that it impacts slightly the Sun-S/c-New Norcia angle after separation. However the same conclusions are applicable.

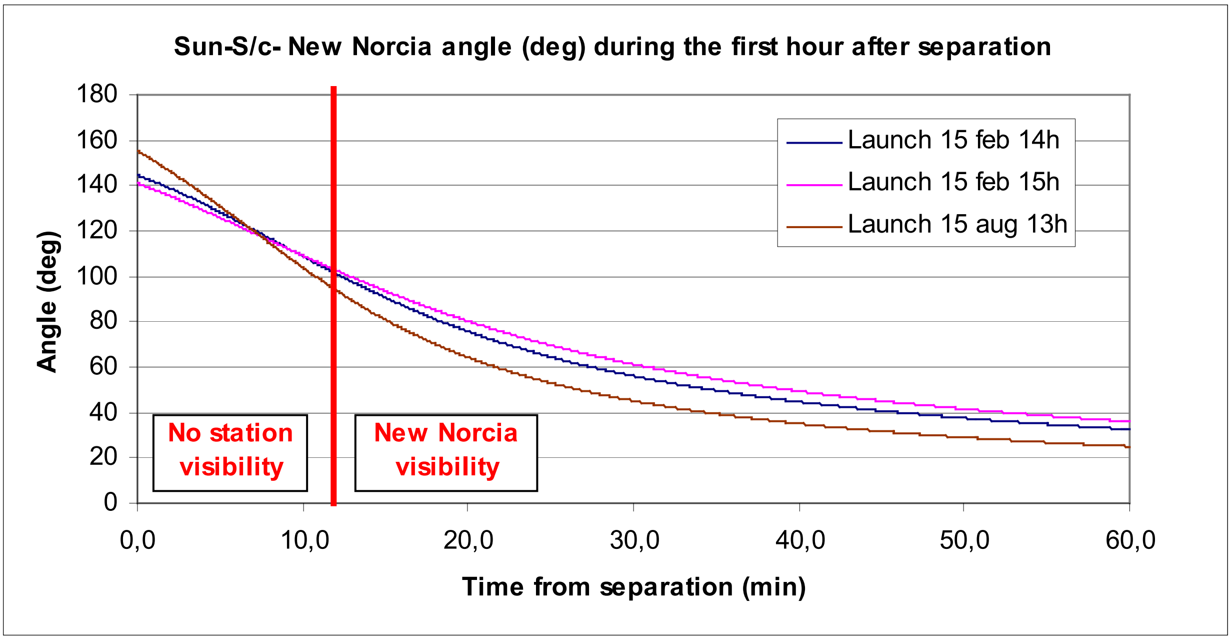


Figure 4.4-12 Sun-spacecraft-New Norcia angle after separation

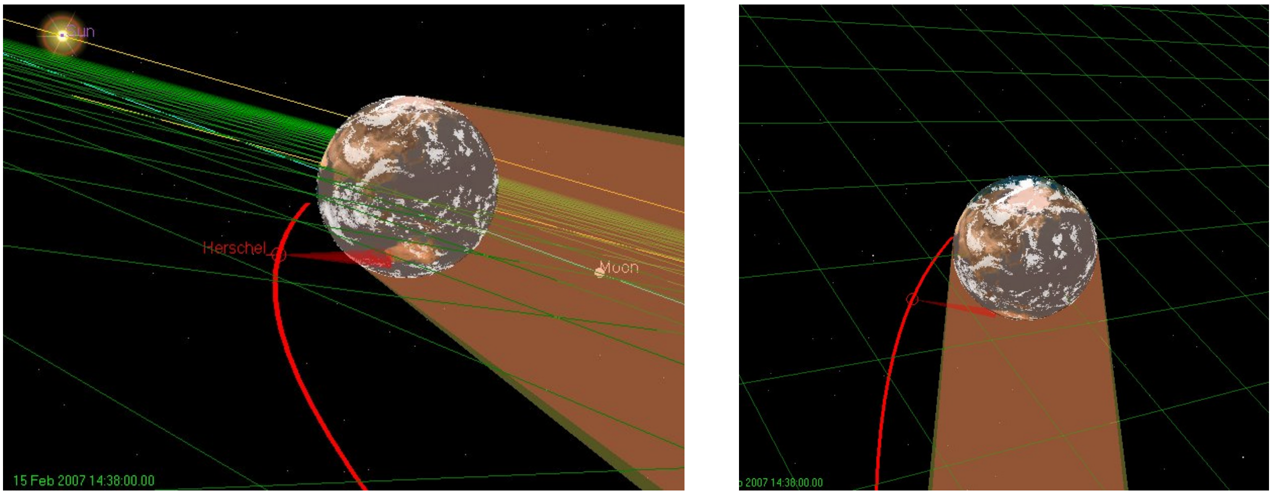


Figure 4.4-13 3d-View of Sun-sC-New Norcia geometry at beginning of visibility slot

4.4.2.3 SSCE constraint for data downlink

When no high rate telemetry is needed (until the beginning of the Performance verification phase, from T0 to T0 + 1 m for Herschel and Planck), omni-directional coverage is provided by the LGAs for both spacecraft.

Concerning MGA usage, the following table summarises the various possibilities:

GROUND STATION	DATA RATE	MAX ANGLE BETWEEN EARTH AND ANTENNA BORESIGHT	MAXIMUM SSCE FOR HERSCHEL	MAXIMUM SSCE FOR PLANCK
New Norcia	High	15 deg	45 deg	25 deg
New Norcia	Medium	15 deg	45 deg	25 deg
Kourou	Medium	10 deg	40 deg	20 deg

As shown in Section 4.4.2, the SSCE during transfer goes up to more than 30 deg. This is not a problem for Herschel but it will limit the data transfer capability with Planck:

- SSCE is above 20 deg during typically 60 days without the possibility to have contact with Kourou at medium rate
- SSCE is above 25 deg during typically 45 days without the possibility to have contact with New Norcia at medium or high rate.

At the time of maximum SSCE, the distance to Earth is close to the maximum so no improvement of the link budget can be expected. On the other hand the declination is close to 0, meaning a daily ground contact with New Norcia of 10.4 hours, equivalent to the one with Kourou (10.7 h). So performance verification can continue using New Norcia when the SSCE is between 20 and 25 deg. However performance verification phase will be interrupted for about 45 days when SSCE is above 25 deg. Taking into account a 2 months duration for this phase it will still finish before the 6 months allocated for transfer phase.

4.4.3 Star tracker blinding by the Moon

The goal of this analysis is to characterise the blinding periods of the star trackers for both Herschel and Planck during their transfer to L2 in order to conclude on the impact of this constraint on the design of the mission. In particular, it is of great importance that the star tracker remains operational during the beginning of the transfer (i.e. during the first four days) since two correction manoeuvre are performed the first 2 days.

4.4.3.1 Assumptions

The trajectory is computed by the direct method applied to dates equally spaced in a Lunar month of 28 days, beginning on February 15th 2007. The analysis is focused on the 5 first days of each transfer trajectory because the Moon blinding occurrences only happen at the beginning of the transfer phase.

Based on data given by Galileo Avionica, a Moon exclusion angle of 20 deg has been considered. This means that an interference with the Moon can occur as soon as the Moon direction is at less than 20 deg from the STR optical axis.

4.4.3.1.1 Herschel attitude

Herschel is controlled on its 3-axis. Its Z axis can be pointed at 30 deg off the Sun direction. To simplify the analysis of Moon interference, it has been considered that the z axis always points the Sun direction. The Startracker is pointed in the –x direction (that means it is collinear to the telescope but in the opposite direction, cf. Figure 4.4-14).

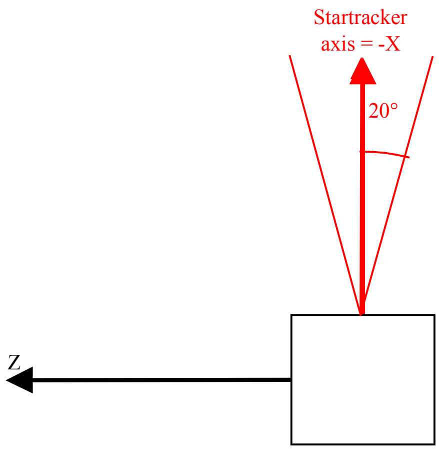


Figure 4.4-14 Herschel attitude

In Figure 4.4-14, we can see that the glares can occur only if:

$$70° \leq SSCM \leq 110°$$

To avoid moon blinding, the attitude around Z of the spacecraft shall be such that the moon avoidance cone of the STR does not include the direction of the Moon.

In order to define precisely the attitude of the spacecraft around z-axis (since it is the only DOF) we have to define a reference frame. It is defined thanks to z-axis that is sun pointed, Yscref that is normal to the ecliptic, and Xscref that is constructed thanks to the crossproduct of Yscref by Zsc. In that particular frame, the attitude of the spacecraft is entirely determined by the teta angle of rotation of the spacecraft frame around the z axis: see Figure 4.4-15.

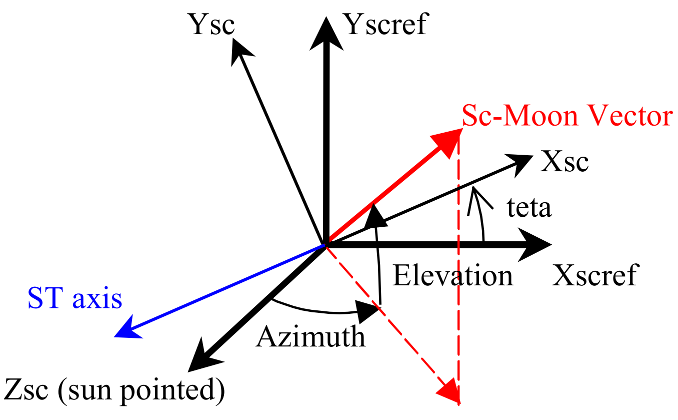


Figure 4.4-15 Herschel reference frame – Definition of azimuth/elev of the Moon

Let's note:

$$\alpha_0 = ST_{openangle}$$

$$a = COS(Elevation) \cdot SIN(Azimuth)$$
$$b = SIN(Elevation)$$
$$\psi = ATAN2\left(\frac{b}{\sqrt{a^2+b^2}}, \frac{a}{\sqrt{a^2+b^2}}\right)$$

Then we can delimit the authorised attitude angles in the following way:

$$\boxed{\theta_{\inf} = -ACOS\left(-\frac{COS(\alpha_0)}{\sqrt{a^2+b^2}}\right) + \psi \le \theta \le ACOS\left(-\frac{COS(\alpha_0)}{\sqrt{a^2+b^2}}\right) + \psi = \theta_{\sup}}$$

4.4.3.1.2 Planck attitude

Planck is spinned around its –x axis. The –X axis can be pointed 10 deg off the Sun. For the Moon interference analysis the –X axis is considered Sun pointed. This is justified by the fact that the most critical phase is the delta-V manœuvre on day 2 which will be performed with the –X axis almost Sun. The Star Tracker and its sky coverage is represented on Figure 4.4-16. We will define the dates when the glares can occur: contrary to Herschel, it is not possible to avoid them because the spacecraft is spinned with a rotating velocity of 1 rpm.

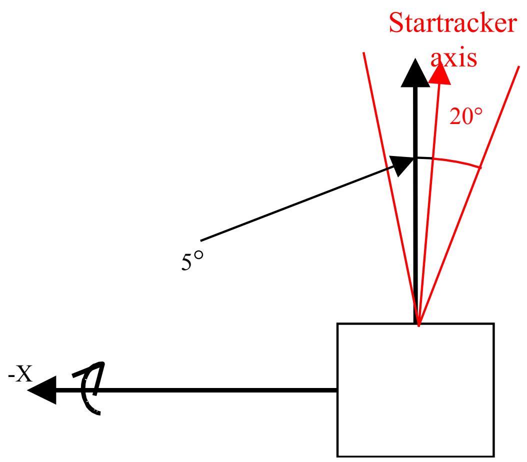


Figure 4.4-16 Planck attitude

On Figure 4.4-16, we can see that the glares occur as soon as:

$$\boxed{75° \le SSCM \le 115°}$$

4.4.3.2 Results

4.4.3.2.1 Dates and durations of the glares

4.4.3.2.1.1 Herschel

We represented the date of the beginning and of the end of the glare periods for Herschel function of the launch date on Figure 4.4-17. We scanned one Moon period beginning on February 15th 2007 with a 3 days step. Remember that contrary to Planck, the glares occur only if the attitude of the spacecraft around Z is in the forbidden area.

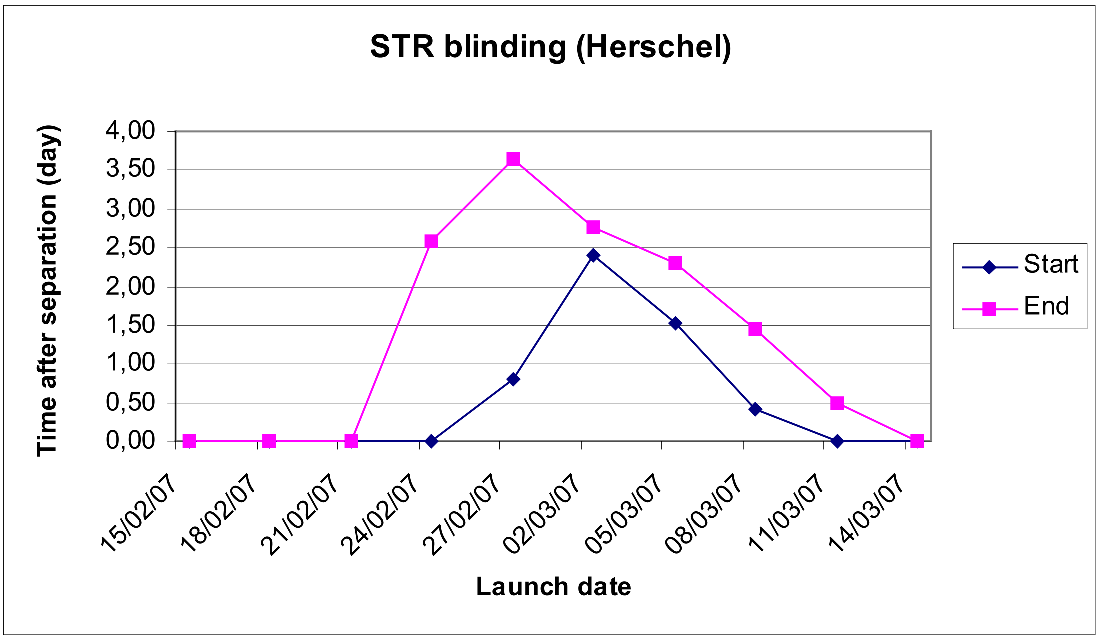


Figure 4.4-17 Glares of the Star Tracker of Herschel on one Moon period

4.4.3.2.1.2 Planck

We represented the date of the beginning and of the end of the glare periods for Planck function of the launch date on Figure 4.4-18. We scanned one Moon period beginning on February 15th 2007 with a 3 days step.

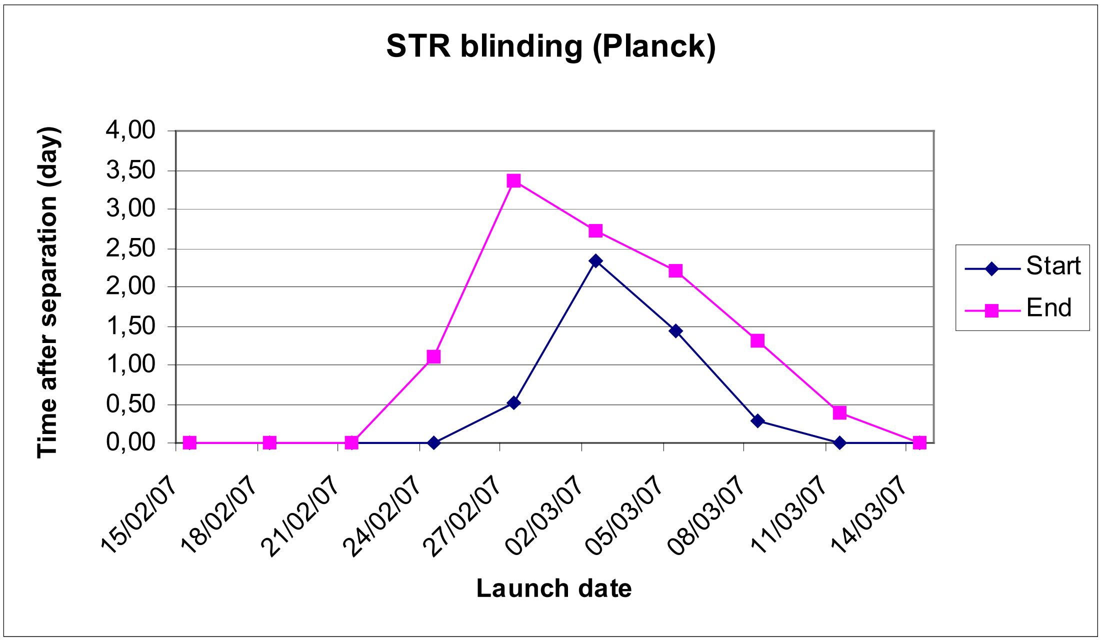


Figure 4.4-18 Glares of the Star Tracker of Planck on one Moon period

4.4.3.2.1.3 Conclusion

For both spacecraft we can remark that there is a 15-day long glare period during one Moon period of 28 days. The duration of the glare period is variable. The maximum duration occurs when the Moon is turning around Earth in the same direction as the spacecraft (see Figure 4.4-19). We remark that a glare period can last up to 3 days.

In order to conclude, it is important to study the magnitude of the glares during a glare period. This is the reason why we are going to study in 4.4.3.2.2.2 the apparent angle of the Moon seen from the spacecraft during the glare periods.

For Herschel the attitude constraints around Z axis during blinding periods are also estimated.

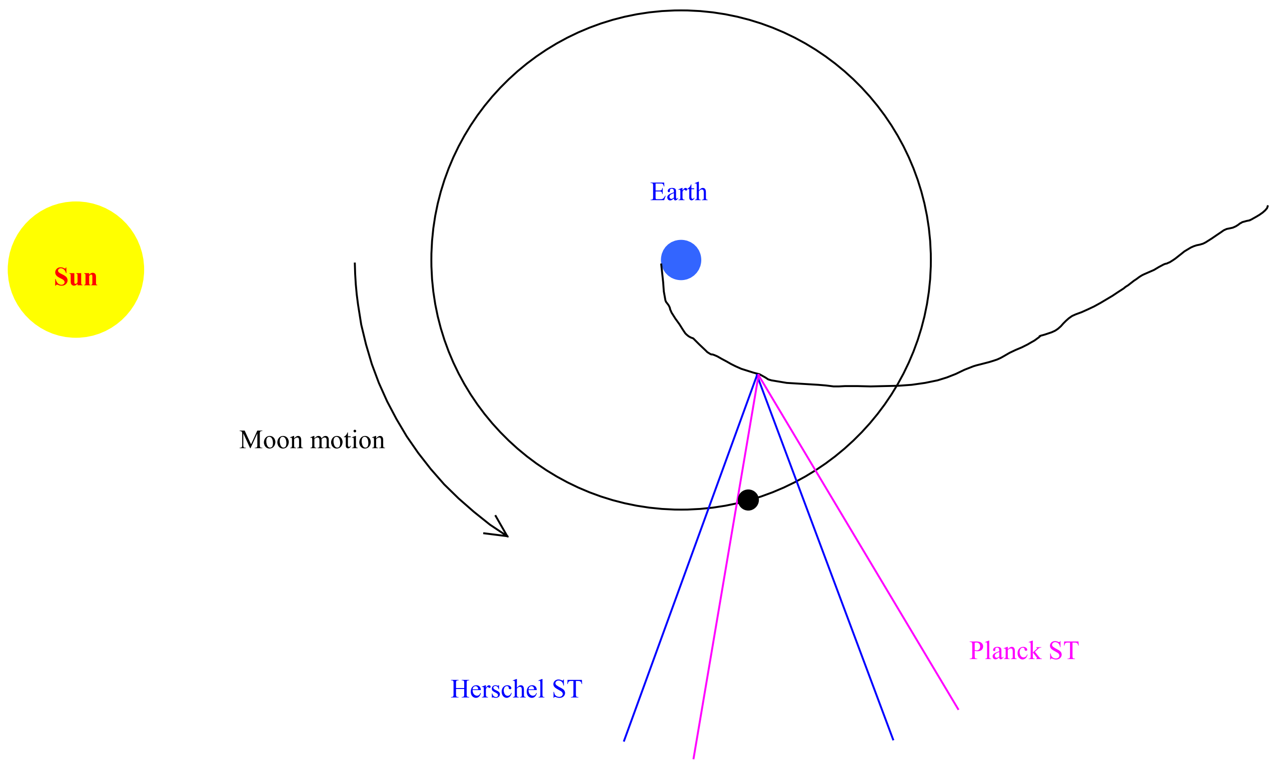


Figure 4.4-19 Simplified geometry of STR moon blinding occurrences

4.4.3.2.2 Impact of the glares

4.4.3.2.2.1 Herschel

On Figure 4.4-20, we represented the limits of the unauthorised attitudes around Z for Herschel during the glare periods for 6 possible launch dates.

We can conclude that the unauthorised attitudes strongly vary with the launch date. Yet, the unauthorised ranges of attitudes are very narrow: < about 40° (this is linked to the STR FOV and to the apparent diameter of the moon).

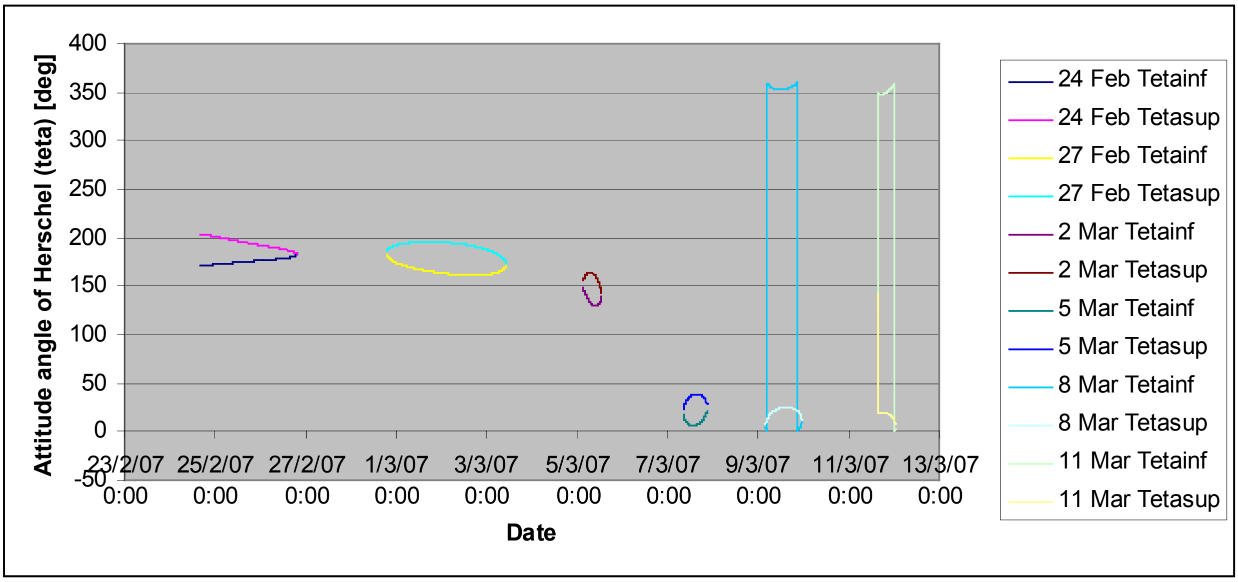


Figure 4.4-20 Unauthorised attitude ranges for Herschel to avoid moon blinding

4.4.3.2.2.2 Herschel and Planck

On Figure 4.4-21 we represented the spacecraft-Moon distance as function of the lunar day for all the launch dates leading to STR blindings. We can see that the closest approach to the Moon occurs after about 2 days of flight. It is precisely the time when the launcher dispersion manoeuvre is performed.

The apparent angle of the Moon seen from spacecraft is directly linked with the spacecraft-Moon distance thanks to the following relation:

$$MAA = 2 \cdot ATAN\left(\frac{R_{MOON}}{D_{scmoon}}\right)$$

On Figure 4.4-22, we represented the MAA as function of the lunar day for all the launch dates leading to STR blindings. We can see that there will be glares when the MAA is not negligible (e.g. 3.5° MAA during the glare period of the March 2nd launch). More generally the apparent angle of the moon will be around 0.5-1°.

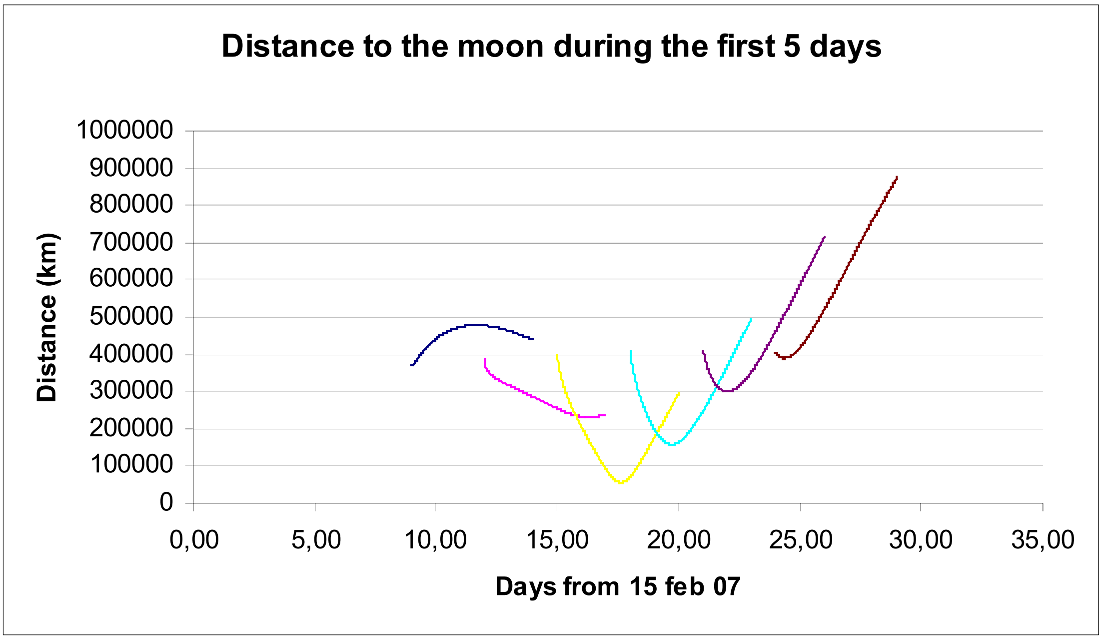


Figure 4.4-21 Distance to the moon (each curve represents a different launch date)

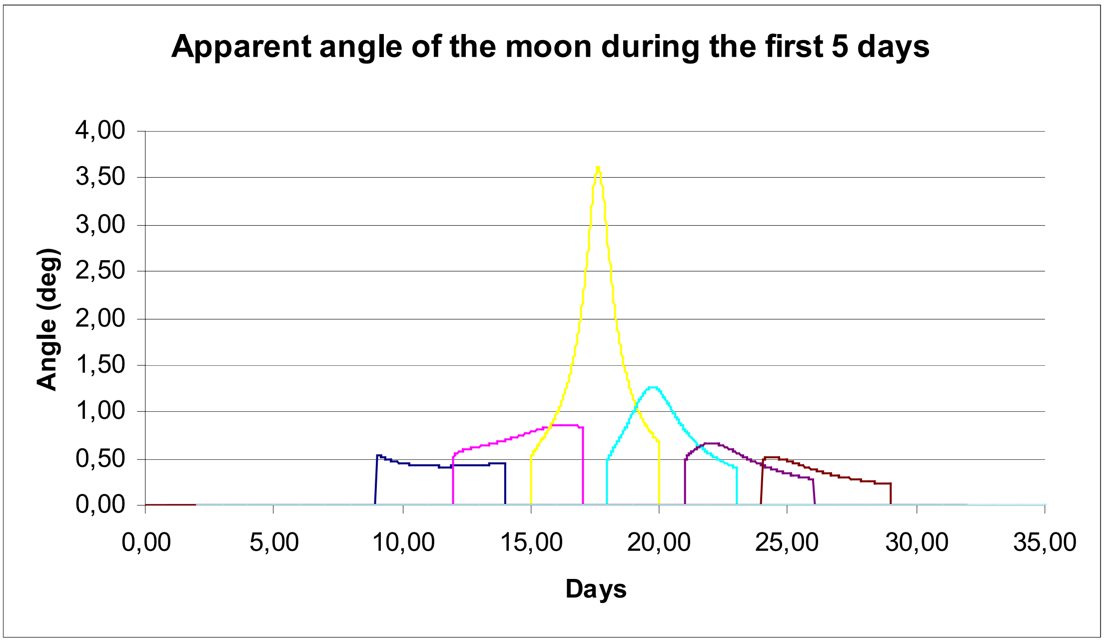


Figure 4.4-22 Apparent angle of the Moon (each curve represents a different launch date)

4.4.3.3 Conclusions

We have delimited the unauthorised attitudes of Herschel depending on the date and on the launch date, and seen that the ranges of unauthorised attitudes around Z are quite narrow (< 40°).

Due to the manoeuvrability of Herschel, the Moon interference will have to be taken into account when determining the attitude for the manœuvres of the first 2 days. As the SAA of these manœuvres is close to 180 deg, they will have to be decomposed into 2 manœuvres in any case. This will give more flexibility to find an attitude in which the STR is not blinded by the Moon.

For Planck, the impact of the Moon interference is more severe. Planck will not be able to avoid glares during the glare periods since its attitude has to remain at a few degrees from Sun during delta-V manoeuvres. In the worst case, the first 2 manœuvres have to be delayed to a period without Moon interference. Considering that the manœuvres are delayed to day 3, 2 days have to be removed from the launch window every Lunar month which means 11 days per year. Taking into account the amplification factor of the manœuvres with time, the impact is the following:

	Nominal planning		**Manœuvres delayed on Day 3**	
Perigee velocity variation	Day 1	10 m/s	Day 3	16.7 m/s
Removal of launcher dispersion	Day 2	40 m/s	Day 3	48.8 m/s
TOTAL		**50 m/s**		**65.5 m/s**

As the efficiency of these manœuvres are low due to the SAA close to 180 deg, the impact on the fuel budget is close to 30 kg. A provision will be taken on the fuel budget to cover this case.

Alternative approach in which manœuvres are performed during the Moon interference are discussed in section 6.3.5: even if this would allow to reduce the impact on the fuel budget this approach is considered risky.

4.5 Operational orbit

After transfer orbit phase, the mission phase begins at satellite insertion into operational orbit around L2.

4.5.1 Environment conditions

This section presents environment conditions on operational orbit: distance from Earth and Moon, Sun-satellite-Earth angle, and declination to Earth equator.

It is underlined that the following figures correspond to typical evolution of these parameters: the precise variation of these environment conditions will depend of course of the final launch date/time.

4.5.1.1 Distance to Earth and Moon

Figure 4.5-1 presents the distance to the Earth, which will drive the telecommunications and the radiation and thermal environment, and also the distance to the Moon. The left curves represents Herschel, and the right ones Planck over 4.75 years of mission for Herschel, and 2.75 years of mission for Planck. Note that the distance to the Earth and Moon are different for Herschel and Planck satellites after the Planck insertion manœuvre.

As required Herschel distance to Earth remains below 1.8 Mkm and Planck distance to Earth remains below 1.6 Mkm.

Herschel **Planck**

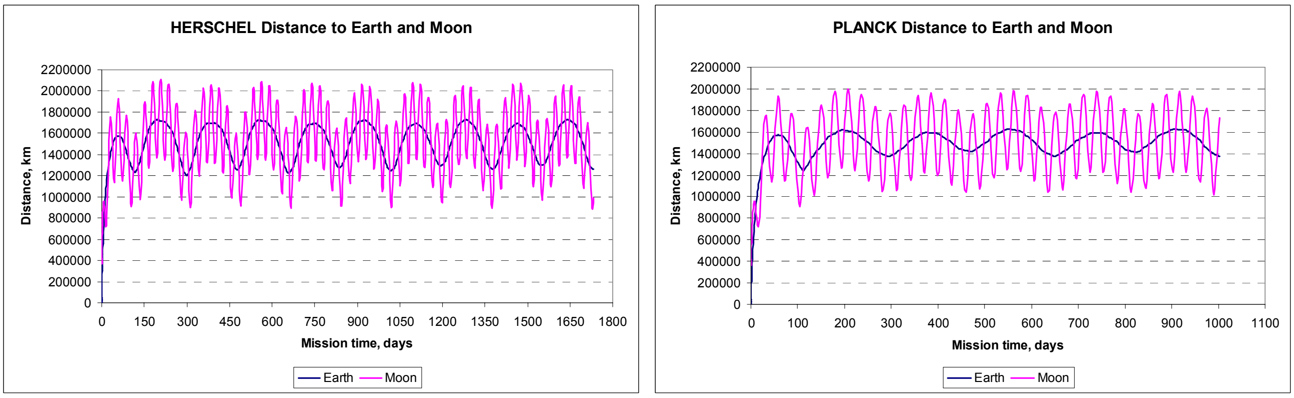


Figure 4.5-1 Herschel and Planck distance to Earth and Moon on operational orbit

4.5.1.2 Sun-Satellite-Earth angle

The Sun-Satellite-Earth aspect angle is very constrained for both spacecraft due to the nature of the mission and the on-board equipment. It can be noticed in the following figures that maximum SSCE constraints of 40° for Herschel and 15° for Planck are verified.

Herschel **Planck**

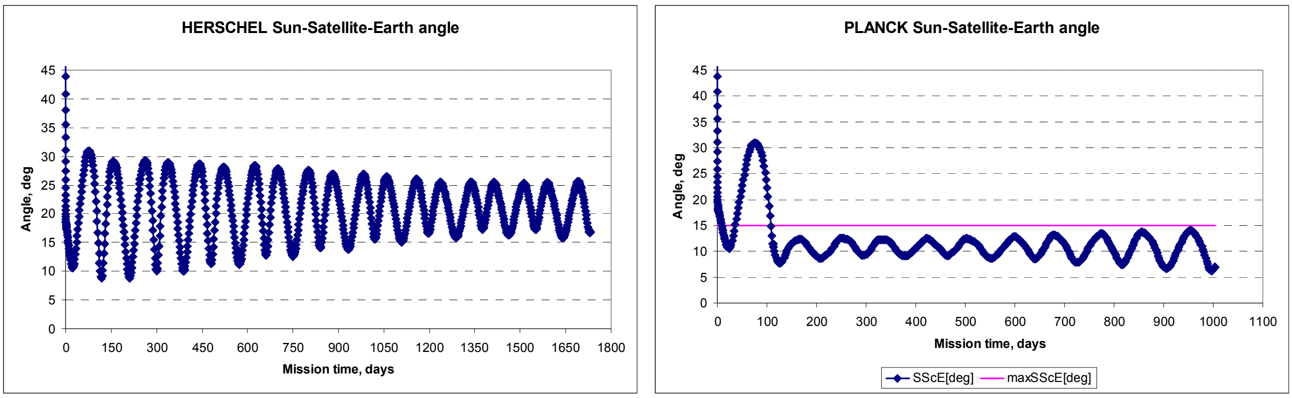
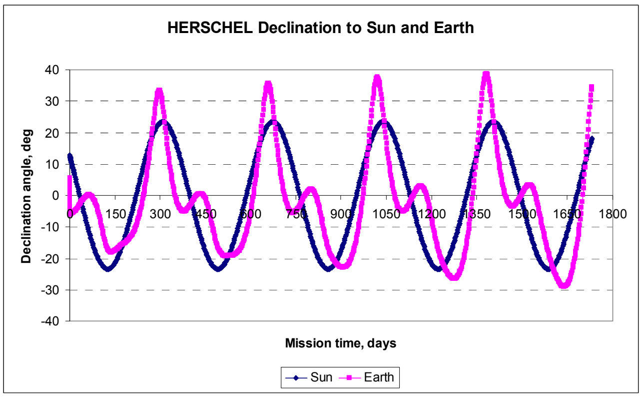


Figure 4.5-2 Herschel and Planck Sun-satellite-Earth angle on operational orbit

4.5.1.3 Declination to Earth

Figure 4.5-3 presents the declination to the Earth, which will drive the telecommunications. Dedicated analysis on station visibility analysis is presented further in Section 4.5.2.

Herschel



Planck

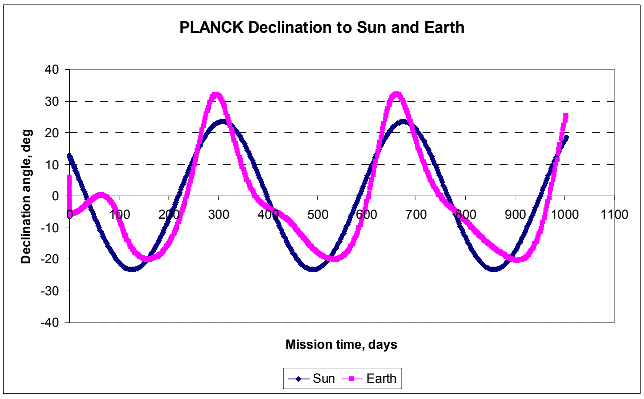


Figure 4.5-3 Herschel and Planck declination to Earth on operational orbit

4.5.2 Telecommunications during operational phase

4.5.2.1 Characteristics of daily visibility slots

See analysis of ground station visibility characteristics in Section 4.4.2.1.

During operational phase New Norcia is considered as the baseline ground station. As presented in the following figure, visibility problems with New Norcia (i.e. visibility slots shorter than 3 hours) occur when the spacecraft declination is above 45 deg. Contrary to the previous launch windows (based on A5 ECA with perigee shift and later launch time), the new launch window (based on A5 ECA without perigee shift) is fully compatible with a maximum declination below 41 deg over the full Herschel lifetime. So daily visibility slots with elevation above 10 deg and duration longer than 3 hours are always available with New Norcia.

As mentionned in Section 4.4.2.1, the range rate (Doppler) on the operational orbit is small with respect to the beginning of the transfer phase. It is mainly due to the Earth rotation, and varies within about +/-0.5 km/s.

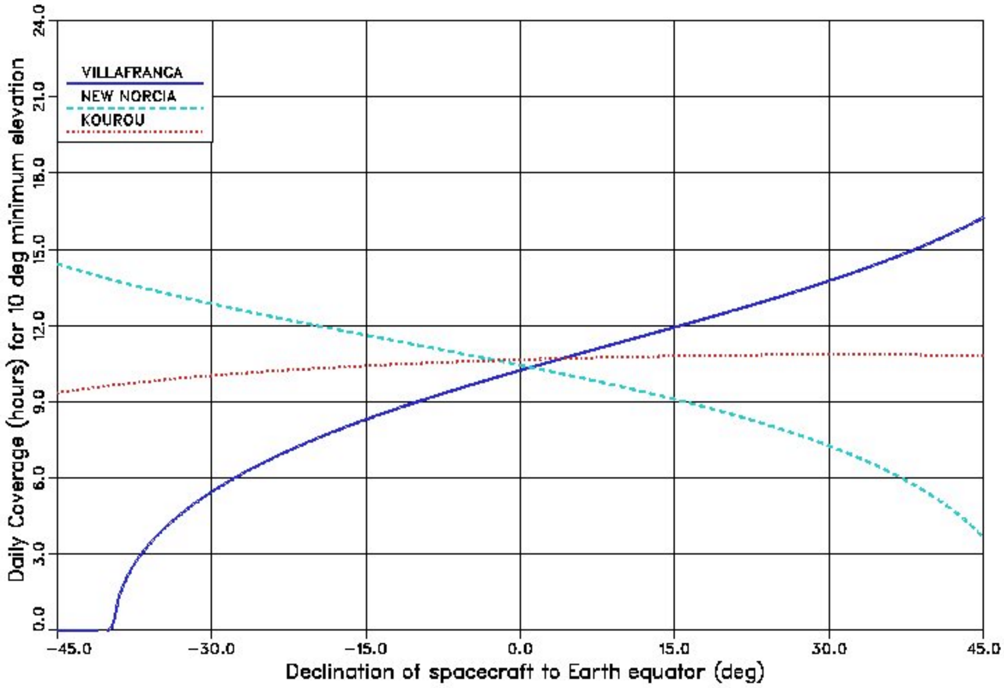


Figure 4.5-4 Daily coverage duration vs s/c declination - elev > 10 deg (from Crema)

4.5.2.2 SSCE constraint for data downlink

Herschel

During observation phase, the Herschel spacecraft is repointed to Earth before each DTCP in order to ensure optimal communications. The telemetry link is established via the MGA, in order to ensure high data rate link. This antenna is oriented along the spacecraft Z axis.

Since the MGA has an half cone aperture of 15 deg, in the worst case SSCE of 40 deg the Sun can be maintained at a maximum angle of 25 deg w.r.t. solar array normal. This is shown in Figure 4.5-5. At 15 deg aperture, the antenna gain is 16 dB which is compliant with the need for high data link rate with New Norcia. So, in the power budget, a maximum SAA of 25 deg has been taken for the nominal DTCP with New Norcia.

For telecommunication with Kourou, higher antenna gain is needed: the link budget is positive with a maximum angle between antenna axis and Earth direction of 12 deg. So, in the power budget, for the Kourou case a SAA of 28 deg has been considered.

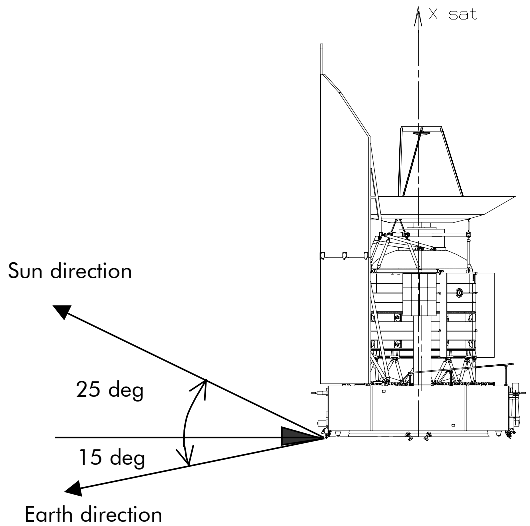


Figure 4.5-5 Herschel communication with Earth (New Norcia case)

In the case of communication with New Norcia, the MGA has a half cone aperture of 15 deg. This means that if the SCCE is above 30 deg, Earth and Sun have to be within the satellite (X, Z) plane. No rotation around the two axes X and Z is then allowed. Rotation around Y can be allowed as long as Earth remain within 15 deg from antenna axis.

When the SSCE is below 30 deg, with an adequate choice of the Z axis orientation, rotation around this axis can be performed. This allows some flexibility for spacecraft pointing for scientific observation during the DTCP.

Planck

During operation orbit, the satellite spin axis can be depointed 10 deg from the Sun and the SSCE can be up to 15 deg with the increased Planck orbit size. Combining these two cases could lead to have the Earth at 25 deg from the spin axis. However, during operational orbit, mission planning will ensure that the Earth remains below the maximum SSCE, i.e. 15 deg. With a -X pointed MGA, the Earth will be at maximum 15 deg from antenna axis during operational orbit as shown in Figure 4.5-6.

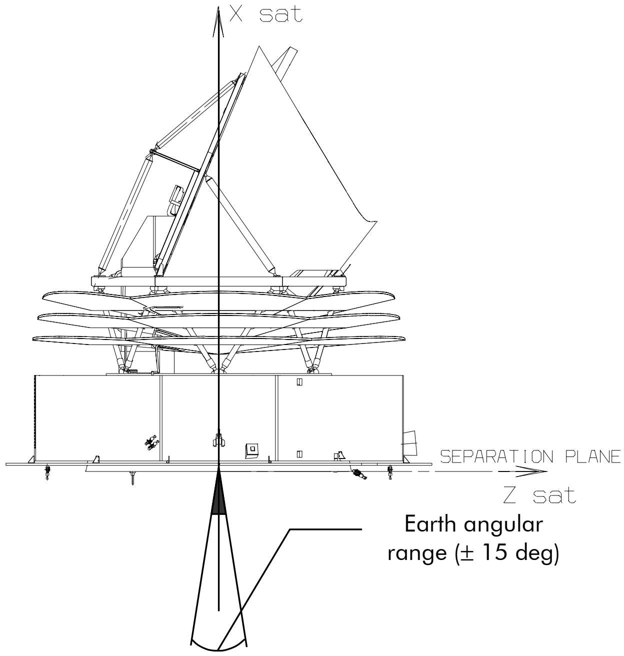


Figure 4.5-6 Planck communication with Earth

4.5.3 Moon transit

When sun-spacecraft-moon angle gets close to 0 deg, there can be some slots with partial sun eclipse by the Moon. Since sun apparent radius is 0.25 deg and since Moon apparent radius on the operational orbit is typically between 0.1 deg (distance moon-S/c: 1 000 000 km) and 0.05 deg (distance moon-S/c: 2 000 000 km), a partial eclipse can happen whenever the SSCM angle is below 0.35°.

As presented in CREMA, it is recommended to design Planck spacecraft by assuming:

- 4 eclipses per year
- with a maximum shadowing of 15% (impact on available power)
- and a typical duration up to 8 hours. .

No impact is expected for Herschel, as the Sun power reduction of 15 % is equivalent to a depointing of 30 deg which is nominal for Herschel. So Herschel has to be maintained Sun pointed during moon transit

For Planck, the SVM is required to be sized for an eclipse of 10 hours with a Sun shadowing of 16 %.

4.5.4 Orbit determination

On operational Lissajous orbit, orbit determination will be performed routinely everyday on the basis of tracking data acquired at each New Norcia visibility slot.

- Two ranging measurements (5 minutes each) are performed at the start and at the end of New Norcia visibility slot. The reduction to 2 range points was done because the link budget did not allow ranging and commanding at the same time. It is assumed that:
    - range noise is below 2 m (1-sigma) above 15° elevation

- range noise is below 20 m (1-sigma) under 15° elevation
- and bias below 20 m (1-sigma).

– Doppler tracking is done simultaneously with commanding and telemetry transmission during the New Norcia visibility interval. It is assumed that Doppler sample points are acquired every 10 min during 3 hours, and that:

  - Doppler noise = 0.1 mm/s (1-sigma) above 15° elevation
  - Doppler noise = 1 mm/s (1-sigma) under 15° elevation
  - And no Doppler bias.

It is noted that these assumptions (considered in Crema 2.2) are a little more optimistic than the Doppler noise error reachable with the TTC transponder (> 0.5 mm/s). It could have a small impact on orbit determination accuracy performances.

The requirements related to ranging measurements that shall be fulfilled by the transponder are issued from PSS 04 104 (March 1991) on Ranging MPTS:

– Width of on-board RNG channel (§ 2.2.2.)

– Group delay less than +/- 30 ns variation (§ 2.4.3.)

– Amplitude response less than +/-0.5 dB over full RNG bandwidth (§ 2.4.5.).

With Crema 2.2 assumptions recalled here above, the reachable orbit determination accuracy is (at 1-sigma):

– For Herschel:
  - Position: 0.3-14 km
  - Velocity: 2-11 mm/s.

– For Planck:
  - Position: 0.5-8 km
  - Velocity: 2-8 mm/s.

4.5.5 Orbit maintenance on operational orbit

4.5.5.1 Orbit maintenance strategy

The objective of the orbit maintenance strategy is to correct the deviations observed on the satellites. Due to the instability of the Lagrangian point, it is necessary to correct these orbit deviations without too much time delay and with a good accuracy.

The Lissajous orbits are not stable orbits: if one solves the linear equation for arbitrary initial conditions, exponential terms with positive exponent appear in the solution for the X and Y components. The initial conditions have to be carefully chosen to get a non-escape orbit with periodic terms and decreasing exponential terms only in the solution.

It can also be proven that any Delta-V performed along a specific direction in the [X, Y] plane, called the non-escape direction, produces a transfer from a non-escape orbit to another non-escape orbit with a different amplitude. This non-escape direction lies in the [X, Y] plane at an angle 61.6 deg from the X axis (see Figure 4.5-7).

On the other hand, Delta-V performed along the escape direction, perpendicular to the non-escape direction, produce a transfer from a non-escape orbit to an escape orbit or vice versa.

The escape direction, with an angle of 28.4 deg to the X axis, is the one used for orbit maintenance: it allows to cancel any unstable terms appearing in the orbit due to external disturbances.

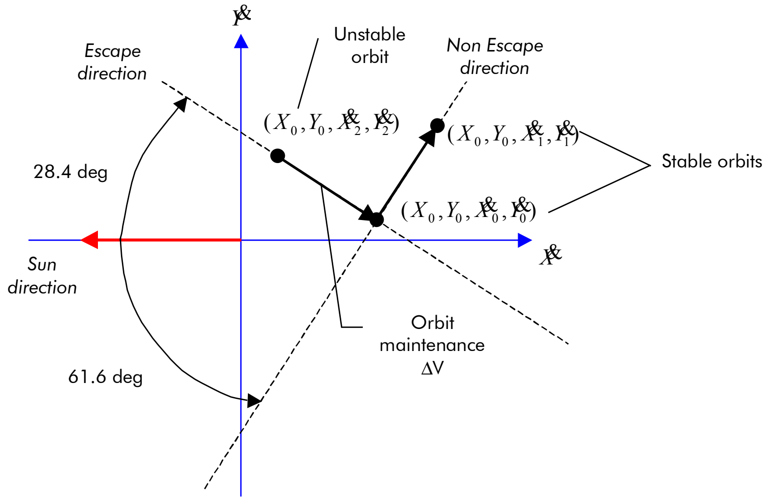


Figure 4.5-7 Escape and non-escape directions in the XYZ Earth rotating frame

One major factor is the eclipse avoidance which is ensured by the orbit maintenance strategy. This is performed by eclipse avoidance manoeuvre which can be performed, for instance, along the non-escape direction.

Several methods have been applied to compute the orbit correction strategy for both spacecraft. The results give an orbit maintenance cycle including one manoeuvre per month. The amplitudes of the correction may vary but averaged value of 1 m/s per year for both spacecraft has been selected .

The wheel off-loading thrusts affects the orbit maintenance strategy since they can generate delta-V along escape direction. The impact have been investigated in RD03.12: allocations of 4.4 m/s and 2 m/s respectively for Herschel and Planck are taken in the delta-V budget to cover this effect.

4.5.5.2 Mission Delta-V budget

This paragraph synthesises the Delta-V results for both spacecraft which will allow to compute the satellite mass budget breakdown from beginning of life to end of life.

It includes the contributions from the transfer phase and also the orbit maintenance contribution explained in Section 4.5.5.1.

Each manoeuvre has been determined using a guidance scheme which targets to remove the velocity component along the escape direction. A modified approach with a Monte-Carlo simulation with re-optimisation of the transfer Delta-V helps to reduce the required Delta-V (cf. Crema). The main hypotheses of the computation are:

- Launcher dispersion performances as given in Section 4.3.3
- Orbit Determination accuracy (typical data: see Section 4.5.4 for assumptions)
- Solar radiation standard deviation error of 10 %
- All the orbit manoeuvres are considered inertial for Herschel and Planck.

Table 4.5-1 present the Delta-V budgets for Herschel and Planck for the direct injection scenario with the A5-ECA launcher.

MANOEUVRE	HERSCHEL DELTA-V (M/SEC)	PLANCK DELTA-V (M/SEC)	DIRECTION OF DELTA-V (SUN ASPECT)
Perigee velocity correction Day 1: T_0 = lift off + 1 day	10	10	[145-175] deg
Removal LV dispersions Day 2	40	40	[145-170] deg
Manoeuvre 2 Day 12	4	4	[0-180] deg
Mid course corrections $T_{injection}$ – 20 days	3	3	[0-180] deg
Planck orbit insertion	0	225	[123.5-126.5] deg
Correction for Planck insertion $T_{injection}$+ 2 days	0	5	28.4 or 208.4 deg
Orbit maintenance for extended lifetime	4.5	2.5	28.4 or 208.4 deg
Orbit maintenance due to attitude control	4.4	2	28.4 or 208.4 deg
Total	**65.9**	**291.5**	

Table 4.5-1 Delta-V budget for Herschel and Planck (A5-ECA, 15 deg orbit)

Based on the inputs of the Crema 2.3 the fuel budgets in RD02.3 have been built with the following assumptions:

MANOEUVRE	HERSCHEL DELTA-V (M/SEC)	PLANCK DELTA-V (M/SEC)	DIRECTION OF DELTA-V (SUN ASPECT)
Perigee velocity correction Day 1: T_0 = lift off + 1 day	10	10	[145-175] deg
Removal LV dispersions Day 2	50	50	[145-170] deg
Manoeuvre 2 Day 12	3	3	[0-180] deg
Mid course corrections $T_{injection}$ – 20 days	2	2	[0-180] deg
Planck orbit insertion	0	215	[123.5-126.5] deg
Correction for Planck insertion $T_{injection}$+ 2 days	0	5	28.4 or 208.4 deg
Orbit maintenance for extended lifetime	4.5	2.5	28.4 or 208.4 deg
Orbit maintenance due to attitude control	4.4	2	28.4 or 208.4 deg
Total	**73.9**	**289.5**	

Table 4.5-2 Delta-V budget for Herschel and Planck (A5-ECA, 15 deg orbit), updated from Crema 2.3

5. PAYLOAD INTERFACE REQUIREMENTS

5.1 Formal Instrument Interface documentation (IID's)

This chapter describes the status of the requirements for the interfaces between Herschel and Planck, and the 5 instruments SPIRE, PACS, HIFI for Herschel, and HFI, LFI and sorption cooler for Planck.

These requirements are formalised in the IID-B's (Instruments Interface Documents). These versions were reviewed and agreed by instruments, ESA and industry.

- SPIRE IID-B: SCI-PT-IIDB 02124_3.2, (01/03/04) signed + Issue 3.3 (21/06/04)
- PACS IID-B: SCI-PT-IIDB 02126_3.2, (02/03/04) signed + Issue 3.3 (12/07/04)
- HIFI IID-B: SCI-PT-IIDB 02125_3.2, 05/03/04 signed with restrictions
- HFI IID-B: SCI-PT-IIDB 04141_3.1, (05/04/04), signed + Issue 3.2 (23/07/04)
- LFI IID-B: SCI-PT-IIDB 04142_3.0_draft 5 (12/07/04) under review
- Sorption cooler ICD: PL-LFI-PST-ID-0023.1_draft 3 (05/04/04) annexed to LFI IID-B, under review.

The definition of the instruments in these documents corresponds to the IHDR's (Instrument Hardware design reviews) which took place around end 2003-beg 2004. Industry reviewed the data-packages, and participated to these reviews.

The satellite side of these interface requirements is formalised in the IID-A. Latest issue is

- IID-A: SCI-PT-IIDA-04624_3.3 (30/06/04).

Complemented by formal satellite to instruments alignment plans and ICD's included in IID-A annexes:

- Annex 01: Herschel Alignment Plan
- Annex 02: Planck Scanning Strategy (from SRS)
- Annex 03: Planck Alignment Plan
- Annex 04: Herschel Pointing Modes (from SRS)
- Annex 05: Interface control drawings SVM
- Annex 06: Interface control drawings Herschel PLM
- Annex 07: Interface control drawings Planck PLM
- Annex 08: Herschel Cryo-harness Interfaces.
- Annex 09: System ICD
- Annex 10: WIH ICD
- Annex 11: Herschel telescope mechanical & optical ICD’s
- Annex 12: SVM Harness Interfaces.

The first part of this section (§ 5.1.) is a description of the instrument and the status of the interfaces compared to the satellite allocations.

In the second part (5.2) are listed the Open points and solutions.

5.1.1 Instrument Description

Herschel and Planck instruments are provided by ESA, and funded, designed, manufactured & tested by consortia of scientific institutes under the lead of a PI (principal investigator), and a Project team.

Herschel and Planck Instruments are cryogenic Instruments, and are therefore composed of a Cryogenic FPU (Focal plane unit), located in the Cryogenic Payload module of each of the satellite, and of warm units located in the Service Modules (SVM) dedicated to control of the instrument, processing of signal, and transmission of TM/TC (scientific & housekeeping data). Cryoharness (or Wave-Guides for LFI) links the warm units to the FPU.

5.1.1.1 Herschel Instruments

The Herschel satellite accommodates 3 instruments:

- PACS Photo-detector Array Camera & Spectrometer. The PACS Consortium is lead by the MPE Garching (D) The PI is A. Poglitch
- SPIRE Spectral Photometer Imaging Receiver. The SPIRE consortium is led by the Cardiff University (UK) where the PI is M. Griffin), and the Rutherford Appleton Laboratory with the project team
- HIFI Heterodyne Instrument for the Far Infra-red. The HIFI Consortium is led by the SRON (Space Research Organisation of the Netherlands, NL), and the PI is T. de Graauw).

The implementation of the FPUs of these instruments FPU onto the Herschel Optical Bench is illustrated in the following figure.

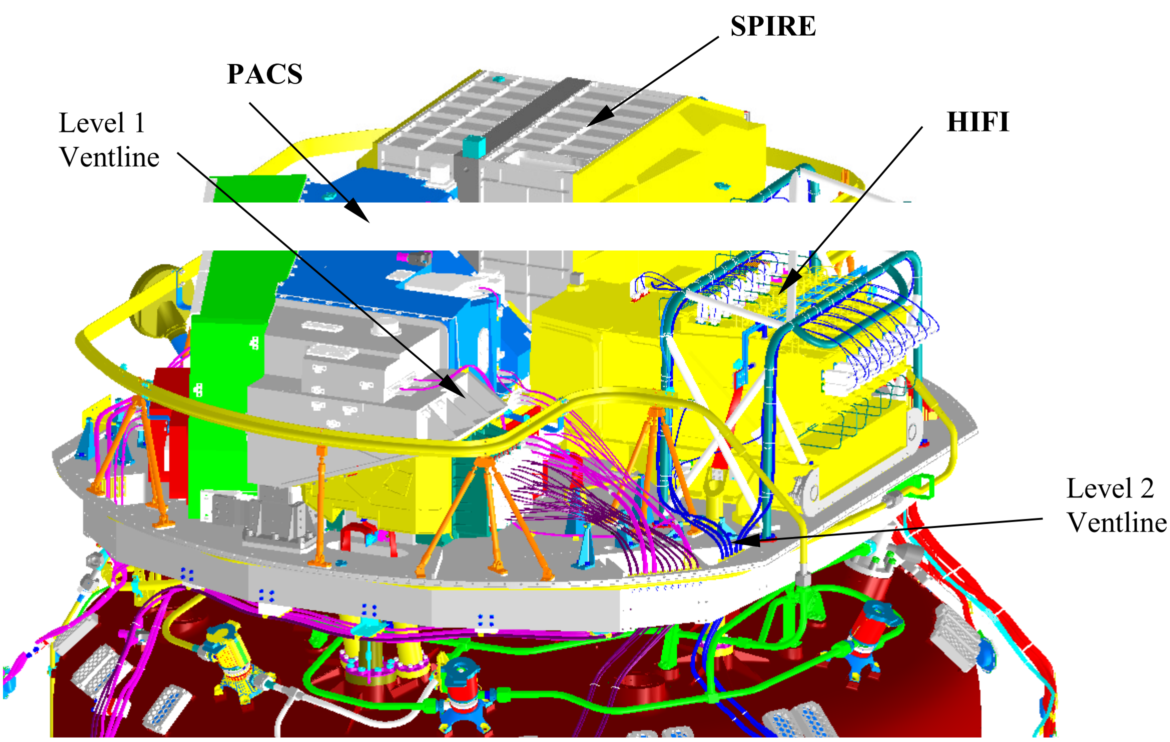


Figure 5.1-1 3D image of the Herschel FPU's on the optical bench/draft view supplied by ASED

5.1.1.1.1 PACS

The PACS Instrument provides imaging photometry and integral field spectroscopy over the spectral band from 57 – 210 μm. Except for the shared entrance optics, the photometer and the spectrometer branches of the instrument are independent sub-units. The entrance optics contains a chopper for sky modulation and 2 calibration sources. At the end of the entrance optics the focal plane is split into separate fields of view, one for photometry and the other for spectroscopy. From there on, the optical trains are fully separated.

The **Photometer** branch employs two large format, filled arrays of silicon bolometers, a fixed dichroic beam splitter, and straightforward re-imaging optics to image the same field of view simultaneously in two spectral bands (60 – 130 μm and 130 – 210 μm), with full diffraction beam sampling. The short wavelength band is divided into two sub-bands (60 – 85 μm or 85 – 130 μm) by exchangeable filters such that either one of them can be observed together with the long wavelength band. The bolometer arrays are cooled to 0.3 K by an instrument-internal 3He sorption cooler which works against the He II level (L0) provided by the satellite.

The **Spectrometer** uses a reflective image slicer which feeds a long-slit grating spectrograph in Littrow mode, to achieve simultaneous spectral multiplexing and two-dimensional imaging with the two-dimensional photoconductor arrays. A fixed dichroic beam splitter is used to separate the grating diffraction orders and distribute them to the two detector arrays. The first diffraction order (105 – 210 μm) is detected with a high-stressed Ge:Ga array operated at ~1.8 K while the second (57 – 105 μm) and third (55 –72 μm) orders are detected with a low-stressed Ge:Ga array operated at ~2.5K. Exchangeable filters are moved in front of the short-wave detector to select one or the other of the 2nd and 3rd orders.

PACS is composed of:

Project code	Instrument unit
FPFPU	Cold Focal Plane Unit
FPDECMEC	Detector & Mechanism Control
FPBOLC	Bolometer / Cooler Control
FPDPU	Digital Processing Unit (DPU nominal + redundant)
FPSPU	Signal Processing Unit (SPU nominal + redundant)
FPWIH	"Warm" Interconnect Harness

At the time of the System CDR, PACS has built a Structural Model of the FPU, which has been submitted to cryo-vibration tests in CSL, an FPU CQM driven by warm electronics DM/QM, currently submitted to functional tests, and which should be delivered to the satellite fall 2004. And the Flight models are under manufacturing

The following figure show the PACS FPU (3D view and photos of the QM), the warm units, and the instrument Block Diagram.

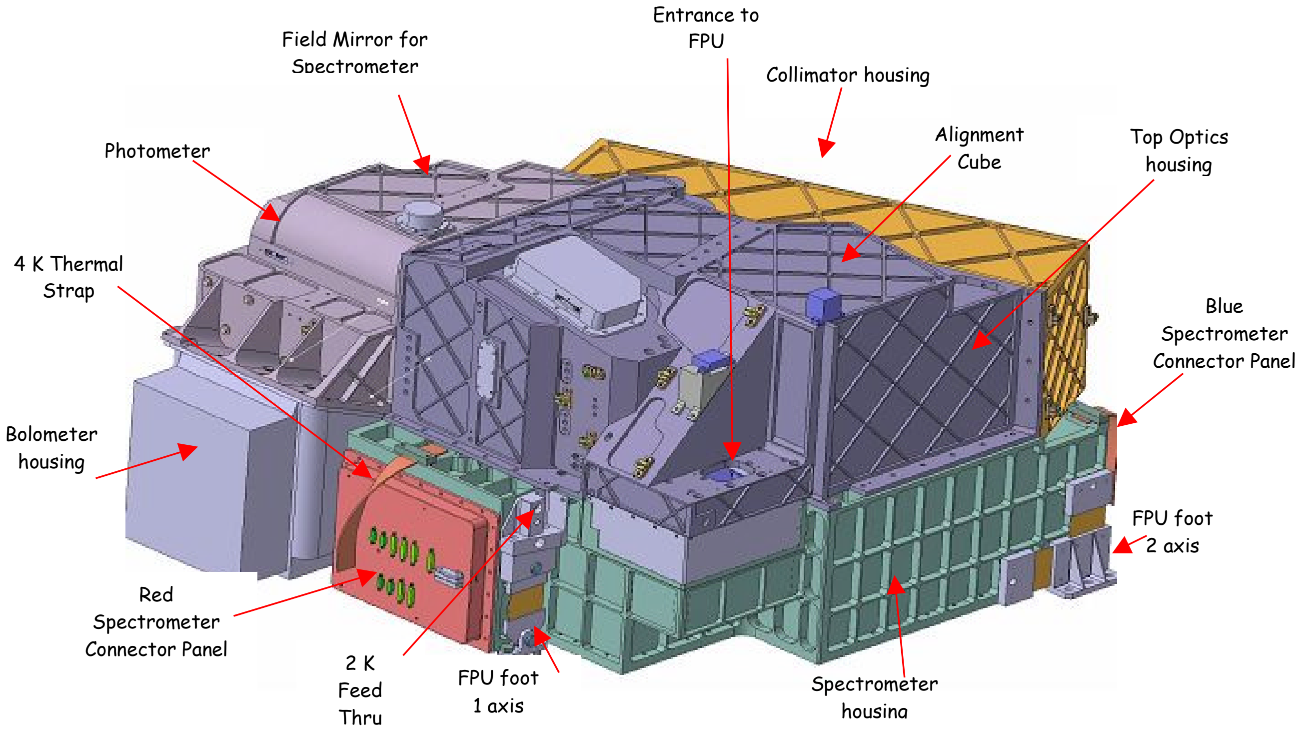


Figure 5.1-2 Overview of the PACS focal plane unit

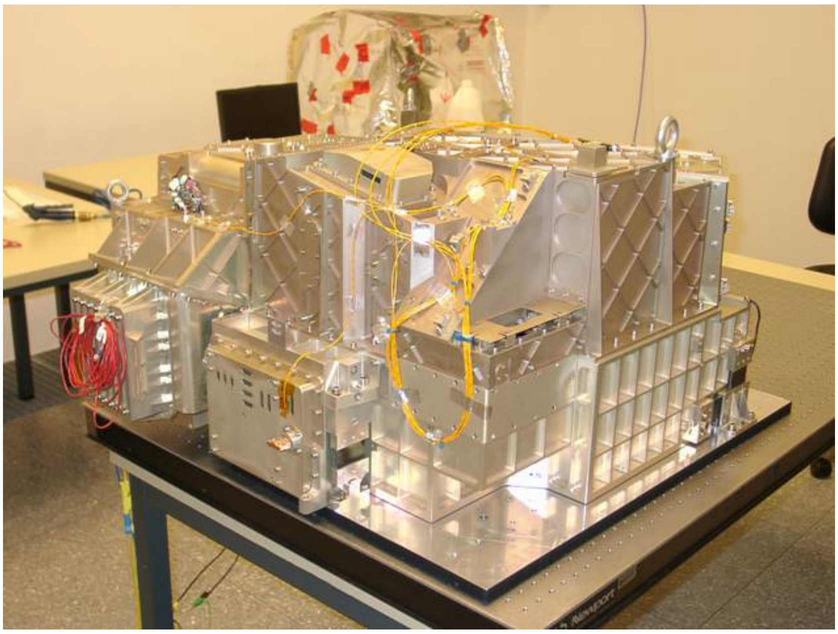


Figure 5.1-3 Photo of the PACS FPU STM prepared for cryo-vibration tests

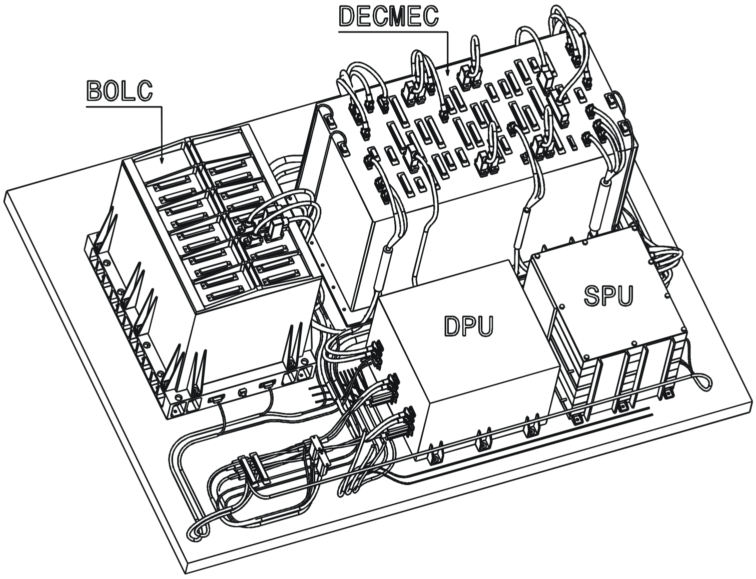


Figure 5.1-4 PACS Warm units assembled with WIH on SVM panel

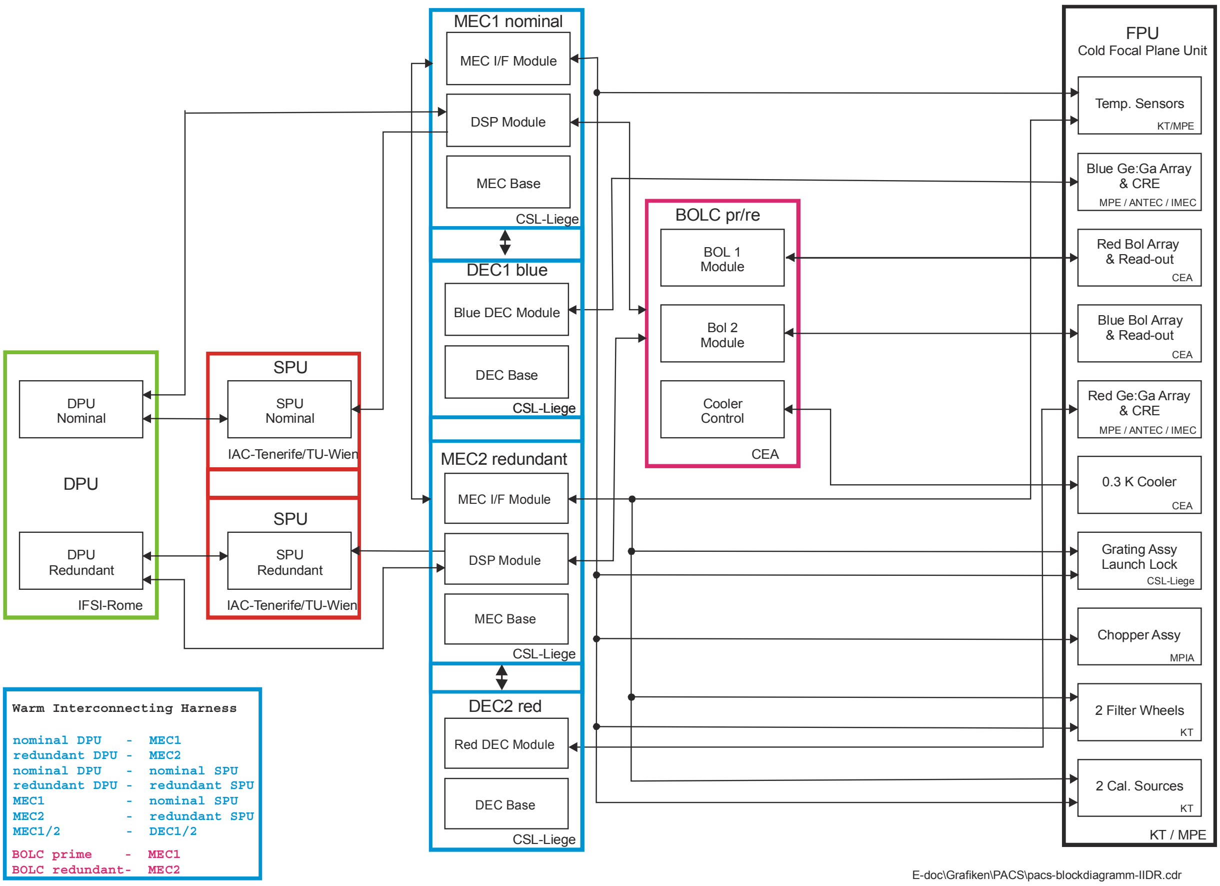


Figure 5.1-5 PACS internal Block Diagram

5.1.1.1.2 SPIRE

SPIRE (Spectral & Photometric Imaging REceiver) is a **bolometer** instrument comprising a three-band imaging **photometer** covering the 200-500 µm range and an imaging Fourier Transform **Spectrometer** (FTS) with a spectral resolution of at least 0.4 cm^{-1} (corresponding to $\lambda/\Delta\lambda = 100$ at 250 µm, covering wavelengths between 200 and 670 µm. The detectors are bolometer arrays cooled to 300 mK using a ^3He refrigerator. The photometer is optimised for deep photometric surveys, and can observe simultaneously the same field of view of 4 x 8 arcminutes in all three bands.

The SPIRE instrument consists of:

HSFPU	Focal Plane Unit (FPU): This interfaces to the cryostat optical bench, and the 4-K and 2-K temperature stages provided by the cryostat. Within the unit, further cooling of the detector arrays to a temperature of around 300 mK is provided by a ^3He refrigerator which is part of the instrument.
HSJFP	JFET box for the photometer detectors This box is mounted on the optical bench next to the photometer side of the FPU and contains JFET preamplifiers for the detector signals. The JFETs operate at around 120 K, and are thermally isolated inside the enclosure.
HSJFS	JFET box for the spectrometer detectors This box is mounted on the optical bench next to the spectrometer side of the FPU and contains JFET preamplifiers for the detector signals. The JFETs operate at around 120 K, and are thermally isolated inside the enclosure.
HSDCU	Detector Control Unit (on Herschel SVM) A warm analogue electronics box for detector read-out analogue signal processing, multiplexing, A/D conversion, and array sequencing.
HSFCU	Focal Plane Control Unit (on Herschel SVM) A warm analogue electronics box for mechanism control, temperature sensing, general housekeeping and ^3He refrigerator operation. It conditions secondary power both for itself and for the DCU.
HSDPU	Digital Processing Unit (on Herschel SVM) A warm digital electronics box for signal processing and instrument commanding and interfacing to the spacecraft telemetry.
HSWIH	Warm interconnect harness (on Herschel SVM) Harness making connections between SPIRE electronics boxes.

At the time of the System CDR, PACS has built a QM of the FPU (photometer channel only), which has been submitted to warm vibration tests, functional tests, cryo-vibration test and is currently again submitted to functional tests. It which should be delivered to the satellite fall 2004. And the Flight models are under manufacturing

There are some concerns with the availability of the DRCU (Detector control Electronics) due to schedule delays in the procurement of this unit (from CEA Saclay).

For QM tests, the QM1 can be loaned by SPIRE for as short as possible interface checking (up to end 2004 when DRCU QM2 becomes available) as SPIRE will be testing the FM with this same QM1 Unit.

For FM, SPIRE will be delivered with the DRCU QM2 unit to be swap with FM DRCU when it becomes available.

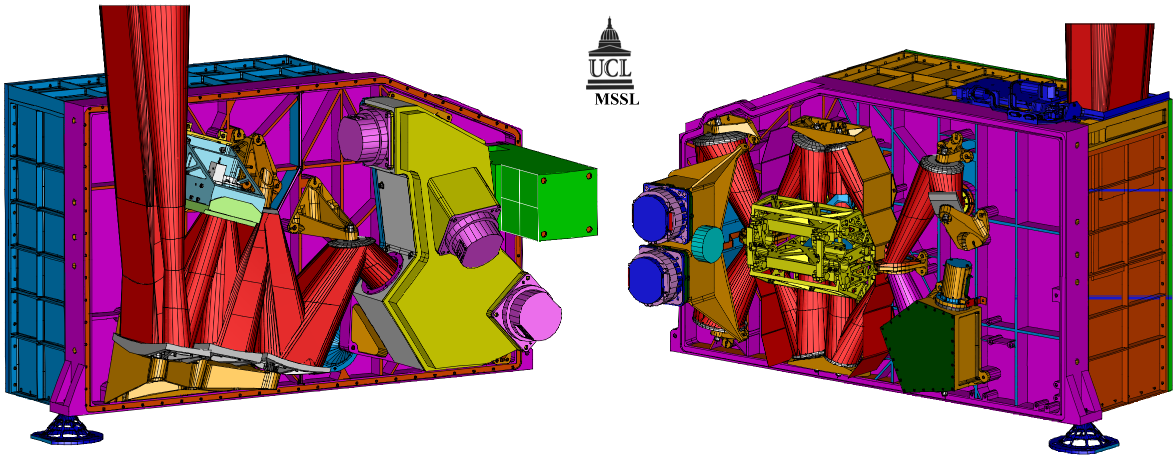


Figure 5.1-6 Two halves of SPIRE FPU: Photometer shown on left, Spectrometer on the right

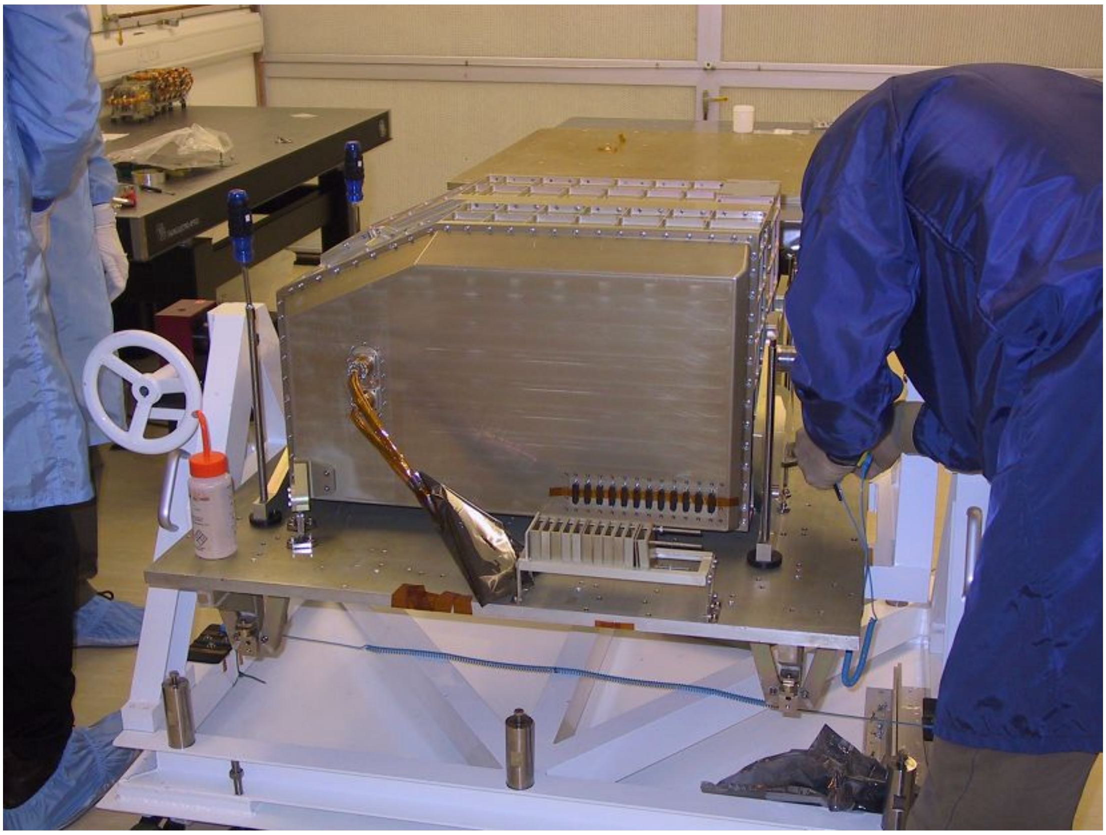


Figure 5.1-7 SPIRE FPU QM prepared for functional test 1 (dec 03)

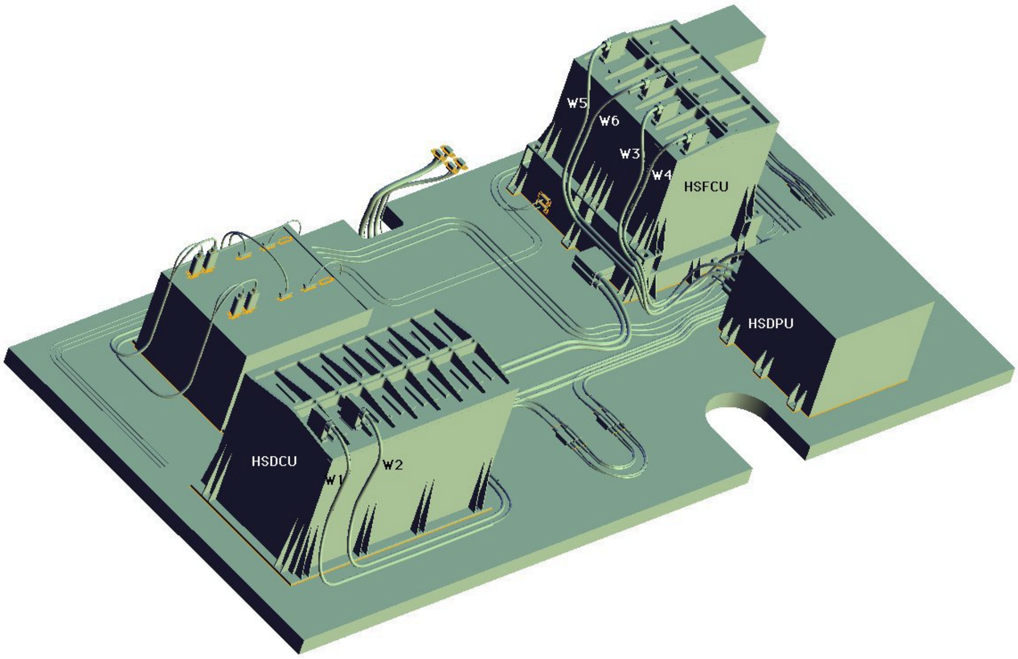


Figure 5.1-8 SPIRE Warm units as mounted on SVM Panel

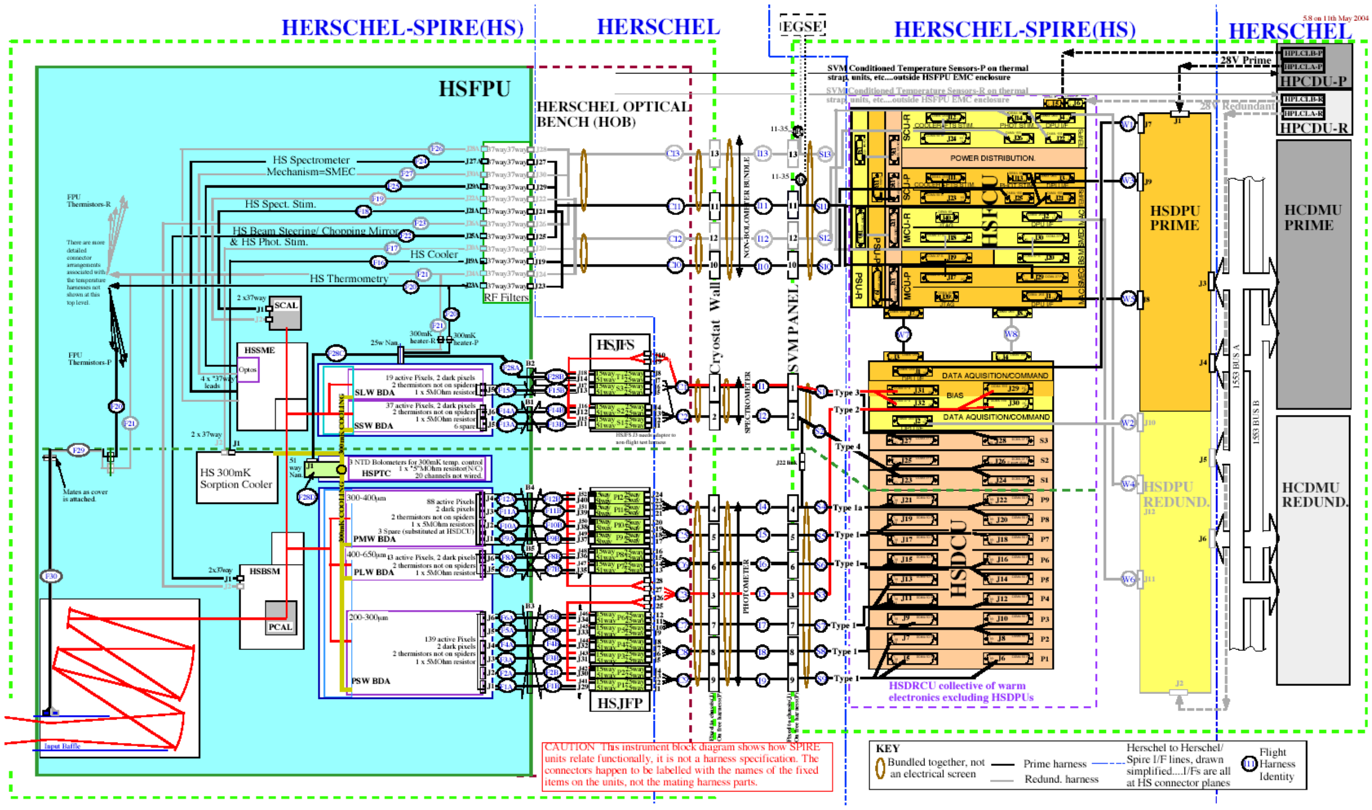


Figure 5.1-9 SPIRE Block Diagram

5.1.1.1.3 HIFI

The HIFI instrument will provide continuous frequency coverage over the range 480 to 1250 GHz in five bands with approximately equal tuning range. An additional pair of bands (6) will provide coverage of the frequency range 1410-1910 GHz. The instrument will operate at only one frequency at a time. In all mixer bands two independent mixers will receive both polarisations of the astronomical signal for maximum instrument sensitivity. The first 5 bands will use SIS mixers; band 6, consisting of two sub-bands 6L and 6H, will use Hot-Electron Bolometers (HEB's).

The HIFI Back-End subsystems will allow to process at the same time the signal coming from both polarisations of the Front-End. The Back Ends consist of a Wide-Band Spectrometer (Acousto-Optical Spectrometer - AOS), covering a total frequency range of 8 GHz, and High-Resolution Spectrometer, (Auto-Correlation Spectrometer - ACS), covering up to 4 kHz. The Wide-Band Spectrometer (WBS) will have a resolution of 1.1 MHz (~0.6 to 0.16 km/s in the frequency range of the HIFI). The High-Resolution Spectrometer (HRS) will have four observing modes, a normal one with 270 kHz spectral resolution (1 GHz total bandwidth), a high resolution mode with 140 kHz resolution (0.5 GHz total bandwidth), a low resolution mode with 0.54 MHz resolution (2 GHz total bandwidth) and a wide band mode with 1.1 MHz resolution (4 GHz total bandwidth). The HRS modes give instrument velocity resolutions of 180 to 65 m/s and 100 to 55 m/s respectively in the frequency range of HIFI after including the effect of the local oscillator finite line-width.

HIFI consists of:

Project code	Instrument unit
FHFPU-XX-Y	HIFI Focal Plane Unit
FHFCU-XX-Y	HIFI Focal Plane Control Unit
FHIFH- XX-Y	IF up-converter Horizontal
FHIFV- XX-Y	IF up-converter Vertical
FHLOR-XX-Y	HIFI Local Oscillator Radiator
FHLOU-XX-Y	HIFI Local Oscillator Unit
FHLCU-XX-Y	HIFI Local Oscillator Control Unit
FHLSU-XX-Y	HIFI Local Oscillator Source Unit
FHHRV-XX-Y	HIFI High-Resolution Spectrometer, Vertical polarisation
FHHRH-XX-Y	HIFI High-Resolution Spectrometer, Horizontal polarisation
FHWEH-XX-Y	HIFI Wide-Band Spectrometer Electronics Horizontal Polarisation
FHWEV-XX-Y	HIFI Wide-Band Spectrometer Electronics Vertical Polarisation
FHWOH-XX-Y	HIFI Wide-Band Spectrometer Optics Horizontal Polarisation
FHWOV-XX-Y	HIFI Wide-Band Spectrometer Optics Vertical Polarisation
FHICU-XX-Y	HIFI Instrument Control Unit
FHWIH-XX-Y	HIFI "Warm" Interconnect Harness

Legend:

XX = model: DM, EM, QM, FM, FS

Y = serial number, if relevant.

At the time of the CDR, HIFI has built a FPU DM (channels 2 & 5) and a FPU QM (channel 3H & 3V) driven by QM electronics.

The FPU QM is submitted to environmental test (vibration tests should take place in July 2004) before delivery to satellite fall 2004. DM is functionally tested in parallel at SRON.

EMC testing is an important aspect for HIFI, and will be important for EQM tests.

FM HIFI is under manufacturing.

Major concern is the schedule of the LSU (Procurement from CSA), and now the delivery schedule of the FM unit.

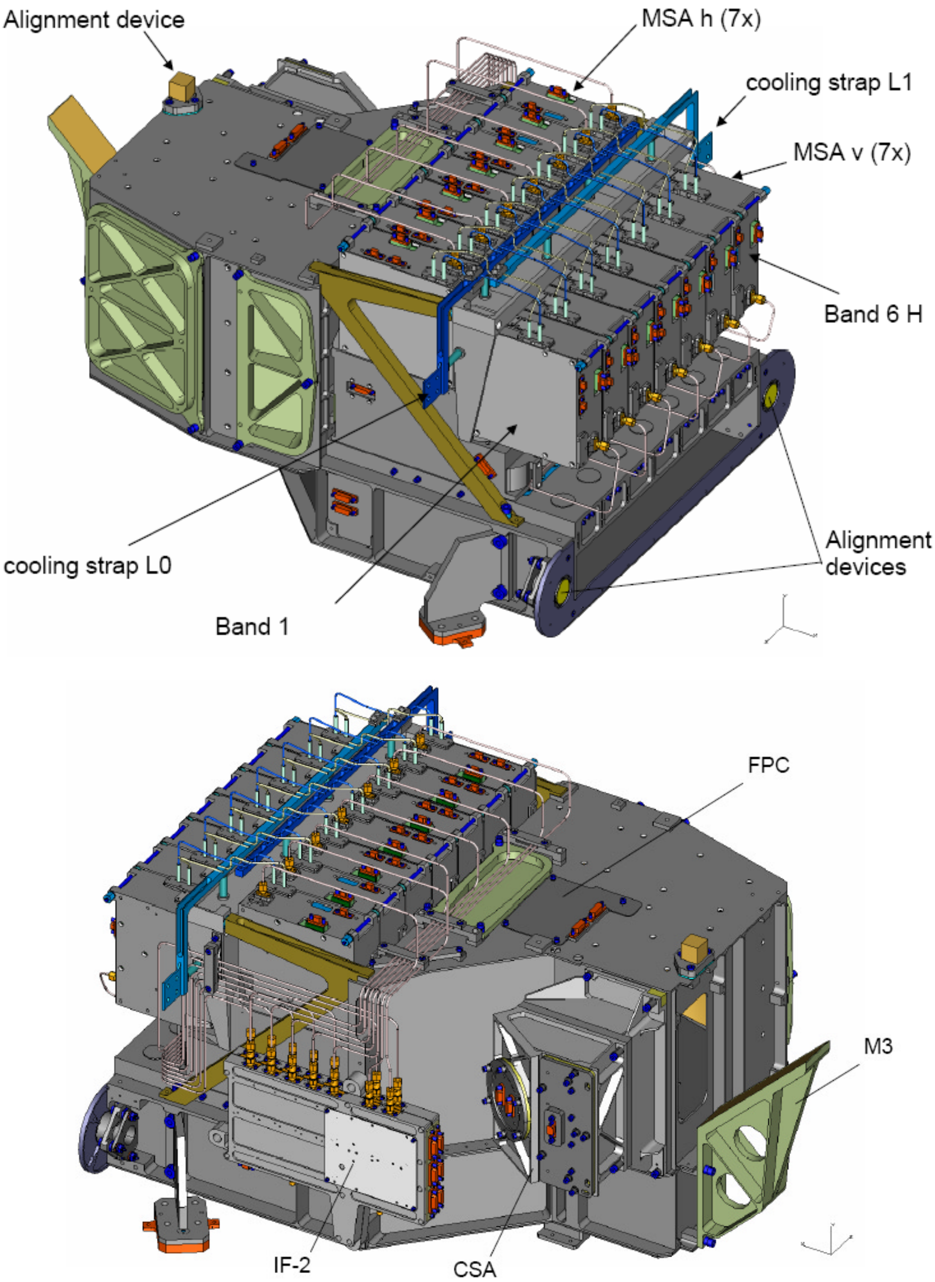


Figure 5.1-10 HIFI FPU

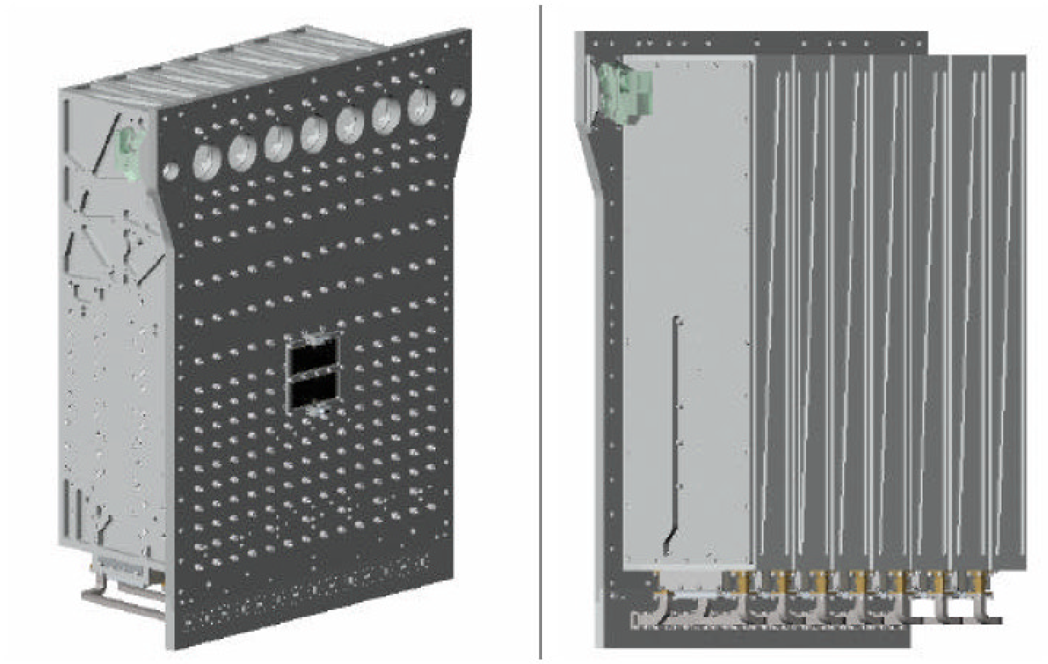


Figure 5.1-11 HIFI LOU on HFI base plate

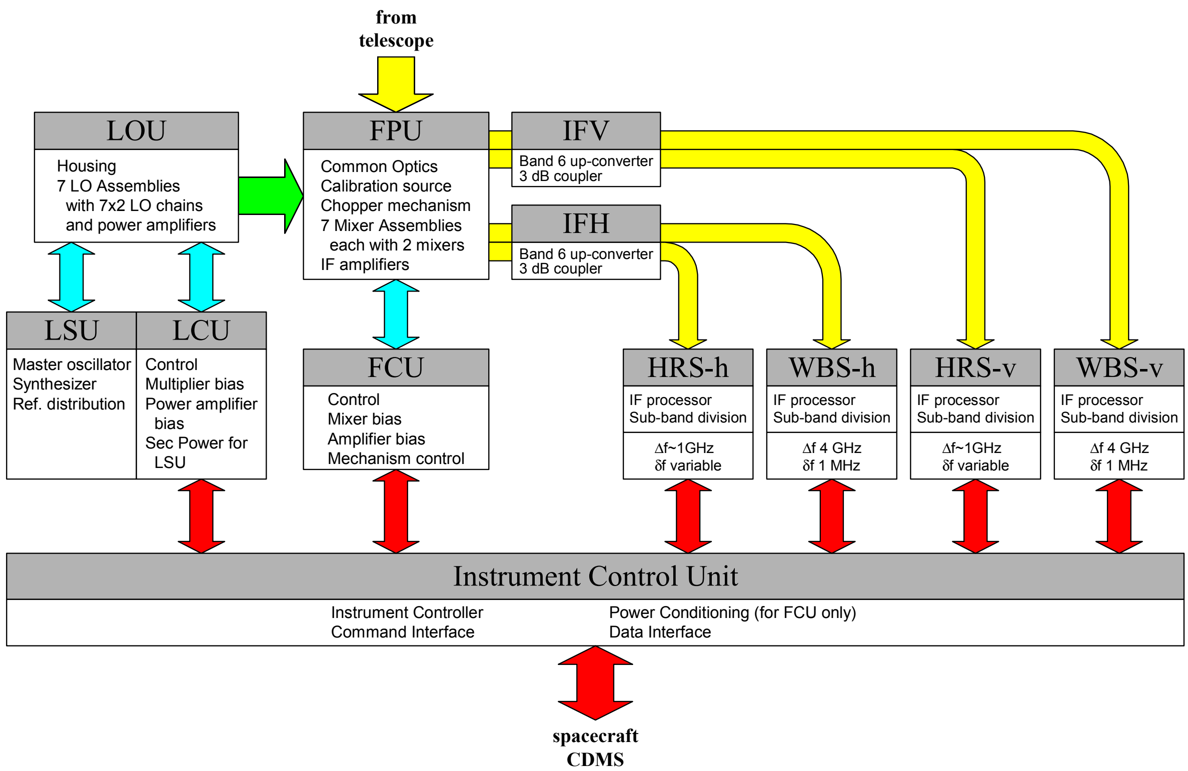


Figure 5.1-12 HIFI functional Block Diagram

5.1.1.2 Planck Instruments

The Planck Satellite accommodates 2 instruments:

- LFI Low Frequency Instrument, developed by a Consortium led by N. Mandolesi (TESRE-Bologna-I)
- HFI High Frequency Instrument, developed by a Consortium led by J.L. Puget (IAS-Orsay-F).

Common to the 2 instruments is the sorption cooler, developed by JPL (one of the 6 US contributions to the Herschel/Planck program). The Sorption cooler is a subsystem of LFI, and managed by LFI. The Sorption cooler electronics is developed under the responsibility and funding of HFI.

Both instruments have a cryogenic Focal Plane unit (FPU) that receive and process the CMB signal, hosted by the Planck Payload Module (PPLM) and a set of warm units that amplify, digitise and process the electrical signal and that are accommodated in the Planck Service Module. The link between FPU and SVM is via Wave-guides + harness (LFI) and Harness (HFI).

Both instruments have also dedicated chains of coolers that provide the instrument with their ultimate temperatures (20 K for LFI, 0.1K for HFI), and that interface the satellite at in the SVM (compressors, control electronics), in the PPLM (heat exchangers and pipes).

The Satellite provides the services (Power, data handling, pointing, TM/TC, security,…) and the proper environment (Mechanical at launch, thermal) both for the warm units (270 - 300 K) and the PPLM (Telescope, Precooling at 50 K for the coolers, Straylight insulation).

The key issues to succeed the Planck mission is to master the cryogenic chain which is complex and with distributed responsibility, and to control the systematic (i.e. all perturbations (thermal, EMC, straylight, vibrations) which might affect the signal).

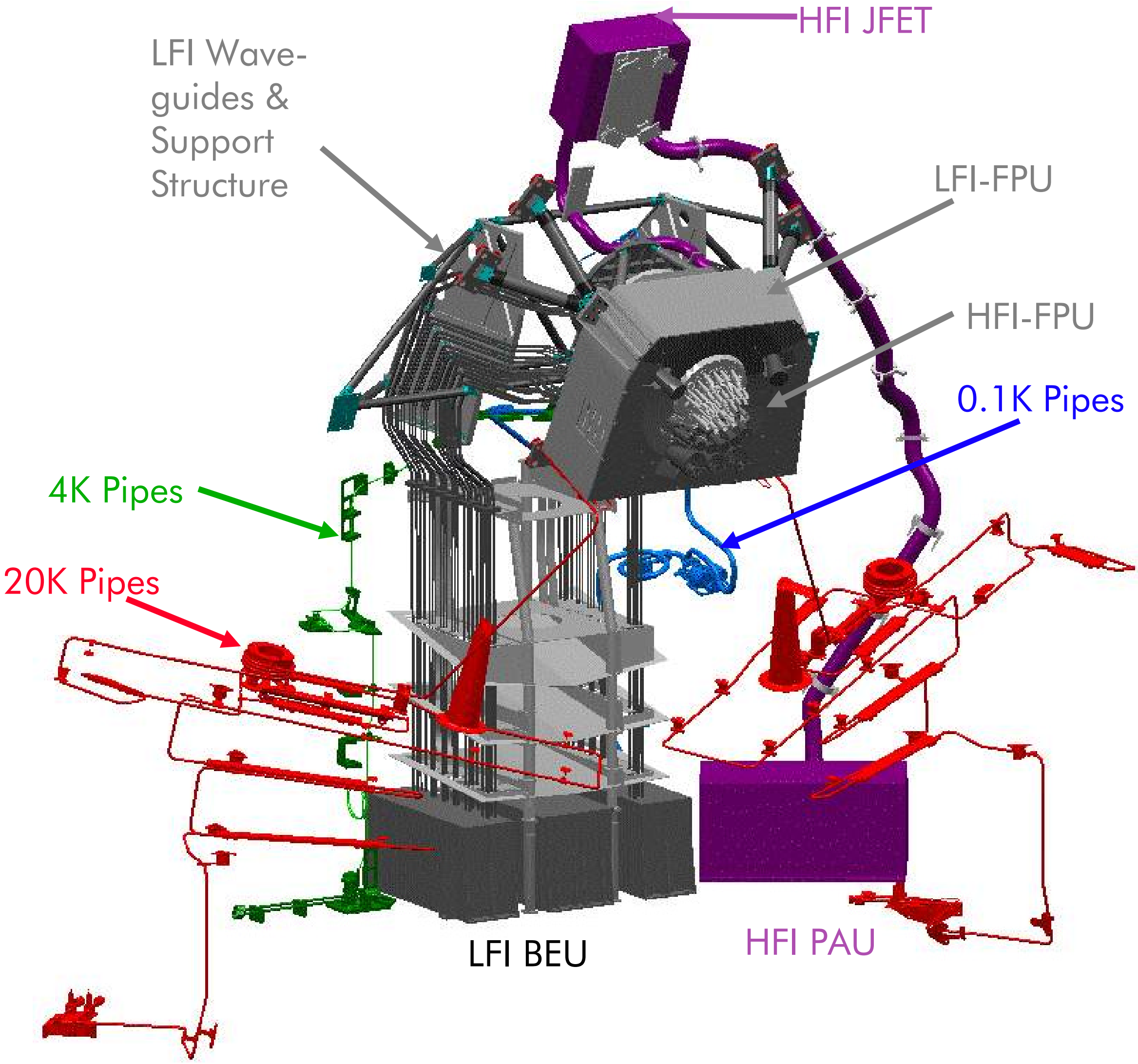


Figure 5.1-13 Planck instruments to be accommodated on PPLM

5.1.1.2.1 HFI

The High-Frequency Instrument (HFI) is designed to carry out high-sensitivity, multi-frequency microwave measurements of the diffuse sky radiation in the frequency range 83-1000GHz.

These measurements will be used, together with those from the Low-Frequency Instrument (LFI), to produce a map over most of the sky of the anisotropies of the Cosmic Microwave Background (CMB). This map will in turn be used to constrain the main parameters that determine the large scale structure of the Universe.

HFI is composed of the following units:

description	code	code
Focal Plane Unit (FPU)	PH	A
Data Processing Unit (DPU) Nominal & Redundant	PH	BA-N, R
JFET Box	PH	CA
Pre-Amplifier Unit (PAU)	PH	CBA
Readout Electronics Unit (REU)	PH	CBC
4K Cooler Compressor Unit (CCU)	PH	DA
4K Cooler Ancillary Unit (CAU)	PH	DB
4K Cooler Electronics Unit (4K-CDE)	PH	DC
4K Cooler Cold End (CCE), pipes and cryoharness & brackets from SVM bracket to FPU	PH	DD
4K Cooler Current Regulator (CCR)	PH	DJ
4K warm pipework and harnesses from CAU to SVM bracket	PH	DE
0.1K Dilution Cooler GSU He Tanks	PH	EAAA, B, C, D
Tank-/0.1K-DCCU piping + Support	PH	EABA, B, C, D
0.1K Dilution Cooler Control Unit (0.1K-DCCU)	PH	EB
Helium exhaust	PH	EEF
0.1K Cooler Pipes	PH	ECxx
WIH & Cryo-Harnesses	PH	

HFI has built a DM of the FPU, which has been successfully passed the cryogenic tests down to 0.3K in 2003.

In parallel, a STM of the FPU went through several warm vibration tests at CSL. This HFI FPU STM has been delivered to ASP for Planck system acoustic & cryogenic tests.

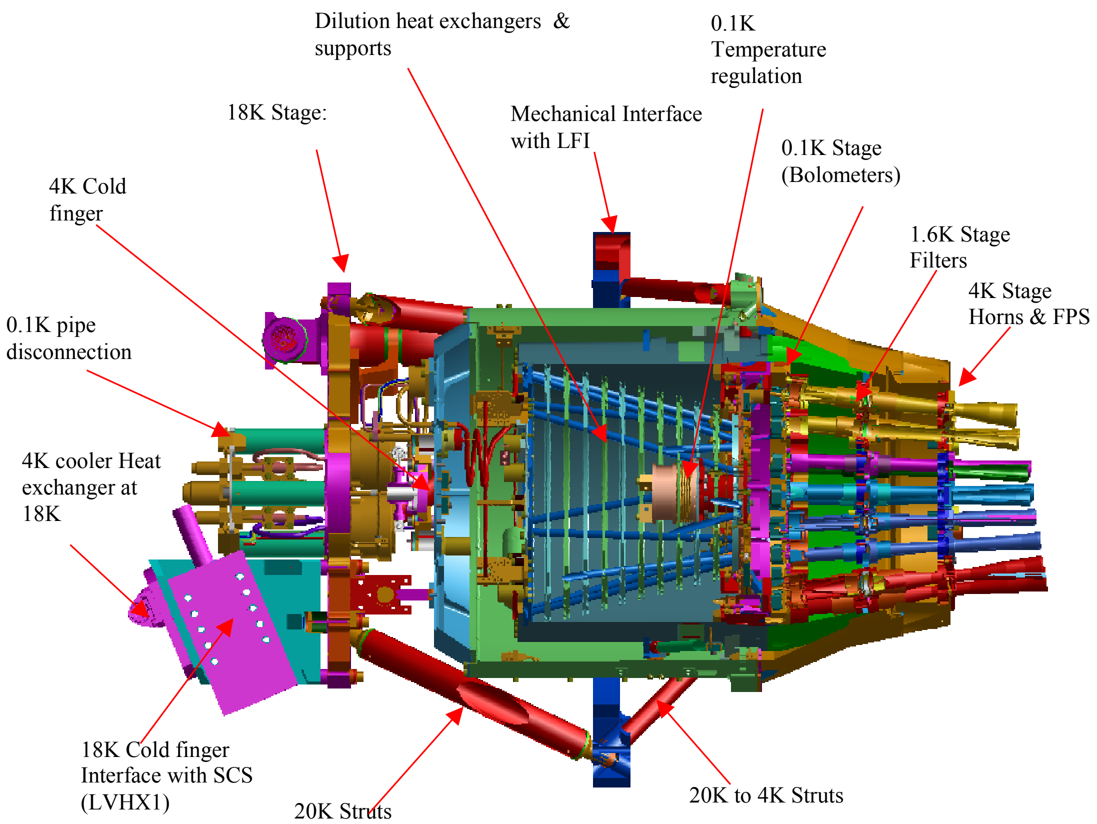


Figure 5.1-14 HFI FPU

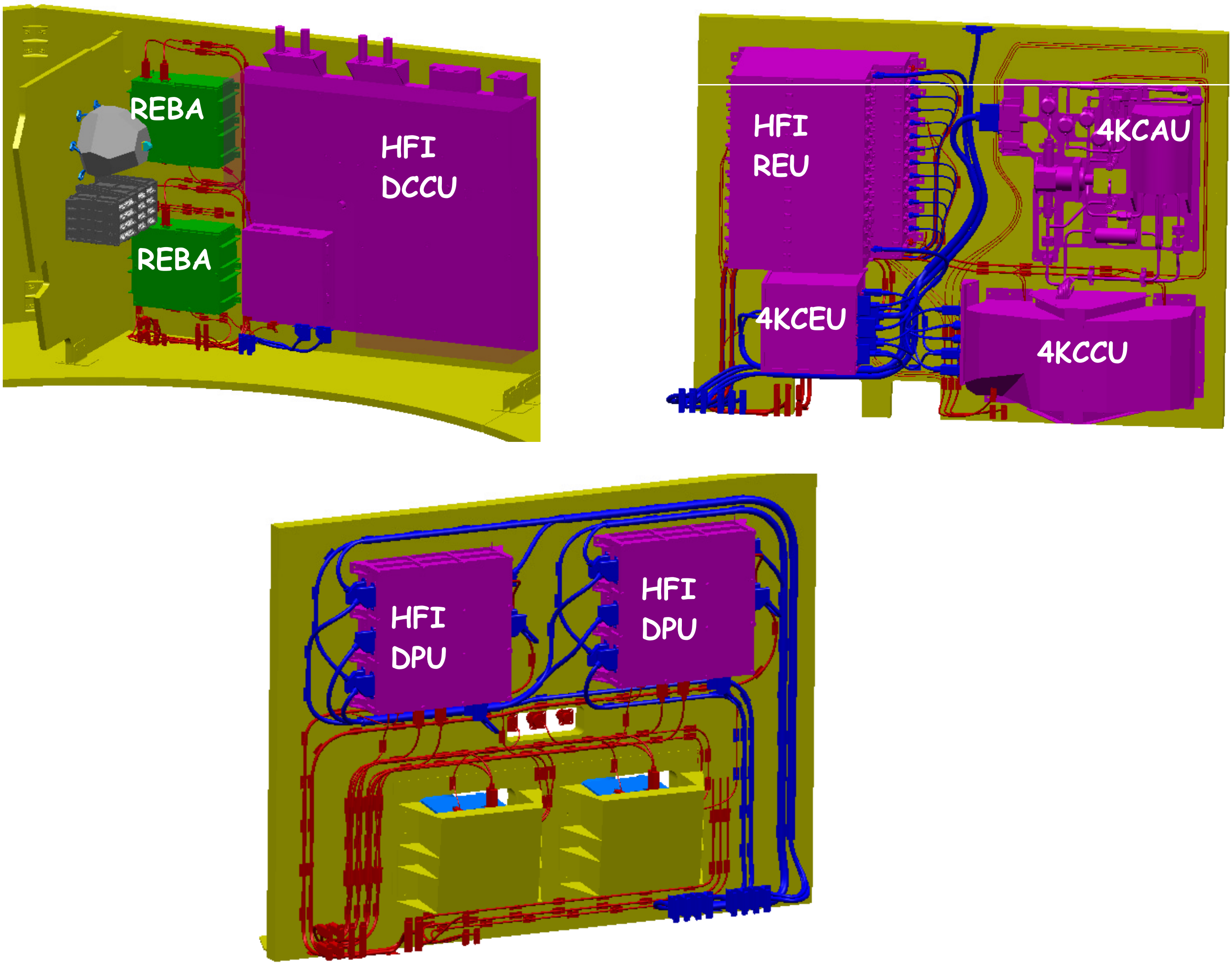


Figure 5.1-15 HFI Warm units (4KCCR & PAU not shown)

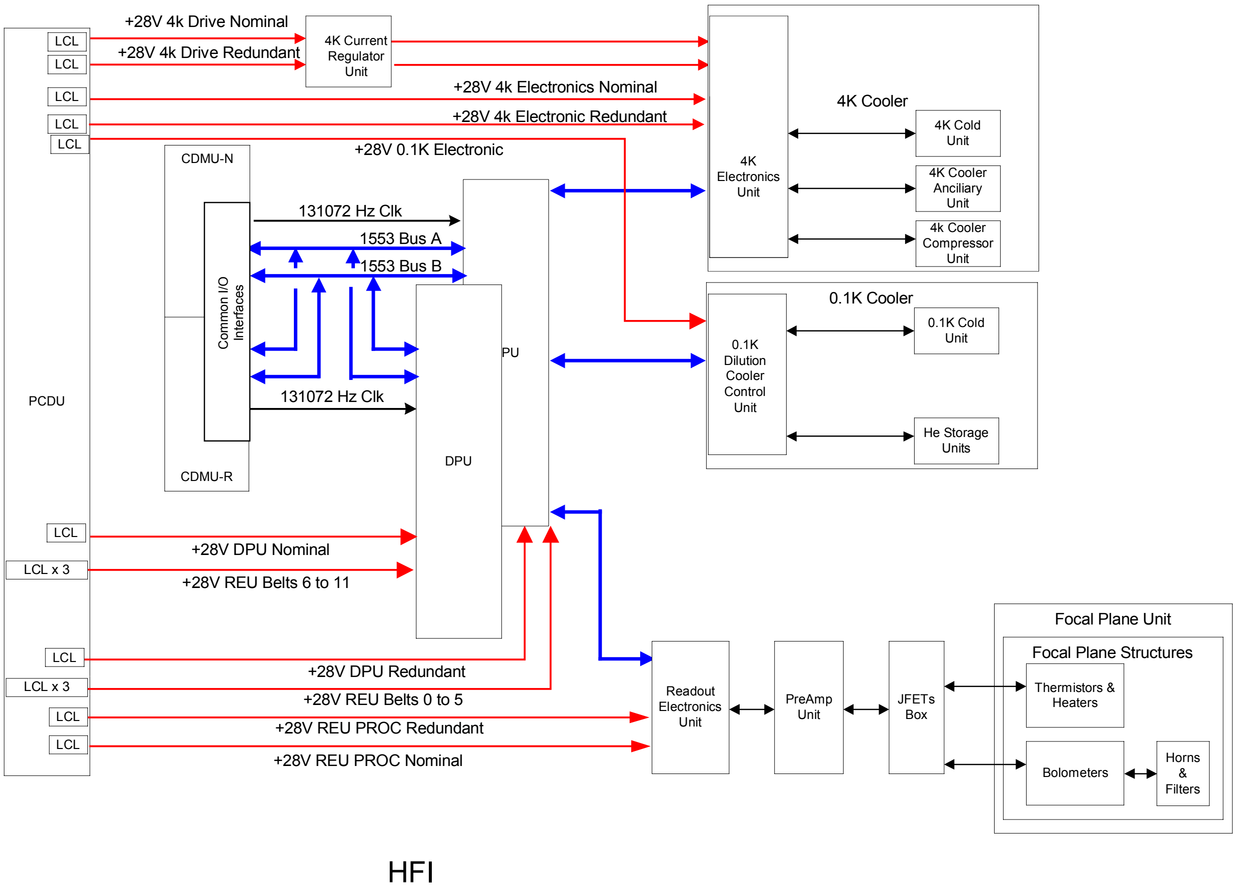


Figure 5.1-16 HFI electrical interfaces Block Diagram

5.1.1.2.2 *LFI*

The Low-Frequency Instrument (LFI) is designed to produce high-sensitivity, multi-frequency measurements of the microwave sky in the frequency range 30-70 GHz (2.3-4.2 mm wavelength). These measurements will be used, together with those from the High Frequency Instrument (HFI) to produce a full-sky map of the anisotropies of the Cosmic Microwave Background (CMB) with unprecedented precision. This map will in turn be used to extract a wealth of cosmological information, including the accurate determination of the main cosmological parameters which characterise the large scale structure and the evolution of the universe.

The coherent LFI receivers will operate at four well-separated bands: 30, 44 and 70 GHz (see also table in 4.3). Note that, due to a funding crisis, the 100 GHz channel originally foreseen in LFI has been descoped. These frequencies are chosen to provide an excellent CMB anisotropy signal with sufficient range to allow clean separation of galactic and CMB signals. Combined with the High Frequency Instrument (HFI) the full frequency range of minimum foreground emission will be sampled to determine all known galactic emission components and still have independent, redundant CMB anisotropy measurements.

The receivers are split into the cold Front End Modules (FEM), located in the Front End Unit (FEU) in the Focal Plane Unit (FPU) at 20K, and the Back End Modules (BEM) part of the Back End Unit (BEU) located on the upper platform of the SVM, and connected to the FEM by a set of 4 x 11 = 44wave-guides. (was 4 x 23 = 92 before removal of the 100 GHz)

LFI is composed of the following units:

Project code	Instrument unit
PLFEU	Front End Unit including 4K load, cryo-harness, and FEU internal harness (LFI part of common LFI/HFI FPU)
PLWG	Wave-guides (2 bundles) and support structure
PLBEU	Back End Unit (BEU)
	BEU internal harness
	Power box to BEU and BEM harness
	DAE Power Box
PLREN	REBA nominal (2)
PLRER	REBA redundant (2)
PLIH	REBA to BEU harness

Due to financial shortage resulting in schedule incompatibilities, LFI will not deliver a QM. However, a QM model of LFI has been built and is being tested. at Laben The environment tests is made at subunits levels. For instance, the LFI wave guides are tested only at the level of flange connections.

An LFI FPU MTD has been procured by Alcatel (and has been delivered by LABEN) for acoustic and cryogenic tests of Planck QM.

LFI FM is under manufacturing.

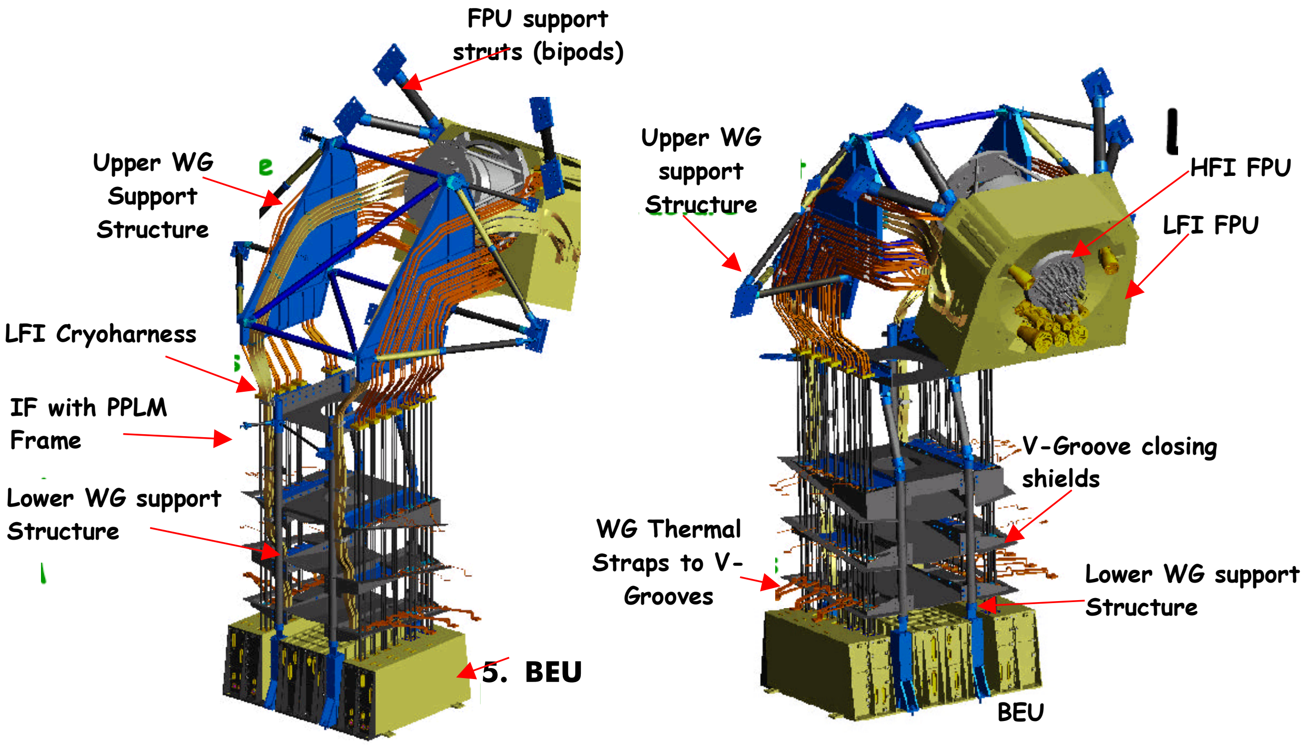


Figure 5.1-17 LFI RAA (FEU, wage-guides and BEU) (Note: HFI also shown inside LFI)

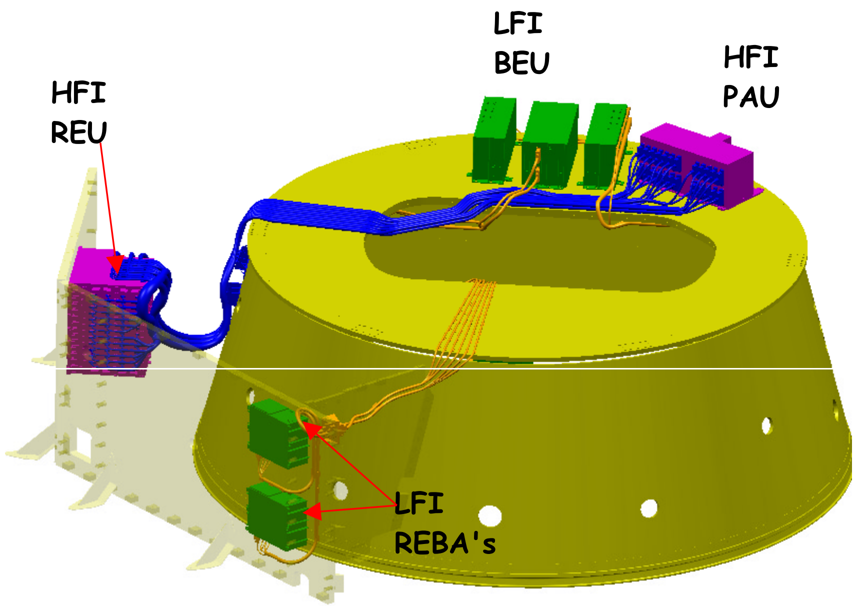


Figure 5.1-18 LFI Warm units on SVM

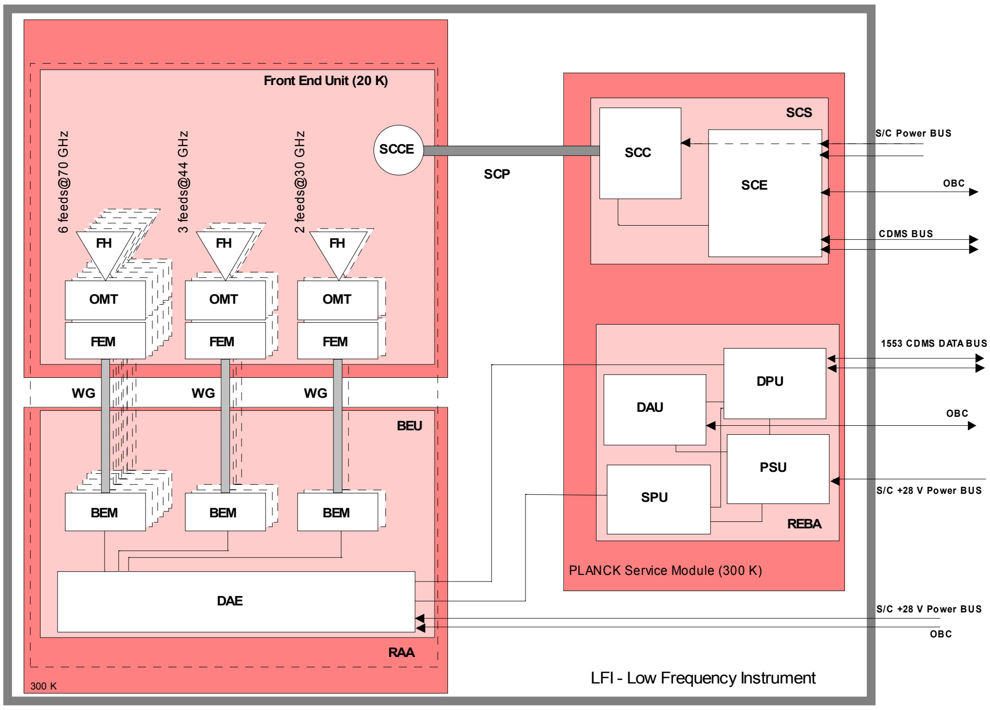


Figure 5.1-19 LFI Block Diagram

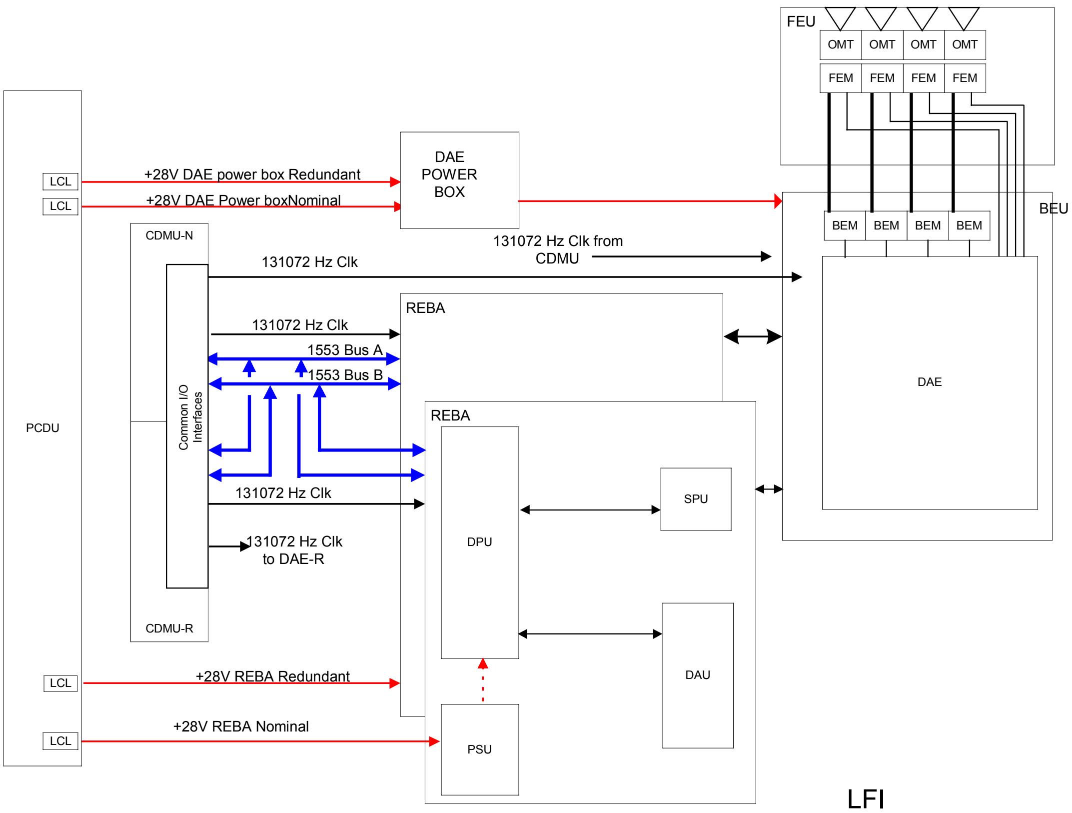


Figure 5.1-20 LFI electrical interfaces Block Diagram

5.1.1.2.3 Planck Sorption Cooler

Planck sorption cooler is not an instrument but is part of LFI. However, due to its complexity, and the amount of S/C resources needed by this instrument (needs that area of 3 SVM Panel, consumes 570W/1kW allocated to instruments, pipes non disconnectable from compressor), it has a dedicated interface document (SCS ICD), annexed to LFI IID-B.

The responsibility sharing is also complex, as the Thermo-machanical part of the SCS is provided by JPL, as participation of NASA to the LFIO instrument. The sorption cooler Electronics (SCE) is financed by HFI.

The responsibility of the Sorption cooler subsystem is in principle under LFI, but is practically inexistant.

The LFI FEU is cooled to 20 K by the operating hydrogen sorption cooler (the nominal or the redundant version). The operating cooler also provides 18K pre-cooling to the HFI 4-K cooler.

Each cooler is a Joule-Thomson cooler in which ~0.0065 g/s of hydrogen expands from 5 MPa to ~0.03 MPa through a Joule-Thomson (J-T) expander. The high and low gas pressures are maintained by the fact that the equilibrium pressure of gas above the sorbent bed is a strong function of temperature.

The sorption cooler subsystem comprises the following units both main and redundant:

- a Sorption Cooler Compressor assembly (SCC)
- a Sorption Cooler Cold End (SCCE)
- the Sorption Pipe Assembly and Cold End (PACE)
- the Sorption Cooler Electronics (SCE)
- the internal harnesses.

It should be noted that the SCC, SCCE, and PACE in each of the nominal and redundant coolers form an all-welded, principally stainless steel assembly of fluid loop components which, with associated permanently installed wiring and adapter brackets, is handled and installed as a single, non-separable unit.

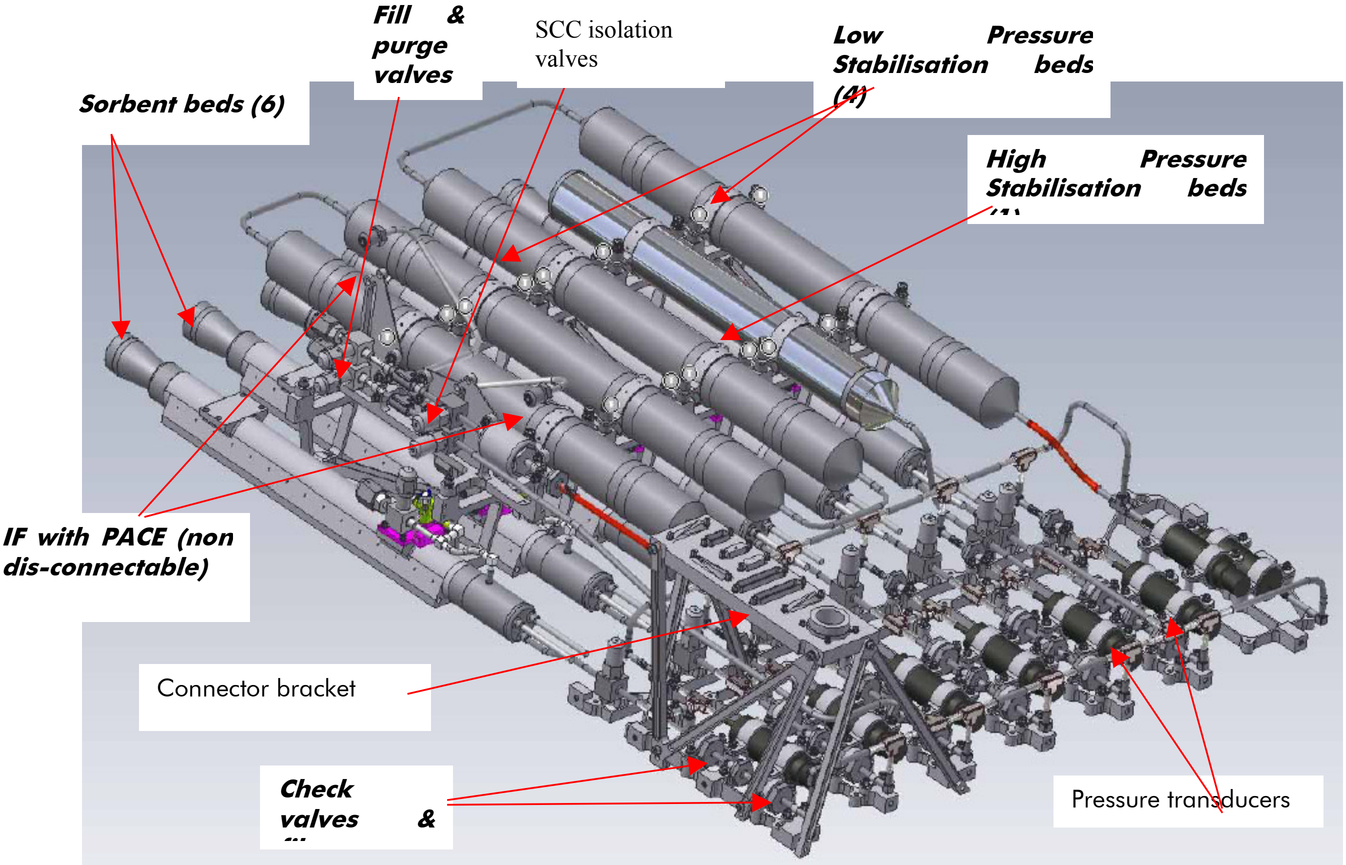


Figure 5.1-21 Sorption cooler compressor sketch

Figure 5.1-22 Sorption cooler FM1 compressor under vibration tests

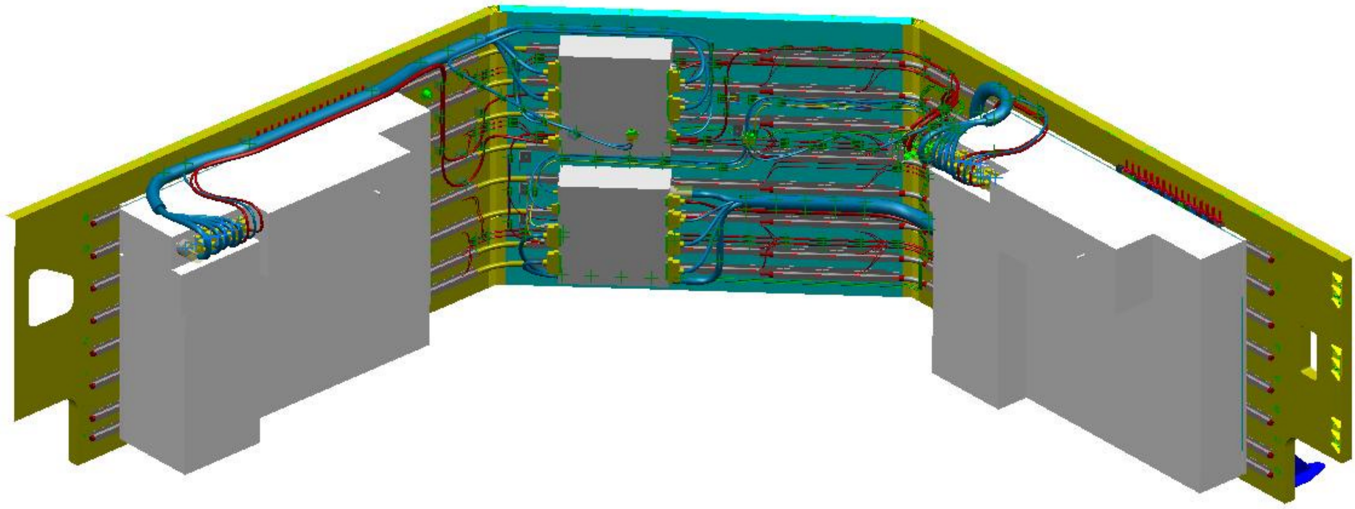


Figure 5.1-23 Sorption cooler compressors and Electronics integrated on 3 SVM panels, on heat pipes. Compressors are shown as their envelope volume (CAD model is not deliverable)

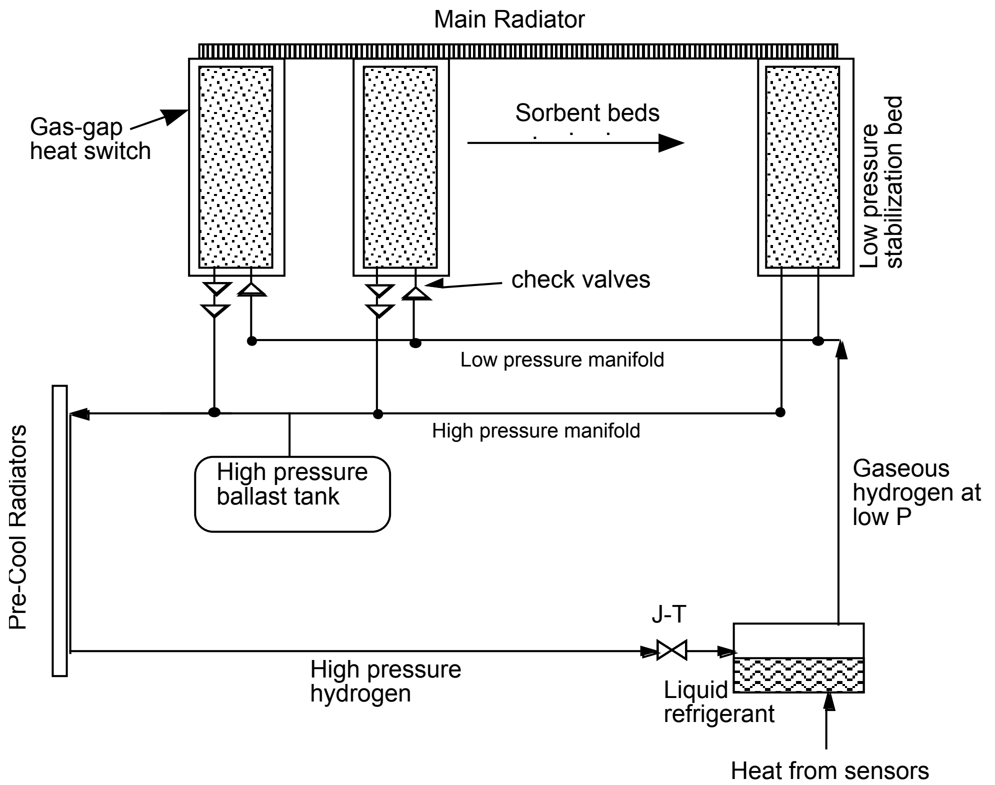


Figure 5.1-24 SCS functional Block Diagram

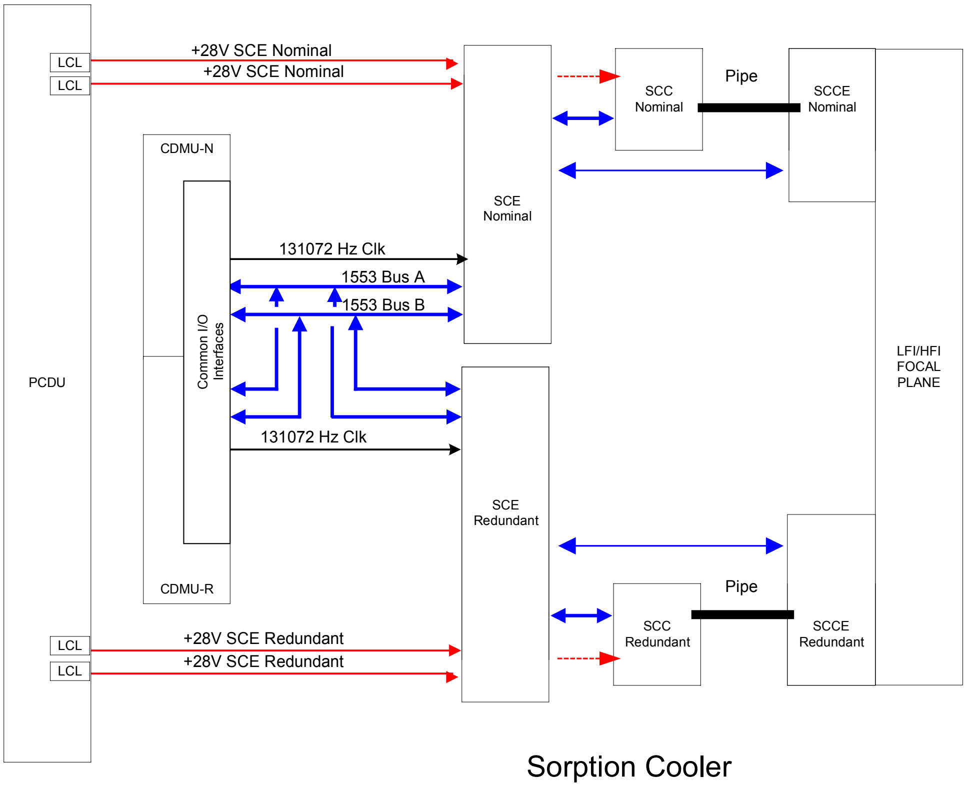


Figure 5.1-25 SCS electrical interfaces Block Diagram

5.1.2 Evolution of Instrument and satellite Interface design

5.1.2.1 Instrument evolution since PDR

Since the PDR, the instrument design manufacturing & test has continued. Instruments Hardware Design reviews took place mid-End 2003 beginning 2005, oriented toward the instrument AVM/CQM testing, and lead to the confirmation of the design and verification program, the need to freeze the Spacecraft interfaces, consolidation of the schedule, together with a recovery action related to instrument software.

MEETING	REPORT	REFERENCE	DATE FROM	DATE TO	LOCATION
SPIRE IHDR	Board report	SCI-PT-19056	09/07/2003	10/07/2003	RAL/UK
HFI IHDR	Board report	SCI-PT-21314	27/10/2003	29/10/2003	IAS Orsay
PACS IHDR	Board report	SCI-PT-22746	12/11/2003	13/11/2003	MPE/Garching
HIFI IHDR	Board report	SCI-PT-23117	15/12/2003	16/12/2003	ESTEC
LFI IHDR	Kick off Minutes (board report not yet issued)	SCI-PT-25791	24/03/2004	25/03/2004	IASF-Bologna
	Collocation meeting Minutes (board report not yet issued)	SCI-PT-28024	13/05/2004	14/05/2004	Laben/Milano

The main instrument evolutions which have influences on the interfaces are summarised in the following list:

All Instruments:

- convergence of mass budget (now stable and compliant with allocations)
- convergence of power budget (now stable and compliant with allocations)
- convergence on Instrument Units ICD's (now available & stable for all instrument units)
- update LCL definition (minor updates to fit more adequately to instrument demand)
- update communication bandwidth (sub-frame allocation, for similarity Herschel-Planck)
- WIH Routing (now frozen for instruments, & compliant with Cryo-harness & SVM harness)
- finalisation of instrument units accommodation
- convergence on Instrument tests at system level (formalised inAD13 to 16 of IID-A)
- instrument FDIR, now included in IID-B. To be finalised with system level OBCP's.

Planck

Planck common:

- finalisation of pipes design (0.1K & 4K, 0.1K)
- radiators & doublers on PAU & BEU (part of TCS).

LFI:

- remove 100GHz channels (FEU, BEU & WG)
- redesign of BEU into 3 boxes (for 100GHz, and to reduce the unit mass)
- finalise upper & Lower Wave-Guides support structure
- LFI QM is not deliverable (ASP procured MTD used)
- add LFI FPU heater (to be finalised)
- removal of LFI FPU heat switch
- LFI RAA MGSE (Open, needed for FM only)
- LFI Alignment (to be finalised).

HFI:

- move REU from DPU panel to 4K panel (for satellite balancing)
- 4K shield around 4K compressor (delivered by ASP)
- finalisation of routing of Bellow - PAU-JFET (along strut, definition of fixation)
- JFET fixation pattern (4 feet instead if 6, to reduce PR panel deformation)
- update micro-vibration requirement (reduced, compatible with CSL test facility)
- definition of DCCU interfaces & access (valves, pipes for test (pre-cooling, filling & purge)
- definition of 4K CAU interfaces & access

- definition of 4K CRU
- change of PAU size & fixation pattern
- bonding of Pipes & harness (50cm for pipes, 20cm for bellow.

SCS:

- redesign of Compressor fixation on heat pipes (reinforcement of the panel)
- definition of Compressor mechanical specification based on stresses in the FEM model
- temperature fluctuation of compressor (7K, 4.7K, 4.7K instead of 6K, 2K, 1K on beds neighbours to the desorbing one
- SCC cryo-harness 300K to 50K defined & routed
- sorption cooler pipes are not disconnectable any more (->impact on integration)
- delivery of QM PACE.

Herschel

Herschel common:

- convergence on Cryo-harness (spec & definition/routing)
- convergence of FPU thermal interfaces (add Open pods for PACS & SPIRE cooler evaporators)
- cryo-cover actively cooled mirrors have been added to reflect PACS & SPIRE FPU to themselves
- radiation of cover - baffle gap closed with MLI collar
- implementation of instruments reduced thermal models & timelines.

SPIRE:

- SPIRE QM is simplified (no Spectro channel)
- deliverable items (DRCU QM1 for QM, and DRCU QM2 used for FM integration & swap)
- agreement on cryo-harness shielding (daisy chains)
- Thermal link to JFET: Level 3 added + thermal insulation of JFET from OBA
- JFET integrated together with FPU
- deletion of SPIRE FPU shutter.

PACS:

- removal of BOLA
- convergence on DECMEC (Latest ICD)
- update most of the instrument units ICD's.

HIFI:

- LOU base-plate responsibility & design
- LOU Radiator responsibility (HIFI) & design
- LOU thermal control responsibility (HIFI)

- LOU wave-guides interfaces (Flanges, Bridging WG to LSU)
- LOU windows cleanliness: Transmission requirement has precedence)
- LOU window baffles (Open)
- implementation of LOU purging
- IF Change 3dB Couplers to Up-converter
- warm units base-plates (belly contact to SVM. Mass impact)
- warm units coating
- update most of the instrument units ICD's
- standing waves
- iteration of cleanliness (LOU, windows)
- LOU alignment refinement.

5.1.3 Instrument accommodation

The activity of accommodation initiated before the PDR has been finalised for the CDR.

Instrument have now a stable configuration in the satellite, for all units (warm units and FPU), harnesses, pipes.

One of the major difficulty between the PDR and the CDR was to freeze this instrument accommodation with instrument definition not completely frozen, and often with the lack of ICD's.

Formalism for management of changes has been reinforced (Change Requests).

ICD's for all units, with CAD models when available have been requested from instruments. Missing ICD's (PACS DECMEC, HIFI LSU & IF-up-converters, HFI DCCU & 4K CRU) were produced by ASP to continue the accommodation (applicable to both parties), and were replaced by instruments ICD's when they become available. All units ICD's are annexed to the IID-B's, & corresponding satellite ICD's are annexed to IID-A.

5.1.3.1 Warm units accommodation

The accommodation of the instrument warm units in the SVM proposed at the PDR has been refined taking into account the constraints of the integration constraints, the routing of the harness (WIH, Cryo-harness & SVM harness), and the access required for valves actuation, GES pipes connection.

There is a current commonly agreed configuration which is described in the annex 5 of the IID-A (AD04-1) and more detailed in the ALENIA design report (RD 01.1), the SVM interface control drawings as part of the Herschel & Planck MTICD's (AD 07.4 (Herschel) & AD 07.5 (Planck)).

The main modification wrt the PDR configuration are:

- definition/Update of all instruments warm units ICDs (several iterations)
- displacement of the HFI REU from the DPU panel to the 4K panel for Planck satellite balancing (& stability of spin axis)
- displacement of the HFI 4KCCR on a shear web
- routing of all warm units Warm interconnection harness (refer to section 6.3.7 of this document, formalised in Annex 10 of IID-A,)

- routing of Herschel warm cryo-harness, and definition of Brackets on upper platform
- routing of all Planck pipes, & definition of disconnection brackets on upper platform
- refinement of Planck sorption cooler compressor fixation on the heat pipes.

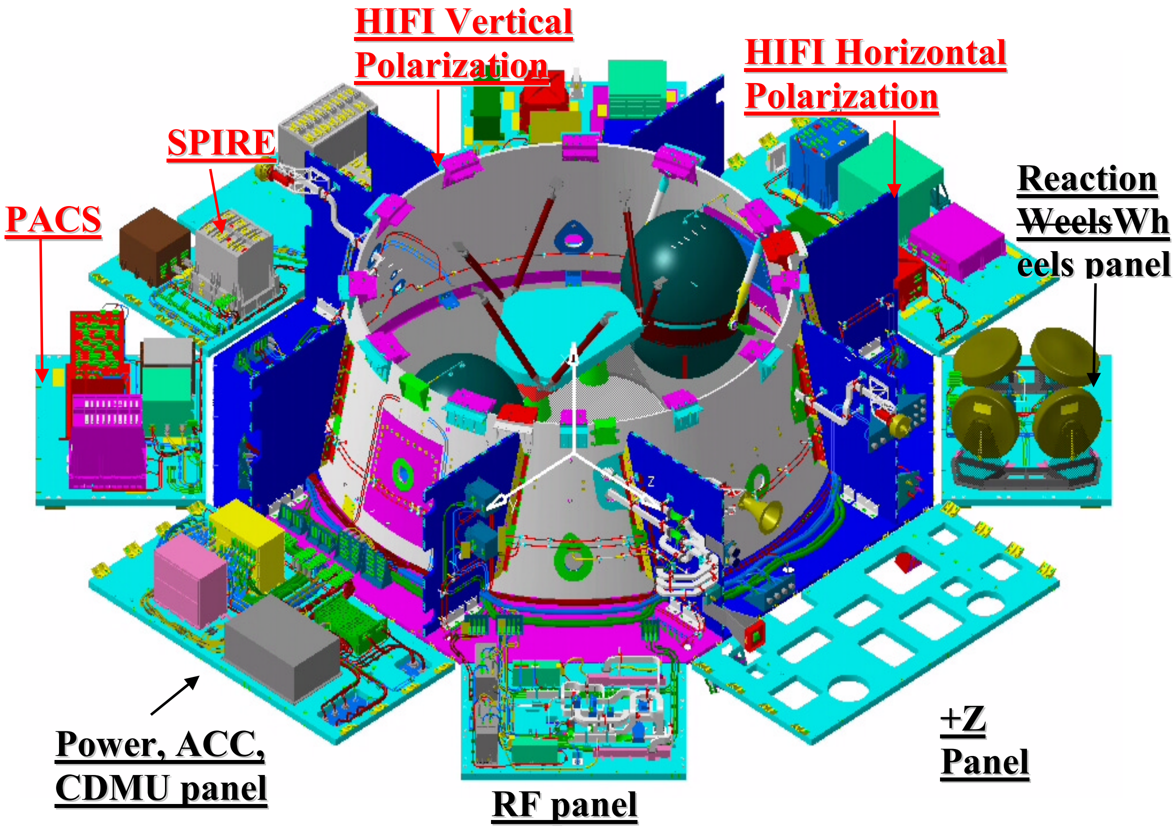


Figure 5.1-26 Accommodation of Herschel warm units on SVM

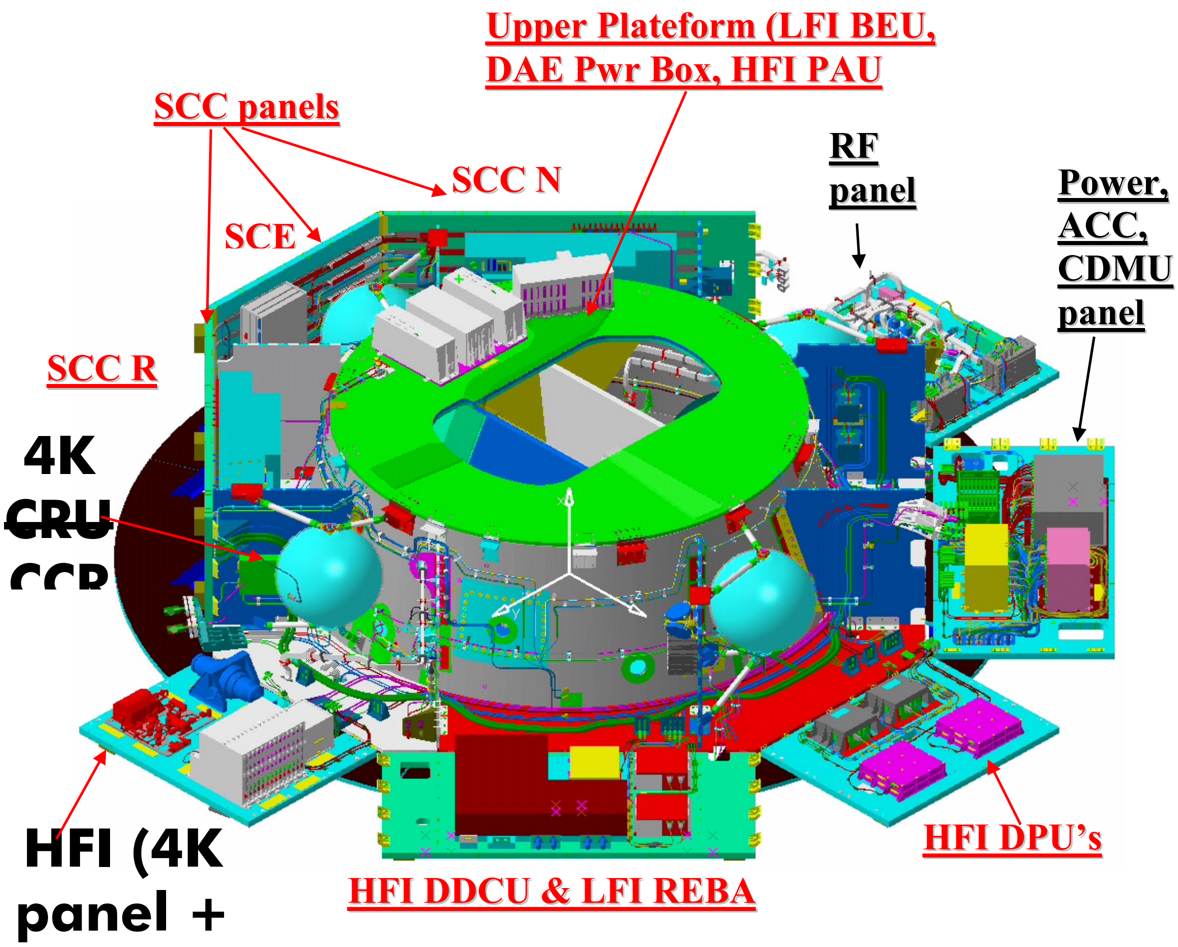


Figure 5.1-27 Accommodation of Planck warm units on SVM

5.1.3.2 Herschel FPU and CVV attached item accommodation s

The Herschel FPU accommodation are described in the IID-A (Section 5.3.1.1, 5.6.1, and annex 6 for ICD's), and ASTRIUM design report (RD 01.2), and in the Herschel MTICD (AD 07.4).

The main modification since PDR is the freezing of thermal straps interfaces to Level 0, 1, 2, the adjunction of the level 3 specific to the SPIRE JFET's. Open pods for Level 0 connection to PACS & SPIRE coolers evaporators have been added to the existing closed (external straps) to ensure a good condensation efficiency of the coolers, and 48h recycling period.

The PACS BOLA has been removed from the CVV.

Iteration on the LOU interfaces responsibility, and mechanical & thermal design have been long and difficult, but results now in a clear responsibility sharing and design: LOU is delivered with an optical bench (LOU Base Plate) supporting the LOA's (the 7 elements composing the LOU), interface to the wave-guides & cryoharness, and the alignment pentaprisms. The satellite (H-PLM) provides a mounting structure (LOU Support Plate with insulating struts to the CVV), which will carry the LOU, and the LOU radiator. In addition, it will accommodate the LOU alignment camera (HACS = Herschel Alignment Camera Subsystem).

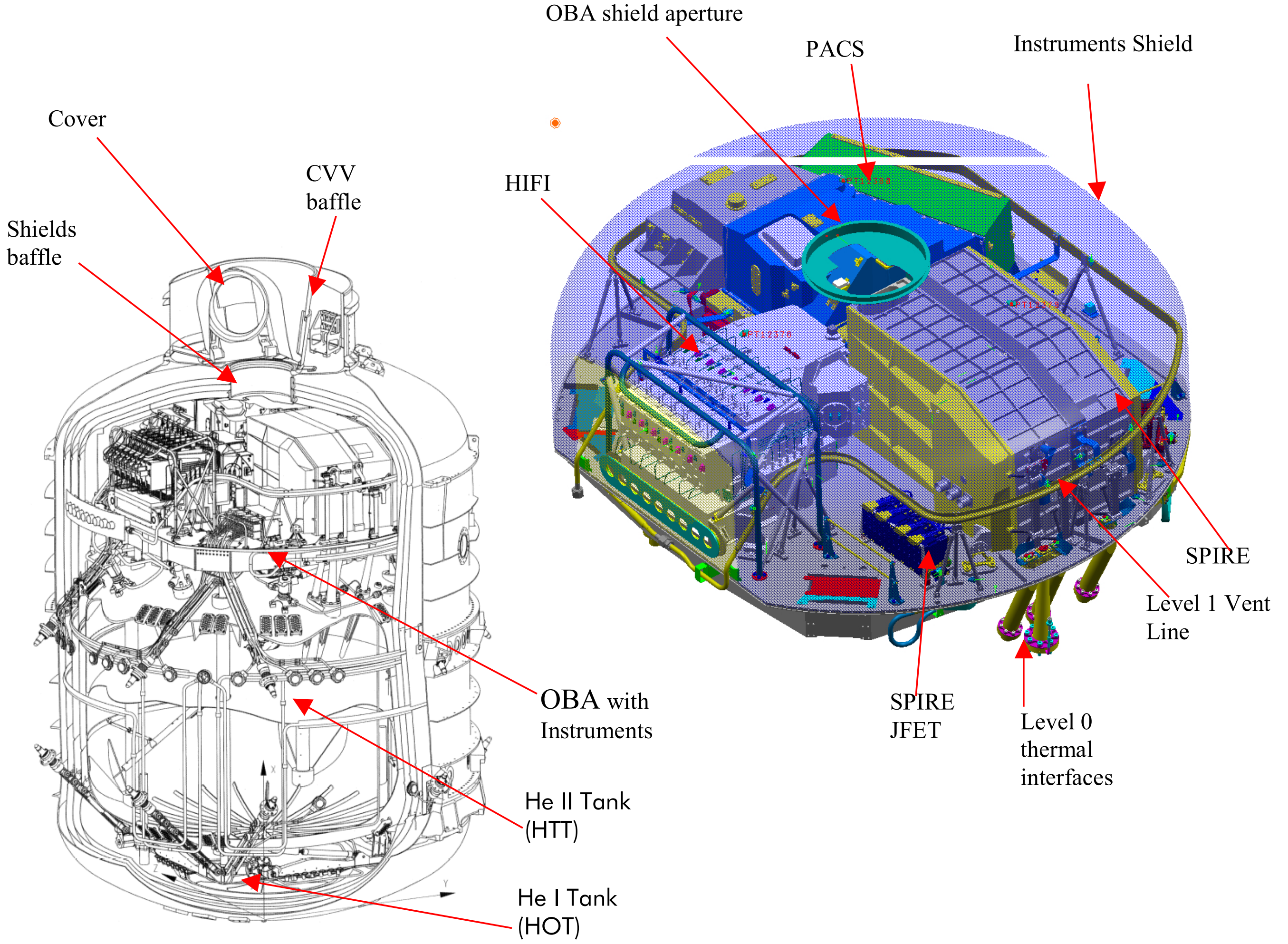


Figure 5.1-28 Accommodation of Herschel FPU'S on OBA

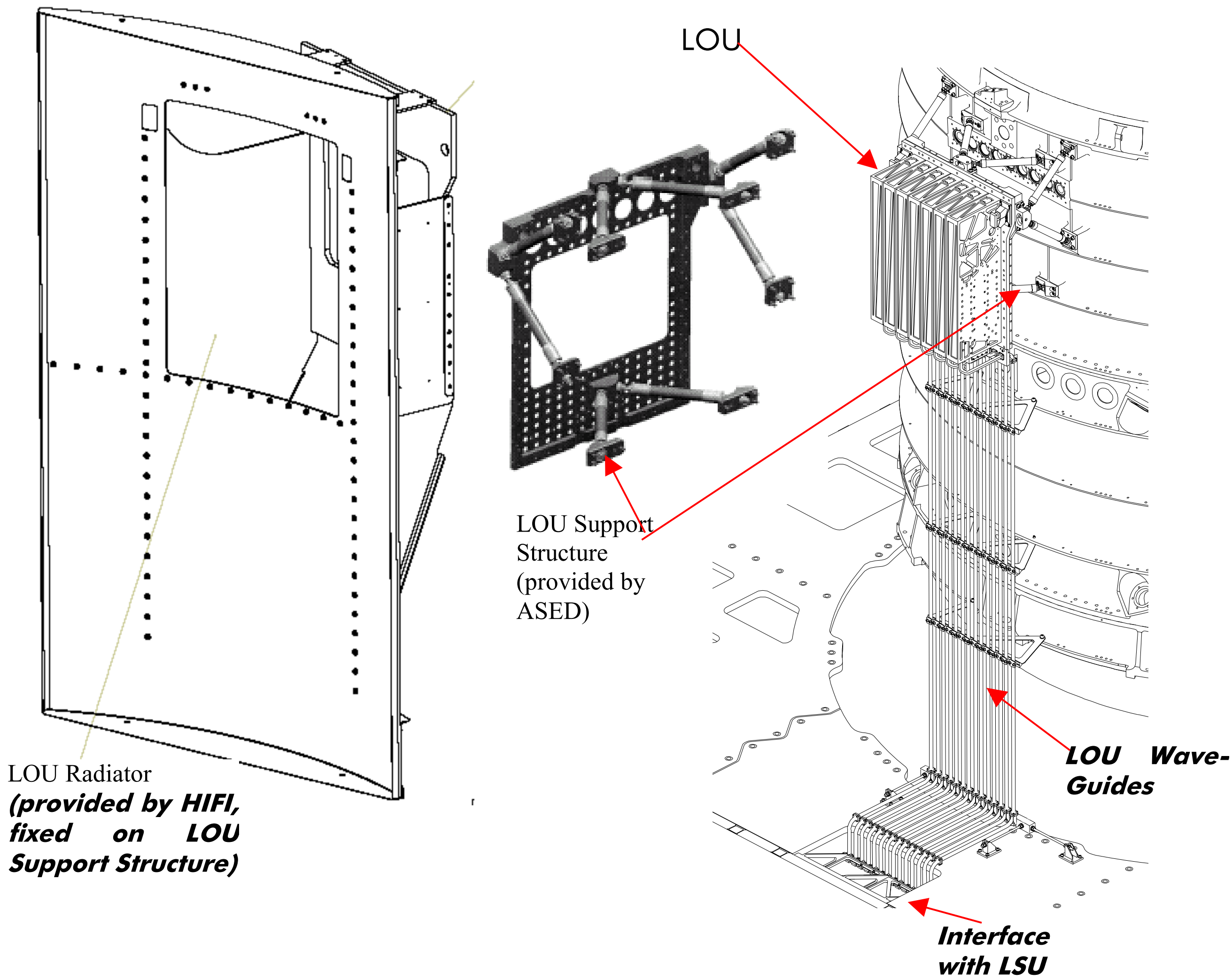


Figure 5.1-29 Accommodation of HIFI LOU & Wave-Guides on Herschel CVV

5.1.3.3 Herschel instruments Cryo-harness

Due to the need of early integration inside the HPLM cryostat, the Herschel instrument cryo-harness is designed and manufactured by industry.

A significant effort was spend between PDR and CDR to finalise the instrument cryo-harness (named SIH for Scientific Instrument Harness) requirements, which are now agreed, and included in IID-B.

In parallel, the design of the cryo-harness has been done, and updated several times following several clarification and the instrument change requests. In particular, the internal over-shield which was specifically excluded (because of the cryostat shielding effect) has been included for SPIRE.

The following diagram gives an overview of the Cryo-harness (CCH + SIH) in the Herschel cryostat.

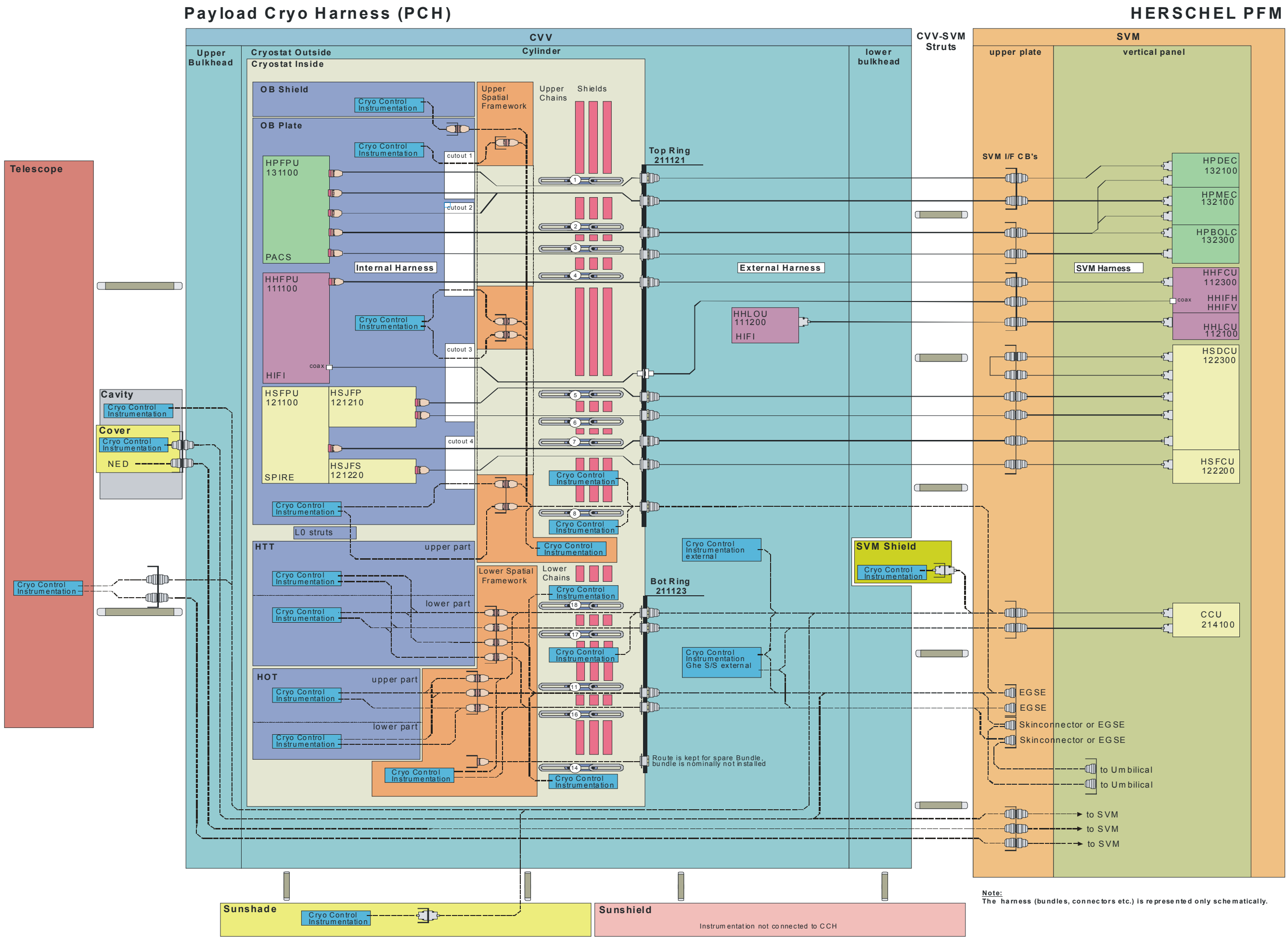


Figure 5.1-30 Herschel PFM cryo-harness overview

The cryo-harness is composed of 3 sections:

- Internal to the cryostat (FPU connectors to CVV vacuum feed-through)
- External to the CVV (CVV vacuum feed-through to SVM brackets)
- SVM cryo-harness (SVM brackets to warm units).

The HIFI LOU has specific cryo-harness with the 2 last sections only, plus a set of wave-guides (see Figure 5.1-29).

More details on the cryo-harness definition can be found in IID-A annex 8, and in the H-PLM EICD.

The QM cryo-harness (only the SVM part) has been simplified taking into account that the redundant functions are not present, and that not all detectors are included.

It has been proposed by ASED to perform an independent physical verification of the Cryo-harness database (used to define and test the cryo-harness) against the instrument test cryo-harness This will be performed this autumn.

5.1.3.4 Planck Payload accommodation.

Planck FPU accommodation is described in the IID-A 3.0 Section 5.3.1.2 and 5.6.2, completed by interface drawings in Annex 7, plus the PPLM design report (RD 1.3), and in the Planck MTICD (AD 07.5).

The main driver for design and integration is due to the large number links between cold and warm sides of the instruments(harness, pipes, wave-guides), and the fact that many un-disconnectable units have to be shared between the PLM and SVM (LFI RAA, with FPU & BEU connected with wave-guides, HFI PAU & JFET connected by Bellow, Sorption coolers compressor & pipes). This is a driver in the

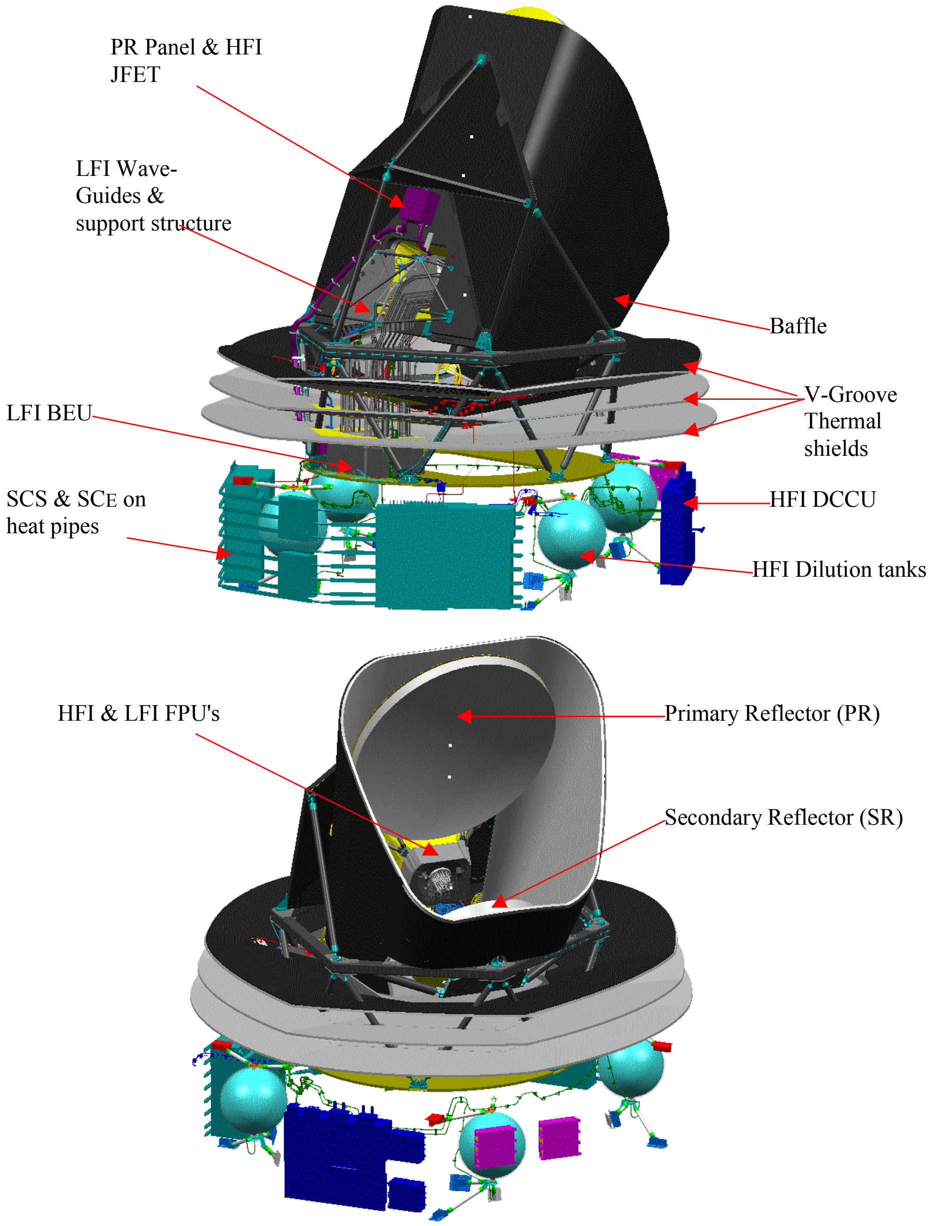


Figure 5.1-31 Planck instruments on PPLM

5.1.4 Instrument budgets and related satellites resources

5.1.4.1 Margin Philosophy at instrument and system level

In order to avoid adding margins to margins at both instrument and spacecraft levels, the instruments margin philosophy is based on the following:

- in the IID-A (and SRS), instruments are given allocations of the satellite resources (mass, power, heat rejection, data-rate,…). This allows the spacecraft to be designed on a stable basis with respect to the resources allocated to the instruments. The relevant information (resource) for the spacecraft is the sum of the allocations for all instruments. However, to simplify the design on both sides, the total instrument allocations have been shared between instruments, and also between warm and cold units
- in parallel, the instruments are being designed, and their nominal budgets are published in their respective IID-B's. The difference between the nominal budget and the allocation can be considered as margin.

In addition, the SRS specifies:

- that the satellite structural design shall be compatible with the instrument nominal mass as agreed in the IID-B, at beginning of phase B + a 20 % margin (SINT-015)
- and that the thermal design shall be compliant with the instrument's nominal IID-B dissipations + 20 % at cryogenics temperatures and + 10 % for the SVM (SINT-035). It has been agreed to reduce the design margin of the sorption cooler heat losses on V-Grooves to 10% to give more allocation to LFI.

In cases where the total resources requested by the instruments exceed the allocations, the on-going satellite design is confronted with uncertainty in instrument interface requirements and the instruments have been requested to re-address design issues.

Currently the PDR spacecraft system budgets are based on instruments allocations (IID-A or SRS), which are compatible with the instrument demands.

5.1.4.2 Instruments budgets & associated Satellite resource allocation

In the following chapter, we propose the resources that we can allocate to the instruments (as allocated in the IID-A) and compare them to the current instrument demand as reflected in the latest IID-B's. The margin is the difference between these numbers.

During Phase B, there was a clear tendency to increase the resources required by instrument from spacecraft. These requests have been contained. The allocations have not been changed between PDR and CDR.

There was a significant evolution of HIFI instruments near the IHDR (end 2003): + 24kg + 37W.

At the CDR, the instruments nominal mass budget is slightly higher than the allocation (2.97kg), but HIFI nominal mass includes still some hidden margins (2 to 5%) which should be removed in the next issue of IID-B.

The Power demand is compatible with the allocation with 6.8% margin for Planck and 1.38 % margin for Herschel.

5.1.4.2.1 Mass of instruments and Mass Allocation

The following Table 5.1-1 gives the distribution of the current Nominal mass of the instruments (without Margin) compared to the allocation. The table gives the Delta wrt the allocation, and the evolution since PDR.

The Figure 5.1-32 below gives the evolution of the masses of the instruments

Instruments Mass budgets at CDR (~ June 2004) | **ref**

Planck

	IIDB 3.2/3.0	IIDA 3.3	Delta IID-B / Allocation		evolution since PDR (July 02)		ref
Instrument	Nominal Mass	Allocation	Delta	delta	Delta	delta	
	kg	kg	kg	%	kg	%	
HFI	*226.5*	**244**	17.5	7.17%	10.0	**4.36%**	HFI IID-B 3.1
LFI	*90.3*	**89**	-1.3	**-1.46%**	-6	-5.67%	LFI IID-B 3.0_draft5
Sorption	*118.4*	**112**	-6.4	**-5.71%**	-3.4	-2.97%	SCS ICD 3.0 draft 3
Total Planck	***435.2***	**445**	9.8	2.20%	0.6	**0.13%**	

Herschel

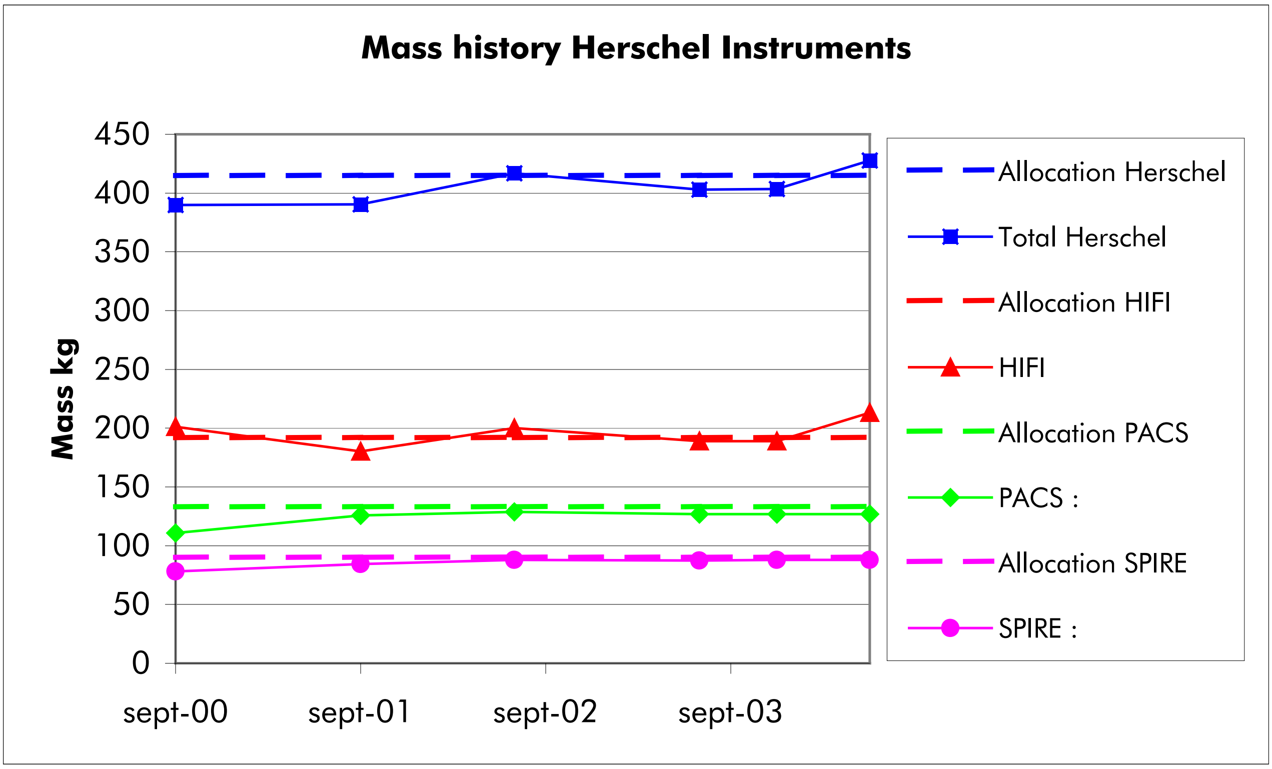
	IIDB 3.2	IIDA 3.3	Delta IID-B / Allocation		evolution since PDR (July 02)		ref
Instrument	Nominal Mass	Allocation	Delta	delta	Delta	delta	
	kg	kg	kg	%	kg	%	
PACS :	*126.8*	**133**	6.2	4.66%	-2	-1.59%	PACS IID-B 3.2
SPIRE :	*87.8*	**90**	2.16	2.40%	-0.05	-0.06%	SPIRE IIDB 3.2
HIFI	*213.1*	**192**	-21.1	**-10.99%**	13	**7.22%**	HIFI IID-B 3.2
Total Herschel	***427.7***	**415**	-12.7	**-3.07%**	11.0	**2.80%**	

note: HIFI nominal mass includes some margin (2 to 5%) which will disapear

Herschel + Planck

	IIDB 3.2/3.0	IIDA 3.3	Delta / Allocation		evolution since PDR (July 02)	
Instrument	Nominal Mass	Allocation	Delta	delta	Delta	delta
	kg	kg	kg	%	kg	%
Total	***862.9***	**860**	-2.94	**-0.34%**	11.6	**1.37%**

Table 5.1-1 Mass budget and allocations of Herschel & Planck instruments



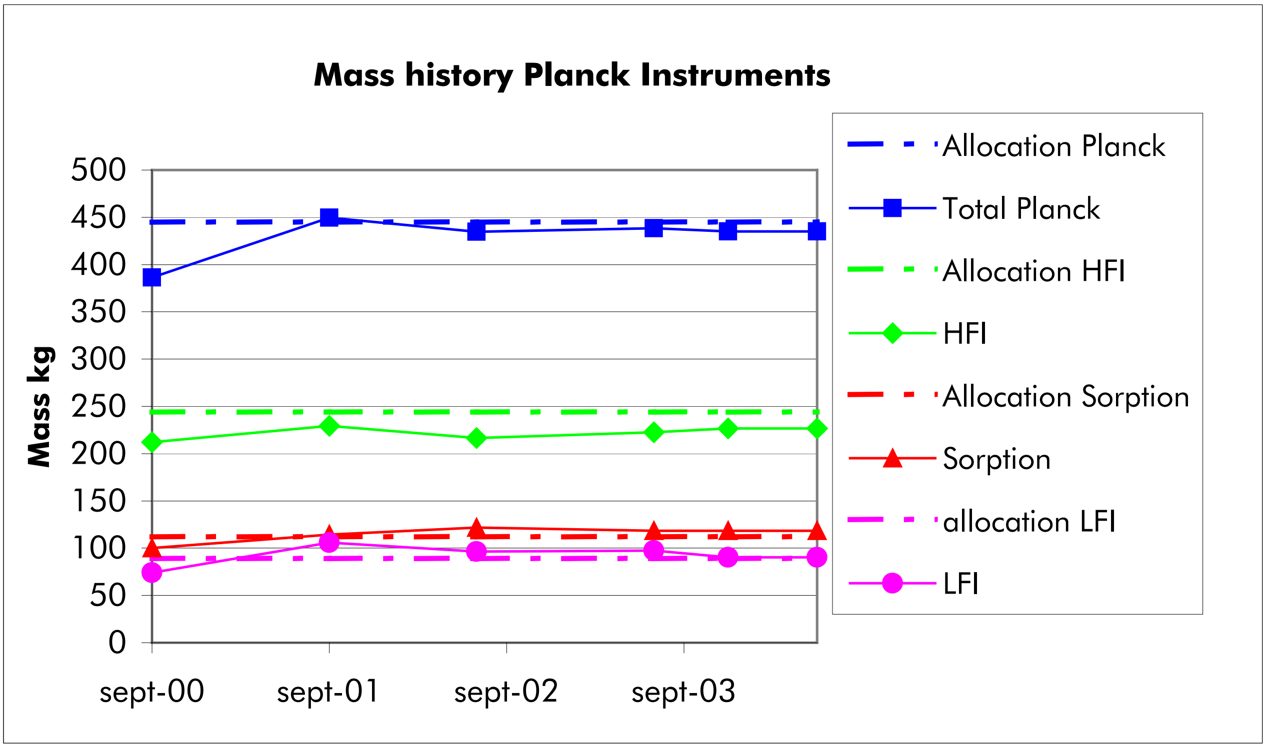


Figure 5.1-32 Mass budget history of Herschel and Planck instruments

The mass allocation for instrument has not changed since the ITT, despite significant design changes of the instruments. 3kg allocated for the LOU wave-guide have to move from HIFI mass budget to H-PLM mass budget.

The margin is now negative for Herschel + Planck Instruments [-0.34 %, 2.94kg], distributed into [+2.2 % 9.8kg] for Planck and [–3.07 % 12.7kg] for Herschel instruments (see above remark on HIFI margins on nominal mass).

We believe that as most of the Instrument QM units are manufactured & weighted, no significant mass evolution is expected for the FM.

However, it is proposed after the CDR, following launch optimisation, to redistribute some of the mass margin to the instruments. to restore about 10% margin between instrument nominal mass and allocation

The following new allocation will be proposed to instruments:

Planck			juil-04				
	IIDB 3.2/3.0	**IIDA 3.3**	**in next IIDA 3.4**				
Instrument	**Nominal Mass**	**Allocation**	**New Allocation**	**Allocation increase**		**New margin**	
	kg	**kg**	**kg**	**kg**	**%**	**kg**	**%**
HFI	*226.5*	**244**	**244**	0	0	17.5	7.7%
LFI	*90.3*	**89**	**104**	15	16.9%	13.7	15.2%
Sorption	*118.4*	**112**	**132**	20	17.9%	13.6	11.5%
Total Planck	***435.2***	**445**	**480**	35	7.9%	44.8	10.3%

Herschel							
	IIDB 3.2	**IIDA 3.3**	**in next IIDA 3.4**				
Instrument	**Nominal Mass**	**Allocation**	**New Allocation**	**Allocation increase**		**New margin**	
	kg	**kg**	**kg**	**kg**	**%**	**kg**	**%**
PACS :	*126.8*	**133**	**140**	7	0.053	13.2	10.4%
SPIRE :	*87.8*	**90**	**96**	6	6.7%	8.16	9.3%
HIFI	*213.1*	**192**	**229**	37	19.3%	15.9	7.5%
Total Herschel	***427.7***	**415**	**465**	50	12.0%	37.26	8.7%

Herschel + Planck							
	IIDB 3.2/3.0	**IIDA 3.3**	**IIDA 3.4**				
Instrument	**Nominal Mass**	**Allocation**	**New Allocation**	**Allocation increase**		**New margin**	
	kg	**kg**	**kg**	**kg**	**%**	**kg**	**%**
Total	***862.9***	**860**	**945**	85	9.9%	82.06	9.5%

Table 5.1-2 Proposed mass allocation for instrument (after CDR)

5.1.4.2.2 Instrument Power demand and power dissipation Allocations

For the power, we consider the following allocations: The maximum average power demand (at input of the instrument), and the average power dissipation (at output of the instrument) which should be similar[1], plus the short and long peak Power demands, used to select the proper LCL type.

On both spacecraft the area dedicated to the Solar Array is limited. This is particularly true on Planck on which the Solar Array is located on the back of the spacecraft, and its size limited to 4.2 m by the diameter of the launcher fairing. Deployment is not advised for temperature stability. Therefore the Solar Array area has no growth potential. In addition, most of the Planck power is allocated to the payload (1 kW out of 1.550 kW), and half of it required by the sorption cooler.

The following Table 5.1-3 gives the current situation for Power allocation and power demand for the instruments, together with the evolution since the ITT.

Herschel Power allocation in the IID-A (including Instrument margins) has been increased at the PDR from 500 W to 550W), and did not move since. (remark: allocation was 454 W at ITT).

Calculation of max power demand takes into account the fact that one instrument is prime at a time, the others are in stand-by mode, and that there is a small difference in dissipation between Prime and standby mode.

the calculation of the maximum power demand has to list the possible instrument mode combination, as shown in Table 5.1-4. We have a current small margin of 1.36% (7.5W) for Herschel Instruments.

For Planck, the margin is now larger: 5.84 % (58.4W)

Power demand & allocation history for Herschel & Planck is shown on the following Figure 5.1-33.

1 These 2 values should be similar, except for RF components. The main difference for standard units will come from the difference in definition between maximum average power demand and the average dissipation.

The maximum average power demands (ref IID-A, § 5.9, GDIR § 6.7.5) assumes a moving averaging window of 5 mn, whereas the average power dissipation is smoothed by the thermal time constant of the unit + radiator (can be hours), therefore the difference between the 2 averages could be of a few % (Maximum average Power Demand ≥ Average Power dissipated).

The difference between demand and dissipation can be large for the power peaks (IID-A § 5.9, GDIR § 6.7.6). In that case, the peak power dissipated can be very large due to heat storage, as illustrated by the sorption cooler on Planck.

	Power budgets at CDR (June 2004)	ref/Rem

Planck							
	IID-B 3.0/3.1	IID-A 3.3	Delta / Allocation		evolution / PDR		
Instrument	Nominal	Allocation	Delta	delta	Delta	delta	ref/Rem
	W	W	W	%	W	%	
HFI	285	310	25	8.06%	0.2	0.06%	HFI IID-B 3.1
LFI	86.6	120	33.4	27.83%	-33.6	-28.00%	LFI IID-B 3.0_draft5
Sorption	570	570	0	0.00%	44	7.72%	SCS ICD 3.0 draft 3
Total Planck inst.	941.6	1000	58.4	5.84%	10.6	1.06%	

Herschel								
	IID-B 3.2		IID-A 3.3	Delta / Allocation		evolution / PDR		
Instrument	Nominal	Stand by	Allocation	Delta	delta	Delta	delta	ref/Rem
	W		W	W	%	W	%	
PACS :	131.4	81.8	125	-6.4	-5.12%	5.5	4.04%	PACS IID-B 3.2
SPIRE :	95.3	95.3	110	14.7	13.36%	0	0.00%	SPIRE IIDB 3.2
HIFI :	352.8	315.8	315	-37.8	-12.00%	37.2	12.87%	HIFI IID-B 3.2
(1 operating & 2 sta	542.5		550	7.5	1.36%	5.7	1.10%	

Total PACS Prime	542.5
Total SPIRE Prime	492.9
Total HIFI prime	529.9

Table 5.1-3 Power budget and allocations of Herschel & Planck instruments

Mode		HIFI	PACS	SPIRE	total
1	HIFI Prime	352.8W	81.8W	95.3W	529.9W
2S	PACS Prime Spectro	315.8W	130.9W	95.3W	542.0W
2P	PACS Prime Photo	315.8W	131.4W	95.3W	542.5W
3S	SPIRE Prime Spectro	315.8W	81.8W	95.3W	492.9W
3P	SPIRE Prime Photo	315.8W	81.8W	95.3W	492.9W
4	Parallel	315.8W	131.4W	95.3W	542.5W
5	Serendipity	315.8W	81.8W	95.3W	492.9W
Allocation		315.0W	125.0W	110.0W	550.0W

Table 5.1-4 Detail of power demand taking into account the instrument modes, and the fact that one instrument is operating at a time

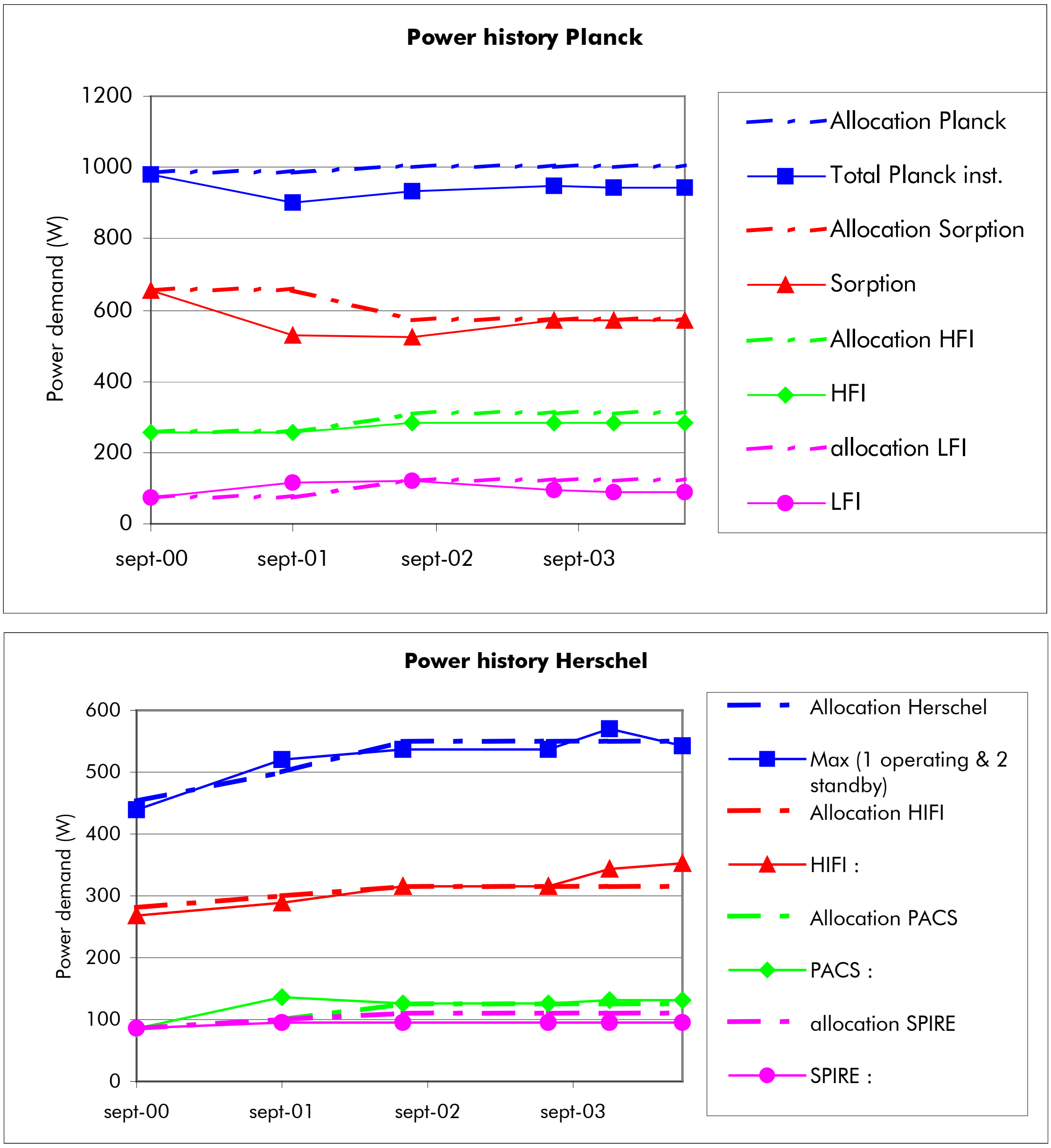


Figure 5.1-33 Power budget evolution of Herschel & Planck instruments

The power is distributed to instrument warm units using the following allocated LCL's.

Herschel Allocation	To	Type	Protected	Class
HIFI HRH	**FHHRH**	LCL	YES	III
HIFI HRV	**FHHRV**	LCL	YES	III
HIFI ICU Nom	**FHICU**	LCL	YES	III
HIFI ICU Red	**FHICU**	LCL	YES	III
HIFI LCU Nom	**FHLCU**	LCL	YES	III
HIFI LCU Red	**FHLCU**	LCL	YES	III
HIFI WEH	**FHWEH**	LCL	NO	II
HIFI WEV	**FHWEV**	LCL	NO	II
PACS BOLC Nom	**FPBOLC**	LCL	YES	II
PACS BOLC Red	**FPBOLC**	LCL	YES	II
PACS DPU Nom	**FPDPU**	LCL	NO	II
PACS DPU Red	**FPDPU**	LCL	NO	II
PACS MEC1	**FPMEC1**	LCL	YES	II
PACS MEC2	**FPMEC2**	LCL	YES	II
PACS SPU Nom	**FPSPU1**	LCL	NO	II
PACS SPU Red	**FPSPU2**	LCL	NO	II
SPIRE HSDPU Nom	**FSDPU**	LCL	YES	I
SPIRE HSDPU Red	**FSDPU**	LCL	YES	I
SPIRE HSFCU Nom	**FSFCU**	LCL	YES	III
SPIRE HSFCU Red	**FSFCU**	LCL	YES	III

Planck Allocation	To	Type	Protected	Class
LFI DAE Power Box Nom	**PLBEU**	LCL	YES	III
LFI DAE Power Box Red	**PLBEU**	LCL	YES	III
LFI REBA Nom	**PLREN**	LCL	YES	II
LFI REBA Red	**PLRER**	LCL	YES	II
HFI DCE	**DCE**	LCL	NO	II
HFI DPU Nom (PHBA-N)	**PHBAN**	LCL	YES	II
HFI DPU Red (PHBA-R)	**PHBAR**	LCL	YES	II
HFI REU belts group 0&1	**PHBAR**	LCL	NO	II
HFI REU belts group 2&3	**PHBAR**	LCL	NO	II
HFI REU belts group 4&5	**PHBAR**	LCL	NO	II
HFI REU belts group 6&7	**PHBAN**	LCL	NO	II
HFI REU belts group 8&9	**PHBAN**	LCL	NO	II
HFI REU belts group 10&11	**PHBAN**	LCL	NO	II
HFI REU Proc Nom	**PHCBC**	LCL	YES	I
HFI REU Proc Red	**PHCBC**	LCL	YES	I
HFI 4KC Drive bus Nom	**PHDC**	10A-LCL	YES	10A
HFI 4KC Drive bus Nom	**PHDC**	10A-LCL	YES	10A
HFI 4KCDE Nom (PHDC)	**PHDC**	LCL	NO	II
HFI 4KCDE Red (PHDC)	**PHDC**	LCL	NO	II
Sorption Cooler Compressor Nom	**PSM4**	20A-LCL	YES	20A
Sorption Cooler Compressor Red	**PSR4**	20A-LCL	YES	20A
Sorption Cooler Electronics Nom	**PSM4**	LCL	YES	III
Sorption Cooler Electronics Red	**PSR4**	LCL	YES	III

10A-LCL = combination of 2 class III
20A-LCL = combination of 4 class III

Table 5.1-5 Herschel & Planck instruments LCL allocation

5.1.4.2.3 *Temperature ranges for SVM warm units*

The following table summarises the temperature range requested by instruments, together with the TCS guaranteed temperature range.

Satellite	Instrument	Project code	Unit	Temperature required by Instrument: Operating Min °C	Operating Max °C	Stability (slope) DT/dt K/h	Start-up °C	Switch-off °C	Non-operating Min °C	Non-operating Max °C	T Guaranteed by TCS: Operating Min °C	Operating Max °C	T Stability DT/dt K/h	Non-operating Min °C	Non-operating Max °C
Herschel	SPIRE	HSDPU	Digital Processing Unit	-15	45	N/A	-30	50	-35	60	-15	45	3	-35	60
		HSFCU	FPU Control Unit	-15	45	N/A	-30	50	-35	60	-15	45	3	-35	60
		HSDCU	Detector Control Unit	-15	45	N/A	-30	50	-35	60	-15	45	3	-35	60
	PACS	FPDECMEC	Detector (spectro) & Mechanism Control	-15	45	N/A	-30	50	-30	60	-15	45	3	-30	60
		FPBOLC	Bolometer (photometer)&Cooler Control	-15	45	N/A	-30	50	-30	60	-15	45	3	-30	60
		FPDPU	Data processing Unit	-15	45	N/A	-30	50	-30	60	-15	45	3	-30	60
		FPSPU1/2	Signal Processing Unit (stacked)	-15	45	N/A	-30	50	-30	60	-15	45	3	-30	60
		FPWIH	Warm Intercinnecting Harness												
	HIFI	FHFCU	FPU Control Unit	-10	40	5.0	-25	40	-25	55	-10	40	5	-25	55
		FHLCU	Local Oscillator Control Unit	-10	40	1.1	-25	40	-25	55	-10	40	1.1	-25	55
		FHIFH	IF up-converter Horizontal	-10	40	1.1	-25	40	-25	55	-10	40	1.1	-25	55
		FHIFV	IF up-converter Vertical	-10	40	1.1	-25	40	-25	55	-10	40	1.1	-25	55
		FHLSU	Local Oscillator Source Unit	10	40	1.1	-25	40	-25	55	10	40	1.1	-25	55
		FHHRV	High Resolution Spectometer - Vertical Polarisation	-10	40	1.1	-25	40	-25	55	-10	40	1.1	-25	55
		FHHRH	High Resolution Spectometer - Horizontal Polarisation	-10	40	1.1	-25	40	-25	55	-10	40	1.1	-25	55
		FHWEV	Wide Band Spectrometer Electronics - Vertical Polarisation	0	30	1.1	-25	40	-25	55	0	30	1.1	-25	55
		FHWEH	Wide Band Spectrometer Electronics - Horizontal Polarisation	0	30	1.1	-25	40	-25	55	0	30	1.1	-25	55
		FHWOV	Wide Band Spectrometer Optics - Vertical Polarisation	5	15	1.1	-25	30	-25	55	5	15	1.1	-25	55
		FHWOH	Wide Band Spectrometer Optics - Horizontal Polarisation	5	15	1.1	-25	30	-25	55	5	15	1.1	-25	55
		FHICU	Instrument Control Unit	-25	40	5.0	-30	50	-30	60	-25	40	5	-30	60
		FHWIH	Warm interconnecting Harness	-10	40	5.0	na	na	-25	55	N/A	N/A	N/A	-25	55
		FHLWU	LOU wave-guides (LSU side)	-10	40	1.1	na	na	na	na	N/A	N/A	N/A	na	na
Planck	HFI	PHBA-N	DPU N (Data processing Unit - Nominal)	-10	40		-20		-20	50	-10	40	3	-20	50
		PHBA-R	DPU R (Data processing Uni - Redundantt)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
		PHCBC	REU (Read Out Electronics)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
		PHCBA	PAU (Power Amplifier Unit)	-10	30	1.1	-20		-20	50	-10	40	1.1	-20	50
		PHDA	4KCCU (4K Compressor Unit)	-10	40	N/A	-20		-20	40	-10	40	3	-20	40
		PHDB	4KCAU (4K Ancillary Unit)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
		PHDC	4KCDE (Cooler Drive Electronics)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
		PHDJ	4K CRR (current regulator)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
		PHEAA	He3 Tank (+Z)	-10	40	N/A	N/A		-20	50	-10	40	3	-20	50
		PHEAB1	He4 Tank +Y	-10	40	N/A	N/A		-20	50	-10	40	3	-20	50
		PHEAB2	He4 Tank -Z	-10	40	N/A	N/A		-20	50	-10	40	3	-20	50
		PHEAB3	He4 Tank -Y	-10	40	N/A	N/A		-20	50	-10	40	3	-20	50
		PHEC	DCCU (Dilution Cooler Control Unit)	-10	40	N/A	-20		-20	50	-10	40	3	-20	50
			Cables and Pipes	-10	40	N/A	N/A		-20	50	N/A	N/A	3	-20	50
	LFI	PLREN	REBA Nominal	-20	50	N/A	-30		-30	50	-20	50	3	-30	50
		PLRER	REBA Redundant	-20	50	N/A	-30		-30	50	-20	50	3	-30	50
		PLAEF	DAE Power box (Data acquisition Electronics	-20	50	N/A	-30		-30	50	-20	50	3	-30	50
		PLBEU	BEU (Back end Unit)	-20	40	0.2	-30		-30	50	-20	40	0.2	-30	50
	SCS	PSM3	SCC (Sorption Cooler Compressor Nominal)	-13	7	3, 1, 0.5K (*)	-20		-20	50	-13	7	7,4.7,4.7	-20	50
		PSR3	SCC (Sorption Cooler Compressor Redundant)	-13	7	3, 1, 0.5K (*)	-20		-20	50	-13	7	7,4.7,4.7	-20	50
		PSM4	SCE (Sorption cooler Electronics Nominal)	-10	40	N/A	-10		-20	50	-10	40	4.7	-20	50
		PSM4	SCE (Sorption cooler Electronics Redundant)	-10	40	N/A	-10		-20	50	-10	40	4.7	-20	50

(*) never accepted due to 1.2 kW peak and limited radiator size & mass

Table 5.1-6 Herschel & Planck instruments temperature requirements

A significant amount of work has been performed by the SVM TCS subsystem team to implement the fine temperature control for HIFI units. (ref. RD06.14), to guarantee the HIFI spectrometers the required temperature stability.

5.1.4.2.4 *Allocation for temperatures and Power dissipation on FPU's*

The instrument power dissipation and heat leaks on the cryogenic focal planes should be managed closely at system level to guarantee the compatibility between the various components, and a proper operation of the complex cryogenic systems.

The total allocation is defined by the heat lift available at a given temperature stage, and shall be split between the payload (support, radiation, …), and the instruments.

5.1.4.2.4.1 Herschel

On Herschel, the thermal interfaces between the instruments and the spacecraft are on 4 identified levels.

Level 0 (< 2 K) direct connection to the Helium tank, Level 1 (< 5 K) and Level 2 (= OBA, < 12 to 20 K) and Level 3 (15K SPIRE JFETs) on the helium vent line.

The following table summarises the temperature and instruments heat loads allocations on these 3 levels, together with the current estimated temperature (from H-PLM Thermal transient analysis (ref. RD 06.11)

Herschel instruments FPU In-Orbit thermal requirements											**Estimated max operating T**	
SPIRE FPU thermal I/F		**Temp @ Heat Load**			**Start-up**	**Switch-off**	**Non-operating**		**Bakeout**	**Stability**	**Estimated max operating T**	
level	thermal interface	Requirement	Goal	Cooler State	Min °C	Max °C	Min. K	Max. °C	°C	K/s	K	uncertainty (K)
L0	Detector Box	2 K @ 4 mW	1.71 K @ 1 mW	Operating				60	80		1.74	0.06
	Cooler Pump	2 K @ 2 mW	2 K @ 2 mW	Operating				60	80		1.69	0.06
		10 K @ 500 mW peak	10 K @ 500 mW peak	Recycling				60	80		9.77	0.06
	Cooler Evaporator	1.85 K @ 15 mW	1.75 K @ 15 mW	Recycling				60	80		1.7	0.06
L1		5.5 K @ 15 mW	3.7 K @ 13 mW	Operating				60	80		4.22	0.18
L2	Optical bench / FPU legs	12 K @ no load	8 K @ no load	Operating					80		10.6	0.5
L3	HSJFP (JFET Photometer)	15 K @ 50 mW	15 K @ 50 mW	-					80		15.1	0.5
	? HSJFS (JFET Spectrometer)	15 K @ 25 mW	15 K @ 25 mW	-					80		13.7	0.5
-	Instrument shield (eq. Radiative temperature)	16 K	16 K	-								

PACS thermal I/F		**Temp @ Heat Load**										
level	thermal interface	Requirement in Operating conditions		Comments	Start-up	Switch-off	Non-operating		Bakeout (72h	Stability	**Estimated max operating T**	
		Max	Min		Min °C	Max °C	Min. K	Max. °C	°C	K/S	K	uncertainty (K)
L0	FPFPU Red Detector	1.75 K @ 0.8 mW	1.6 K (i)	(i) Min temperature for all L0 I/F				60	85		1.68	0.06
	FPFPU Blue Detector	2 K @ 2 mW						60	85		1.73	0.06
	Cooler Pump	10 K @ 500 mW peak		Peak during pump cooling Low temp.operation				60	85		12	0.06
		5 K @ 2 mW						60	85		1.73	0.06
	Cooler Evaporator	1.85 K @ 15 mW (*)		(*) During 200s at end of condensation				60	85		1.796	0.06
L1	FPFPU Photometer	5 K @ 10 mW (**)	2 K	(**) : Assuming 12 K at L2 (the sum of 30 mW may be distributed as appropriate)" : Min temperature for all L1 I/F				60	85		3.55	0.18
	FPFPU Spectrometer	5 K @ 10 mW (**)						60	85		4.24	0.18
	FPFPU Collimator (1)	5 K @ 10 mW (**)						60	85		4.43	0.18
L2	HOB	12 K @ no load	NA					60	85		10.9	0.5

HIFI thermal I/F		**Temp @ Heat Load**										
level	thermal interface	Requirement in Operating conditions		Comments	Start-up	Switch-off	Non-operating		Bakeout (72h	Stability	**Estimated max operating T**	
		Max	Min (K)		Min °C	Max °C	Min. K	Max. °C	°C	Max K / 100s	K	uncertainty (K)
L0	Mixers of FHFPU (Level 0)	20K@22mW	0		NA	40	0	60	80	0.006	1.96	0.06
L1	Parts of FHFPU ** (Level 1)	6K@15.5mW	0		NA	40	0	60	80	0.006	5.37	0.18
L2	FHFPU (Level 2)	20K@6.8mW	0		NA	40	0	60	80	0.015	12.4	0.5

Table 5.1-7 Temperature and heat lift allocation on Herschel FPU, compared to instrument requests

Comments

Since the PDR, there has been refinement of the instrument requirement at the thermal interfaces:

For the PACS & SPIRE sorption cooler evaporator & pump thermal interfaces, as the instrument were requesting lower temperature, to guarantee a good condensation efficiency of the 3He for a 48h operation, the design has been modified to guarantee the interface temperature: 2 Open Pods have been added for these 2 L0 interfaces, with direct contact of the interface with Liquid Helium.

An optimisation of the thermal straps mass vs conductance has been done, leading to extra support for PACS Level 0 straps.

Iteration on the electrical insulation of SPIRE thermal strap result in the initial solution where the electrical insulation is performed on the instrument side (the Kapton sheet proposed at the interface has not been judged reliable enough).

The following table gives the power dissipation allocated for instruments on each level. Original allocation on Level 2 has been split into Level 2 & 3 at the time of the separation. The average heat flow has been estimated from the instrument typical time line (ref. RD 06.11).

Level	Allocation **[mW]**	Average Instrument heat flow on level **[mW]**
Level 0	10	10.1
Level 1	25	34.3
Level 2	35	0.4
Level 3	15	26.2

Table 5.1-8 Heat load allocation on Herschel FPU's

Implementation of the thermal straps Levels 0, 1, 2, 3 is shown on the following figures.

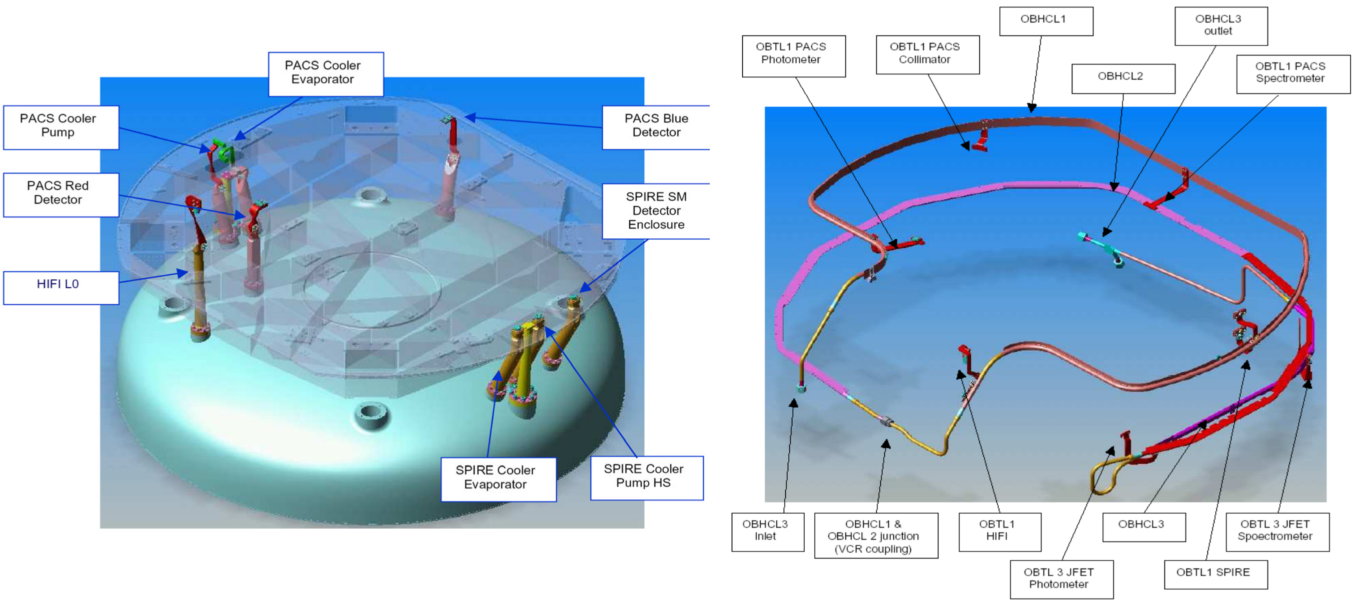


Figure 5.1-34 Herschel Level 0 and Level 1, 2, 3 thermal interfaces:
left: Level 0: Most interface are external pods, except PACS & SPIRE cooler evaporator where an open pod is implemented
Right: Level 1 (upper loop), Level 2 (attached to OBA), Level 3 (SPIRE JFET)

5.1.4.2.4.2 Planck

The situation is different, as our responsibility in term of control of the heat leaks ends up at the 60 K stage (V-Groove 3). The principle of the insulation via the V-Grooves relies on the heat interception of all conductive paths on the intermediate V-Groove shield, therefore we have to propose allocation at each level (V-Groove 1, 2, and 3).

Design temperatures:	***3rd V-Groove (K)***	***2nd V-Groove (K)***	***1st V-groove (K)***
LFI	51.4/57.6 (*)	106	166
HFI	50	110	165
SCS	58.5/56.3/52.3 (**)	108	158

(*) The 2 LFI interface on the 3rd V-groove are on both sides +/-Y, the warmest is on the side of the operating SCS
(**) The 3 temperatures for SCS interface are on the 3 heat exchangers on V-groove 3 (warm = upstream to cold = downstream)

Table 5.1-9 Typical temperature to be used for heat exchangers heat load estimation V-Grooves 1, 2, and 3

Heat Loads	***3rd V-Groove (mW)***	***2nd V-Groove (mW)***	***1st V-groove (mW)***	***SRS margin (**)***
HFI	620	20	50	20 %
LFI	710	560	5370	20 %
SCS	1175	447	566	10 %
Total	**2505**	**1027**	5986	

Table 5.1-10 Planck heat loads allocation on V-Groove thermal shields

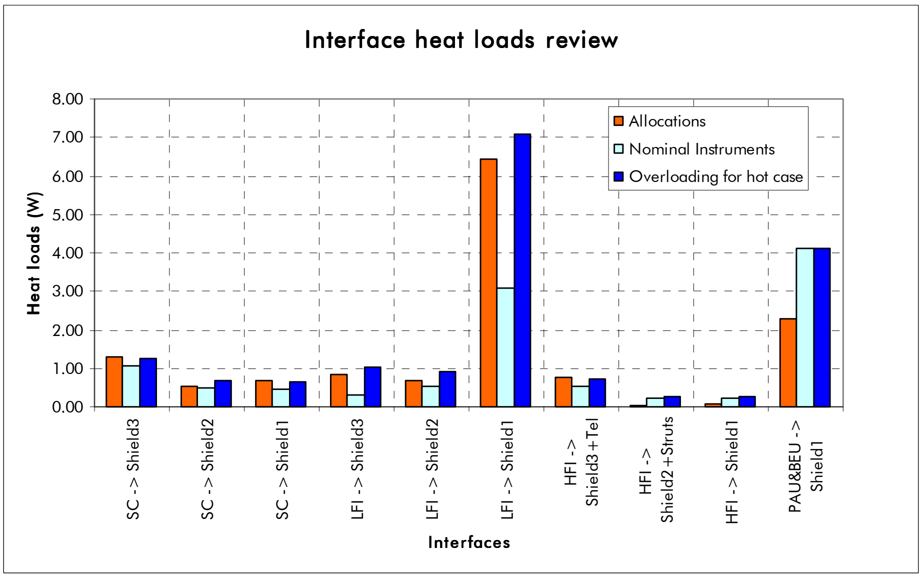


Figure 5.1-35 Planck instrument status of dissipation on V-Grooves

5.1.4.2.5 Data rates Allocation

The data-rate allocation 32 sub-frame/s for Planck, and 33 sub-frames/s for Herschel (Science + Housekeeping). The share is evenly distributed among the 2 instrument for Planck, and allocated to the prime instrument for Herschel (allocation included 3 sub-frames allocated to the House-keeping data of each of the non-primes instruments

These sub-frames can be filled with Science or housekeeping data (up to 8Kbits/sub-frames) up to an average of130kbps (compatible with the mass memory).

For PACS, a burst mode has been implemented (40 sub-frames/s of about 300kbps) special transmission mode) to allow more data to be transmitted for a limited amount of time

The following allocation table has been agreed with instrument during the data-management working group, and is in line with their needs.

PLANCK SUBFRAME ALLOCATION	Launch Mode	S/C Sun Acquisition	Nominal Normal	S/C Earth Acquisition	Survival
LFI TM	0	3	15	3	0
HFI TM	0	3	15	3	0
Sorption Cooler HK TM	0	2	2	2	0
Total number of subframes allocated	**0**	**8**	**32**	**8**	**0**

HERSCHEL SUBFRAME ALLOCATION	Launch Mode	S/C Sun Acquisition	Nominal		S/C Earth Acquisition	Survival
			Normal	Burst Mode		
Prime Instrument TM	0	3	27	40	3	0
Non-Prime1 Instrument TM	0	3	3	3	3	0
Non-Prime2 Instrument TM	0	3	3	3	3	0
Total number of subframes allocated	0	9	33	46	9	0

Table 5.1-11 Data rate allocation for instruments

5.1.4.2.6 EMC

Main changes related to EMC interfaces are:

- On Planck: the adjunction of a mu metal Magnetic shield around the HFI 4K Cooler compressor on Planck, and the low pitch grounding of HFI bellow and pipes.
- Detail definition of EMC testing of instruments at system level has been initiated, based on instrument test results on DM/QM.

5.2 Open points at CDR and Solutions

This paragraph is to summarise the open points concerning the technical interfaces with the instruments.

5.2.1 General

Mass budget

The slightly negative margin between Instrument nominal mass and mass allocations as been solved very recently by allocating some mass margin (gain from launch optimisation), to restore about 10% margin. It is proposed to reallocate 85kg to the instruments: 50kg to Herschel (most of it to HIFI), and 35kg to Planck (LFI & SCS)

Power budget

The power margin is too small (5.8% for Planck, 1.4% for Herschel). However, it is known that some units have still significant margins. For instance, the REBA, for which the power consumption has been measured during the 1553 IF test.

Instrument interface FDIR

Actions have been taken end 2003/2004, through the data-management working group to identify the Instruments interface FDIR requirements (i.e. recovery actions to be initiated by the spacecraft in case of instruments failure). Although not finalised, these requirements are now understood by instruments, identified, and formalised in the IID-B's. The next step, to be undertaken by ASP will be to define the actions to be taken by the spacecraft (mostly in term of OBCP's). This will be done for end 2004

5.2.2 Planck

Planck Common Mechanical loads on Planck cooler Pipes, and pipes qualification

The Random mechanical vibration levels specified for Planck cooler pipes are high (see IID-A Section 9.5), mainly due to the fact that they are attached to large panels susceptible to acoustic vibrations. Some of them are in addition submitted to high pressure It should be proven that the pipes will survive the launch loads, and that they will not leak.

It has been difficult to convince the instruments of the importance of this point, and of the need of a serious analysis to optimise the pipes fixation pattern.

For the sorption cooler pipes, a dedicated acoustic test on a panel with samples (coaxial) pipes has demonstrated that the damping is high as anticipated. However, the mechanical analysis needs to be updated at the light of these test results.

For the 0.1K pipes, the analyses and fixation pattern optimisation have been performed very recently. However, the coexistence of pressure loads (295b for 0.1K pipes between He tanks & DCCU) and launch loads is still to be demonstrated

For the 4K pipes, the analyses have just been initiated, and are not complete.

The question of the cooler pipes qualification by instruments is now also a concern, as virtually no qualification test is performed by instrument, except for the Sorption cooler samples tests.

This concern becomes serious with the fact that the 0.1K & 4K pipes are not available for the Planck CQM acoustic test, together with the recent deletion of the Planck S/C QM mechanical tests. The first serious verification of the integrity of the pipes will occur only on the FM. This has been identified in the risk analysis (RD04.23).

Instrument should undertake before delivery if the FM, a proper qualification of the cooler pipes. An approach similar to JPL is acceptable.

Planck Common Planck End to end test

It has been proposed by ESA (in the Frame of the Planck Telescope working group) to perform a Planck end to end test, using LFI at ambient as a detector and the telescope. However, LFI sensitivity at ambient is not high enough to allow such test. It has then be proposed to replace LFI by a dedicated test horn, to be implemented on LFI FPU. These test would be reduced to verification of alignment and integrity of the PPLM. ALCATEL position is that this test is less accurate that standard alignment methods.

However, the definition of this test is still TBD, and the interfaces on the LFI FPU for a test horn are not defined.

LFI LFI FPU heater

The Planck FPU decontamination heater issue is not closed. The EOL cleanliness analysis (RD04.6) indicates that the FPU EOL contamination level is acceptable by instruments without FPU heater (and there was a formal statement from instruments on this issue). However, Planck reflectors are equipped with heaters, to be used at the early stage of the mission. Therefore, to avoid the out-gassing of the reflectors to condensate on the FPU, instruments have been asked to implement a heater on the FPU.

These heaters are powered by CDMU, and the related channels and harnesses are defined up to a connector on the SVM upper platform (ref. to IID-A Annex 12, or Planck EICD, AD07.7)

HFI replied that the Heat switch to LFI is sufficient to maintain HFI at room temperature if LFI is warmed, and that no heater is needed.

LFI is very reluctant to implement a heater on the FPU, as it affects the cryogenic performances.

Definition of these heaters, and cryo-Harness between upper platform and FPU are still not finalised (action to LFI)

LFI LFI RAA MGSE

The definition of the LFI FM RAA MGSE is still not finalised. LFI clamed that there are too many "external" requirements for them to finalise it (such as dismountability for HFI pipes, and interface loads requirements (momentum & pressure) on the SVM upper platform).Actions have been taken to solve this issue ASP made some guidelines for the design of this MGSE (teleconference on 20/7). LFI/LABEN works on finalising the RAA MGSE design.

LFI LFI Alignment

LFI has started to work on alignment (LFI to S/C and LFI to HFI) only very recently. This aspect has been highlighted at the IHDR as an important aspect to be improved. An TN related on alignment has been issued after the IHDR by LFI (LFI Alignment Evaluation And Recovery Proposal - PL-LFI-PST-TN-054_1_1). The alignment method has then been agreed (shimming of the LFI FPU). However, the actual position of the FPU at cryogenic temperature, and the corresponding accuracy on this position are still not known. It has been suggested to LFI to measure it.

SCS Temperature stability

If most of the previously critical temperature stability requirements have been solved, the one of the sorption cooler compressor is still open.

The Sorption cooler compressor JPL proposed requirement (6K, 2K, 1K peak-peak on a cycle period for compressor beds neighbours to the desorbing one) has never been accepted by ASP, as unrealistic, given the configuration which dictates the time constant of the system (if C is radiator + compressor mass x heat capacitance, R is the equivalent resistance corresponding to the radiative coupling to deep space, the time constant of the system is τ = RC, and the response to the compressor heat pulse Q (1.2kW) is therefore known.

Alcatel proposed instead the temperature stability given by the response of the system (7K, 3.7K, 3.7K, including 10% margin) (now included in the sorption cooler ICD).

The compatibility of this fluctuation with the 20K temperature regulation performances (TAS) has still to be confirmed.

SCS Sorption cooler pipes disconnectability

After several iteration on the subject, including qualification of filled joints by JPL, the current and definitive situation is that the SCS compressor are permanently welded to the PACE (at the difference with 4K & 0.1K which have both 2 disconnections: upper platform & HFI FPU).

The consequence is that the integration procedure is more complex (starts with the sorption cooler and build Planck around), and that any further need to dismount part of the sorption cooler is impossible.

SCS Definition of Compressor mechanical specification based on stresses in the FEM model

The mechanical requirement on SCS compressor has been updated recently to stress levels (110Mpa) on several locations on the SCC internal pipes (ref. Section 5.6.3.2 of SCS ICD), identified as nodes in the FEM model used for the coupled analysis.

The verification of this requirement is not obvious, as strain gauges cannot be accommodated at these exact locations in the compressors FM's. Proposition are to install them nearby, and to use a transfer function.

Acceptability of this approach has to be given.

SCS SCC cryo-harness 300K to 50K

Sorption cooler cold end instrumentation cryo-harness from SCE to cold end has been defined recently: JPL is responsible of the 50K to 20K part (accommodated along the pipes), and HFI provides the 300K to 50K part (named W101/102 for the 300K part, and W021/022 for the cryo part). The routing of this cryo-harness is performed by ASP (PPLM). Design has been initiated, CAD model already exchanged, but no formal ICD exists yet It should be available soon.

5.2.3 Herschel

Herschel Common Routing of SVM part of the cryo-harness

The routing of the SVM part of the cryo-harness (SVM brackets to warm units) is not yet available in annex 10 of IID-A. Main reason are very late changes of some instrument warm units configuration (DECMEC). This definition is in progress, and will be delivered soon to instruments.

HIFI LOU windows cleanliness/Transmission requirement

After long discussions with HIFI on the LOU window cleanliness and transmission, it has been agreed that the transmission requirement is the driver. The current design is compliant with this transmission requirement (80 %) Therefore ASP will issue a RFD on cleanliness requirement (H-P- 100000- ASP-RD-007).

After this agreement, HIFI still maintain a caveat against the signature of IID-B, that the LOU window should be equipped with heaters. We consider this as un-realistic.

HIFI LOU window baffles

The definition of the LOU window baffles (7 cylindrical black anodised baffles attached to the 2nd heat shield of the cryostat, between the windows and the OBA shield) has been questioned at the H-PLM CDR, as the heat flow reaching the OBA and the HIFI instrument during ground tests has significantly increased among the last issues on the H-PLM thermal analysis (main issue is instrument testability on ground). The origin of the problem is the reflectance of this baffle. A solution based on vanes has been proposed by ASED to reduce the reflected flow to OBA.

H-PLM Thermal and straylight analyses of the ground testing conditions show that the instruments test should be feasible with the current definition

HIFI position on the subject is that their instrument would not be affected by this heat flow, as most of it is blocked by the fore optics.

HIFI Standing waves

Testing of standing waves between the telescope and HIFI have been excluded very early from system tests, first because the need was not clearly identified, and second because such tests would be very heavy & extremely difficult to undertake, with no clear criteria. Negotiation with HIFI has been transferred to ESA, who undertook Standing waves analyses, showing that no significant problems are expected. However, this point is still blocking the signature of HIFI IID-B.

6. SYSTEM DESIGN

6.1 Main design evolutions since PDR

This chapter summarises the main evolutions of the system design since PDR. It is focusing on the most important evolutions, other evolutions being described in the following section of this chapter.

From an overall spacecraft configuration point of view, the main evolutions occurred on Herschel. The first main evolution took place when, taking benefit of the launcher capacity increase due to baseline launcher change to an Ariane 5 ECA, the height of the H-PLM was increased by 100 mm. This allowed a He II tank capacity increase corresponding to 4.5 months of lifetime. At that opportunity, the ESA margin on cryogen was increased from 10 % to 15 % to cope with potential instrument focal plane units dissipation increase. The remaining part of lifetime increase allowed to comfort compliance to Herschel cryogenic lifetime requirement.

The second main evolution on Herschel was the conclusion of the trade-off on STR implementation. At the time of PDR, a baseline using a beam across the SVM cone to support the STR was used. A backup was to mount the STR on a platform directly attached to the CVV. Decision to implement interface points on the CVV was taken at that time. Eventually, the backup became the baseline when it appeared that the beam baseline was not meeting the pointing requirements and that by careful thermal design the thermal impact on the H-PLM of the STR implementation on the CVV could remain small (14 days lifetime).

On Planck the main design evolution was the re-accommodation of the instrument warm units to have a better balancing: the REU which was initially on the +Z panel has been moved to the +Y panel. This has the consequence to put on the same panel the 4K cooler which generates high levels of low frequency AC magnetic field and the REU which is sensitive to magnetic field. To solve this potential incompatibility, a magnetic shield is foreseen on the 4K cooler, which will be installed if tests confirm the incompatibility.

Other evolution on Planck is linked to the finalisation of the sub-platform design. Several iterations were conducted to converge on a design meeting the requirements with a reasonable mass impact.

Main updates of the thermal design were linked to the launcher attitude control. During Phase C, we were informed by Arianespace that, contrarily to what was defined previously, the launcher was not able to keep the Sun close to Herschel +Z axis and that transients could be expected at EAP and EPC separation. This was impacting H-PLM external MLI design due to illumination by the Sun of MLI's which were not designed for this environment. In addition, Sun reflection on the Herschel telescope created moving hot spots on the Sunshade. This required an update of the external MLI design to make it robust to high temperatures.

Concerning electrical architecture, few changes occurred since the PDR. The following ones can be highlighted:

- removal of 2 switches in the RFDN: these switches allowed a combination of antenna/transponders which was not needed for operations
- introduction of the FOG (Fiber Optic Gyro) on Planck: this equipment is connected to the ACMS 1553 bus but is not used in the Planck ACMS loop. It is implemented on Planck for experimental purposes.
- study of a SOHO-like failure case has allowed to confirm that the electrical architecture was robust to such extreme failure cases. Minor modifications have been introduced in the software to cope with such failure cases.

Other evolutions are related to operations and autonomy:

- the satellite modes were streamlined
- the timeline definition has been refined and the use of subschedules has been clarified
- FDIR concept has been consolidated. In particular, the FDIR implementation has been clarified with instruments.

6.2 Mechanical and thermal design

6.2.1 Herschel overall configuration and updates

6.2.1.1 Overall configuration description

The overall configuration of Herschel spacecraft is displayed in Figure 6.2.1-1.

The current Herschel configuration presents some evolutions with Herschel configuration at PDR, but keeps the same general configuration as explained hereafter. These evolutions reflect the phase C/D development and module evolutions (i.e. SVM and PLM), regarding their general configuration, equipment layout and S/S design.

Herschel satellite remains of a modular concept, with two main modules:

- the **H-PLM** (Herschel Pay-Load Module) which includes:
  - a large Cryostat Vacuum Vessel (CVV) in which are suspended the He I and He II Tanks, Optical bench with focal plane units. The CVV carries external instrument LOU Assy and LOU radiator (part of HIFI).
  - a 3.5 m Telescope in Silicium Carbide (SiC) supported on the top of the cryostat by a dedicated isostatic mounting structure
  - a sunshield and sunshade (HSS) forming a large screen surrounding the H-PLM on sun side, ensuring a shadowing function of the cryostat and telescope and protecting them from direct sun illumination. It ensures also a function of solar generator with a Solar Array implemented on sunshield.
- The **SVM** (Service Module) is formed by an octagonal box built around a conical tube (cone):
  - the SVM houses the equipment of the Avionics and Servicing S/S's, the payload "warm" units (WU) for HIFI, PACS and SPIRE Instruments.

    Herschel SVM is designed to provide suitable mechanical and thermal environments during launch and in-orbit phases to the various equipment and instruments installed in it.
  - the SVM supports the H-PLM Cryostat support truss on the top of the cone. It supports other H-PLM items as the SVM Shield for radiative de-coupling between SVM and cryostat, and HSS support truss (both on the top of the cone and upper closure panels).
  - the SVM ensures the mechanical link with the Launcher through the Interface ring, and therefore ensures the main load path during launch.

As a recall Herschel and Planck SVM present some communality at SVM level, as explained in details in the SVM Design Report.

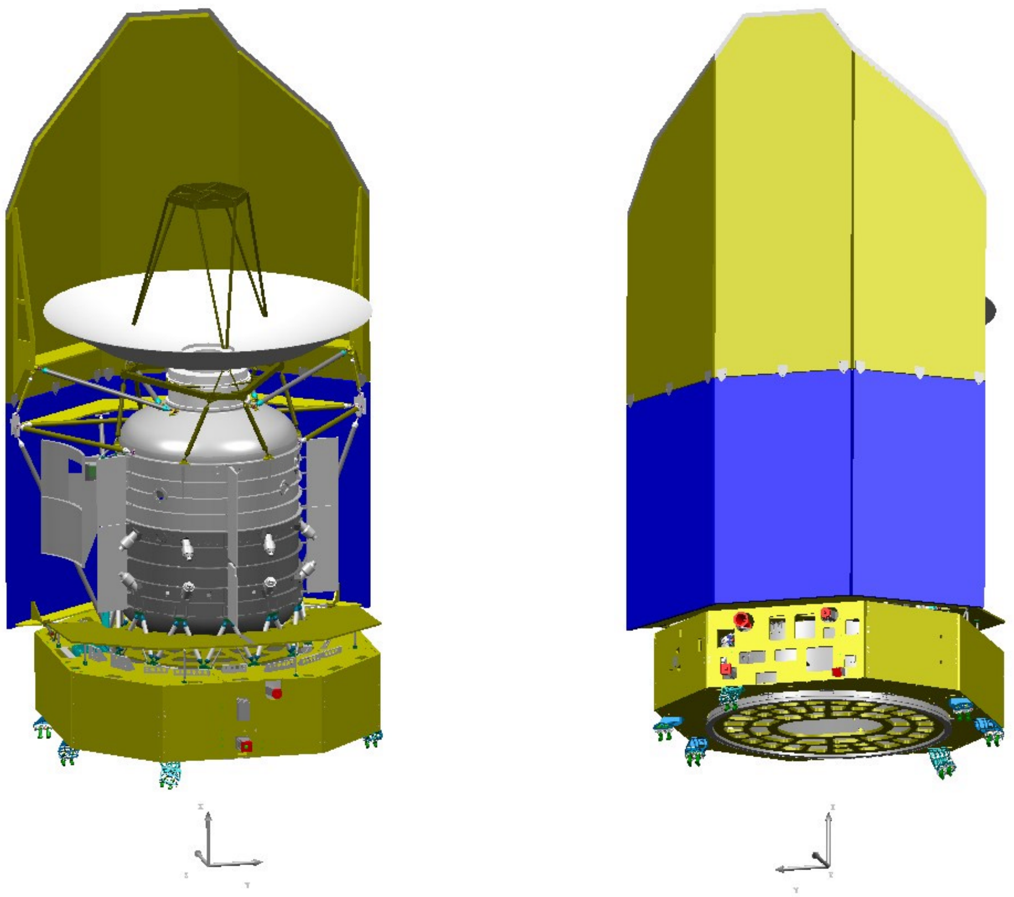


Figure 6.2.1-1 Herschel spacecraft overall configuration

6.2.1.2 Main design evolution since PDR

Main updates relatively to PDR configuration refer to changes in System, H-PLM and the SVM configuration. It is also incorporating refinement and improvement of modules and S/S's design implemented in course of Phase C/D.

Update of Satellite configuration

Herschel satellite overall configuration remains very close from the PDR configuration, as explained hereafter.

The general evolutions in Herschel configuration are to be presented here before describing them with more details in SVM and H-PLM sections:

- refinement of H-PLM and SVM mechanical interfaces related to PLM main supporting (CVV struts), HSS supporting, SVM shield and LOU WG supporting
- finalisation of Cryogenic harness routing at the interface between PLM and SVM, with definition of new Cryogenic harness brackets for mechanical dismountability

- review of Star Trackers accommodation, as post-PDR analysis evidenced that STR's configuration with STR on –Z panel did not reach expected performances in term of thermo-elastic stability.
- An intermediate solution with the STR supported on a beam set across the cone was withdrawn due to not sufficient performances.
  - New investigations allowed finding a suitable concept with STR's suspended to CVV.
- **Update of H-PLM configuration**

The H-PLM overall configuration presents the following changes or evolutions wit regard to PDR design:

- increase of height of 100 mm for lifetime extension, by extending the CVV intermediate ring, the HTT and the thermal shields. This lead to elongate also the Sunshade to keep the same shadowing capability toward Telescope and CVV
- optimisation of Sunshield/Sunshade configuration and supporting, in order to cope with large in-orbit thermo elastic with CVV
- change of LOU radiator shape: LOU radiator is kept thermally coupled with LOU by radiative link and by conductive link via the LOU baseplate to which both are attached. LOU radiator is enlarged, and adopts a curved shape to favour radiative exchange with cold space
- the LOU interface with the LOU support have been clarified. An interface plate is present in both sides of the interface. The function of the instrument plate is to endure the unit integrity before mating. The function of the support plate is to provide mechanical stiffness, to serve as interface for the LOU radiator, and to provide a plane on plane mounting for the LOU
- consolidation of Cryogenic harness design and routing, Cryogenic harness brackets design, and Interfaces with SVM
- detailed design of the PLM supporting struts (CVV struts) with the goal of lifetime optimisation
- maintain of Instruments up-to-date on OB and CVV, with modification from Instruments teams.

These modifications leads to a new H-PLM configuration described with more details in § 6.2.3.

Update of SVM configuration

The SVM configuration presents the following changes or evolutions with regard to PDR design:

- Update of CFE layout:
  - SREM moved to outside of SPIRE panel (-Z), at the former place of Star Trackers
  - Relocation of VMC location and review supporting concept: VMC moved on +Z lateral panel for reducing mechanical environment (random loads) on the unit.
- Update of Instruments layout:
  - in course of Phase C/D, numerous modifications from Instruments were still issued after edition of IID-B Issue 2.2 (SPIRE/HIFI) or 2.1 (PACS). These modifications needed each time to be evaluated from all engineering point of view (mechanical, thermal, electrical), and submitted to SVM contractor for implementation when judged necessary to maintain the performance of the system.
  - From a mechanical point of view, main changes concerned interface points, impacting structure interface definition.
  - From a thermal point of view, these new changes affected mainly thermal interfaces (contact area), giving new assumptions or requirements for dimensioning the SVM thermal control (TCS), leading to important changes for this sub-system but without requiring drastic accommodation changes. Refer to Section 6.2.4 for more details.

- From harness point of view, many changes regarding connectors layout on Instruments conducted to several design loop before completing the SVM harness, WIH and Cryoharness design. Refer to Section 6.3.6 for more details.

– Update of equipment layout:

- consolidation of SVM harness design and routing, and Interfaces with SVM
- consolidation of Instrument harness design and routing, and Interfaces with SVM
- consolidation of Antenna layout
- consolidation of RCT's layout, including thrusters re-accommodation and final definition of RCS pipe work and interfaces with SVM
- move of STR from outer –Z SPIRE panel, first to a beam connected to SVM cone and finally to a support structure suspended to CVV. STR's are mounted underneath a platform attached to CVV via a truss assy. This change of configuration aimed improving thermo-elastic behaviour of STR supporting, and therefore to recover acceptable STR in-orbit de-pointing budget.

The result of these modifications leads to a new SVM configuration described with more details in § 6.2.3.

6.2.2 Planck overall configuration and updates

6.2.2.1 Overall configuration description

The overall configuration of Planck spacecraft is displayed in Figure 6.2.2-1.

The current Planck configuration presents some evolutions with configuration at PDR, but remains globally the same as explained hereafter. These evolutions reflect the phase C/D development and module evolutions (i.e. SVM and PLM), regarding their general configuration, equipment layout and S/S design.

Planck S/C keeps also of a modular concept, and is basically composed of two modules:

– the **PLM** (Pay-load Module) which houses the "cold" part of the satellite and the focal plane unit.

Its main constituents are:

- the Cryo structure supporting the telescope
- the Focal Plane Unit with associated electronics and cooling systems accommodated on the PPLM, and on the SVM structure via the Payload sub-platform and lateral panels
- the main baffle enclosing the telescope and the FPU, for stray-light protection.

– The **SVM** (Service Module) is formed by an octagonal box built around a conical tube, which:

- houses the equipment of the Avionics and Servicing S/S's, the payload "warm" boxes for HFI and LFI/SCS Instruments; Planck SVM is designed to provide the various equipment and instruments housed in it with suitable mechanical and thermal environments during launch and in orbit phases
- supports with the P-PLM Cryo. structure truss.
- ensures the mechanical link with the Launcher adapter, and therefore ensures the main load path during launch.

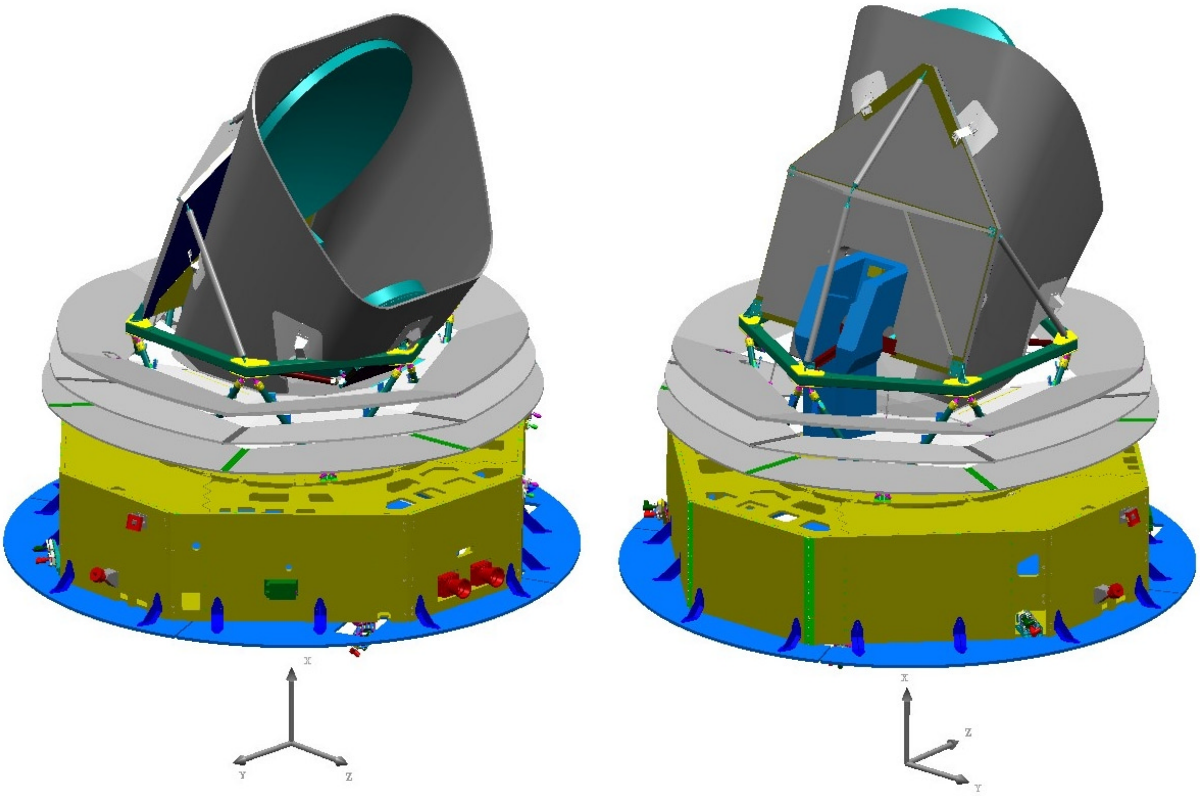


Figure 6.2.2-1 Planck spacecraft overall configuration

6.2.2.2 Main design evolution since PDR

This chapter describes briefly the main updates relatively to PDR configuration refer to changes in System, P-PLM and SVM configuration. It reflects also refinement and improvement of modules and S/S's design that have been implemented in course of Phase C/D. These changes and evolutions are developed with more details under § 6.2.5.

Update of System configuration

Planck satellite overall configuration remains very close from the PDR configuration.

At System level main intervention rests in

- the refinement of P-PLM and SVM mechanical interfaces with PLM supporting (cryo. structure), management of P-PLM slip-down allowed by IF optimisation
- support for definition of pipes and harness Interfaces on P-PLM and SVM.

Update of P-PLM configuration

The P-PLM overall configuration presents the following changes or evolutions wrt PDR design:

- maintain of Instruments up-to-date on FPU, with modification from Instruments team
- definition of pipes routing, interfaces and allocated volume to specific elements
- optimisation of instrument boxes on sub-platform to cope with thermal dissipation
- optimisation of Telescope structural architecture.

The result of these modifications leads to a new P-PLM configuration described with more details in § 6.2.5.

Update of SVM configuration

The SVM configuration presents the following changes or evolutions wrt PDR design:

- update of Instruments layout in SVM.

  As on Herschel, updates of the instrument interfaces following edition of IID-B Issue 2, necessitated updates and refinement of instrument layout.
- Consolidation of WIH and SVM harness design and routing, and Interfaces with SVM.
- Consolidation of Antenna layout.
- Consolidation of RCT's layout.
- Re-accommodation of REU unit on +Y panel to allow for a better SVM mass balancing. This modification induced a complete review of +Y panel layout and +Z panel layouts.

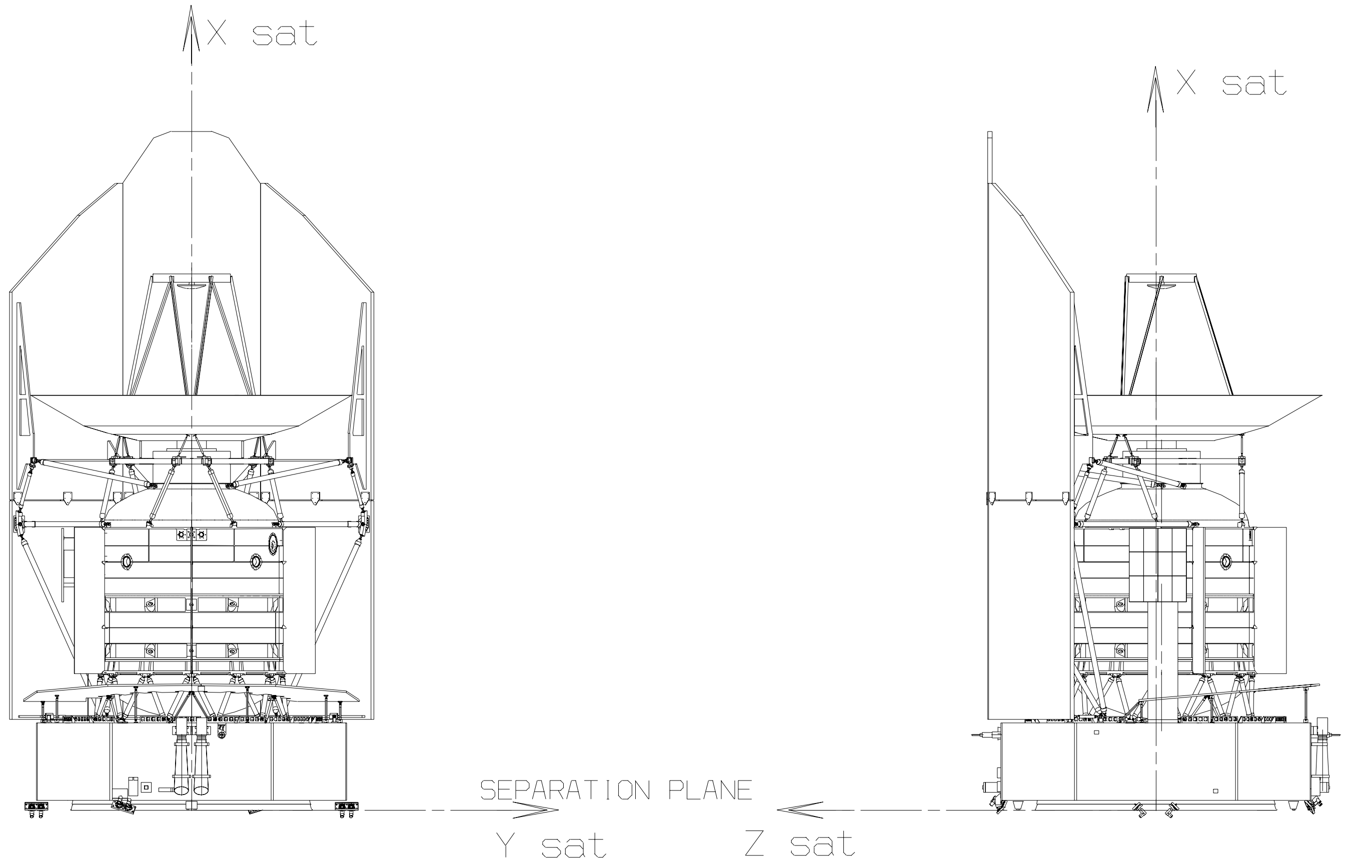
The result of these modifications leads to a new SVM configuration described with more details in § 6.2.5.

6.2.3 Herschel mechanical design

6.2.3.1 Axis convention

As a recall, Herschel satellite reference frame (O, X_X, Y_X, Z_x) is a right-handed Cartesian system with:

- its origin O located at the point of intersection of the longitudinal launcher and the satellite /launcher separation plane.; the origin coincides with the centre of the satellite/launcher separation plane
- Xs axis coincides with the nominal optical axis of Herschel telescope. Positive Xs axis is oriented towards the target source. The Xs axis coincides with the launcher longitudinal axis
- Zs is in the plane normal to XS-axis, such that nominally the Sun will lie in the (XS, ZS) plane (zero Roll angle with respect to Sun). Positive ZS-axis is oriented towards the Sun
- Ys completes the right handed orthogonal reference frame.



6.2.3.2 S/C configuration and updates

Herschel baseline configuration and updates, are presented hereafter with some details. Herschel overall configuration is kept very similar to PDR original configuration.

General update of S/C configuration

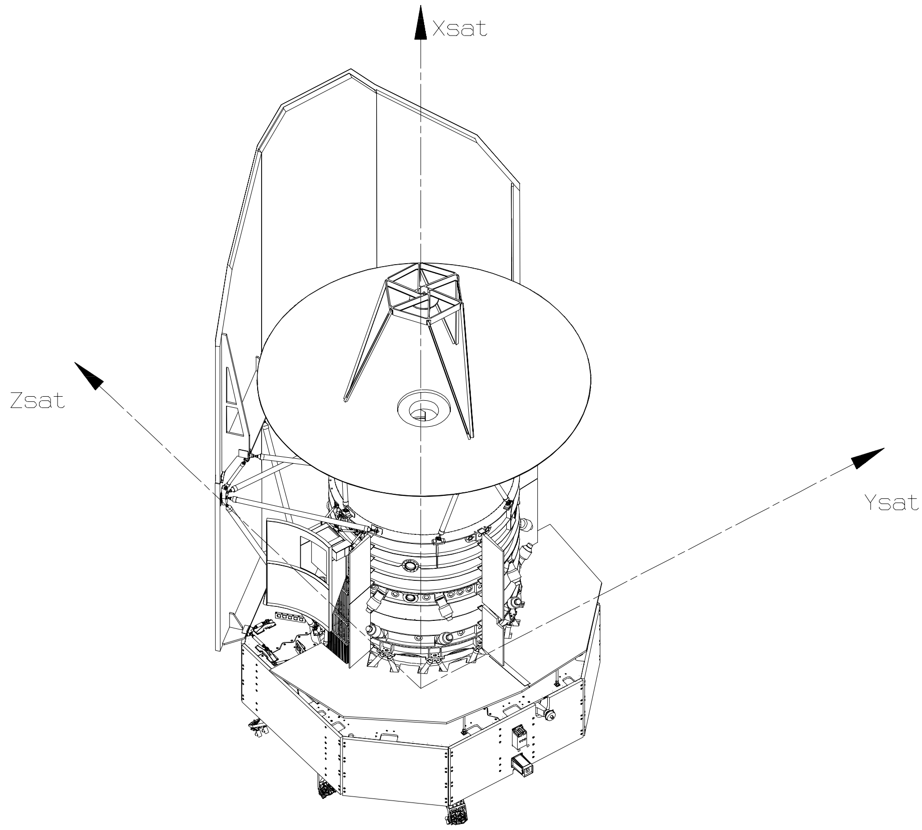
Herschel overall configuration is kept similar to PDR original configuration:

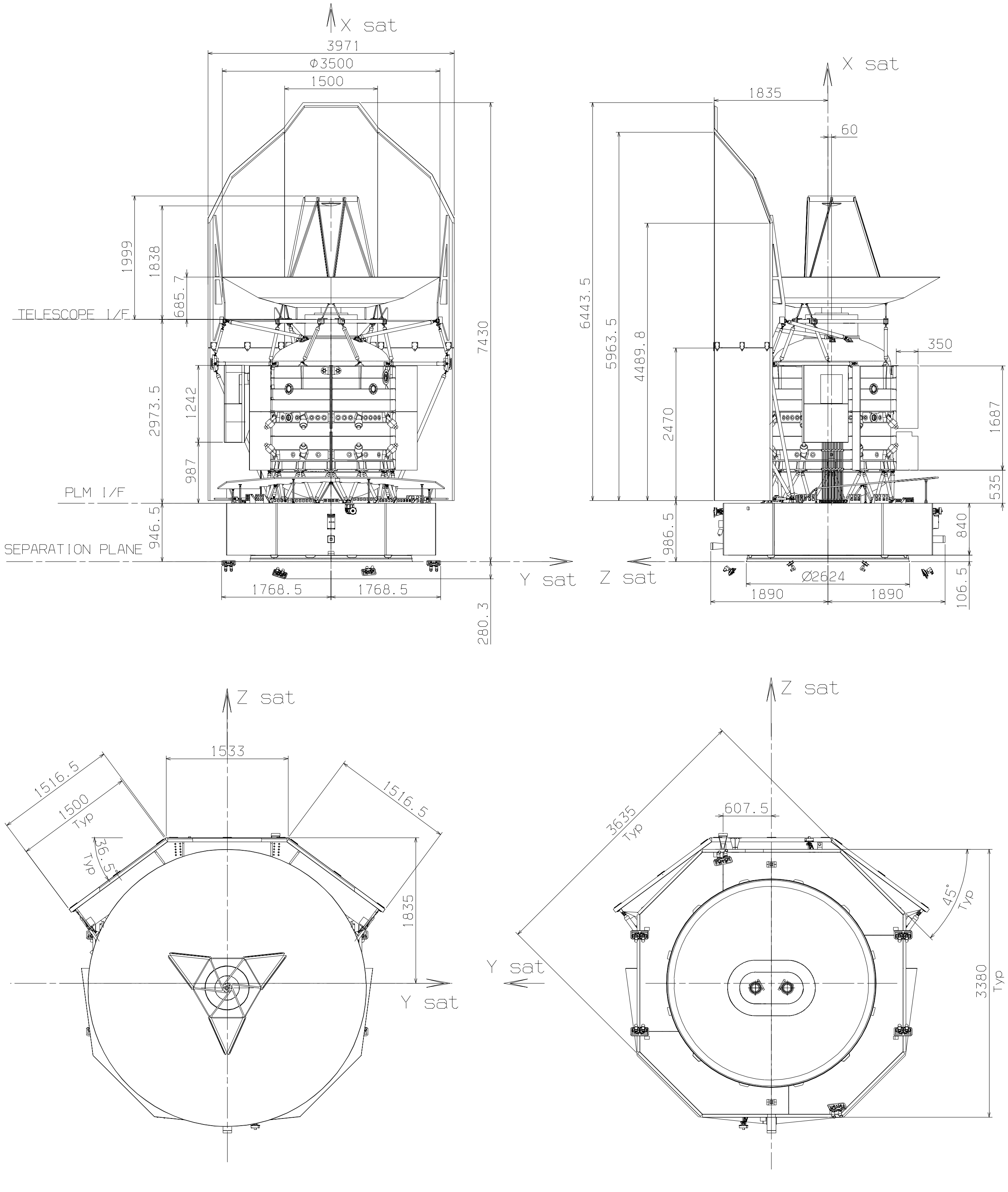
- CVV supporting with a 24 GFRP struts configuration for CVV supporting
- CVV de-centred by 60 mm in -Z direction to maintain H-PLM CoG in a convenient range wrt satellite balancing
- SSH/SSD (HSS) configuration with stiffened panels, and supporting struts to CVV. HSS was moved by 15 mm only, to improve margin with Telescope and prevent dynamic interference
- accommodation of the SiC Telescope on top of CVV, with a secondary mirror hexapod supporting.

The most visible changes with PDR stays in:

- integration of a new LOU radiator concept, LOU wave Guides (WG) and supporting
- refinement of Cryogenic harness routing on CVV, with Cryo. brackets on SVM to make the separation with SVM harness.

Herschel satellite has been increased by 100 mm in height since previous PDR configuration.





X sat
3971
Φ3500
1500
1999
1838
685.7
TELESCOPE I/F
7430
2973.5
1242
987
PLM I/F
946.5
SEPARATION PLANE
1768.5
1768.5
Y sat
280.3
X sat
1835
60
6443.5
5963.5
4489.8
2470
350
1687
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1835
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3635
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Typ

Status of main H-PLM to SVM interfaces definition

All Modules interfaces are considered frozen at the time of System CDR. This results from common technical discussions between all involved parties (ASP, ALS and ASED) to consolidate and complete previously defined Interfaces at PDR time.

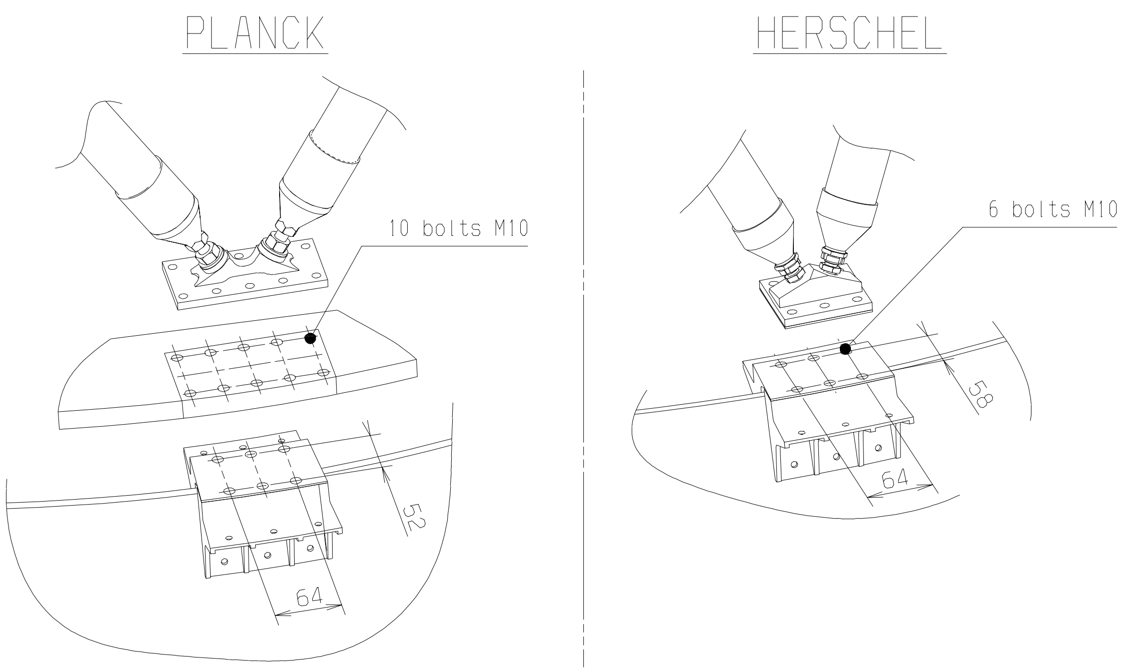
As a recall, the main H-PLM and SVM mechanical Interfaces covers:

- the PLM CVV supporting IF on central cone
- the SSH/SSD IF on central cone and upper closure panel
- the SVM shield IF on central cone and upper closure panel
- LOU WG IF on upper closure panel
- Cryo. harness and brackets IF on cone and upper closure panel
- Star Trackers (STR) assembly IF beneath CVV dome.

The main evolutions and freeze of the PLM IF definition can be summarised as follow.

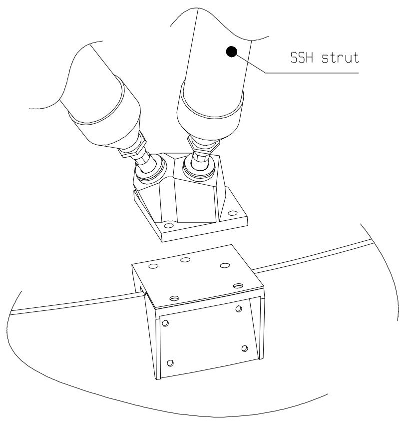
CVV struts IF on central cone: see drawings in RD 05.3 and 05.4

- IF basically frozen by February 2002, keeping a common IF concept with Planck P-PLM with similar IF brackets on central cone. Minor evolution as clarification on holes positional tolerances, helicoils class finally implemented in following updates. See figure below

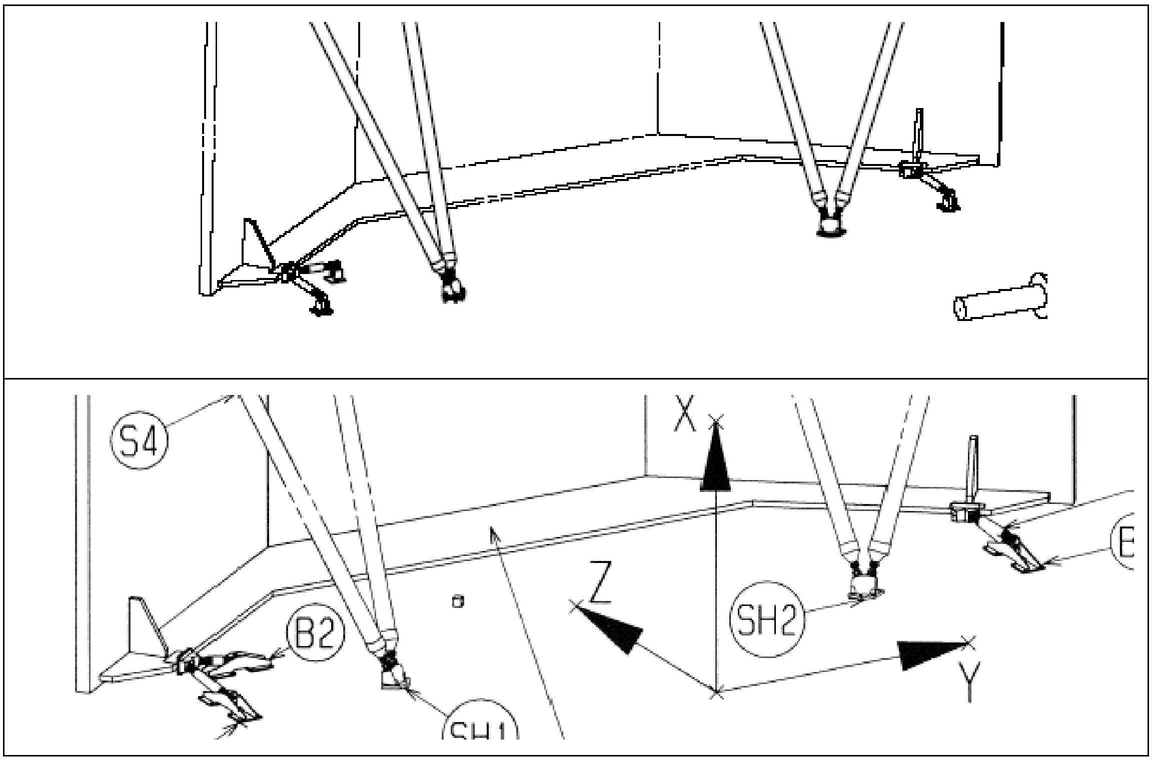


SSH/SSD IF on central cone: see drawings in RD 05.3

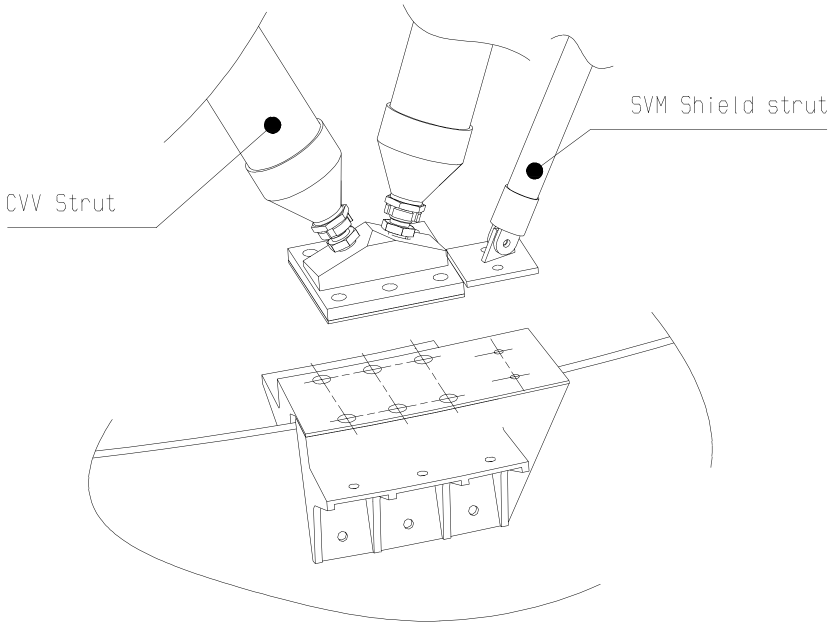
- SSH IF on central cone for 2 vertical struts have been basically frozen by December 2001. Minor evolution as clarification on holes positional tolerances, helicoils class finally implemented in following updates. See Figure below.



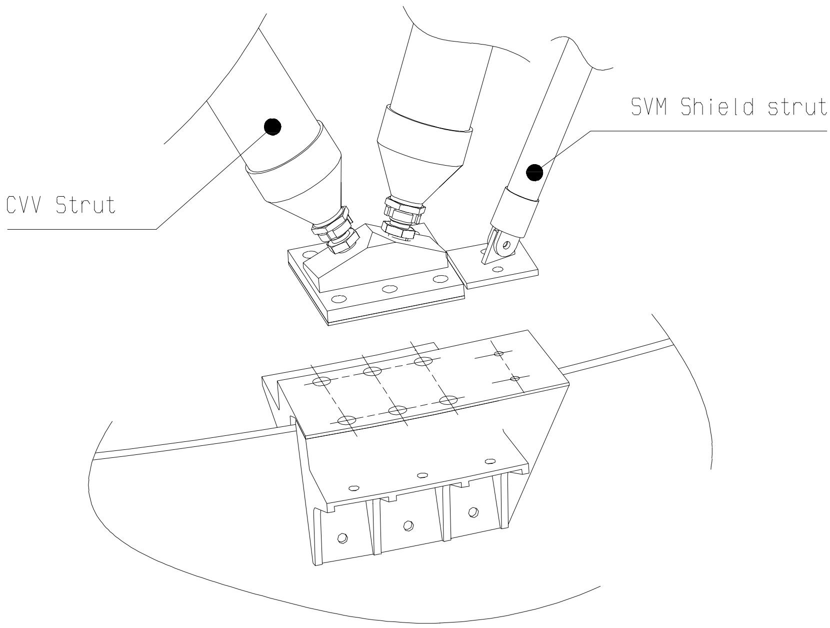
- ***SSH/SSD IF on upper closure panel: see drawings in RD 05.3***
- SSH IF on upper closure panel had to be reviewed after PDR to cope with higher loads calculated by ASED coming from HSS. IF on upper closure panel provides IF double feet brackets to make IF loads compatible with single inserts capabilities in upper closure panel.
- SSH IF on upper closure panel have been basically frozen on this basis by March 2003. Minor evolution as clarification on helicoils class finally implemented in following updates. See Figure below.



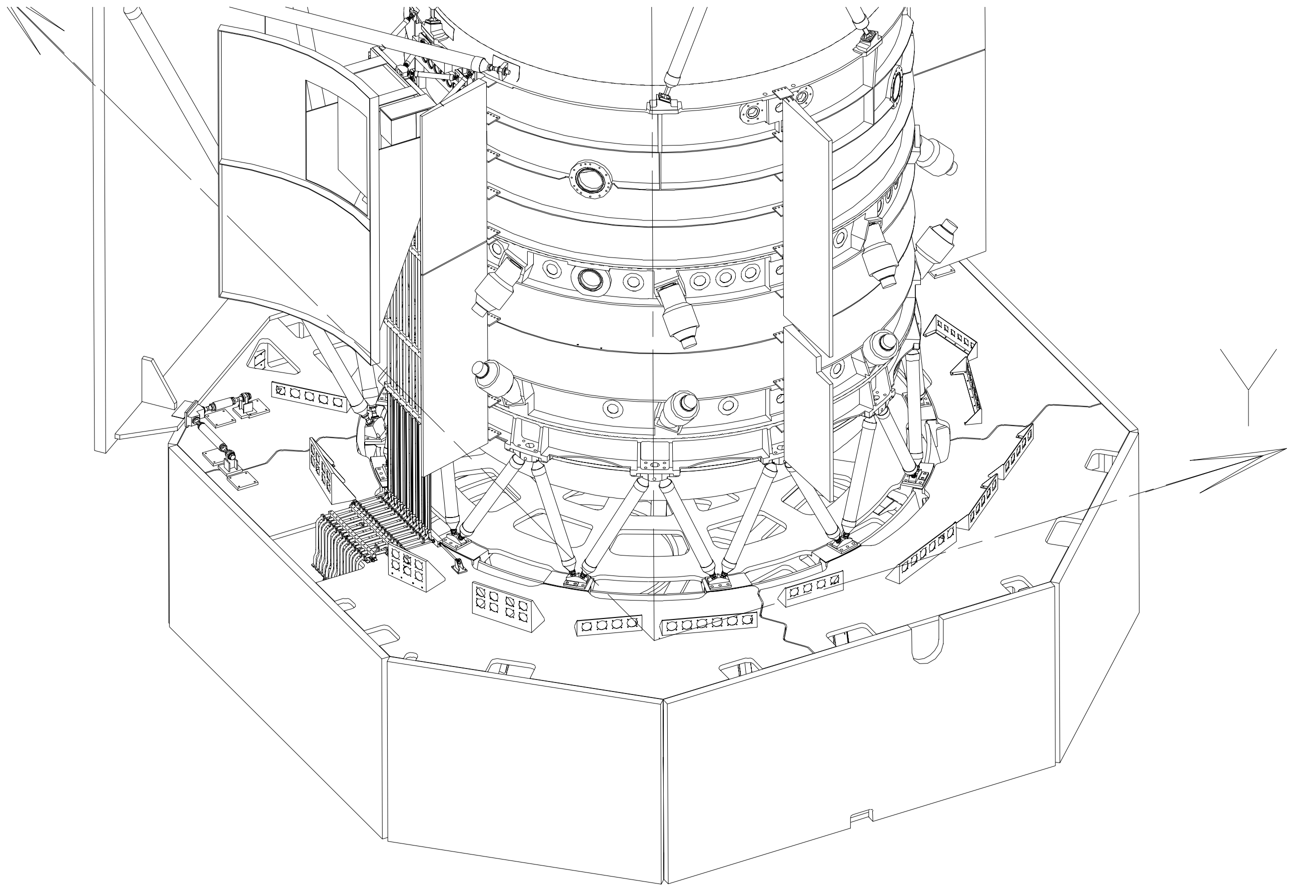
- ***SVM shield IF on central cone and platform: see drawings in RD 05.3***
- SVM shield on cone and upper closure panel have been basically frozen by February 2002. See Figure below. Minor evolution as clarification on helicoils class finally implemented in following updates.



- SVM shield IF on central cone for vertical struts are conjugated with PLM IF to make use of a single common bracket in 6 IF area with central cone. See Figure below.
- SVM shield IF on upper platform for supporting bi-pods and mono-pods are defined near to platform edges to get stiff rests.



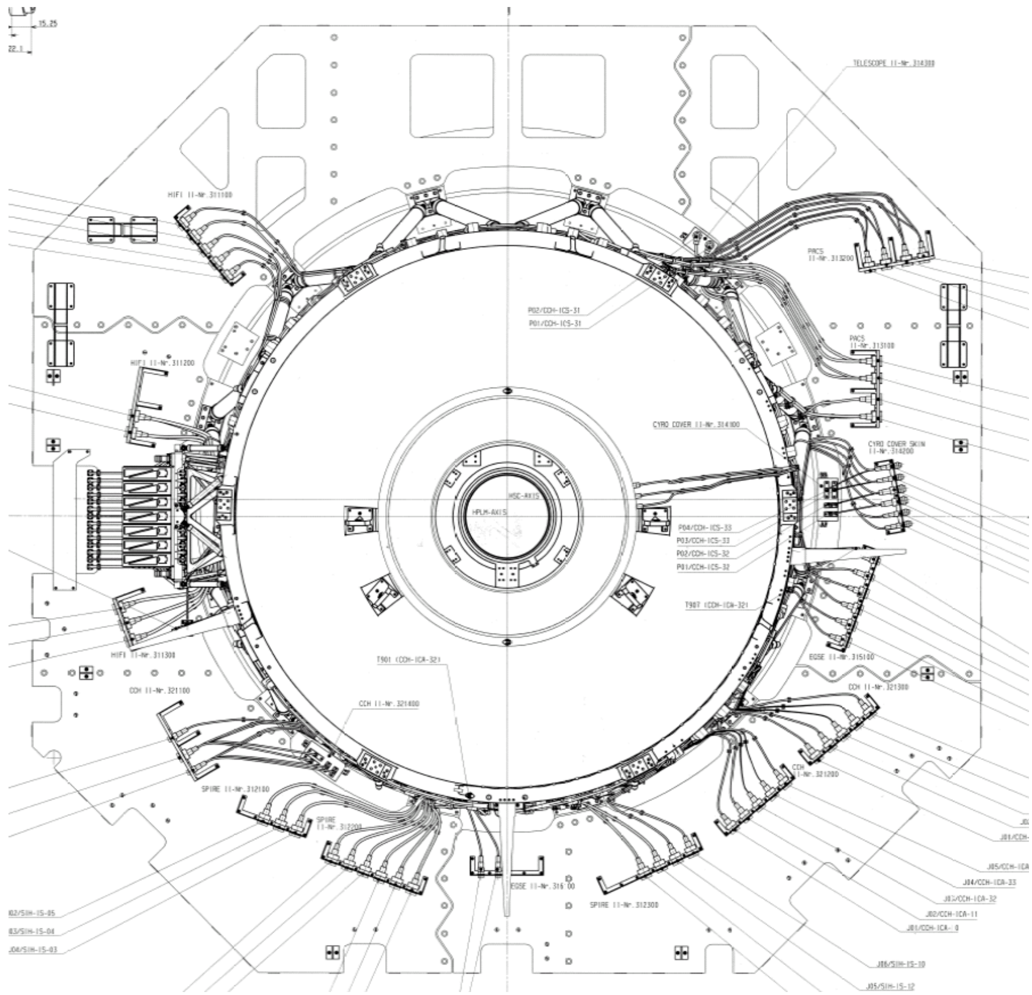
- ***LOU WG IF on upper platform: see drawings in RD 05.3***
- WG supporting IF on upper closure panel had to be reviewed after PDR on request of ASED to allow a better isostatic mount on SVM. This modification consisted in removing a fixation bracket on upper closure panel for relaxing high stress in LOU WG due to relative dynamic motion between SVM and CVV with sine excitation. It consisted also in adding a bracket on SVM panel to prevent high loads at LOU WG to FHLSU IF. Also, a flexible mounting was implemented in order to provide mechanical de-coupling in satellite axis direction.
- WG supporting on upper closure panel have been basically frozen on this basis by January 2004. Minor evolution as clarification on holes positional tolerances , helicoils class finally implemented in following updates. See Figure below.

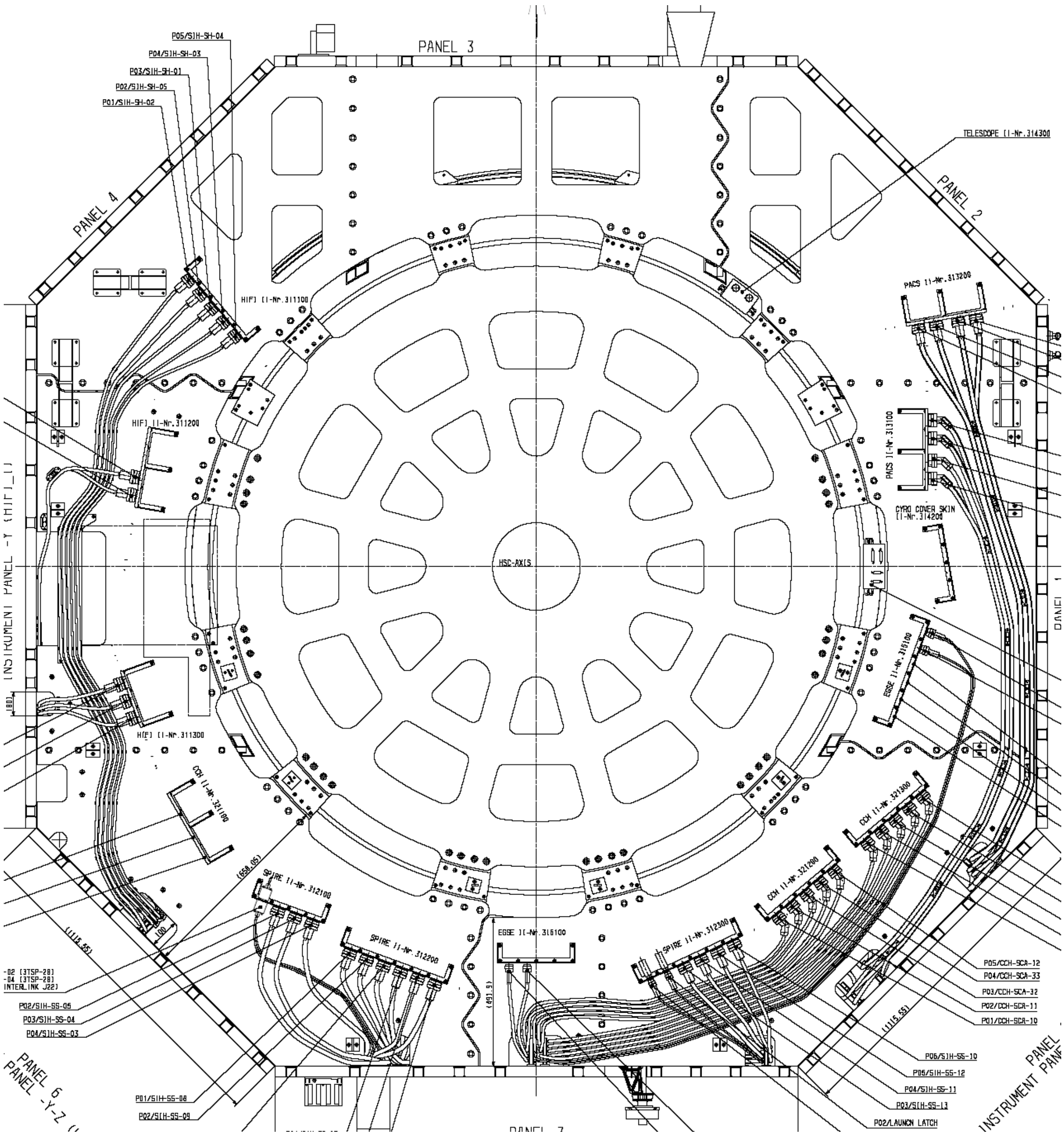


- Cut-out in upper platform allows connection with FHLSU and tiltability of SVM panel (+Y panel with HIFI WU).

Cryo. harness and brackets IF on upper platform: see drawings in RD 05.3

- Cryo-brackets IF on Herschel have been progressively finalised according to maturity and development of Cryo-harness by ASED. The configuration of the main Cryo-bracket on upper closure panel has been frozen by September 2003, according to layout proposed by ASED. Then, additional steps and iteration were needed to complete Cryo-bracket configuration with incorporation of Cryo-cover, Telescope heaters, and umbilical brackets on central cone. The Cryo-brackets IF definition was completed and considered frozen by January 2004, with a minor update by May 2004 for umbilical bracket.
- Cryo. harness routing on SVM bounded from PLM struts to cryo. harness brackets, and then continued up to WU in SVM harness.
- Numerous cryo. brackets arranged on upper closure all around the CVV basis to feed all WU in SVM and providing also EGSE connection.
- Cut-out implemented in the edge of upper closure panels to allow connection with the WU on SVM panels and compatibility with integration procedure.
- Cryo. harness is including Instrument harness, but also Cryo-cover command harness, Telescope heaters for thermal monitoring, umbilical harness for CVV monitoring needs during launch phase (connection extended to Satellite umbilical connectors).

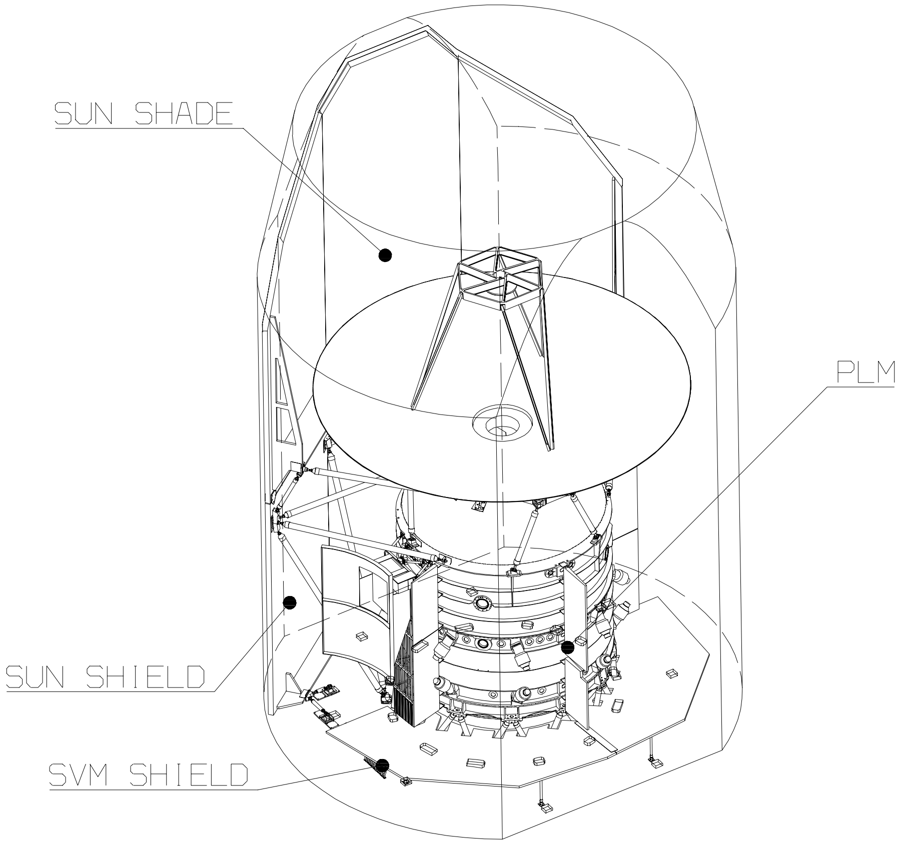




PANEL 3
PANEL 4
PANEL 2
PANEL 6
PANEL -Y-Z
PANEL
INSTRUMENT PANEL -Y
P05/SIH-SH-04
P04/SIH-SH-03
P03/SIH-SH-01
P02/SIH-SH-05
P01/SIH-SH-02
HIFI (I-Nr.311100
HIFI (I-Nr.311200
HIFI (I-Nr.311300
TELESCOPE (I-Nr.314300
PACS (I-Nr.313200
PACS (I-Nr.313100
CRYO COVER SKIN (I-Nr.314200
HSC-AXIS
EGSE (I-Nr.315100
CCH (I-Nr.321300
CCH (I-Nr.321200
CCH (I-Nr.321100
SPIRE (I-Nr.312100
SPIRE (I-Nr.312200
SPIRE (I-Nr.312300
(658.05)
(1115.55)
100
-02 [3TSP-28]
-04 [3TSP-28]
INTERLINK J22)
P02/SIH-SS-05
P03/SIH-SS-04
P04/SIH-SS-03
P01/SIH-SS-08
P02/SIH-SS-09
P05/CCH-SCA-12
P04/CCH-SCA-33
P03/CCH-SCA-32
P02/CCH-SCA-11
P01/CCH-SCA-10
P06/SIH-SS-10
P05/SIH-SS-12
P04/SIH-SS-11
P03/SIH-SS-13
P02/LAUNCH LATCH
INSTRUMENT PANE

Allocated volumes for SVM and H-PLM: see drawings in RD 05.3

The SVM allocated volume remains the same as defined for PDR.

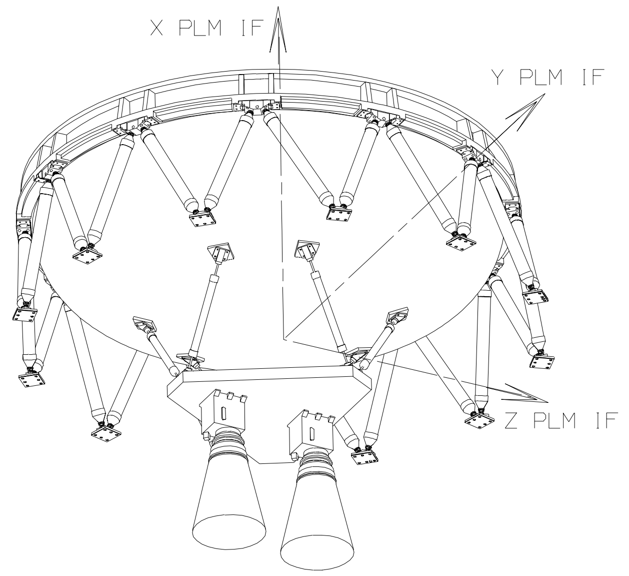


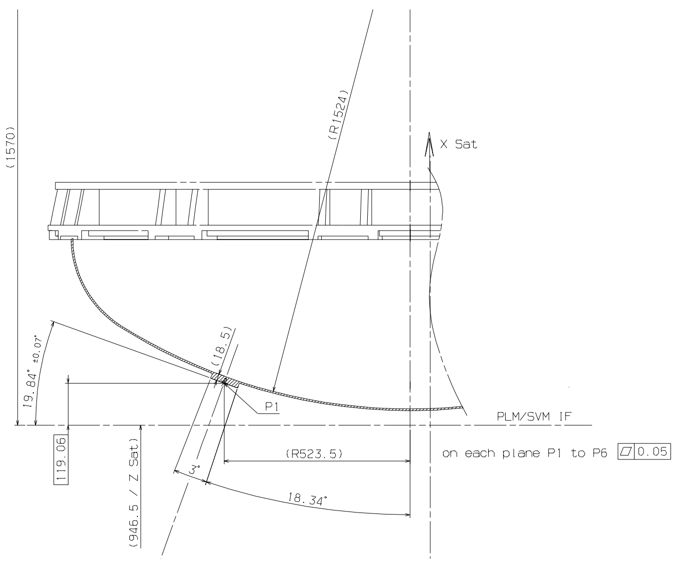
The definition of the H-PLM allocated volume allows the PLM to exploit the full space provided at the top of the Fairing without restriction. A small modification was however implemented in February 2004 to introduce a window in H-PLM volume for targeting alignment cubes on SVM upper closure panel.

STR IF on CVV dome: see drawings in RD05.3

The STR IF on CVV dome is a new interface between SM and H-PLM, generated by the move of the STR assembly from SVM to H-PLM for a better thermo-elastic stability.

The STR IF on CVV has been negotiated with ALS and ASED, and was started by end 2002 and basically frozen in September 2003, with a minor evolution for clarification of helicoils class finally implemented in last update.





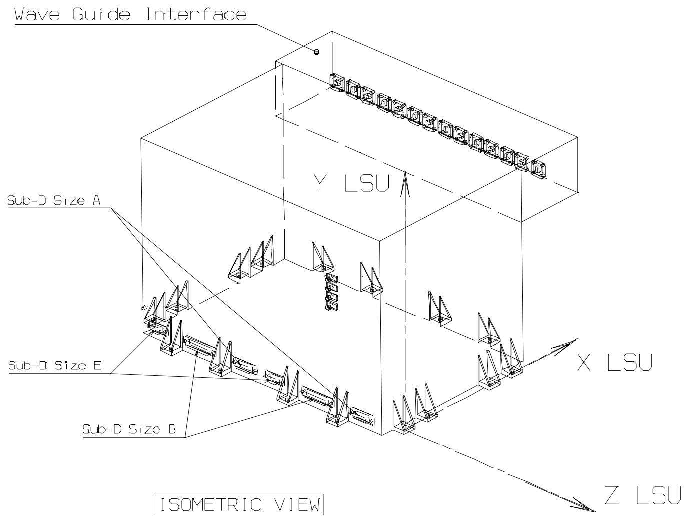
- The STR assembly is resting on 6 bosses built-in the CVV dome shell.
- Each mounting plane (boss) provides 4 fixation holes M6, and one centring pin for accurate and reproductive positioning of STR assembly.

Status of Instruments to SVM and H-PLM interfaces definition

The Instruments ICD were progressively produced and made applicable to Herschel modules. However, it was necessary for some of them to produce interface drawings at the place of Instruments to provide modules with a minimum of interface data for equipment implementation.

These interface drawings are now being superseded by Instruments ICD which have been issued.

As an example, the HFI FHLSU interface drawing was finalised in July 2003, and provided equipment main dimensions, mounting interfaces, and interfaces with LOU wave guides.



Other Interfaces specification

In addition to the PLM/SVM and Instruments Interfaces, a certain number of Interfaces has been defined in RD05.3:

- satellite level:

  ALIGNMENT CUBE ACCESS

- Launcher IF:

  INSIDE ARIANE5 LONG FAIRING UPPER SYLDA5

  SSH STATIC ENVELOPPE

  VOLUME FOR FAIRING FILLING RATIO

  I/F RING DEFINITION

- Other SVM IF:

  SVM ALLOCATED VOLUME

  THRUSTERS ACCOMMODATION

  ANTENNA CONFIGURATION

  PACS DECMEC INTERFACES

  HIFI FHLSU INTERFACES

  BALANCING MASSES

- Other PLM IF:

  INTERFACES AND ALLOCATED VOLUME FOR SA SKIN CONNECTORS

Mechanical requirements

All main mechanical requirements were already frozen at the time of the system PDR. No change has been implemented since this time. A short summary of main of main mechanical requirements is provided hereafter.

- ***Stiffness requirements***
- All stiffness or frequency requirements were frozen at system PDR.
- Stiffness requirements are declined in frequency requirements and rigidity requirements. Frequency requirements qualify the global stiffness behaviour of these modules, in consistency with stiffness requirements to be achieved at System level. On the other hands, rigidity requirements are defined at SVM level only, in complement to frequency requirements, to qualify local stiffness needs at specific interfaces.

Frequency requirements for SVM and H-PLM are defined as follows:

- SVM frequency requirement.

  SVM design shall ensure that eigen frequencies of Herschel main global modes fulfil the following mathematical expressions:

  - longitudinal main mode > 65 Hz
  - lateral main mode > 23 Hz.

  Considering a H-PLM of 2400 Kg at an absolute location X = 2.57 m.

- H-PLM frequency requirement.

  The eigen frequencies of H-PLM main global modes shall fulfil the following mathematical expressions:

  - longitudinal main mode > 34 Hz, with 35 Hz minimum as a target
  - lateral frequency > 13Hz

  considering H-EPLM mounted on the SVM FEM (reference H-model dated 7/02/02).

H-PLM/SVM Interface loads

Interface loads at SVM to H-PLM interface (CVV struts roots) are to be simply calculated by application of QSL loads at CVV CoG. H-PLM QSL were already frozen at the time of the system PDR, and are recalled hereafter:

Load Cases	X Axis	Y/Z Axis
1	12.5g	1.56g
2	2g	4g

Table 6.2.3-1 H-PLM to SVM interface loads (design loads)

H-PLM Internal loads

A review of H-PLM internal loads was judged necessary in February 2003 after system PDR, to adjust QSL to:

- higher sine response in lateral direction, generally observed on all H-PLM internal items
- lower response in axial direction for Herschel Telescope.

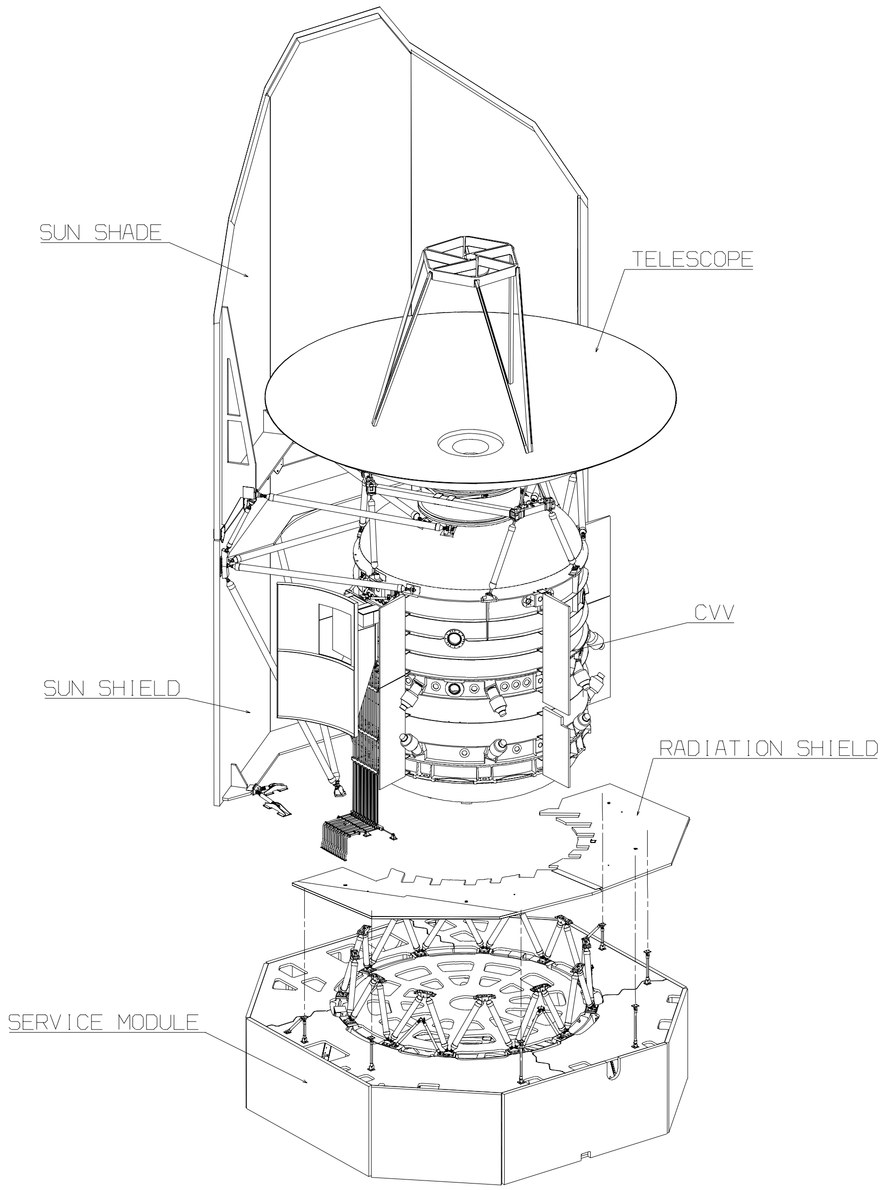
H-PLM Items	**PDR load cases definition**	**Post-PDR load cases definition**
Suspended Mass and He II Tank	15g axial +- 2.5g lateral	15g axial +- 2.5g lateral
	2g axial +- 5g lateral	2g axial +- **7.5g lateral**
Optical bench	16.25g axial +- 2g lateral	16.25g axial +- **4g lateral**
	2g axial +- 7.5g lateral	2g axial +- 7.5g lateral
He I Tank	30g axial +- 2.5g lateral	30g axial +- 2.5g lateral
	2g axial +- 7.5g lateral	2g axial +- 7.5g lateral
Telescope	16g axial +- 3g lateral	**12g axial** +- **4g lateral**
	4g axial +- 10g lateral	**2g axial** +- **11g lateral**

CDR analysis are demonstrating that these QSL loads can be maintained, providing some notching with sine input at S/C basis. Refer to §7.1 for more details.

6.2.3.3 H-PLM configuration and update

General architecture

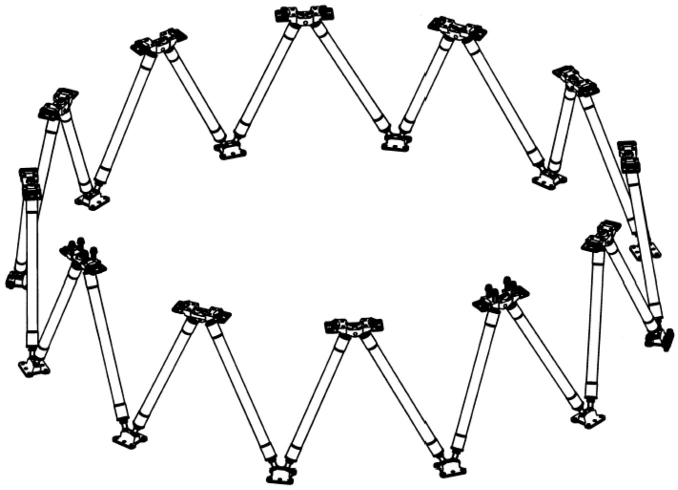
The following figures show the overall view of the H-PLM with the part of the Instruments supported outside the H-PLM.



As explained above, Herschel PLM configuration presents a few evolutions since PDR. These configuration updates, constituting the current baseline are presented hereafter with some details.

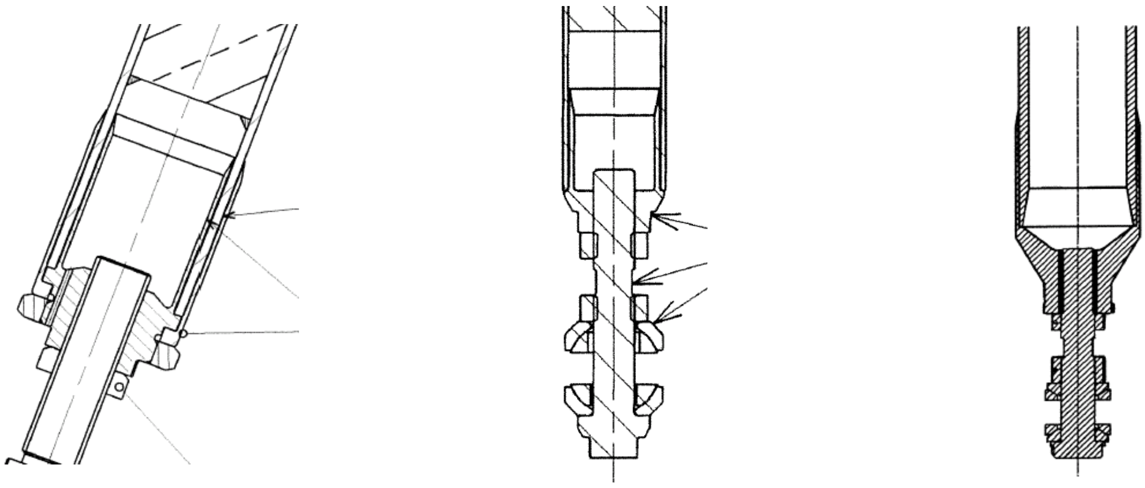
H-PLM Support structures development

The detailed design of the H-PLM support structures was achieved between the PDR and the CDR. The work performed was at the beginning focused on the mechanical/thermal optimisation of the tubes, but the main difficulties were encountered in the design of the struts end-fittings. Several samples of end-fitting configurations were tested: internal, external, double overlap. The double overlap configuration presents the best thermal isolation performance because the tube length can be maximised. Unfortunately, the tests revealed that this configuration as defined by CASA is more sensitive to cold temperatures than internal one.



The selected configuration is then in general:

- external overlap for HSS side at hot T°
- internal overlap for CVV side at cold T°
- double overlap for SVM at ambient T°.



Double, internal and external overlap end fittings

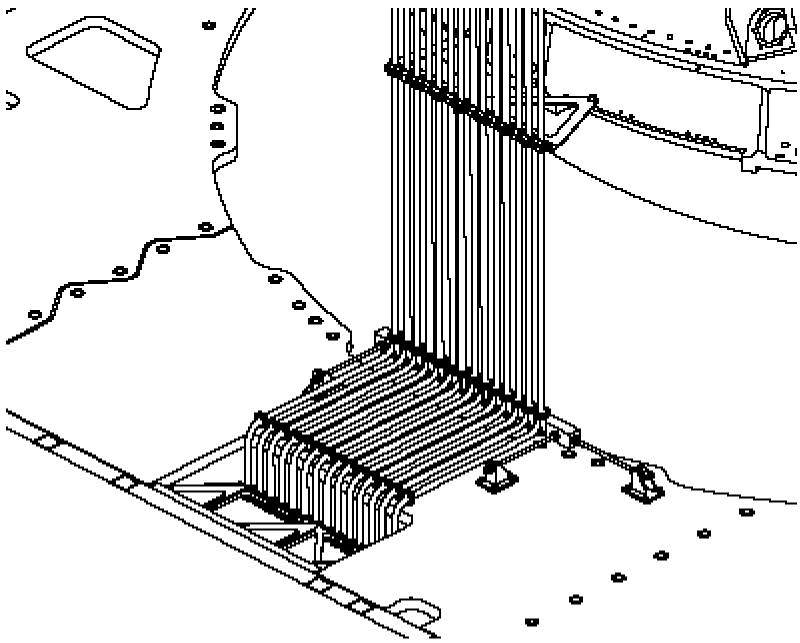
Single internal overlap has been selected for the PLM/CVV struts at cold side, regarding mechanical strength at cold temperature. Nevertheless, the qualification of a double overlap fitting is also in progress for this usage. It could be finally selected if the mechanical qualification is successful, with benefit on PLM lifetime.

Also, the allowable of the adhesives at cold and hot temperatures were tested in the frame of development program. The analyses update using these new allowable evidenced negative margins for two struts.

This issue will be solved by addition of springs at the HSS/CVV interface, already foreseen due to unacceptable increase in IF thermo-elastic loads.

LOU radiator and WG supporting

- The LOU radiator shape was modified by the instrument without major impact on the H-PLM configuration.
- The LOU WG interface was modified on SVM LSU lateral panel and on SVM upper closure panel. This modification was needed for limiting the interface load on the LSU unit and for mechanical de-coupling of the WG in X direction with respect to the upper closure panel. Therefore, the design loads of the wave-guides could be limited in the SVM area.



Cryo. harness

The design and concept of Cryo. harness have been refined at PLM level, with some implication at System and SVM levels. It was optimised in the sense to improve separation between SVM harness and PLM harness, to improve or to ease PLM integration. This optimisation was conducted according to the following steps:

- consolidation of cryo. harness routing with Instruments layout in SVM.
- The cryo. IF brackets have been implemented on upper platform to make a clear and physical separation between cryo. Harness cold part (stainless steel wire or equivalent) and warm part on SVM (copper wires). The electrical dismountability provided by the cryo. bracket is necessary for opening of the SVM panels during AIT operations, and for accessing to Instruments lines without opening the satellite. The main advantage also is to secure the cryo. harness manipulation during PLM mating by limiting its part routing on the SVM to the minimum.

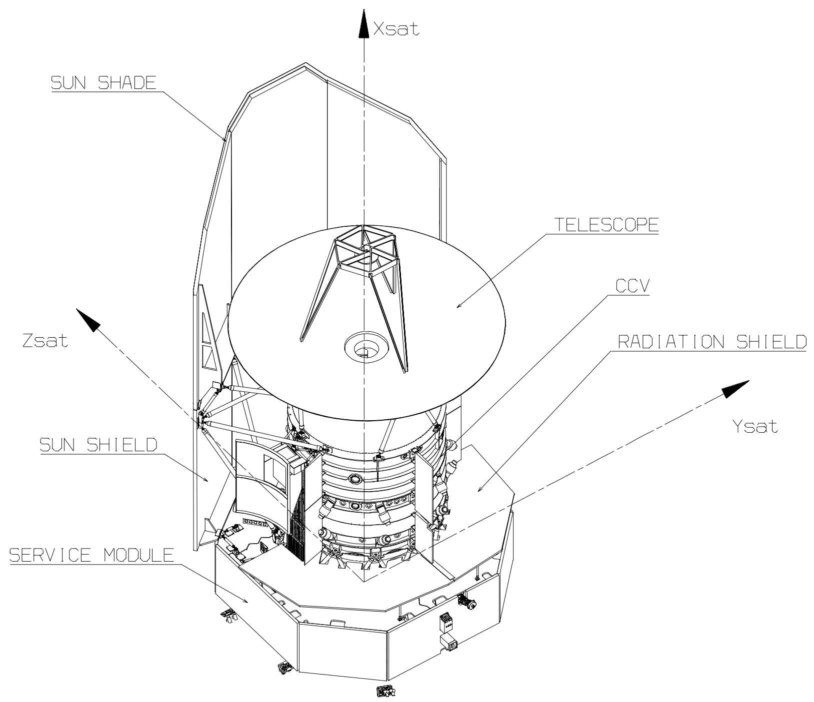
– Implementation of cut-out in upper platform to allow the cryo. harness to pass from Cryo. brackets to WU in the SVM.

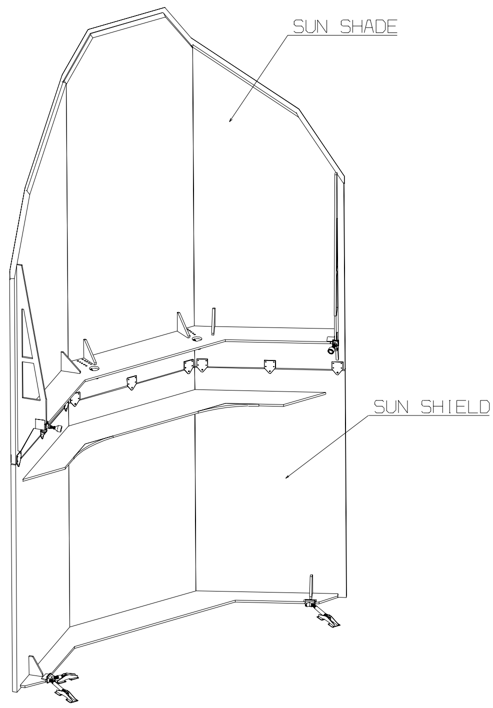
Optimisation of Sunshield/Sunshade configuration and supporting

The general configuration of the HSS was modified after the PDR in two areas:

– the number of attachment points on the SVM upper panels has been doubled in order to cope with higher mechanical loads

– the height has been extended by 100 mm following the CVV extension for lifetime improvement.

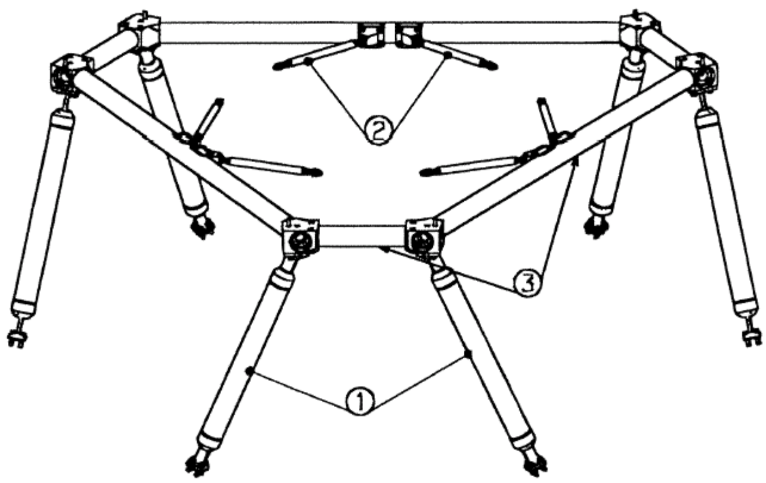




The detail design of the HSS and supporting struts was completed. The main challenges where the mass optimisation and the thermo-elastic behaviour. It was found necessary to implement some springs at two of the struts I/F with CVV. The function of these preloaded springs is to avoid too high thermo-elastic loads in the HSS and struts.

Optimisation of Telescope supporting

The general configuration of the telescope supporting was not modified since the PDR. The detailed design was completed taking into account mainly the stiffness and thermal requirements. The carbon fibre (AS4) was selected, the section of the struts were optimised. (see below figure).

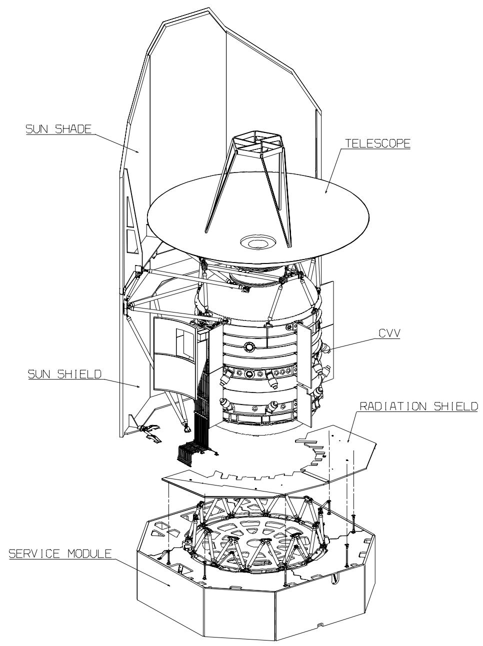


Optimisation of SVM shield and supporting

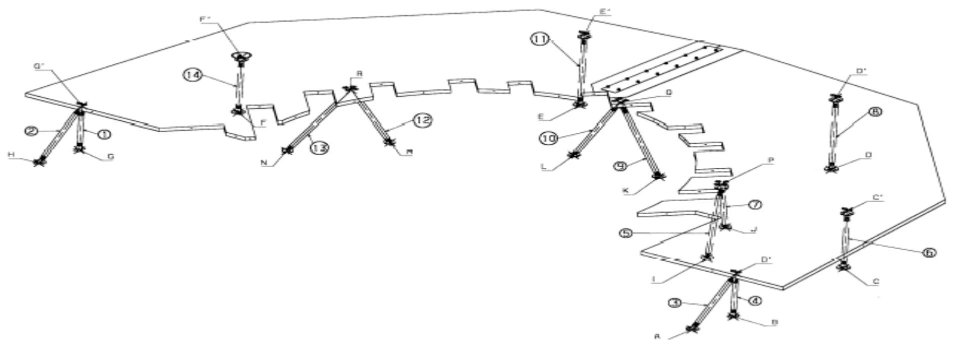
As a recall, the SVM Shield is mounted on top of the SVM, and consists of a Thermal Shield and of a SVM Shield supporting. The major function of the SVM thermal shield is to shield the cold CVV and the telescope rear side from the hot SVM. The shield is tilted 5 degree towards the SVM around the Y-axis. This way it works as a so-called V-groove, which additionally reflects heat coming from the SVM into deep space.

The SVM Shield supporting is provided with five bi-pods and four vertical struts in GFRP to ensure thermal de-coupling with SVM.

The SVM Shield is split into two parts for easier integration and de-integration once the H-EPLM is mounted on the SVM. Cut-outs are made in the shield in order not to collide with the PLM/SVM interface struts during integration.



The general configuration of the SVM shield was not modified since the PDR. The detailed design of the substrate and the struts was completed. No major issue was encountered, but it has been necessary to re-assess the design loads (20g lateral, 75 g axial) which were questioned due to the modal coupling of the shield with the primary satellite and SVM modes. Sine analysis at system level showed that the design loads are still conservative.



6.2.3.4 Update of SVM configuration

SVM structure development and updates

After the PDR, it was decided for schedule optimisation to split the phase C/D design and manufacturing tasks in three batches with three corresponding milestone: MRR1, MRR2, MRR3.

- MRR1 has been held in July 2003 for reviewing the design of the central cones and propellant tanks supports.
- MRR2 has been held in December 2003 for reviewing the design of the 'equipped cone', i.e. the cone plus shear webs, upper and lower closure panels.
- MRR3 will be held by end 2004 for reviewing the design of the lateral panels, subplatforms and secondary structures.

The manufacturing of MRR1 and MRR2 elements for both STM and FM is in progress, the first cone (Herschel STM) has been accepted.

A CDR is also planned in July 2003 with the purpose of reviewing the whole structure and make sure of the compatibility of all the elements, mainly with respect to the interface loads between elements.

The main critical points encountered in the design of the Hershel SVM structure are summarised hereafter.

SVM Box mode

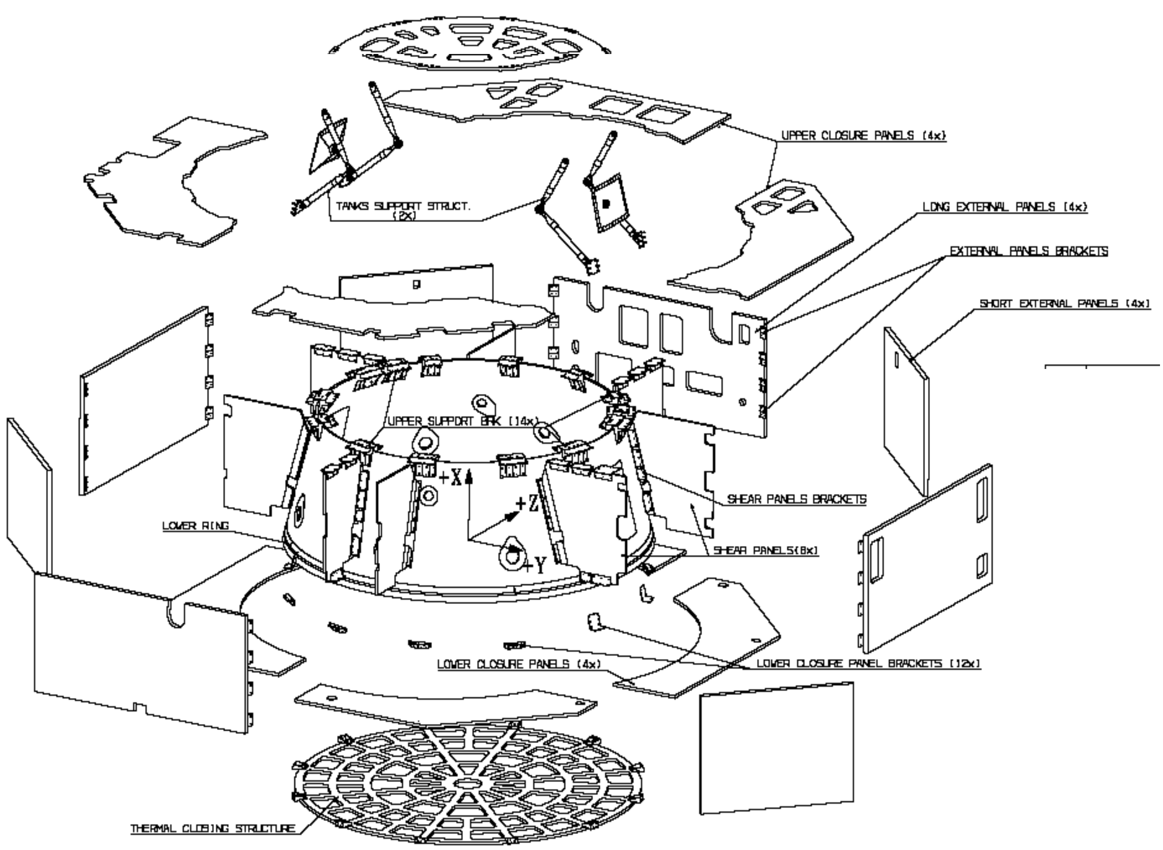
A frequency specification of 45 Hz had been defined before PDR for a global SVM mode referred to as 'box mode', involving the whole octagonal box. This was necessary to avoid a coupling with the primary satellite mode and with the PLM modes. The consequence of this coupling would be to exceed locally the units design loads and high risks for the global structural integrity.

The frequency requirement proved to be difficult to fulfil in one quarter of the SVM where are installed the heavy PACS and SPIRE units. Reinforcement in this area was then necessary. The upper and lower closure panels were reinforced, as well as the shear webs/cone links.

Mass optimisation, modification of the design loads

A permanent mass increase of the structure was observed since the PDR, up to a unacceptable point where the specified launch mass of the satellite was exceeded. A mass saving of about 50 kg for Herschel + Planck structures was then requested. Two actions allowed to reach this objective:

- modification in the design methodology of the lateral panels
- revision of the design loads, based on reduced sine levels at the satellite basis, in agreement with ESA.



Herschel SVM structure, MRR2 status

Equipment layout and updates

Power (PCDU and battery), data (CDMU) and attitude control (ACC) units are located on +Ys long panel, the layout has been improved but they all remain on the same panel. The layout is the same as Hershel one.

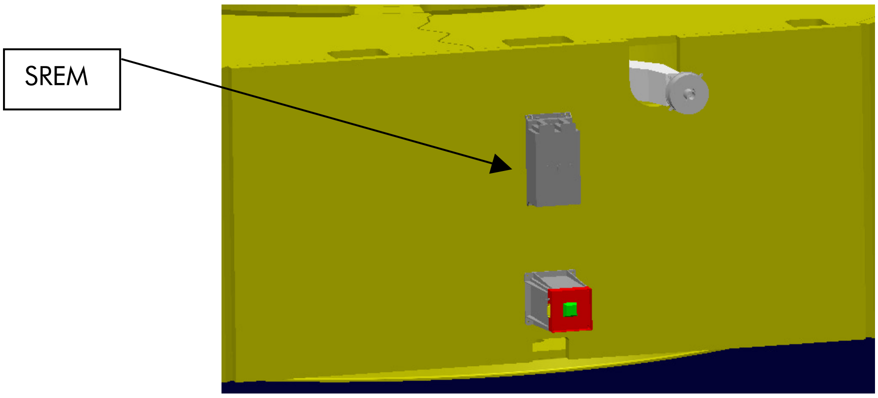
The four Reaction Wheels are accommodated on -Y+Z panel, the Electronics have been integrated to the wheels.

TTC equipment are located on +Y+Z panel. The units keep the same layout as for Planck but the wave-guides differ slightly, mainly due to the difference of antennae location between the satellites.

Herschel ACMS configuration also includes a Gyroscope (GYR), mounted on the +Z(+Y) Shear Panel, 2 CRS on +Y (+Z) shear web, 2 SAS one being on –Z lateral panel and the other on +Z (+Y) shear web with AAD. The Star Trackers are mounted below the CVV dome.

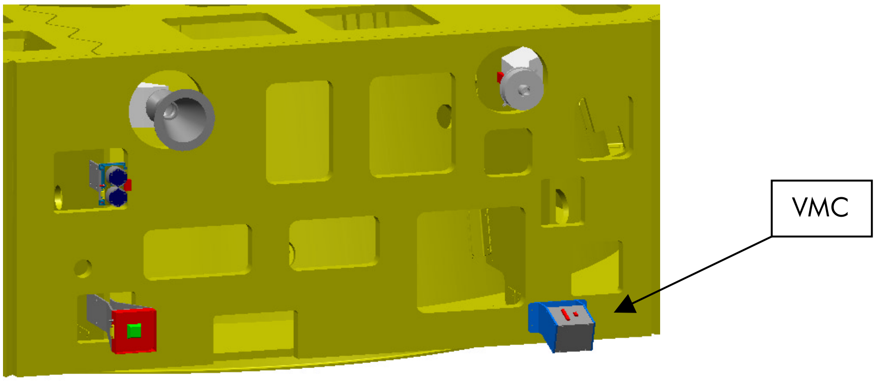
SREM and VMC accommodation

The SREM is accommodated on outside of –Z lateral in-between shear webs above the SAS. Its field of view is perpendicular to the panel toward outer space.



SREM accommodation on –Z panel

The VMC is set outside, in bottom –Y part of +Z lateral panel, near a shear panel for attenuation of mechanical loads. It is carried by a U shape bracket inclined of 18.5° inward so that the VMC can look under the satellite in center direction.



VMC accommodation on +Z panel

STR accommodation and stability

See discussion under §6.1 of the present Design report.

Instruments layout and updates

General

Changes from Instruments seen in the course of the phase C were less important than in previous phase in terms of growing and dimensions. Nevertheless, some units have been finally defined quite late in this phase (FPDECMEC, FHLSU). The other evolution mainly concerned refinement of interfaces: fixation feet definition, base-plate contact type, update of external dimensions and mostly connectors move penalising harness routing stabilisation.

Recall of SVM accommodation constraints

This paragraph intends to explain the different accommodation constraints that come from SVM design.

Accommodation area

- Small panels

  The small panels are linked on their four edges to 2 large lateral panels and lower and upper platforms. Their global area is 1115.5*840 mm. The consideration of structural links between the panel and the SVM results in an effective area for units accommodation of 1000x750 mm.

- Large panels

  The large panels are linked on their four edges to 2 small lateral panels and lower and upper platforms. Their global area is 1731.2*840 mm.

  The panels are divided in three parts, a main centred one in-between shear webs and two small lateral zones outside shear webs. Main area measures 1185*840 mm. Small areas measure 243.1*840 mm.

  The consideration of structural links between the panel and the SVM results in effective areas for units accommodation of 1150x750 mm for the central part, and 150x750 mm for the lateral sides.

Panel tilting

SVM configuration must ensure that accessibility to the warm unit is ensured all along AIT phase up to fully integrated phase.

As lower and upper platforms are not removable (SVM harness routed on first one and Cryo-harness routed on second one), warm units lateral panels shall remain dismountable.

Procedure foreseen is:

- first to shift the panel away from the SVM from 25 mm
- then to tilt it around an axis near its lower edge with a special MGSE

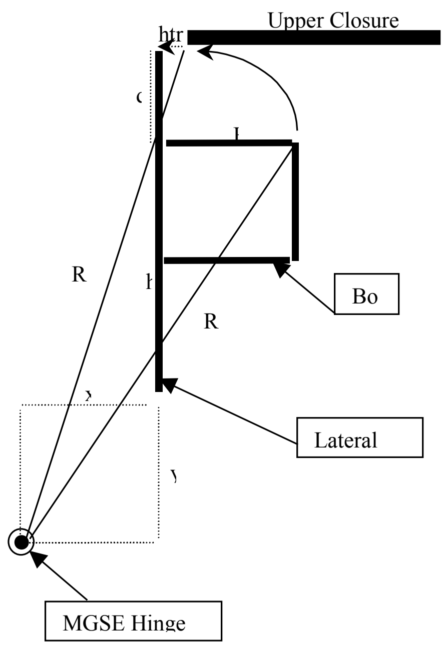


Figure 6.2.3-1 Panel tilting MGSE concept

At the end, this procedure constrains units accommodation, because unit must not interfere with upper platform during the rotation, so a minimum space must be kept free. Of course this distance depends on the unit's height (added with any excrescence like connector, cable …).

SVM connector bracket

SVM harness (from PCDU, CDMU to warm units) is routed on the lower platform via interfacing connecting bracket set in each equipment/instrument partition in order to allow a disconnection before dismounting a lateral panel.

This interface-connecting bracket is set on the lower platform, 100 mm away from the lateral panel, its length varies (depending on the number of connectors needed) from 50 mm to 250 mm.

It can be set anywhere along the length of the panel, but it leads to keep an area free at the bottom of the panel corresponding to this bracket's area.

SVM layout description

The SVM configuration presented below is based upon the hypotheses from updated IID-B's (AD04.2, AD04.3, AD04.4).

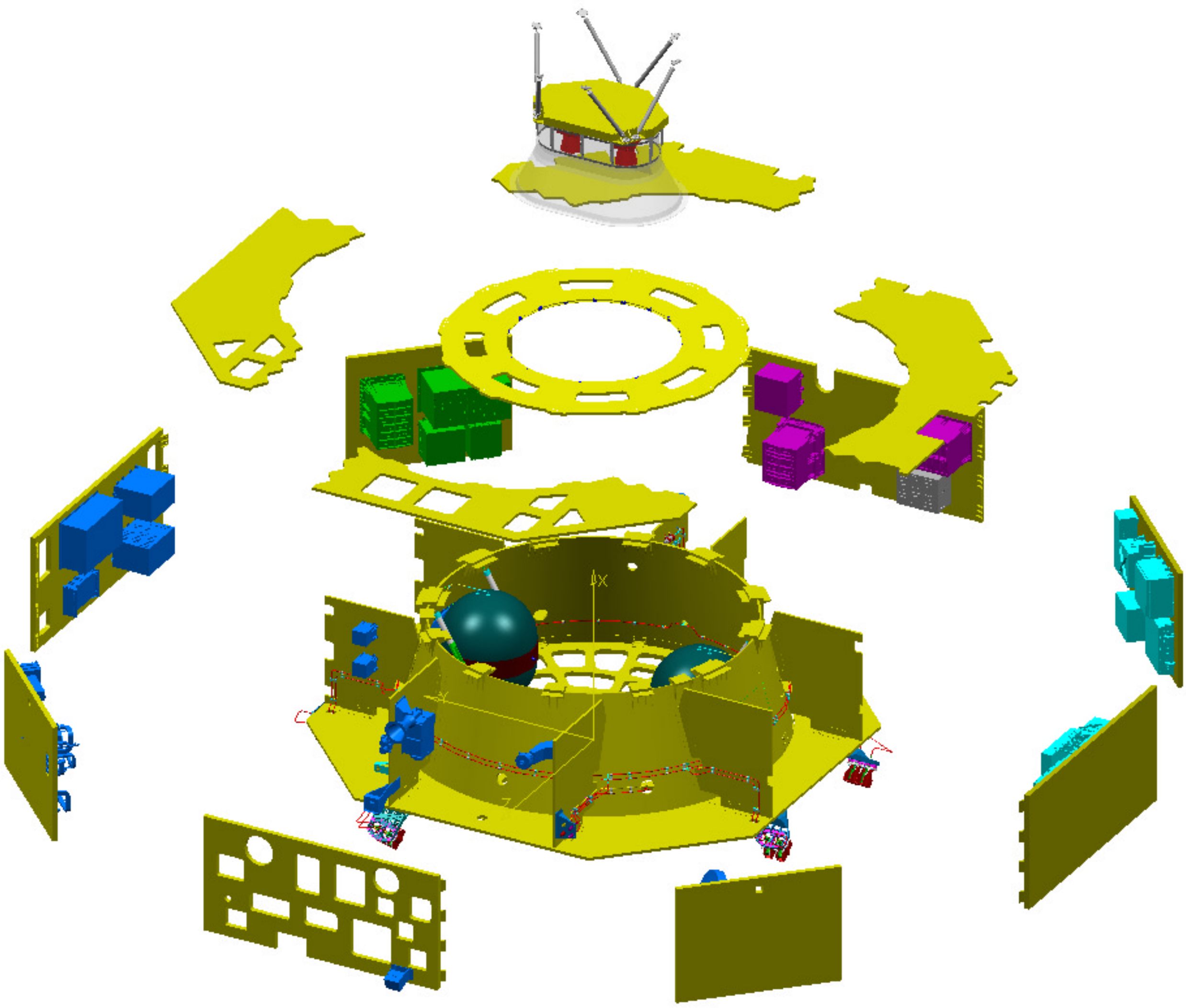


Figure 6.2.3-2a Herschel SVM general layout

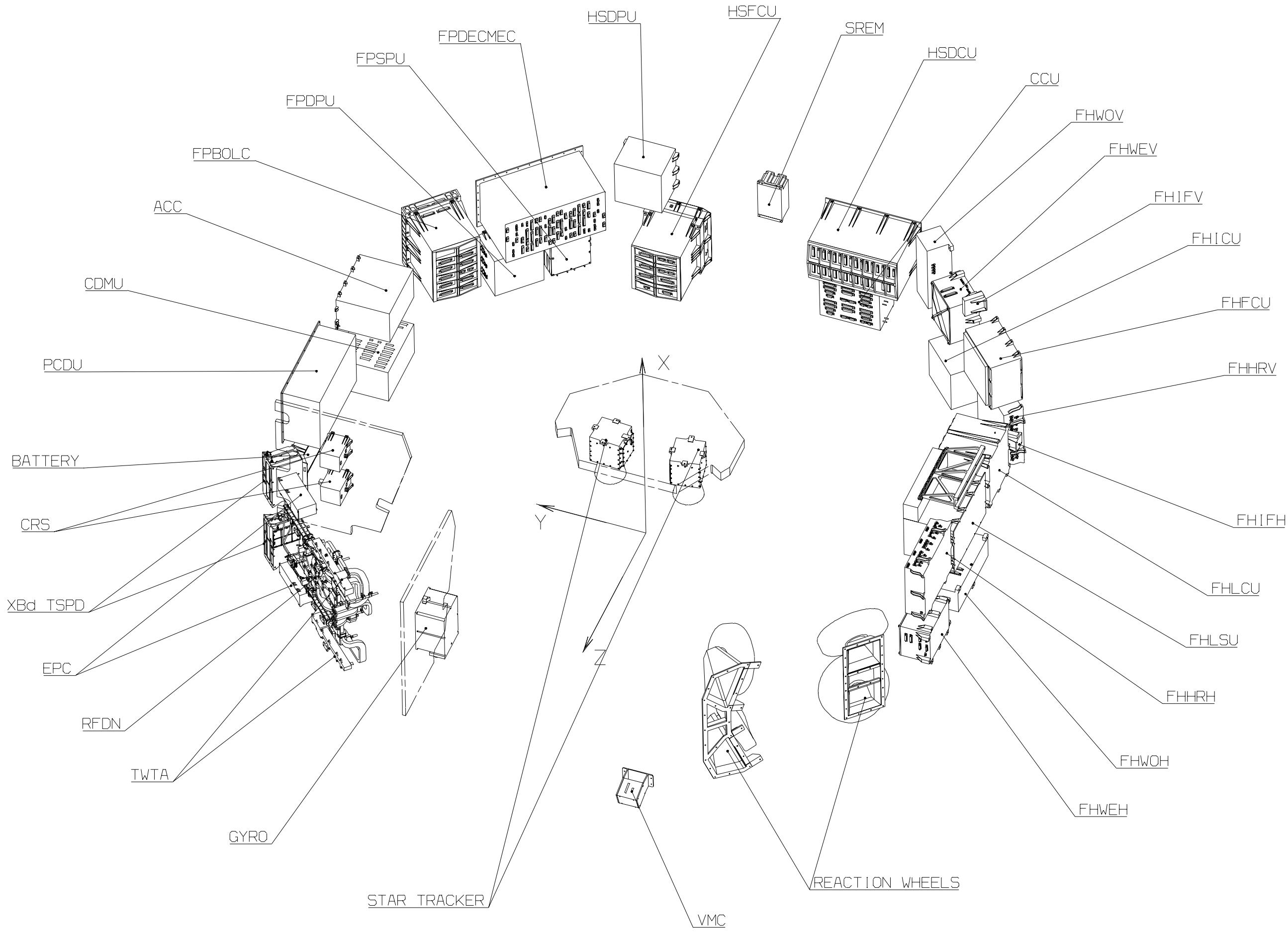


Figure 6.2.3-2b Herschel SVM general layout

HIFI panels

The following changes occurred from IID-B 2.1:

- Up-converters (former 3dB-coupler)and FHLSU have been finally defined.
- LOU waveguides interface with FHLSU has been frozen, leaving finally them straight up to the unit.
- Units have been defined deeper in detail, with several modifications of external dimensions, connectors layout, baseplate contact type.

Panel –Y

Instrument accommodation is presented hereafter.

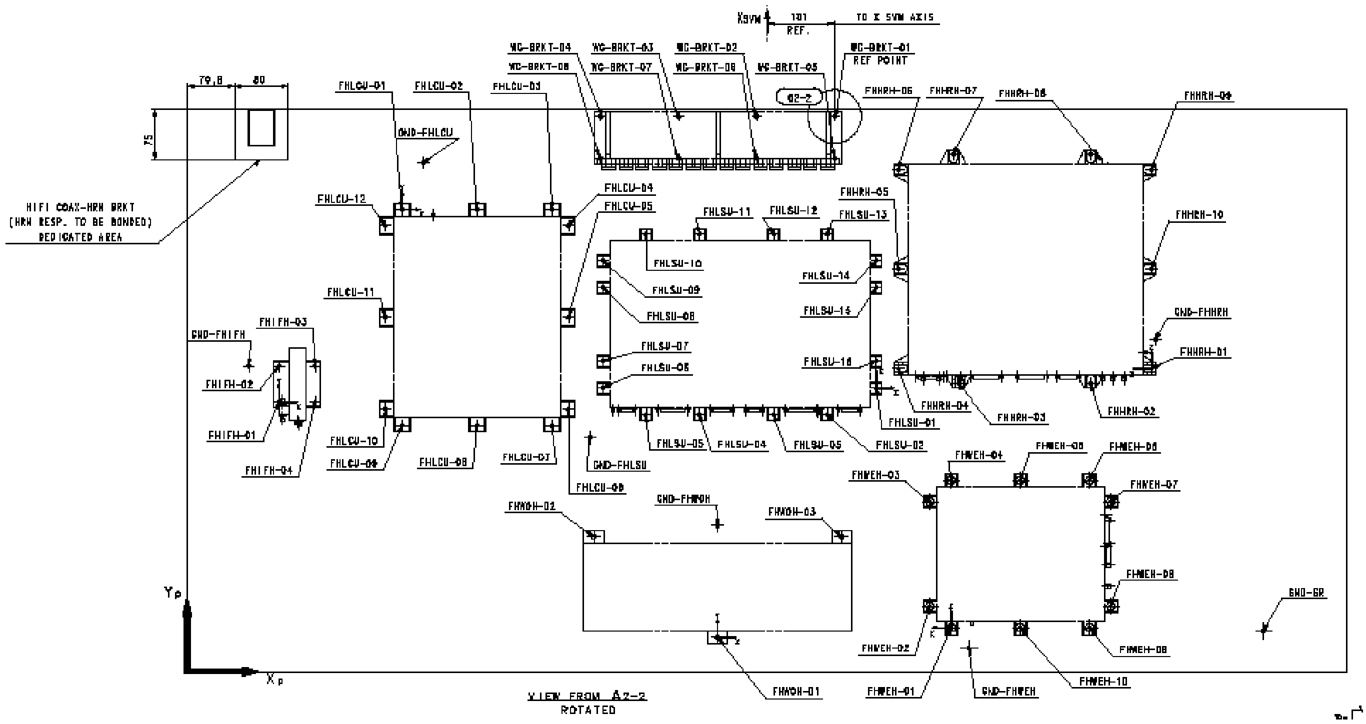


Figure 6.2.3-3a HIFI -Y panel layout

Horizontal Chain assembly has been set on this panel (WOH, WEH, HRH), with LCU and LSU units. The up-converter, set on left area of the panel links LOU and HRH. This last unit also connects the HRV on the next panel via a semi-rigid cable. A connector bracket will be set on the upper platform to ensure a disconnection if any panel dismountability is required.

The FHLSU has been shifted toward –Z along the lateral panel to follow as much as possible H-PLM shifting and LOU location. It remains globally at the centre of the panel.

However, FHLSU could not be ideally set in the axis of the LOU Wave-guides, the LOU Wave-guides have been kept straight up to the LSU waveguide supporting bracket making the interface with FHLSU. The bends are then made in the space in-between this bracket and FHLSU and are of HIFI responsibility.

Brackets at the bottom of the panel are used for SVM harness and panels "–Y" & "-Y –Z" warm units interconnecting harness.

Panel –Y –Z

On this second panel are set the Vertical Chain assembly (HRV, WOV, WEV), FCU and ICU units. Instrument accommodation is presented hereafter.

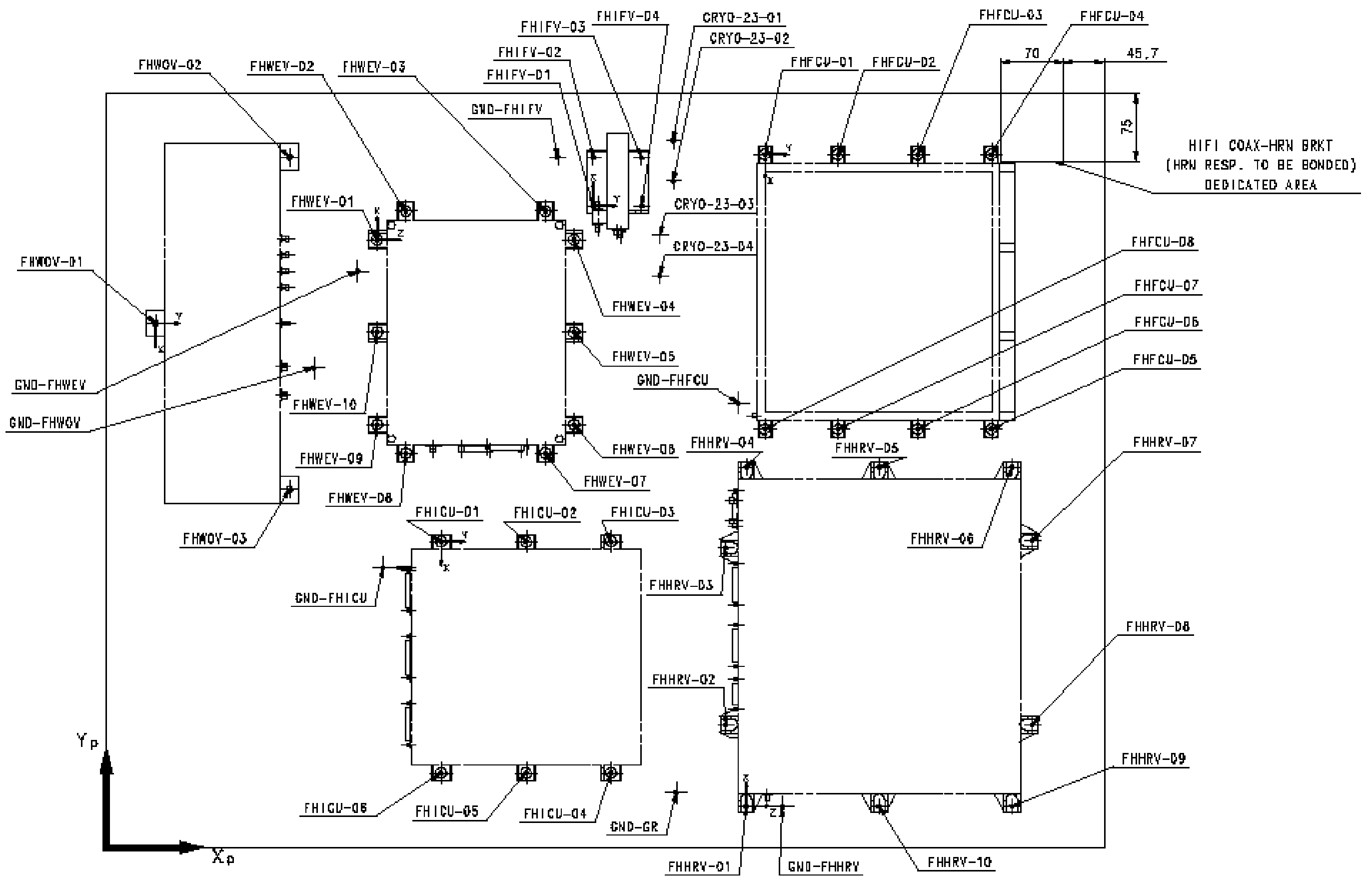


Figure 6.2.3-3b HIFI -Y-Z panel layout

Vertical Chain assembly has been set on this panel (WOV, WEV, HRV), with FCU and ICU units. The up-converter set on centre area of the panel links LOU and HRV. This last unit also connects the HRH on the next panel via a semi-rigid cable. A connector bracket will be set on the upper platform to ensure a disconnection if any panel dismountability is required.

Brackets at the bottom of the panel are used for SVM harness and panels "–Y" & "-Y –Z" warm units interconnecting harness.

PACS panel

The following changes have been implemented With regards to IID-B 2.1:

- DECMEC ICD has been given quite lately in the course of this phase. It is not completely in accordance with the ICD realised by ASP to help industry working with a configured information.
- SPU stacked version ICD has been provided.

Instrument accommodation are presented hereafter.

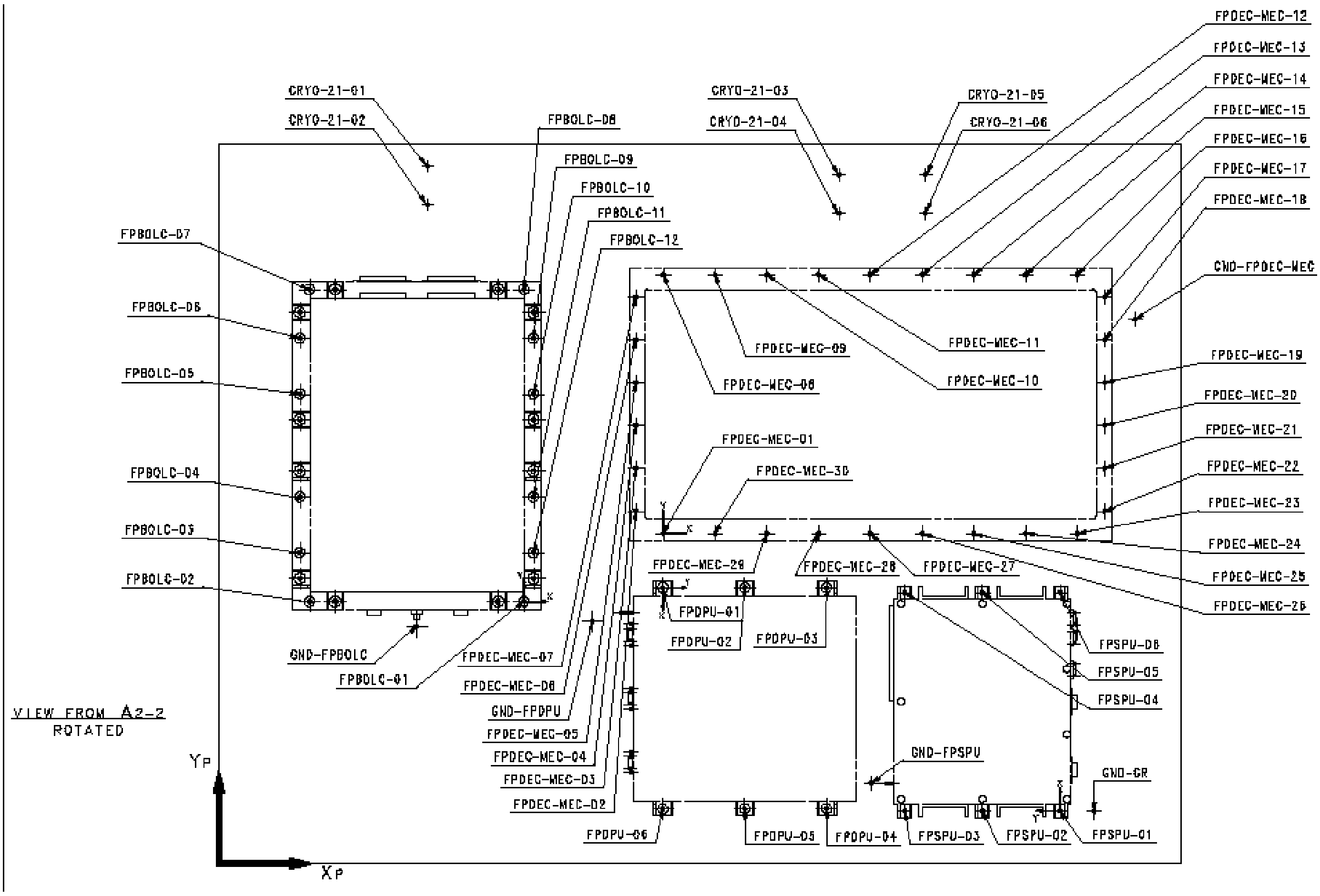


Figure 6.2.3-4 Pacs +Y-Z panel layout

SVM connector bracket has been set at left bottom of the panel.

SPIRE panel

Compared to IID-B 2.1 baseline, minor changes on units occurred.

Instrument accommodation presented hereafter.

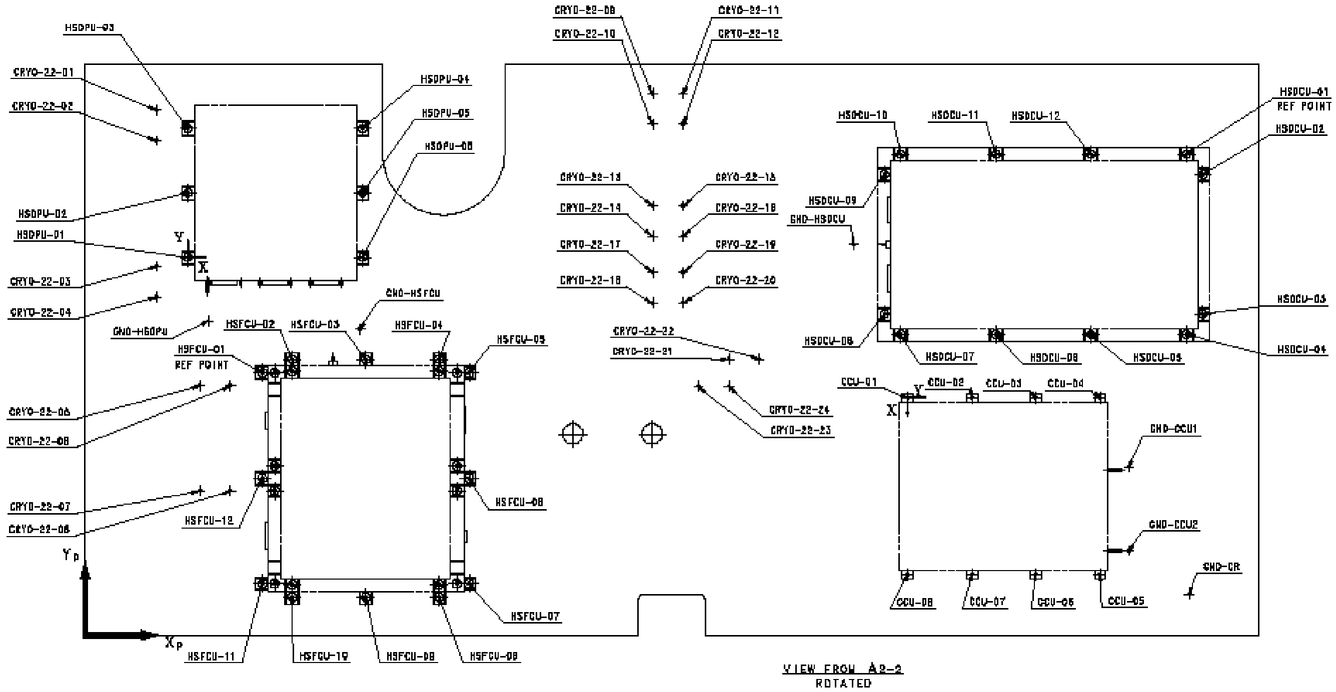


Figure 6.2.3-5 Spire -Z panel layout

In order to ease units' connectors mounting and harness routing, using of connectors with 45° bent back-shells is envisaged (DCU, FCU). Cut-outs are made in shear webs along the lateral panel to allow Cryo-harness passing from one cavity to the cryo. brackets (cryo. harness) or to the other side to connect Instruments on the same panel.

2 SVM connector brackets are placed at the left bottom of the panel and 1 last bracket locate at the bottom center of the panel deserves SREM and SAS on the external side of the panel.

LGA is accommodated on upper left part of the panel hung on the shear web. The lateral panel has an opening, reaching top of the panel, for antenna passing through and allowing the panel to tilt without touching the antenna. The refinement of secondary structure definition led to shift leftward the antenna and therefore the DPU.

As for the other Instruments panels, it has been checked that panel can be tilted without interference between any unit and upper platform.

Cryo-harness interface

The cryoharness is distributed between the Scientific Instrument Harness (SIH) -linking cold units in CVV and warm units in SVM- and the Cryostat Control Harness (CCH) –linking the monitoring function of the H-PLM with CCU and launcher-.

The SIH cryo-harness coming out from CVV and connecting to SVM warm unit is split in 2 parts:

- the first one that runs down to Interface Connecting Brackets (I/F CB) which are set on upper platforms (roughly at a mid-diameter of the platforms). I/F CB relative to an Instrument is set on upper platform, as far as possible in an area where Instruments units in SVM are. (e.g. I/F CB of SPIRE at the top of SPIRE panel)
- the second part that connects this I/F CB to warm units running on upper platform and diving into the SVM through emerging cut-outs made in upper platform at its outer boundaries.
- The CCH leaves the different function on H-PLM and connecting CCU, PCDU, CDMU and launcher is split in2 parts:
- the first one that runs down to Interface Connecting Brackets (I/F CB) which are set on upper platforms (for the connection with CCU) and on cone (for the connection with PDU, CDMU and launcher)
- the second part that connects on one hand the I/F CB to CCU (on –Z panel) running on upper platform and diving into the SVM through emerging cut-outs made in upper platform at its outer boundaries.
- It connects on the other hand the brackets on cone to the PCDU and CDMU for Cryocover and Telescope brackets; and launcher umbilical connectors for H-PLM/SVM umbilical bracket.
- To support the different bundles of the cryoharness on the different structure:
- Huge glued stand-offs are implemented on upper closure panels.
- Inserts have been foreseen in upper closure panels around the cut-outs to set specific supports maintaining the cryoharness before it enters in SVM.
- Inserts have also been added on lateral panel to fix huge stand-offs.

With these dispositions, the dismounting of a SVM panel needs simply to disconnect all relative Cryo-harness cables from the I/F CB, and then the panel is tilted with the cables hung on above it with a MGSE.

For the mating of the 2 modules, H-PLM will come with the cryoharness set on CVV down to I/F CB and brackets (to be set on upper closure panels). The assembly will be integrated to the SVM, coming with the brackets on cone.

The last definition of cut-outs layout proposed by the SVM module remained unchanged since PDR.

These cut-outs have been fully used by ASED to make the cryoharness enter in SVM.

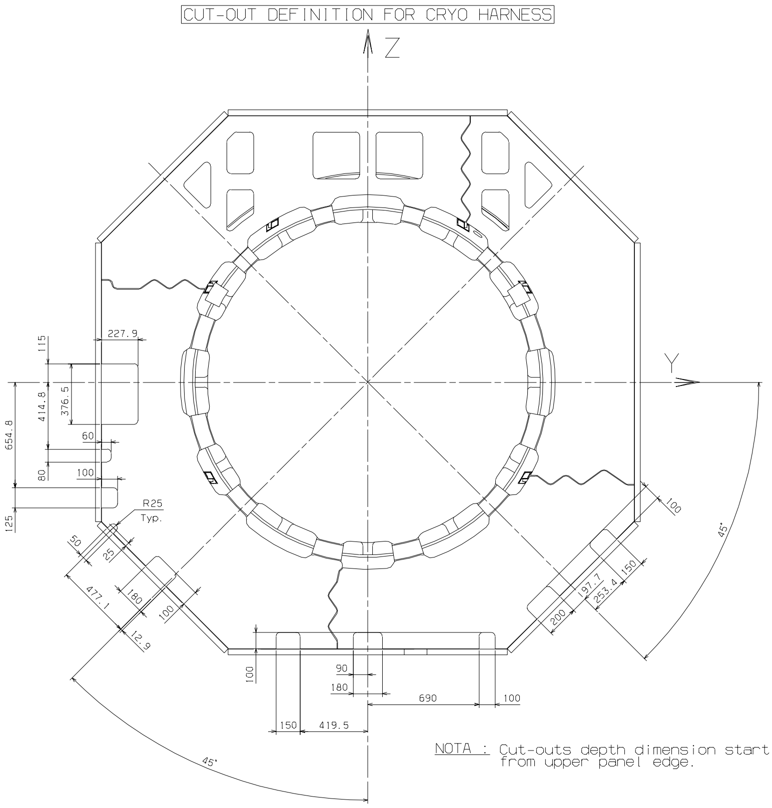


Figure 6.2.3-6 Herschel upper platform cut-outs layout

The final cryo. bracket accommodation is described as follows.

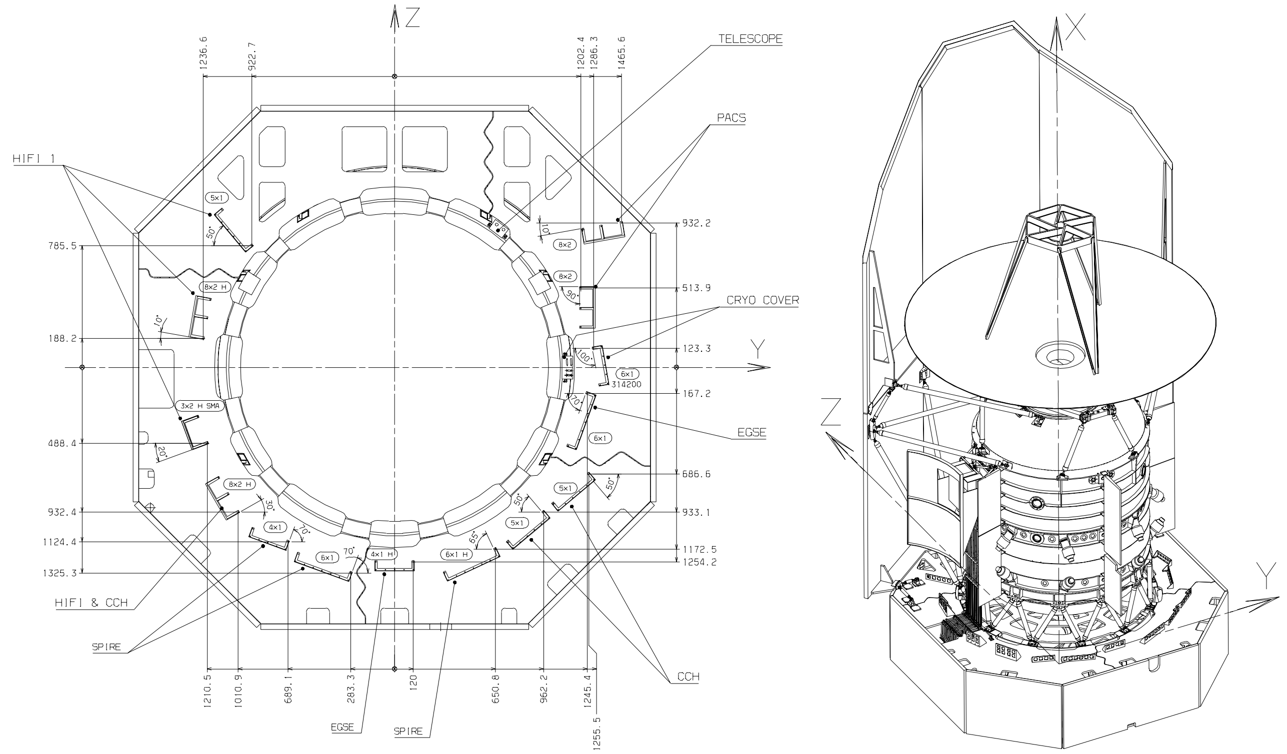


Figure 6.2.3-7 Herschel cryo brackets interface layout

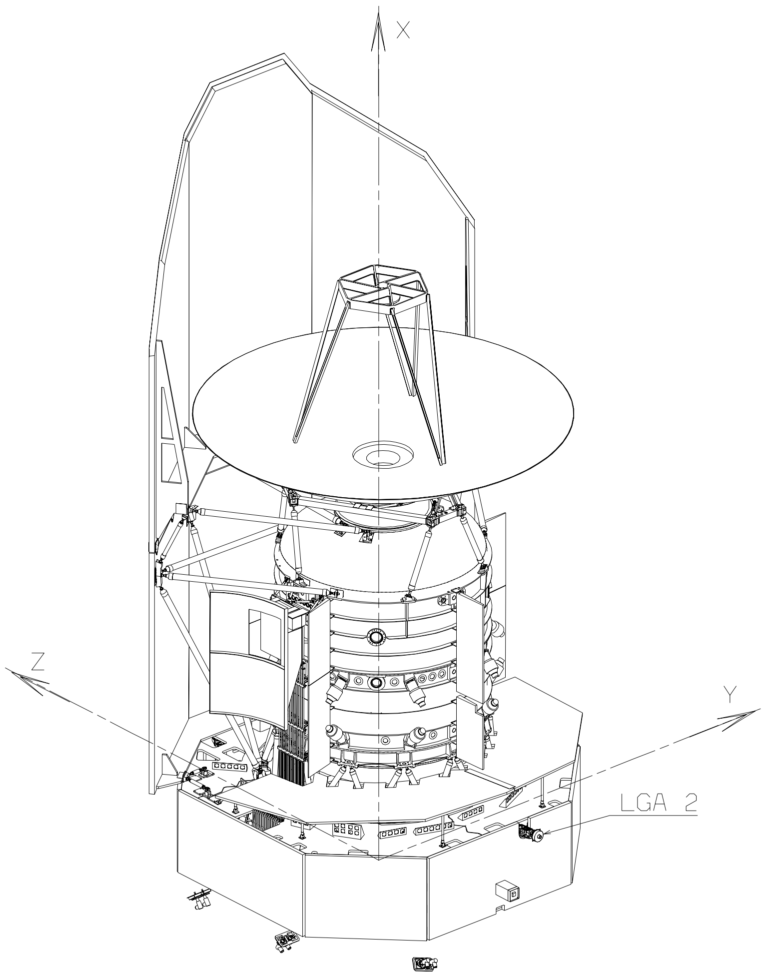
Sensors accommodation

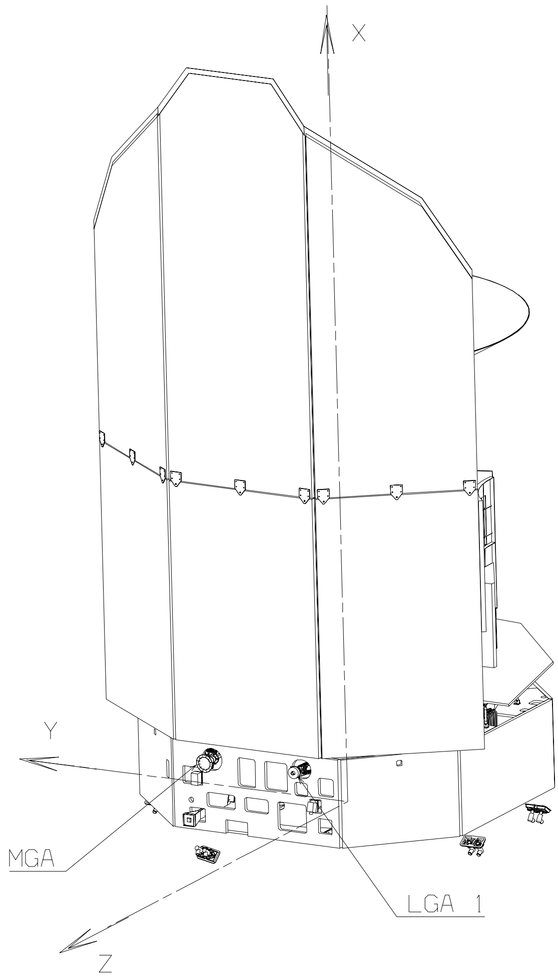
Herschel and Planck ACMS configurations share the below listed common features:

- the Coarse Rate Sensors (CRS) are mounted on the Shear Panels, with their reference axis parallel to the X_S axis.
- the Sun Acquisition Sensors (SAS) are mounted to the external of the SVM structure in accordance with the relevant field of view requirements.
- the ACMS Power Distribution Unit (PDU) has been deleted.

Antennae configuration

The Medium and Low Gain Antennae are mounted to the external of the SVM structure and meet the relevant field of view coverage needs. The RF connection between Low/Medium Gain Antennae and the TT&C panel is then realised by means of Wave Guides, which are mainly routed around/through the cone and on the Shear Panels. Both Herschel and Planck share the same WaveGuides routing concept, so that the highest possible level of commonality is achieved.



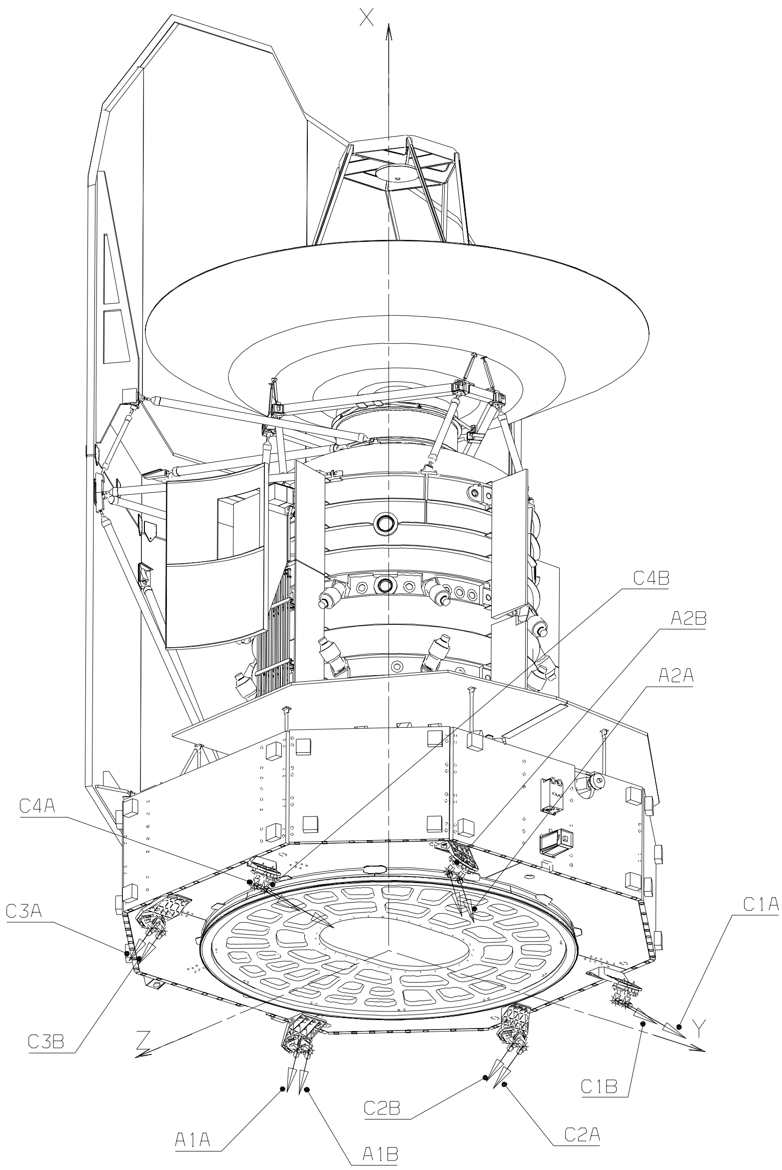


RCS accommodation

The RCS components/piping accommodation shall be organised as follows:

- components that do not need frequent accessibility (e.g.: Propellant Filter, Pressure Transducer, and Latch Valves) are accommodated on the RCS Support Panel (shear web –Z+Y)
- components that need external accessibility (e.g. Fill & Drain, Fill & Vent Valves, and Test Ports) are accommodated through the Lateral Panels and/or the Upper Closure Panels
- main distribution loop is routed along the external and internal surface of the cone, approximately at the same height as the Venting Holes
- the SVM structure provides the mechanical interfaces to the pipes which distribute propellant from the main loop to the Thrusters and from the Fill and Drain valves to the Propellant Tanks
- The thrusters are carried by brackets connected to lower closure panels.

Refer to ALS SVM Design report for details about RCT's accommodation.



SVM harness

The SVM Harness is mainly routed over the Lower Closure Panel. Because of integration/test reasons, all Lateral Panels must be tiltable/removable when fully equipped.

Therefore, dedicated Connectors (and relevant Connector Brackets) are accommodated around the Lower Closure Panel to interrupt the Harness bundles before jumping to the Lateral Panels.

The SVM structure will provide the mechanical interfaces for the fixation of all Harness items, as appropriate.

Thermal control concept

The Thermal Control Subsystem (TCS) hardware is mainly comprised of Multi-Layer Insulation (MLI), Black Paint and Fillers. The external surface of Herschel Lateral Panels is partly covered with Optical Solar Reflectors (OSR), where necessary. All TCS items are attached to the Primary Structure by means dedicated interfaces.

6.2.4 Herschel Thermal design

6.2.4.1 Spacecraft general thermal architecture

6.2.4.1.1 Main Mission Characteristics

In this chapter, we will recall the main mission requirements having a deep impact on the Herschel overall thermal design. As presented hereafter, the thermal design has to be very optimised w.r.t. the on-orbit environmental conditions in order to meet the performance requirements. On the other side, the launch period brings specific constraints, which are in opposition with the need of optimisation in operation. This had led to define some constraints on the launcher (see AD03.5), mainly related to attitude control, in order to limit the impact on the Herschel thermal design, optimised for operating phase.

The requirements reported hereafter come from the EnVironment and Test Requirements document (AD05.2) and the Change Request H-P-ASP-CR-0633. For clarity, we have reported in Figure 6.2.4-1 the Herschel axis definition.

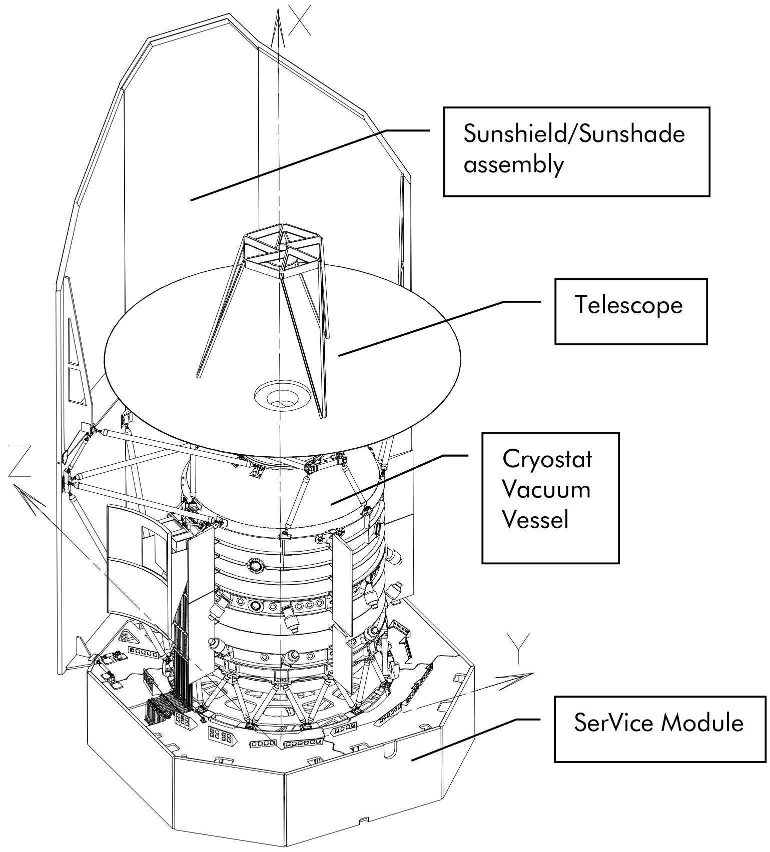


Figure 6.2.4-1 Herschel axis definition

Launch phase

- Aerothermal fluxes: 1135 W/m² maximum occurring at fairing jettisoning, on a plane normal to the trajectory (ENVM-160). An aerothermal flux profile versus time is provided in the CR 633.
- Solar flux: from fairing jettison to launcher separation Herschel shall be compatible with a Sun direction between – 26° and +26° from the (X_s , Z_s) plane, and between + 50° and + 140 ° from the X_s axis (ENVM-170a)
- Herschel is submitted to albedo and Earth fluxes after fairing jettison.
- In addition to those requirements, the spacecraft can be submitted a complete rotation ("BBQ" mode) around Xs axis at fairing jetitison (rotation rate 0.5°/sec) and at upperstage separation (rotation rate 3°/sec). The second ratation occurring during a phase where aerothermal flux imping the spacecraft (see § 6.2.4.4.1.)

On orbit phase

Solar, albedo and Earth fluxes

- Herschel shall be compatible with a Sun direction between – 1° and + 1° from the (Xs, Zs) plane, and between + 60° and + 120° from the Xs axis (ENVM-290).

– In contingency cases, Herschel shall be compatible with a Sun direction between – 10° and + 10° from the (Xs, Zs) plane, and between + 55° and + 125 ° from the Xs axis. Maximum duration of transient is 1 min (ENVM-300).

The maximum allowable Sun Aspect Angle is much higher in the launch phase than on-orbit. Capability to sustain solar flux is a major driver of any spacecraft thermal control. For Herschel satellite, which carries a cryogenic payload, coatings used for low temperature needs are not compatible with Sun-illumination, but may be illuminated during launch phase ("BBQ" modes). The impact of such a large Solar Aspect Angle on the design is discussed in Section 6.2.4.4.

6.2.4.1.2 Spacecraft design description

Herschel spacecraft is basically made of two modules:

– the Herschel-SerVice Module (H-SVM)

– the Herschel-PayLoad Module (H-PLM).

The overall spacecraft design is depicted on Figure 6.2.4-2.

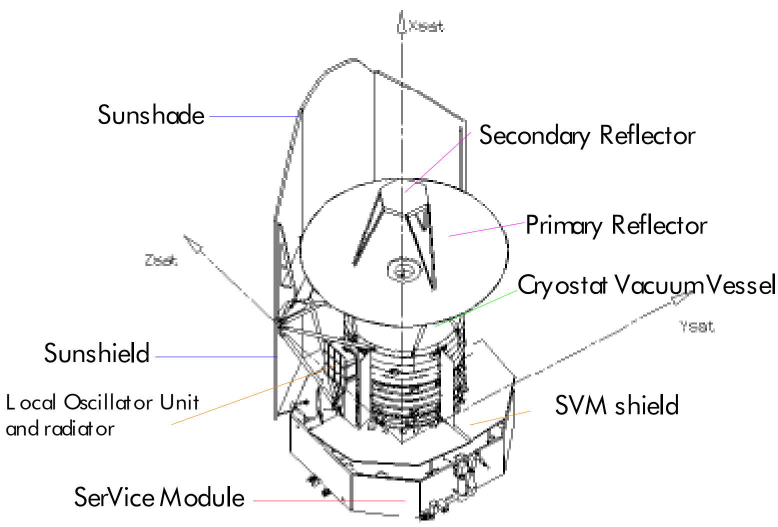


Figure 6.2.4-2 Herschel overall configuration

The SVM carries the different subsystems dedicated to the operation of the spacecraft. The SVM houses also the payload warm units, which are the electronics boxes, provided by the three instruments aboard. Most of the units have "classical" operating and non-operating design temperature range.

The SVM thermal design takes benefit from the development of previous ESA platform such as XMM and Integral. Passive thermal control is widely used in order to fulfil the thermal requirements. The SVM thermal concept is based on well known and already proven design solutions. The specificity of the Herschel thermal design lies rather to the challenging thermal control of its payload. The main components of the payload are (see Figure 6.2.4-2):

– The Cryostat Vacuum Vessel (CVV), filled up with Superfluid Helium for passive cooling of the three instruments focal planes.

- The Telescope (3.5 m primary reflector).
- The Sunshield/Sunshade assembly.
- The sunshield has an H-PLM screening function with regards to Sun illumination. It also supports the solar generator, where As-Ga cells are implemented (on the Sun-illuminated side).
- The sunshade has also a shielding function, and prevents mainly the telescope from Sun illumination.

6.2.4.2 Review of Main thermal requirements

6.2.4.2.1 Temperature levels

Herschel overall thermal design is mainly driven by the H-PLM performance requirements. The more constraining ones are recalled hereafter.

- Lifetime requirement: 3.5 years, from launch till the end of the mission
- Average telescope performance temperature range: [70 K – 90 K] (AD02.1, TEPE-005)
- Instruments temperature levels at their respective Focal Plane Unit (AD04.2, AAD04.3, and AD04.4) (see Table 6.2.4-1).

In-Orbit thermal requirements				
Thermal I/F	**LEVEL**	**Interface**	**Requirement** (Max I/F Temp @ Max Heat Load)	**Analysis results** (Max I/F Temp for a 2.1 mg/s He mass flow)
SPIRE	**L0**	Detector Box	2 K @ 4 mW	1.74 ± 0.06 K
	L0	Cooler Pump	2 K @ 2 mW	1.69 ± 0.06 K
	L0		10 K @ 500 mW peak	9.77 ± 0.06 K
	L0	Cooler Evaporator	1.85 K @ 15 mW	1.70 ± 0.06 K
	L0	OBA units	5.5 K @ 15 mW	4.43 ± 0.35 K
	L1	Optical bench/FPU legs	12 K @ no load	11.4 ± 0.5 K
	L2	Instrument shield (eq. Radiative temperature)	16 K @ -	11.5 ± 0.5 K
	L3	HSJFP (JFET Photometer)	15 K @ 50 mW	1.61 ± 0.5 K
	L3	HSJFS (JFET Spectrometer)	15 K @ 25 mW	14.6 ± 0.5 K
PACS	**L3**	FPFPU Red Detector	1.75 K @ 0.8 mW	1.68 ± 0.06 K
	L0	FPFPU Blue Detector	2 K @ 2 mW	1.73 ± 0.06 K
	L0	Cooler Pump	10 K @ 500 mW peak	12.0 ± 0.06 K
	L0		5 K @ 2 mW	1.73 ± 0.06 K
	L0	Cooler Evaporator	1.85 K @ 15 mW (*)	1.796 ± 0.06 K
	L0	FPFPU Photometer	5 K @ 10 mW	3.60 ± 0.18 K
	L1	FPFPU Spectrometer	5 K @ 10 mW	4.57 ± 0.18 K
	L1	FPFPU Collimator (1)	5 K @ 10 mW	4.34 ± 0.18 K
	L1	HOB	12 K @ no load	11.8 ± 0.5 K
HIFI	**L0**	Mixers of FHFPU	2 K @ 6.8 mW	1.96 ± 0.06 K
	L1	Parts of FHFPU	6 K @ 15.5 mW	5.77 ± 0.32 K
	L2	FHFPU	20 K @ 22 mW	13.3 ± 0.5 K

Table 6.2.4-1 Instruments thermal interfaces at FPU

Level 0 temperatures are provided by thermal connections to the HeII (Superfluid) tank. Level 1 and Level 2 temperatures are provided by thermal connections to the Helium gaseous ventline. A level 3 has been introduced since PDR. This level is the thermal connection between two SPIRE's JFET boxes and the ventline after leaving the OBA and before entering the thermal shields.

Besides the main constraints recalled above, the H-PLM thermal design must also ensures the suitable thermal environment to operate the warm unit mounted on the CVV. The thermal requirements of this unit is recalled hereafter:

- Local Oscillator Unit (LOU from HIFI instrument) support plate to LOU mounting plate: operating range = [90 K; 150 K] (for information, max average LOU dissipation = 7 W).

At SVM level, all units operate at conventional temperature range, and do not exhibit specific constraints on the required temperature level, except two HIFI units. These units are the "Wide band spectrometer Optics Horizontal and Vertical polarisation" boxes (FHWOV and FHWOH). They need to be maintained between 5° C and 15° C. The narrow and rather cold range is demanded for inner components lifetime purpose (LASER diodes).

6.2.4.2.2 Warm units Temperature Fluctuation level

A major characteristic of the SVM Thermal Control Subsystem (TCS) is linked to the temperature stability requirements and goals of HIFI units (see AD04.5). The performances required on three of the units (FHFCU, FHICU and FHWIH) is 140 mK over 100 seconds. The target temperature stability on all the remaining warm units is 30 mK over 100 seconds.

The above specifications have a deep impact on the TCS. Indeed, a fine control law has been implemented to meet the requirements.

SPIRE warm units (HSDPU, HSFCU and HSDCU) also request temperature stability level (AD04.2) for correct operation. The stability required, < 3 K/hour, is met by the TCS.

6.2.4.3 Spacecraft thermal design description

The overall Herschel thermal design is depicted in Figure 6.2.4-3.

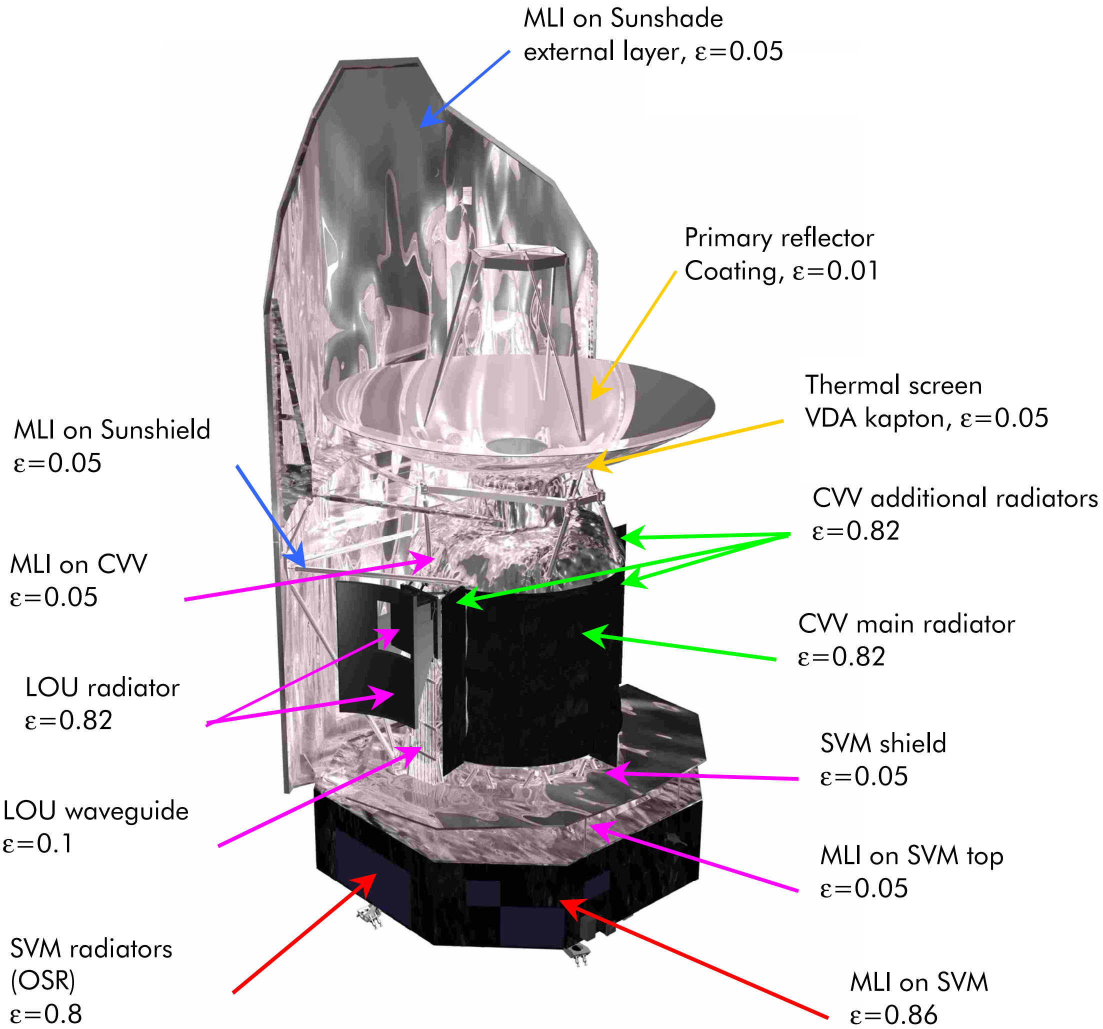


Figure 6.2.4-3 Herschel thermal design

Two very different temperature ranges can be distinguished for the various spacecraft elements:

– conventional range [120 K – 420 K] for:
  - the SerVice Module
  - the sunshield assembly (maximum non-operating temperature up to 140° C)
  - the sunshade (maximum at ~ 280 K).
– Cryogenic range (< 120 K) for most part of the H-PLM
  - Cryostat Vacuum Vessel and all the sub-systems and instruments cold parts inside (temperatures between 0.3 K and ~70 K in operation)
  - electronic box mounted onto the CVV (LOU) from HIFI instruments
  - Telescope (maximum temperature at 90 K).

Specific heat exchange constraints between the two modules are required in order to fulfil the 3.5 years lifetime specification. Basically, cold part of the HPLM is thermally insulated from the H-SVM. This is achieved on one side using Glass Fibber Re-inforced Plastic (GFRP) struts for conductive de-coupling and on the other side by MLI blankets as well as thermal shield to reduce the radiative heat loads between the modules to the lowest levels

The emissivity of the external layer is very low (Aluminium coating, $\varepsilon < 0.05$) in order to limit the radiative exchange between hot and cold MLIs.

To insulate more strongly the SVM from the PLM, a thermal shield is implemented between the SVM and the radiative parts of the CVV (+Z). A dedicated low conductive truss mounted onto the SVM supports this shield. The baseline, proposed by ASED, is to cover the +X side of this shield with a MLI blanket. This MLI may be removed as it is may not withstand the aerothermal flux and be replaced by a aluminised kapton foil glued on top of panel.

Besides the required thermal de-coupling between H-PLM and H-SVM, specific insulation within H-PLM is needed due to large operating temperature differences between sub-modules.

High efficiency MLI blankets are installed on the sunshield and sunshade assembly in direct view with cold H-PLM elements (again, Aluminium coating on external layer is used). The radiative insulation function is extremely important especially on the sunshade part, which have an important view factor with the telescope. It is also mandatory that the sunshade is as cold as possible. This means conductive insulation from the Sun shied, and use of Optical Solar Reflector on the Sun illuminated side.

The CVV needs to be as cold as possible in order to limit the heat loads towards its inner parts, therefore optimise the lifetime. For this purpose, the CVV is wrapped into high efficiency MLI (Aluminium coating for the external layer) where submitted to a warmer thermal environment than its average temperature (~ 70 K). The +Z side of the CVV is left uncovered by MLI and is black anodised in order to provide a high emissive surface. Three additional radiators are implemented in order to enhance the heat rejection capability of the CVV (additional surface exposed to space and shielding from sunshield/sunshade).

The present ASED baseline is to use Black Anodisation for the coating of the main radiator. The emissivity taken into account in the thermal analyses (RD06.11) is 0.82+/-0.03. This value comes from preliminary measurements. Complementary measurement of black anodisation are currently on-going. A decrease of the black anodisation emissivity to 0.58 at ~70K leads to a reduction of ~80 days in lifetime keeping it just above the requirement of 3.5 years.

The completion of telescope temperature requirements ([70K, 90K]) led to the use of thermal design solution similar to the one used on CVV. The telescope temperatures achieved are [72.3K; 92.8K] including margins. A intermediate screen has been introduced by ASEF on the - Xs/-Zs side to withstand sun illumination, that is not yet represented in TMM issue 4 (RD06.11). This screen shall decrease the telescope temperature by 1.8 K (preliminary computation).

6.2.4.4 Launch phase design impact

Herschel Payload Module thermal design is severely constrained by lifetime and by telescope and instruments focal plane temperature requirements as well. Indeed, H-PLM thermal design takes benefit from the orbit (sun and earth on the same side of spacecraft) to provide a high heat rejection capability. This means optimisation of the radiative surface area for high coupling with cold Space and also optimisation of thermal discoupling between cold and hot parts of the spacecraft (Aluminium coating on external sheet of MLIs,…). The thermal design must be however compliant with the requirements over the whole mission, i.e. from ground to end of operation. A major constraint is linked to the launch phase. The drawback of the H-PLM design is that it is very sensitive to Solar, Earth, aerothermal… heat fluxes inputs which may occur during the launch phase. The two important phenomenon arising during launch sequence are described hereafter.

6.2.4.4.1 "Barbecue Mode"

During launch phase, the Arianespace can not guarantee a full control of the attitude of the launcher. In particular, the spacecraft may experience a complete rotation around Xs axis at fairing jettison and at EPC separation with different roll rates. Those rotations induce a full illumination of the parts of spacecraft designed for cold environment. A description of the roll and pitch angle is presented in Figure 6.2.4-4.

In addition, after the EPC separation, the launcher will be submitted to the aerothermal fluxes with a profile defined in Figure 6.2.4-5. The aerothermal flux decreases very steeply from 1135 W/m² at fairing release to low values and then increases to ~450 W/m² to decrease again to 0.

Only Herschel is impacted by these fluxes as Planck is protected by Ariane's Sylda.

The difficulty of this phase is linked to the low emissivity coatings of the MLIs oriented towards –Zs (VDA on external sheet). α/ε is ~2.6 for Aluminium coatings. The external layers of MLIs will hence experience a high temperature during illumination by the sun. As the coating is also very reflective, multiple reflections may produce local concentration of solar flux.

Extensive computation have been performed to determine the heat flux profile on Herschel PLM and SVM and the temperature of the external sheets of MLIs taking into account conservative assumptions. Temperature as high as 650K are found on specific locations (Kapton maximal design temperature is 400° C/673 K in transient). The problem is then to determine the transition from mylar to Kapton foils in the MLI and the location of Dacron net spacer in order not to reach the melting temperature of Mylar or Dacron. An MLI design is proposed which makes extensive use of an additional Kapton blanket (7 embossed foils 0.3 mil + 1external foil from 1 to 5 mil) on top of a classically designed MLI (Mylar + Dacron net) for the most sensitive parts (sunshield /sunshade, SVM shield). A less costly design is proposed for the less critical locations with respect to solar or aerothermal flux.

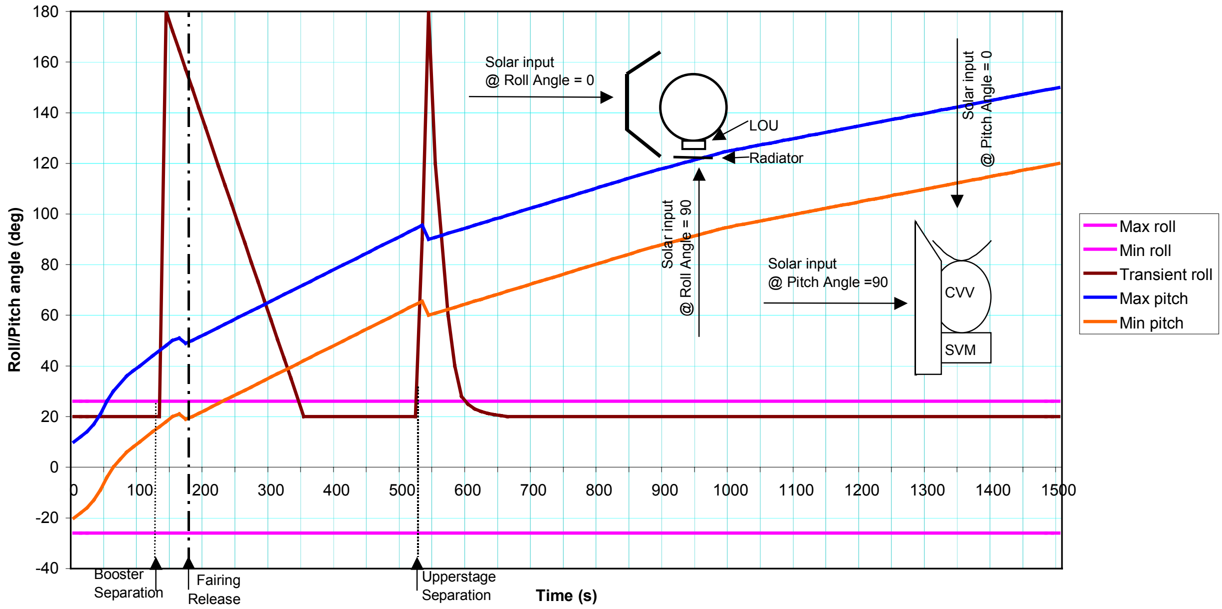


Figure 6.2.4-4 Pitch/Roll profile during launch sequence

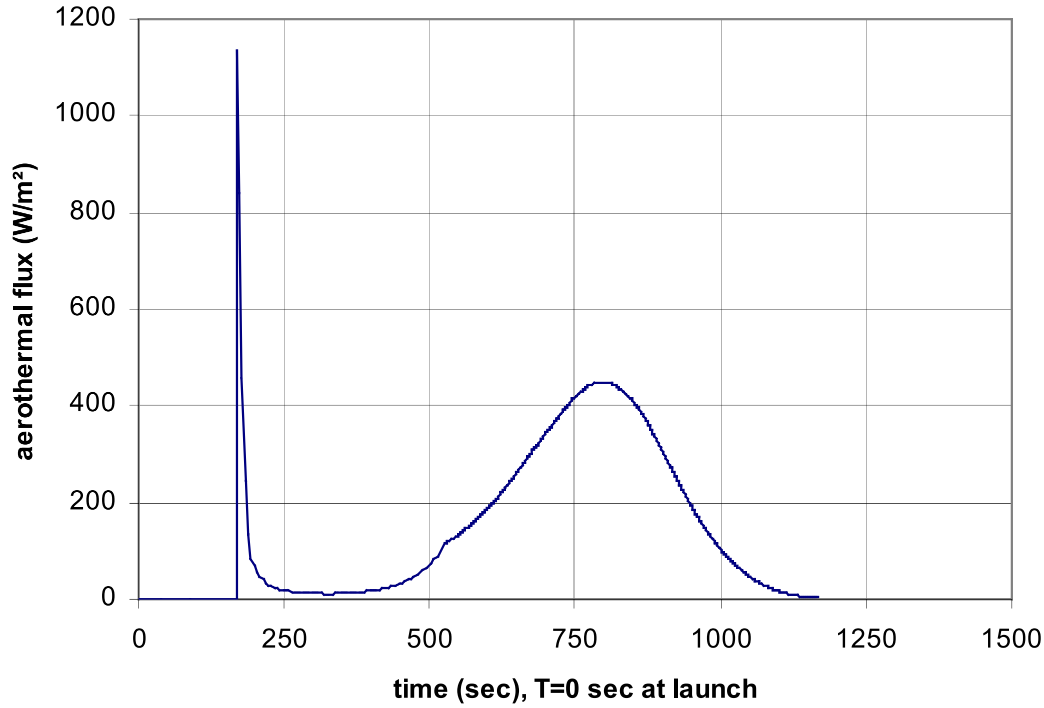


Figure 6.2.4-5 Aerothermal flux profile

6.2.4.4.2 *"Hot Spots Mode"*

During the "barbecue" mode, the reflection of sun on the M1 will fall on the sunshade. As the M1 is not flat, the illumination on sunshade is not uniform but takes the shape of caustics or concentration of solar rays. The shape of reflection depends on the (sun, Xs) angle and may form either almost punctual concentration (Figure 6.2.4-6 a)) or concentration along lines (Figure 6.2.4-6 b)).

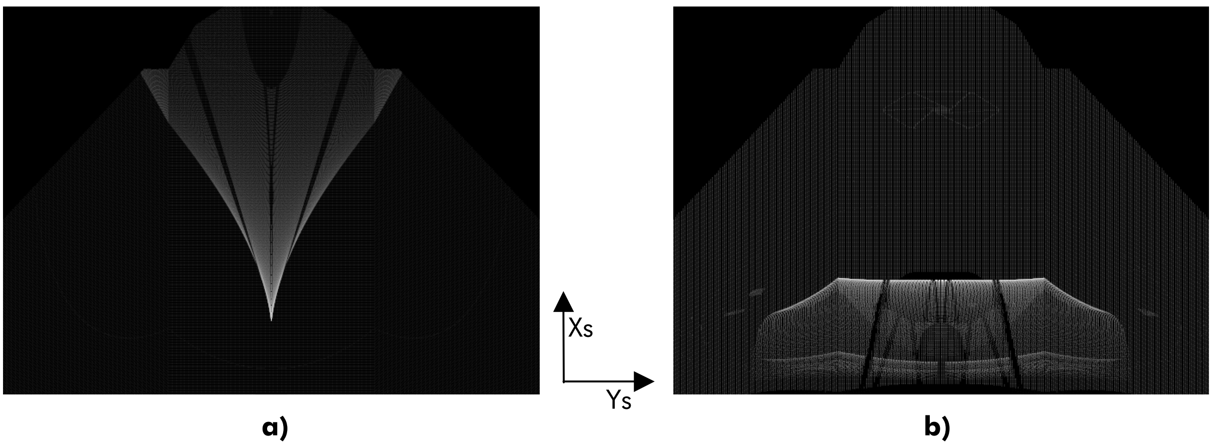


Figure 6.2.4-6 Typical illuminations on sunshade (sun is in –Zs direction)=:

a) (sun, Xs angle)=30°

b) (sun, Xs angle)=70°

Analysis showed that local concentration of solar flux could be as high as 50 times solar illumination (central spot of Figure 6.2.4-6 a)). Nevertheless, the flux can reach about 15 time solar illumination on more extended zones such as the bright line of Figure 6.2.4-6 b).

As the spacecraft rotates around Xs at 0.5°/sec (resp. 3°/sec) axis during the first (resp. second) "BBQ" mode, a local spot will travel across the sunshade at ~16mm/sec during the first BBQ transient and 96mm/sec during the second. For the extended concentration zones such as displayed in Figure 6.2.4-6 b), a point on the sunshade can be submitted to a long exposition during the rotation, leading to high energy deposits.

Two cases were defined to ASED in the frame of CR 633, one after fairing jettison (first "BBQ" transient) and one after EPC separation (second "BBQ" transient with combination of solar and aerothermal flux). Extensive computation performed by ASED showed that the maximum temperature on external layer was not due to the highest local concentration, but to a concentration line similar to Figure 6.2.4-6 b) obtained during the first "BBQ" mode at 50° SAA.

The proposed MLI lay-up what can withstand the reflections on M1 uses an additional MLI Blanket made of seven embossed 0.3 mil VDA kapton layers + one VDA Kapton layer with thickness in the range 1 to 5 mil (external layer) on top of a more classical lay-up made of 0.3 mil kapton, 0.25mil mylar and dacron spacer. The thickness of the external layer (1 to 5 mil) depends on the location of the MLI on the sunshade.

6.2.4.5 Star Tracker assembly

The star tracker have been moved from the SVM to the bottom part of the CVV for thermo-elastic reasons (see Figure 6.2.4-6).

Requirements on the stability of temperature insure the proper pointing of star tracker:

- maximum temperature rate of 25° C/100sec at Star tracker mounting plate
- amplitude of temperature variation below 0.5° C around any set point
- maximum gradient between star tracker feet below 0.4° C.

This new location induces an additional heat load on the CVV due to the conductive losses along the six fixation struts. This heat load has been specified at 200mW on the CVV. The lifetime impact of this new dissipation is ~14 days.

The thermal control of the STR aims at:

- Limiting the conduction from star tracker to CVV by the use of GFRP struts filled with foam
- Preventing the heating of the struts by the SVM by a MLI blanket surrounding the struts
- Insuring a good thermal stability of the star tracker base plate by the use of Al honeycomb with 2+3mm K1100 carbon fibre skins
- Suppressing the solar inputs on star tracker by using an MLI baffle and sun shade, covered by silver Teflon
- controlling the star trackers temperature by an heating line commanded by a fine control law (PI regulation).

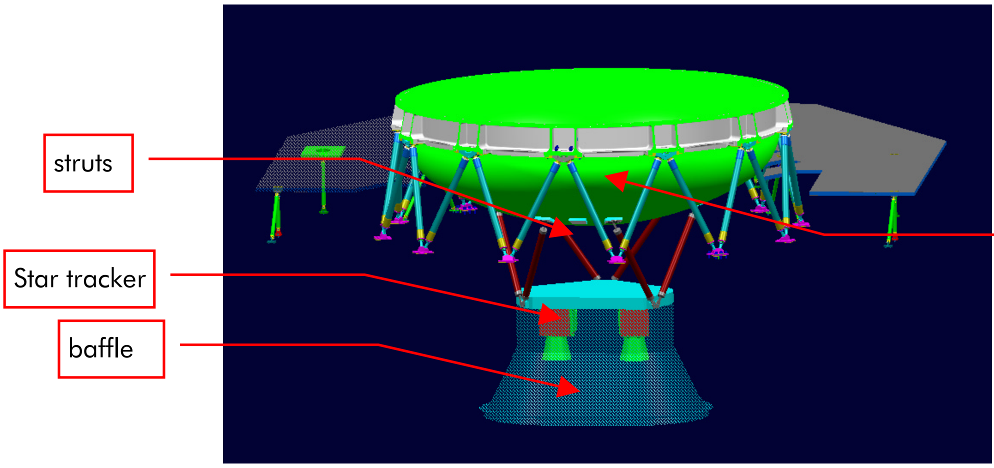


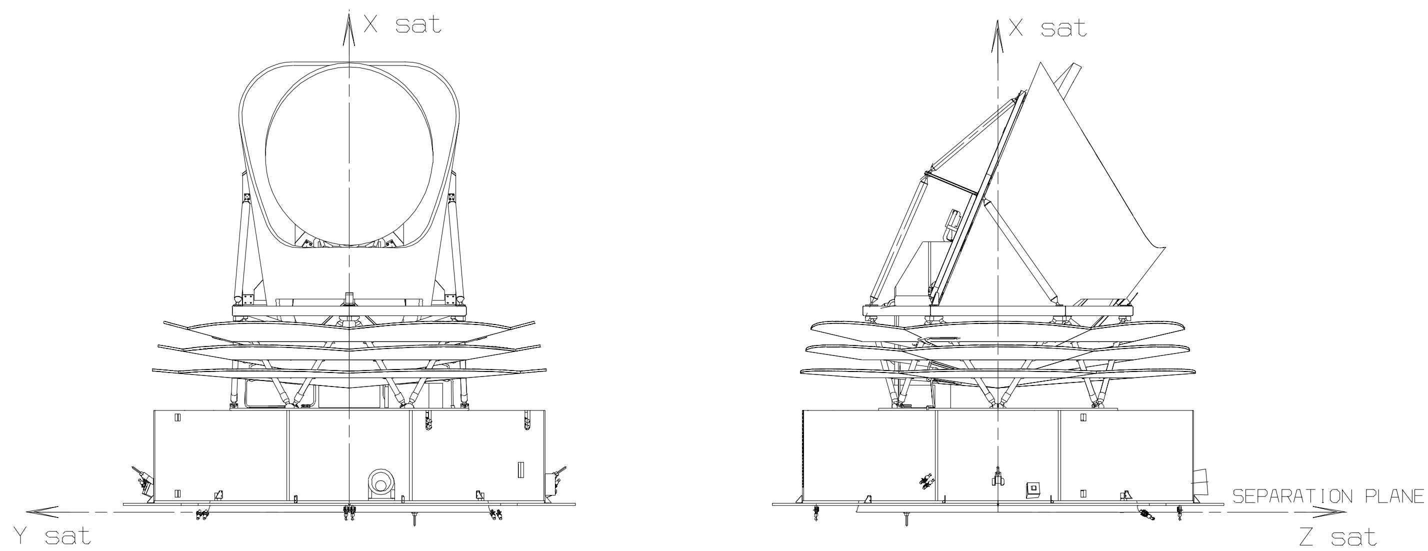
Figure 6.2.4-7 Star tracker implementation on CVV bottom

6.2.5 Planck mechanical design

6.2.5.1 Axis convention

The Planck satellite reference frame (O, X_X, Y_X, Z_x) is defined such that:

- its origin O is located at the point of intersection of the longitudinal Launcher and the Satellite/Launcher separation plane; the origin coincides with the centre of the Satellite/Launcher separation plane
- Xs coincides with the nominal spin axis of Planck. Positive XS axis is oriented opposite to the Sun in nominal operation. The XS axis coincides with the launcher longitudinal axis
- Zs is such that the Planck telescope line of sight is in the (XS, ZS) plane. The telescope is pointing in the +ZS half-plane
- Ys completes the right handed orthogonal reference frame.



6.2.5.2 S/C configuration and updates

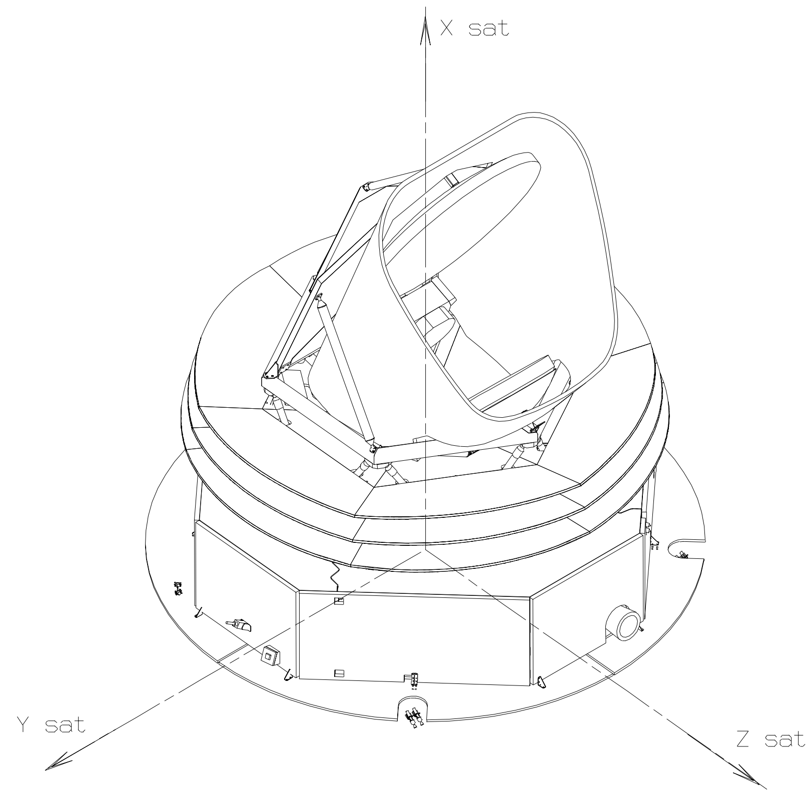
Planck baseline configuration and updates, are presented hereafter with some details. Planck overall configuration is kept very similar to PDR original configuration.

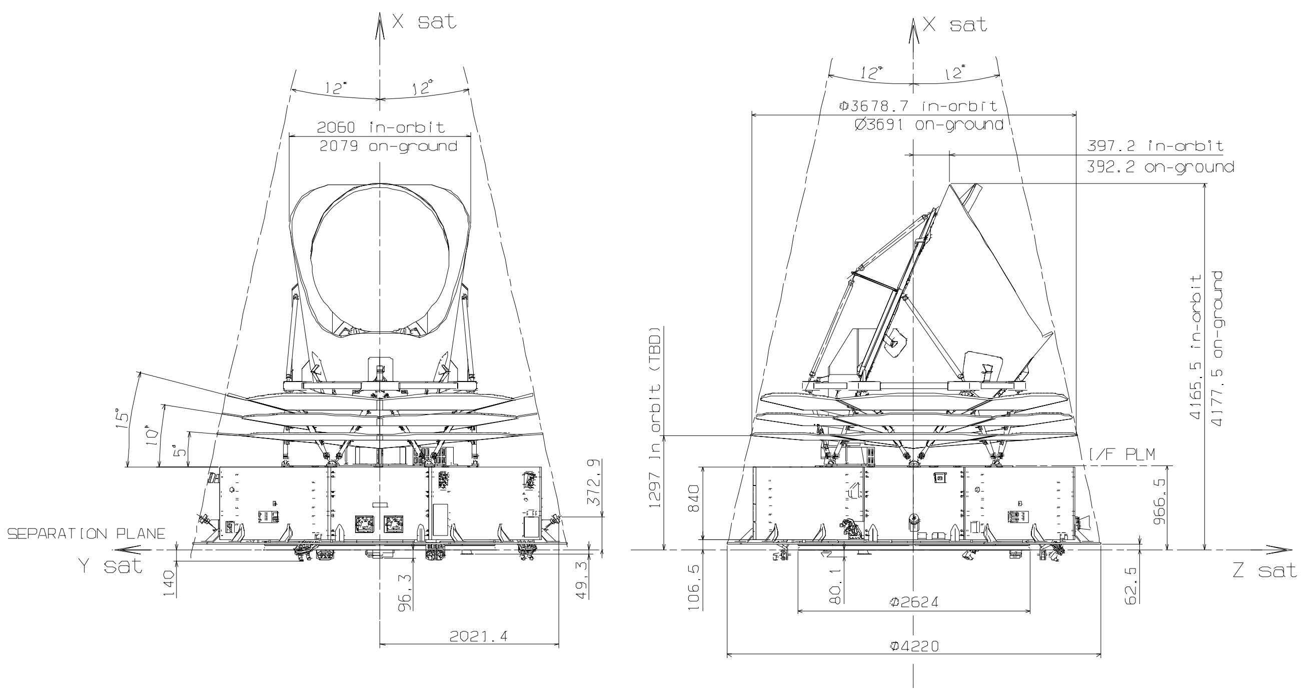
General update of S/C configuration

The most visible changes from PDR are:

- REU has been relocated from +Z to +Y panel
- DPU on shear web has come back on +Z panel
- Layout of units on +Y panel updated
- Definition of instruments pipes routing on SVM
- Definition of harness (SVM and instruments) routing in SVM.

Planck satellite overall dimensions remains quite the same as before.





Status of main P-PLM to SVM interfaces definition

It is considered all Modules interfaces are considered frozen at the time of System CDR. This results from common technical discussions between all involved parties (ASP, ALS) to consolidate and complete previously defined Interfaces at PDR time.

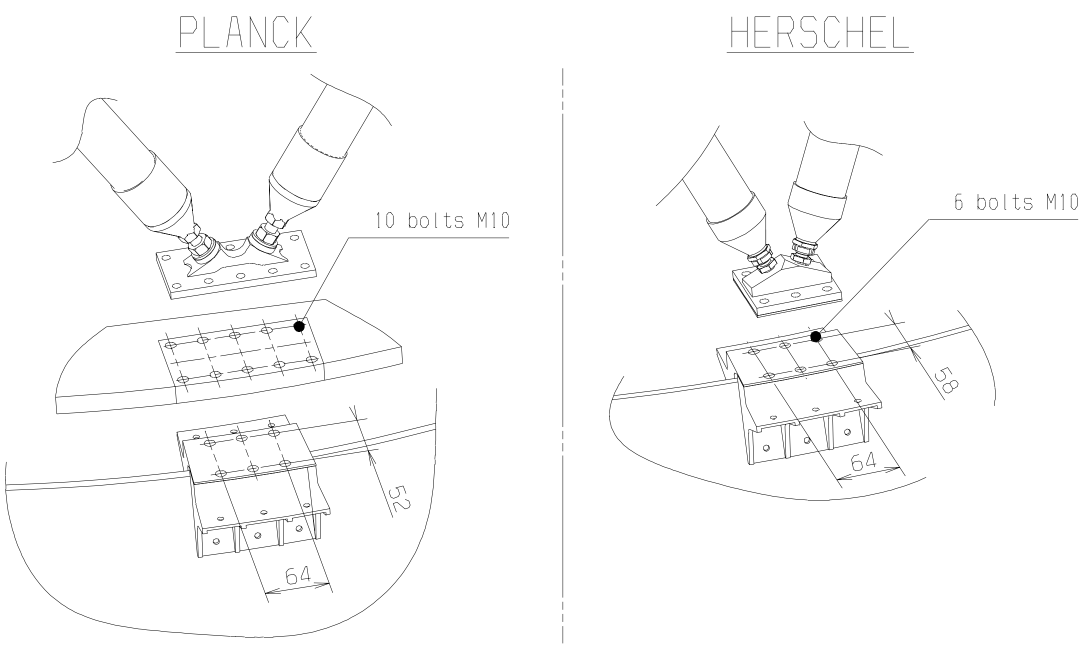
As a recall, the main P-PLM and SVM mechanical Interfaces covers:

- the PLM supporting IF on P-PLM sub-platform
- the P-PLM allocated volume.

The main evolutions and freeze of the PLM IF definition can be summarised as follow.

PLM supporting IF on central cone: see drawings in RD 05.3 and 05.4

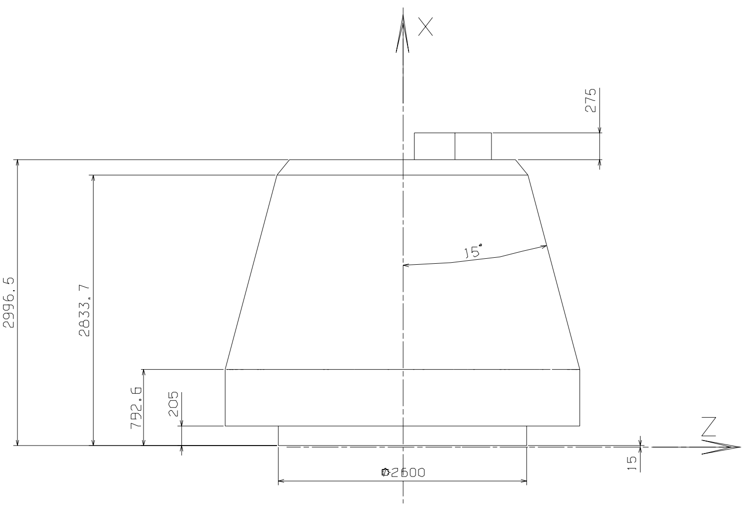
- IF basically frozen by April 2002, keeping a common IF concept with Herschel H-PLM with similar IF brackets on central cone. Minor evolution as clarification on holes positional tolerances finally implemented in following updates. See Figure below.

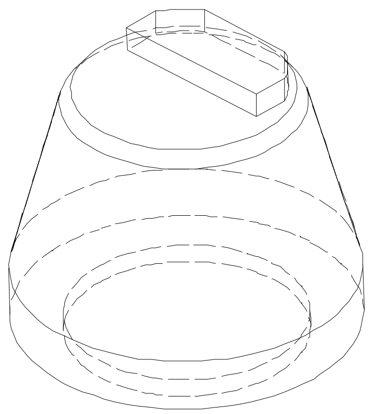


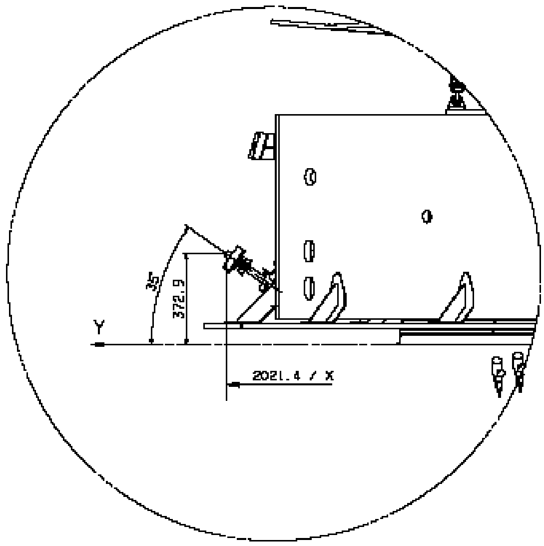
- Footprints definition and location harmonised between H-PLM and P-PLM, with implementation of bolts M10 for Herschel and Planck.
- PLM struts interfacing with P-PLM sub-platform for Planck, when Herschel H-PLM has a direct interface with the SVM cone.
- A direct interface with PLM struts for Herschel (it is a source of mass saving for PLM sub-platform put aside the main load path), with PLM struts connected to SVM brackets fixed on top of the central cone.

Allocated volumes for P-PLM: see drawings in RD 05.4

The P-PLM allocated volume remains similar to the one defined for PDR. A small modification was however implemented in February 2003. The P-PLM volume was reduced in its lower part, to be tailored to P-PLM real shape (at first groove), to allow at SVM level a better consideration of SAS and L/Ga antennae fields of view. This drawing was lately updated to consider new implementation of Planck beneath a SYLDA5 adapter (instead of SPELTRA). This obliged to reduce P-PLM volume at the top to cope with a lower volume inside SYLDA5, because of Satellite adapter height increase (by Arianespace). This was however compatible with physical dimensions of P-PLM. For clarification a volume has been defined in launch configuration and a second one provides in-orbit allocation. Refer to RD 05.4.

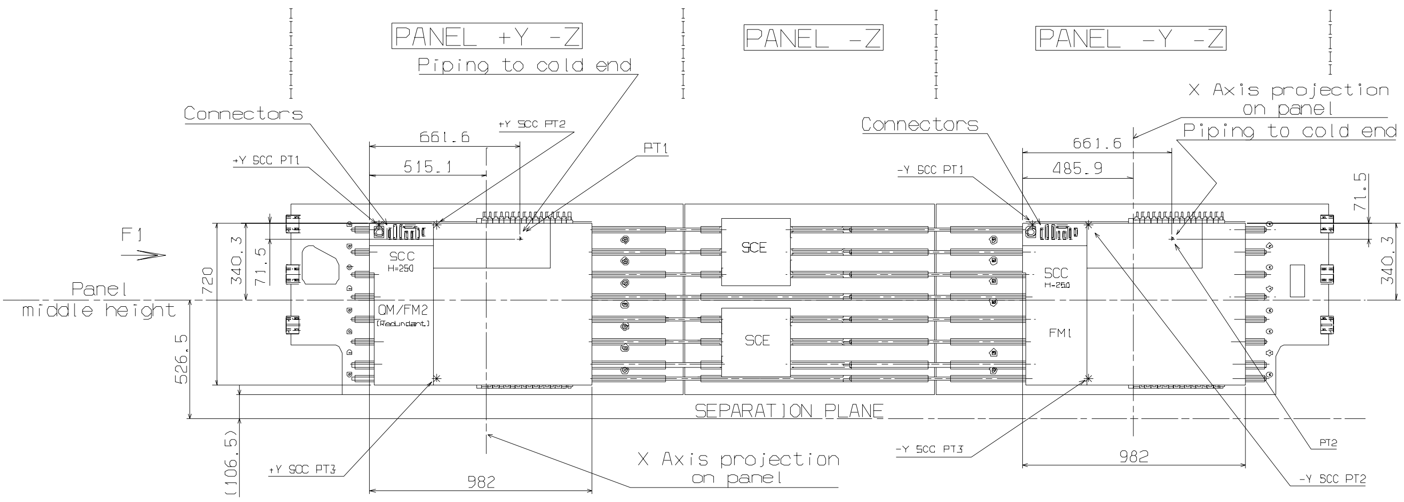


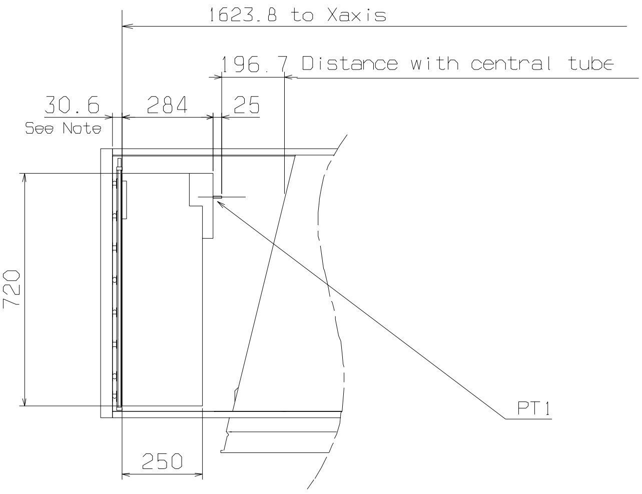




SCC accommodation: see drawings in RD 05.4

The SCC accommodation and access drawing was basically frozen in March 2003. It allows freezing position of SCC on both +Y-Z panels and –Y-Z panels, and location of SCC port on SCC. It was subject to a minor update in February 2004 to account for removal of SCC IF plate, without impact on structural interfaces.



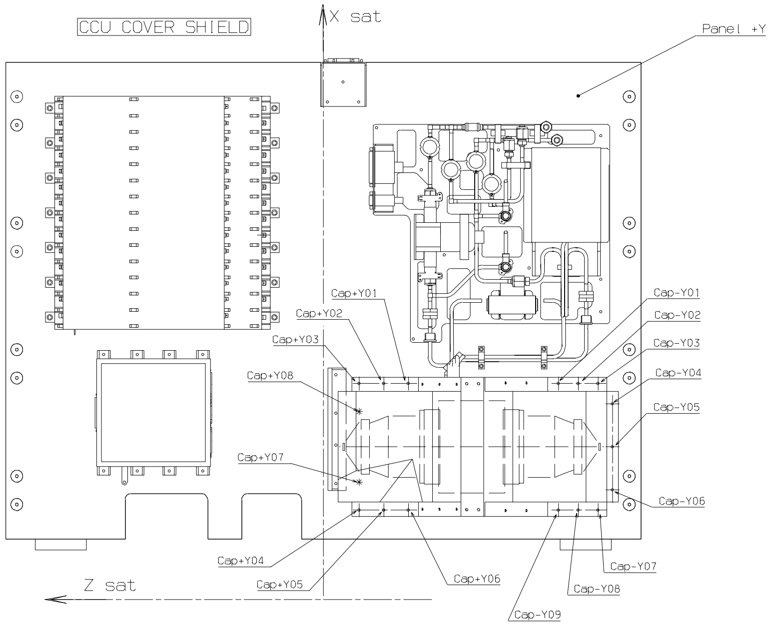


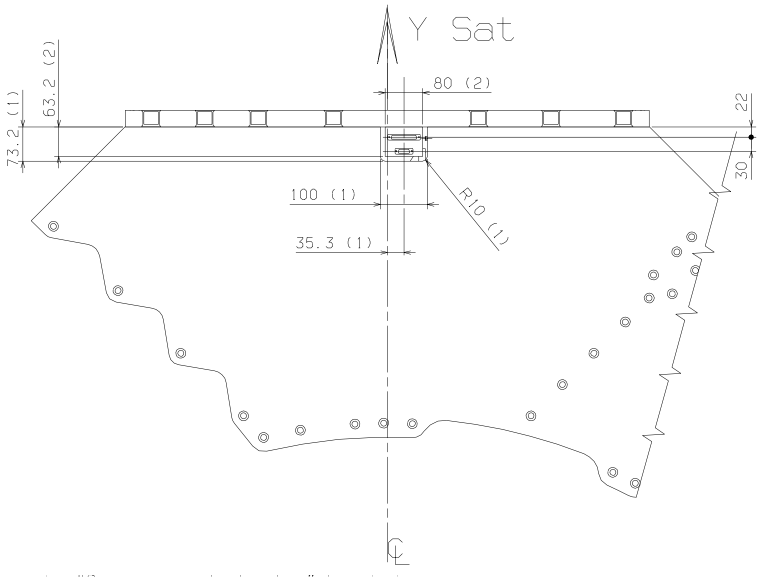
Each SCC is laying down a net of vertical heat-pipes, to homogenise SCC thermal loads between SCC beds:

- SCC assembly on vertical pipes is supported by a net of horizontal pipes crossing all 3 SCC panels, to carry SCC thermal loads from one dissipating panel (SCC on) to the other SC panel (SCC off)
- SCC are supported by height-calibrated stilts, which allows a stiff connection on SCC panel, and allows an homogeneous contact pressure between all thermal interfaces (SCC to vertical heat-pipes, and vertical heat-pipes to horizontal pipes).

4K Accommodation and Access: see drawings in RD 05.4

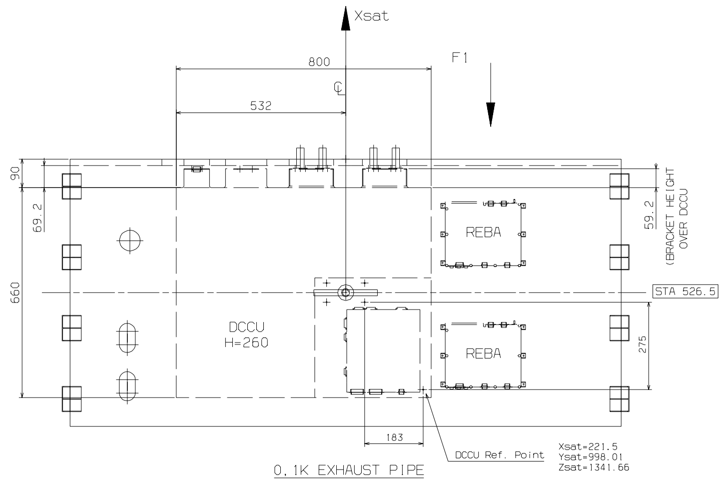
The 4K accommodation and access was started in May 2002. It allows defining cut-out in SVM upper panel to access 4K CCU connector lock (to block internal mechanisms during on-ground testing). It was deeply updated in September 2003 to take into account modification of +Y panel accommodation. The move of REU WU on this panel necessitated to re-arrange of 4K equipment and 4K CCU connector lock. A last change was introduced in October 2003 to define fixation points for 4K CCU EMC shield.

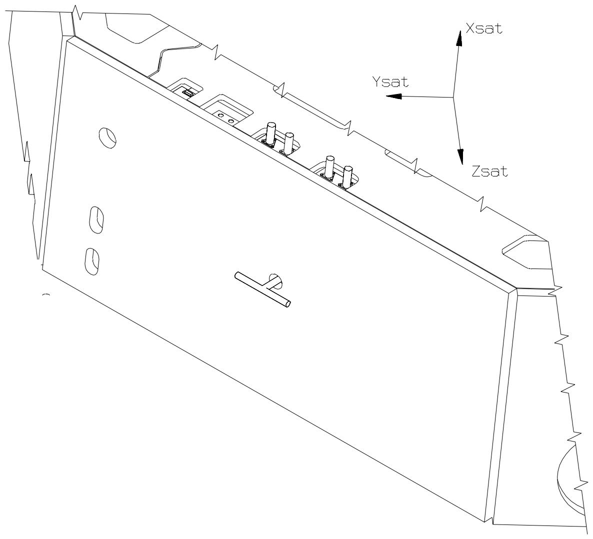




0.1K Accommodation and Access: see drawings in RD 05.4

The 0.1K accommodation and access was frozen in March 2003. It allows defining cut-out in SVM upper panel for on- access to 0.1K units in SVM. A last minor modification was introduced in October 2003 to define fixation points for DCCU exhaust outside +Y+Z panel.



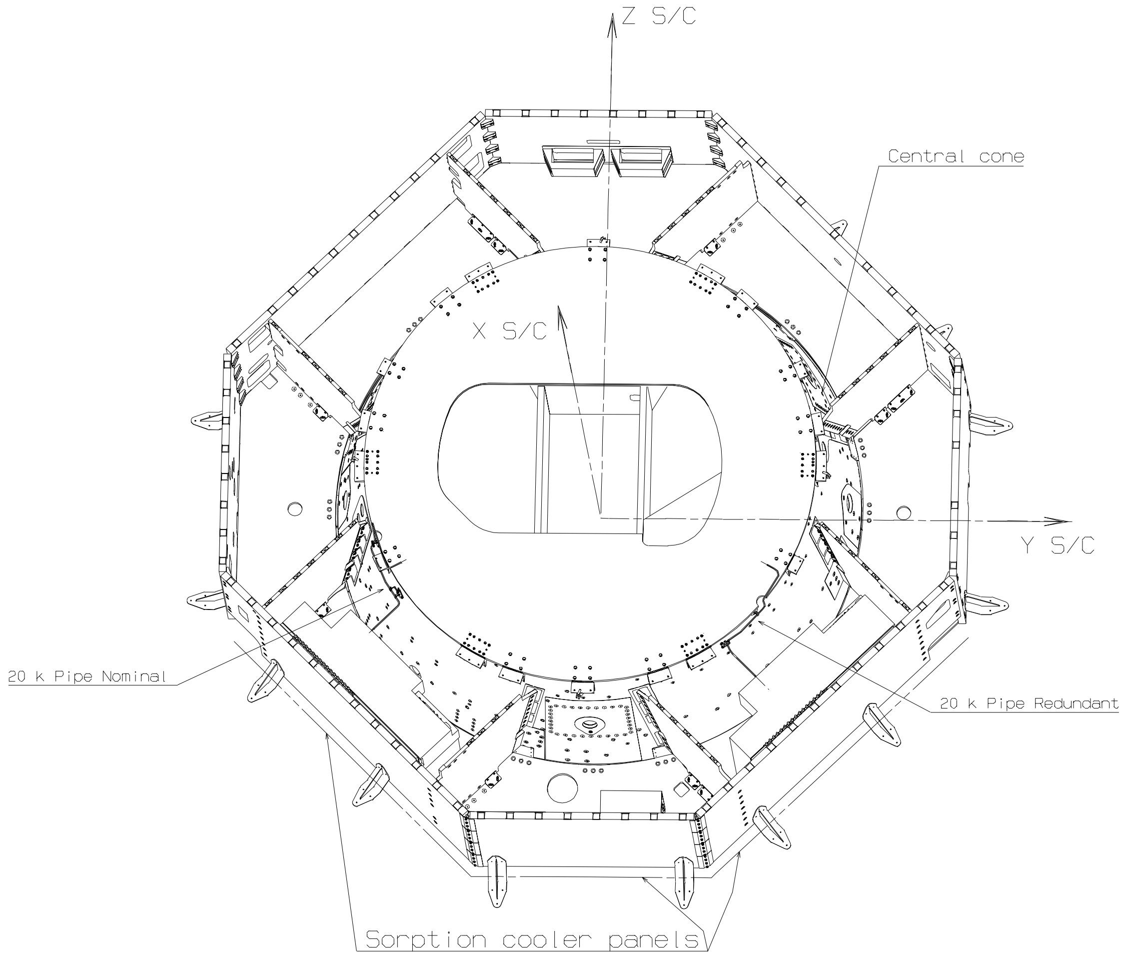


The 0.1K accommodation and access drawing allows defining following interfaces in SVM structure:

- cut-out location and geometry on top of SVM upper closure panel, for access to DCCU fill and drain ports, during on-ground DCC operating
- cut-out location and geometry, for DCCU exhaust passing through and fixation point on SVM panel
- cut-out location and geometry in SVM lower closure panel, to access to port of ^{4}He Tank in –Z quadrant, when SCC panels are in place.

20K Piping Interface: see drawings in RD 05.4

The 20K piping interface drawing was produced in June 2003, with a small modification in May 2004 to modify pipe end at SCC interface, without impact on SVM structure.

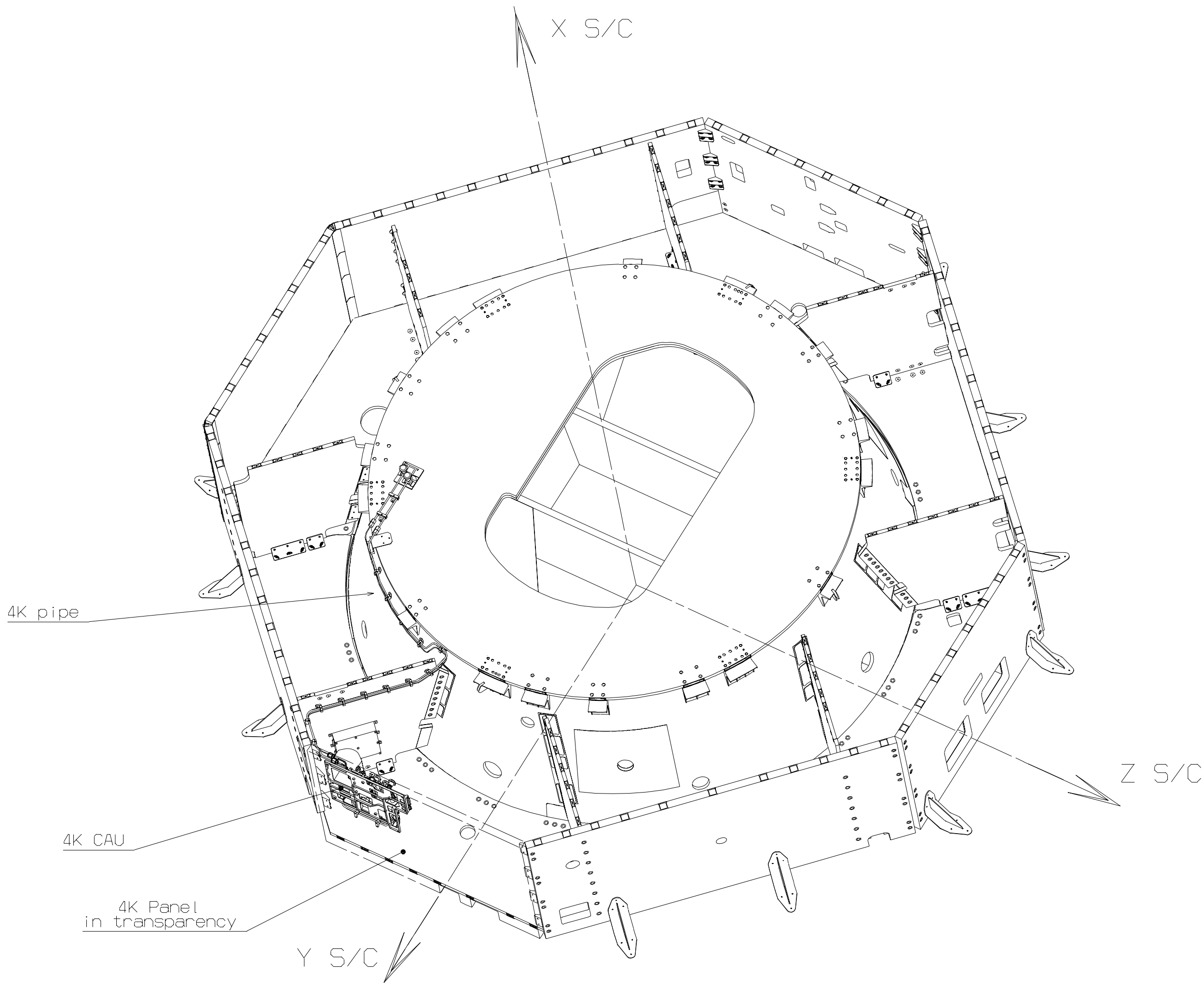


The 20K piping interface drawing allows defining all interfaces and co-ordinates with SVM on cone. It covers both PACE nominal and PACE redundant routing, namely:

- location of SCC ports and co-ordinates
- geometry of pipe routing on SVM, considering maximum bending radius defined by the Instruments, with definition of fixation points co-ordinates at pipe level
- location of pipe support (stand-off) interface points on SVM and co-ordinates. The pitch stand-off was defined in agreement with Instruments (JPL) analysis, necessitating several iteration before to freeze it.

4K Piping Interface : see drawings in RD 05.4

The 4K piping interface drawing was produced in May 2003, with a small modification in February 2004 to modify pipe end at 4K CAU interface in line with instrument last definition, without impact on SVM structure.

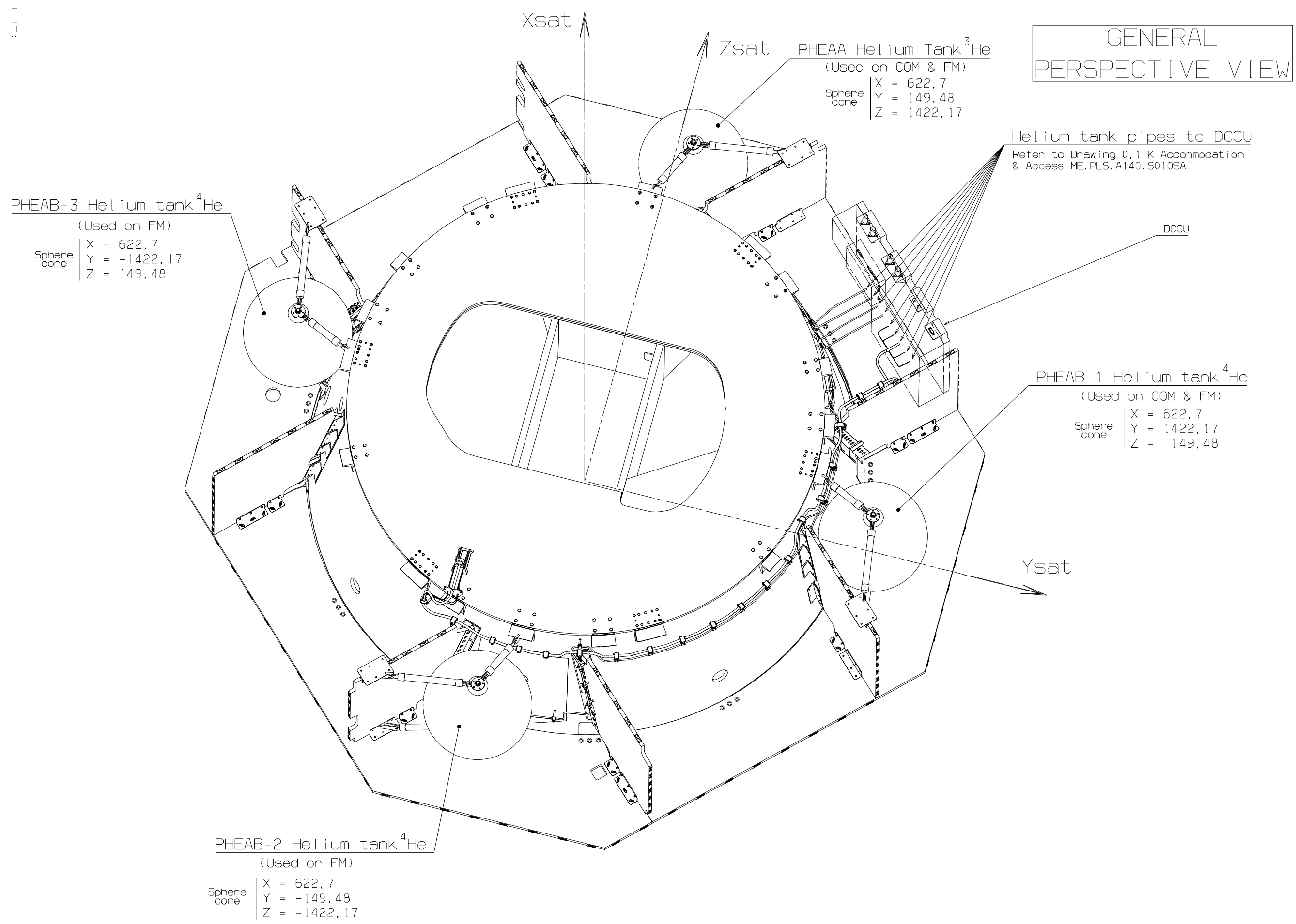


The 4K piping interface drawing allows defining all interfaces and co-ordinates with SVM on cone (mainly) and shear walls. It covers 4K CAU pipe to PLM Interface connector on Planck sub-platform, namely:

- location of 4K CAU ports and co-ordinates
- geometry of pipe routing, considering maximum bending radius defined by the Instruments, with definition of fixation points co-ordinates at pipe level
- location of pipe support (stand-off) interface points on SVM and co-ordinates. The pitch stand-off was preliminary defined in accordance with pipe general design rules (minimum pitch is required for having have pipe frequency above140 Hz as a target), and refined according to Instruments feed-back.

0.1K Piping Interface : see drawings in RD05.4.

The 0.1K piping interface drawing was produced in May 2003, with a small modification in February to take into account a slight move of He Tank decided by SVM Contractor.

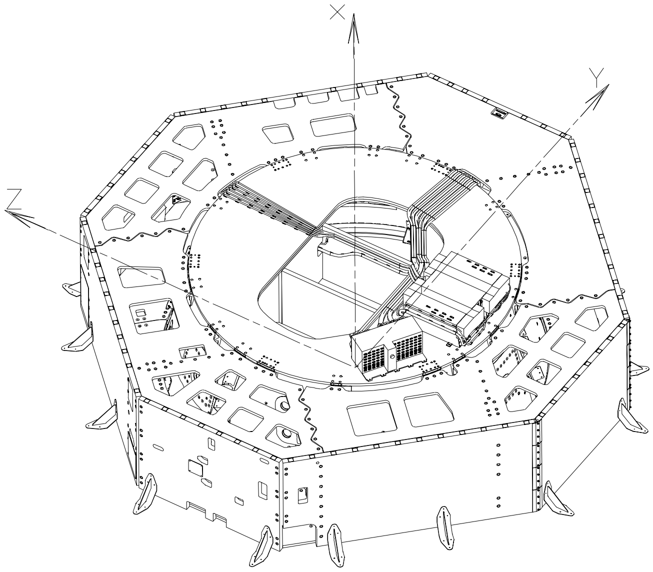


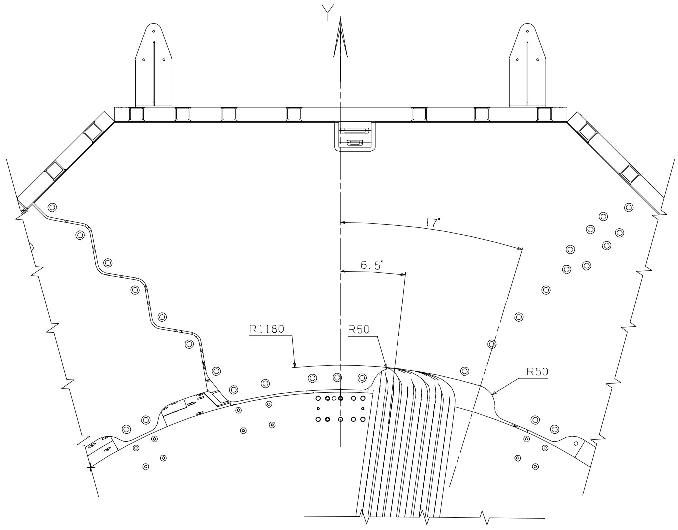
The 0.1K piping interface drawing allows defining all interfaces and co-ordinates with SVM on cone (mainly) and shear walls. It covers DCCU to 4He Tank (x3) II and 3He Tank (x1) pipe and 4K CAU to PLM Interface connector on Planck sub-platform, namely:

- location of He Tank ports and co-ordinates, with definition of allocated for pipe loop
- location of DCCU ports and co-ordinates
- geometry of pipe routing, considering maximum bending radius defined by the Instruments, with definition of fixation points co-ordinates at pipe level
- location of pipe support (stand-off) interface points on SVM and co-ordinates, with rules as defined for 4K pipes.

Stay-in volume for PAU-REU harness: see drawings in RD 05.4

The PAU-REU harness routing and bundles size needs to define a minimum cut-out in SVM upper closure, to allow the PAU-REU harness passing from the sub-platform to the inside of the SVM box. In fact, it was just necessary to enlarge one existing cut among all cut implemented at the edges of the upper closure panel. The Stay-in volume for PAU-REU was finalised in January 2004, in agreement with SVM structure supplier.





Other interfaces specification

In addition of the PLM to SVM Interfaces, a certain number of Interfaces has been defined in RDXX:

- satellite level:
- ALIGNMENT CUBE ACCESS
- Launcher IF:
- INSIDE ARIANE5 SYLDA5
- I/F RING DEFINITION
- ANTENNA CONFIGURATION
- other SVM IF:
- THRUSTER ACCOMMODATION
- BALANCING MASSES
- SCC ACCOMMODATION
- 0,1K ACCOMMODATION AND ACCESS
- 4K ACCOMMODATION AND ACCESS
- other PLM IF:
  - S.A. SHADOWING CAPABILITY

  SVM MLI IN VIEW OF PPLM
- MGSE IF

  SATELLITE HANDLING

Mechanical Requirements

All main mechanical requirements were already frozen at the time of the system PDR. A change in P-PLM QSL loads has been implemented February 2003 on basis of post PDR analysis with P-PLM updated FEM. A short summary of main of main mechanical requirements is provided hereafter.

Stiffness requirements

All stiffness or frequency requirements were frozen at system PDR.

– Stiffness requirements are declined in frequency requirements and rigidity requirements. Frequency requirements qualify the global stiffness behaviour of these modules, in consistency with stiffness requirements to be achieved at System level. On the other hands, rigidity requirements are defined at SVM level only, in complement to frequency requirements, to qualify local stiffness needs at specific interfaces.

Frequency requirements for SVM and P-PLM are defined as follows:

– SVM frequency requirement

  SVM design shall ensure that eigen frequencies of Planck main global modes fulfil the following mathematical expressions:

  - longitudinal main mode > 60 Hz
  - lateral main mode > 35 Hz.

  Considering a P-PLM of 336 Kg at an absolute location X = 2.0 m.

– P-PLM frequency requirement:

  The eigen frequencies of P-PLM main global modes, on a rigid support, shall fulfil the following mathematical expressions:

  - longitudinal main mode > 44 Hz
  - lateral frequency Y > 18 Hz
  - lateral frequency Z > 26 Hz.

P-PLM/SVM interface loads:

Interface loads at SVM to P-PLM interface (cryo. structure struts roots) are to be simply calculated by application of QSL loads at CVV CoG. Modification of P-PLM QSL loads after PDR is highlighted hereafter:

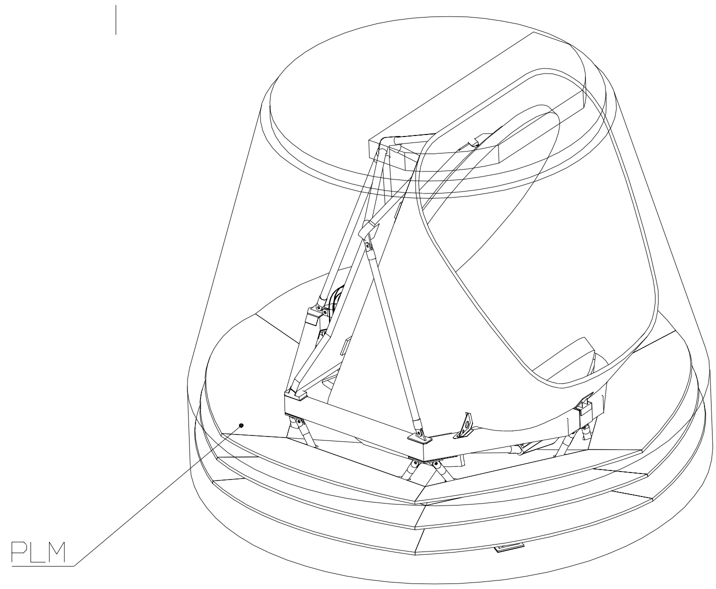
	X longitudinal		**Y lateral**		**Z lateral**	
Load Cases	**new**	**old**	**new**	**old**	**new**	**old**
1	+ 16.5g	+ 15g	-	-	+ 6g	+ 5g
2	+ 16.5g	ND	-	ND	- 6g	**ND**
3	-		+ 13g	+ 15g	-	
4	+ 5g	+ 5g	-	-	+ 13g	+ 15g
5	+ 5g	- 10g	-	-	- 13g	+ 15g

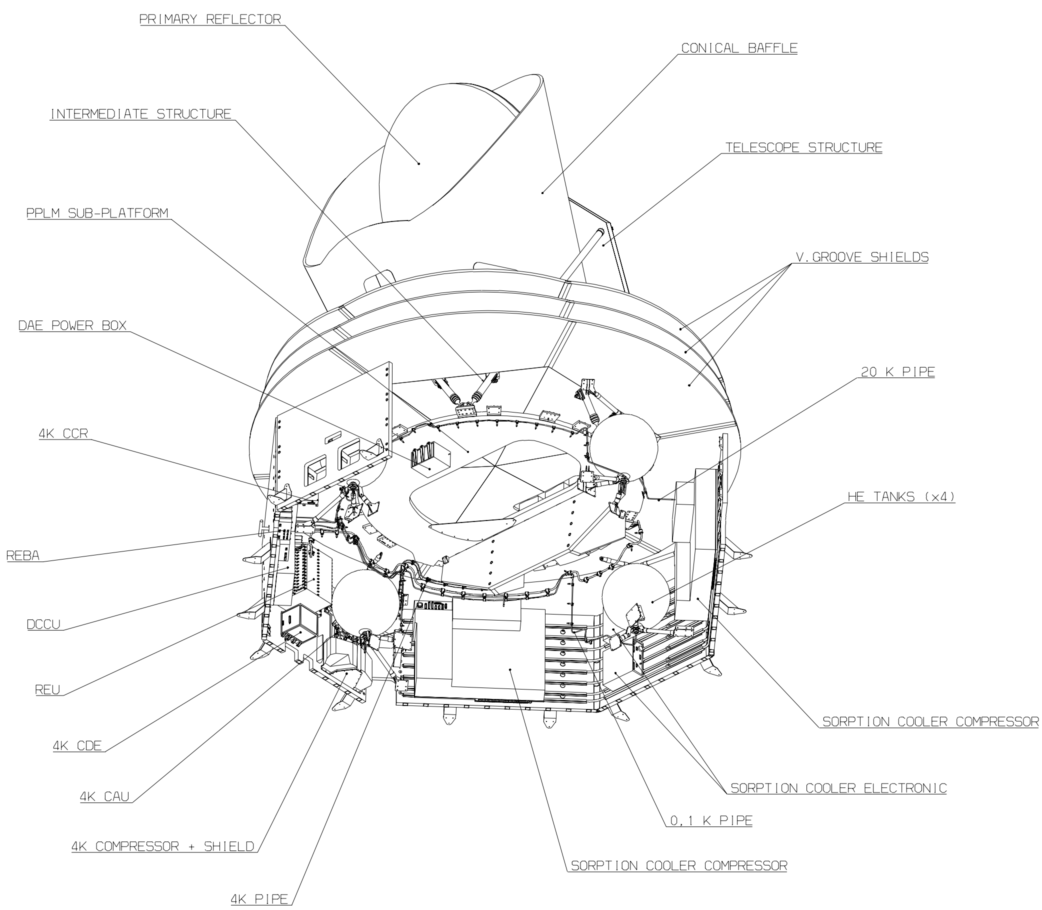
Table 6.2.5-1 P-PLM to SVM interface loads (design loads)

6.2.5.3 P-PLM configuration and update

General Architecture

The following figures show the overall view of the P-PLM with the part of the Instruments supported by the P-PLM.





Main P-PLM evolutions

The main significant evolutions of the PPLM since PDR regarding mechanical and thermal architecture and design can be described as follows:

- Increase of the groove 1 size in order to improve the margin wrt the shadowing constrain for the grooves 2 and 3, the baffle and the telescope
- Implementation of brace struts to minimise the dynamic displacements of the grooves close to the instrument interfaces
- Increase of the telescope SR struts stiffness to optimise the dynamic behaviour of the PPLM and in particular to decrease the mechanical loads on to the SR
- Optimisation of the telescope lower beam design to improve the thermoelastic stability of the FPU interfaces
- Reinforcement of the corner of the telescope frame
- Detailed definition of the thermal shields to close the optical cavity
- Detailed definition of the thermal shields to close the grooves
- Instruments interfaces and accommodation. For details refer to RD 01.3.

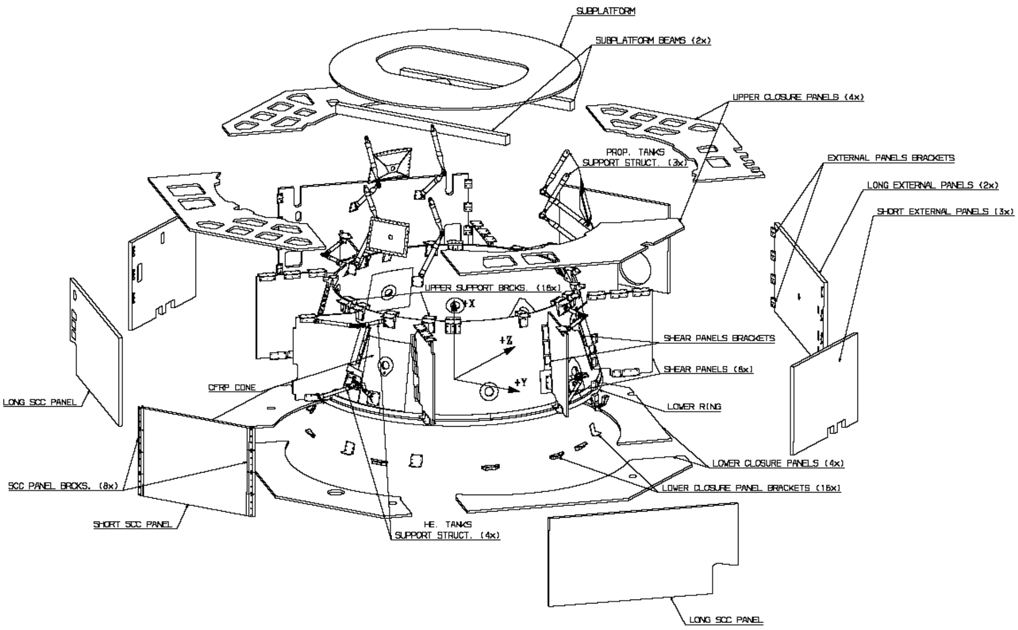
6.2.5.4 Update of SVM configuration

Planck SVM structure

After the PDR, it was decided for schedule optimisation to split the phase C/D design and manufacturing tasks in three batches with three corresponding milestone : MRR1, MRR2, MRR3.

- MRR1 has been held in July 2003 for reviewing the design of the central cones and propellant tanks supports.
- MRR2 has been held in December 2003 for reviewing the design of the 'equipped cone', i.e. the shear webs, upper and lower closure panels, the helium tanks supports for Planck.
- MRR3 will be held by end 2004 for reviewing the design of the lateral panels, sub-platform and secondary structures.

The following pictures is giving an overall view of Planck SVM structure.



The manufacturing of MRR1 and MRR2 elements for both STM and FM is in progress.

A CDR is also planned in July 2003 with the purpose of reviewing the whole structure and make sure of the compatibility of all the elements, mainly with respect to the interface loads between elements.

The main critical points encountered in the design of the Planck SVM structure are summarised hereafter.

Design of the Planck sub-platform

The main design driver for the sub-platform is the modal de-coupling with the propellant tanks and the P-PLM. All along the design phase, it has been necessary to make sure that the natural frequency of the sub-platform presents no coupling with the propellant tanks and P-PLM, to prevent high acceleration levels on the sub-platform units. A frequency range 70-76 Hz was specified for this purpose. This frequency specification was difficult to reach because the interfaces to the cone were already frozen and then the only mean was to reinforce the panel with very large stiffeners.

Mass optimisation, modification of the design loads

A permanent mass increase of the structure was observed since the PDR, up to a unacceptable point where the specified launch mass of the satellite was exceeded. A mass saving of about 50 kg for Herschel + Planck structures was then requested. Two actions allowed to reach this objective:

- modification in the methodology to dimension the lateral panels joints
- revision of the design loads, based on reduced sine levels at the satellite basis, in agreement with ESA.

Very high density of instruments accommodation

One of the main features of the Planck satellite is the very complicated payload interface. The consequence is a very large number of inserts (about 1300) with in some areas inserts proximity's and high loads leading to a difficult structural design. This is specifically the case for the SCC panels and the sub-platform where special inserts grouping several attachment points had to be designed. This was one of the reason of the mass increase during the C/D phase.

Local stiffness of lateral panels

Stiffening of the SCC panels was necessary to reduce dynamic panel bending and resulting stress on SCC internal pipes. Stiffening of 4K panel to de-couple it with 4K compressor fundamental frequencies, to prevent amplification in transmission of 4K compressor micro-vibrations to the payload. It was then necessary to add an external stiffener on one SCC panel. This was not possible for the 4K panel because of the needed radiator surface. The skin thickness of this panel was then increased in order to reach the 50 Hz frequency requirement.

Equipment layout and updates

Power (PCDU and battery), data (CDMU) and attitude control (ACC) units are still located on –Ys +Zs long panel, the layout has been improved but they all remain on the same panel. The layout is the same as Hershel one.

Communication equipment are also still placed on –Ys short panel, design has been refined too leading to minor accommodation improvements (swapping of units). The layout is similar to Hershel one, main disparities being due to difference in antennae location.

SREM, VMC and FOG accommodation

VMC has been finally removed from Planck.

The best location for SREM has been found on outside of +Y+Z lateral panel, under DCCU exhaust pipe. It has been placed to avoid any interference with exhaust pipe plume not to perturb Satellite spin rate.

A cut-out has been made in lower right part of the panel to allow the harness supplying the SREM connecting it. The harness runs partially outside satellite and is shielded in that part.

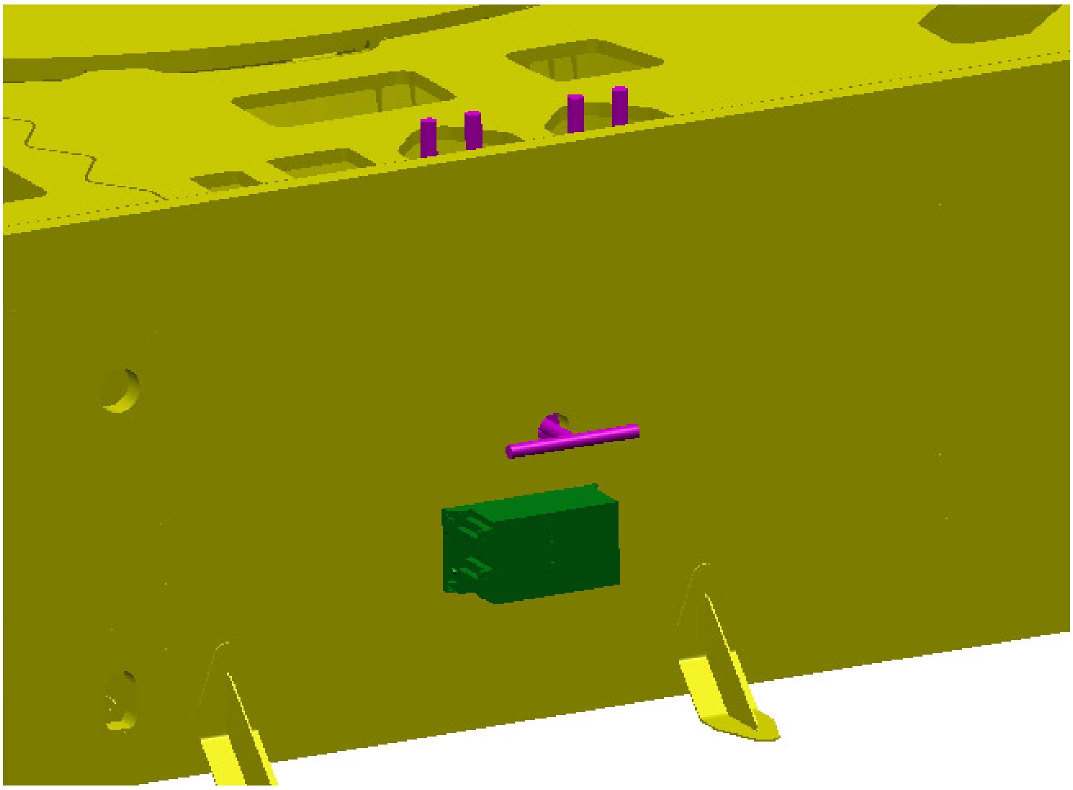


Figure 6.2.5-1 SREM accommodation

The FOG has been set on +Y+Z (+Z) shear panel in DCCU and REBA zone. The ICU, Gyro optics, has been placed over the GEU, electronics with compatible area for interconnecting harness. The location has been also driven by the fact that the interface points have to match the other through inserts used for pipes, bracket and recently 4K CRU.

The harness from PCDU and CDMU is coming from the lower cut-out in shear web.

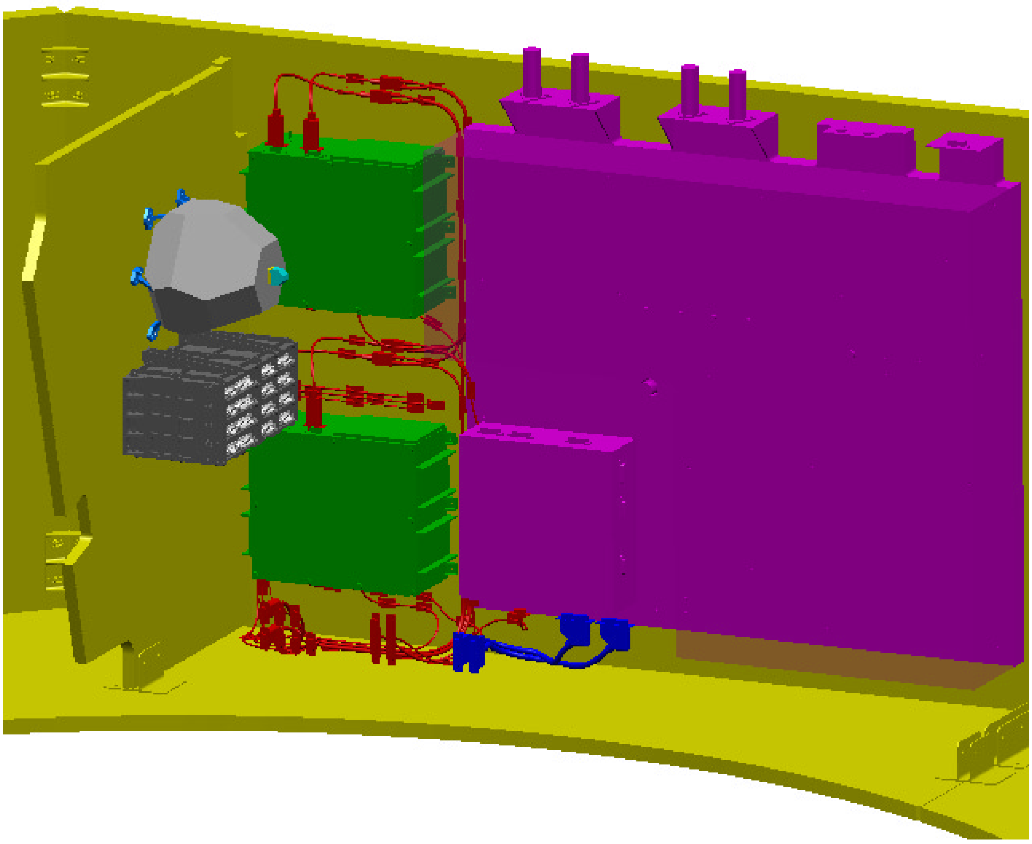


Figure 6.2.5-2 FOG accommodation

STR accommodation and stability

The concept retained at the PDR of two Star Trackers accommodated in place of the previous Star Mapper has been kept. Their line of sight must point toward Zs with an angle of 5° wrt YZ plane.

Their accommodation on +Z panel has been refined taking into account following constraints:

- stay inside Planck 12° shadowing cone (for the protruding baffles)
- minimisation of cut-outs in lateral panel to keep as stiff as possible
- compatibility with panel tiltability and dismountability.

They are finally mounted from the outside of the panel, each on a bracket connected to the internal lateral panel.

There is one cut-out for each Star Tracker, with minimised dimensions, and the REU previously present on the panel has been relocated and replaced by the DPU formerly on next shear web, reducing the global mass on the panel.

The brackets allow the electronics and baffles to stay within the shadowing cone. They remain mountable and removable from the outside (before panel tilting), the interface points being accessible.

From a mechanical and stability point of view, the Star Trackers are accommodated together in the same area, which means that they will be submitted to the same environmental constraints (thermal, mechanical) and then will have the same behaviour.

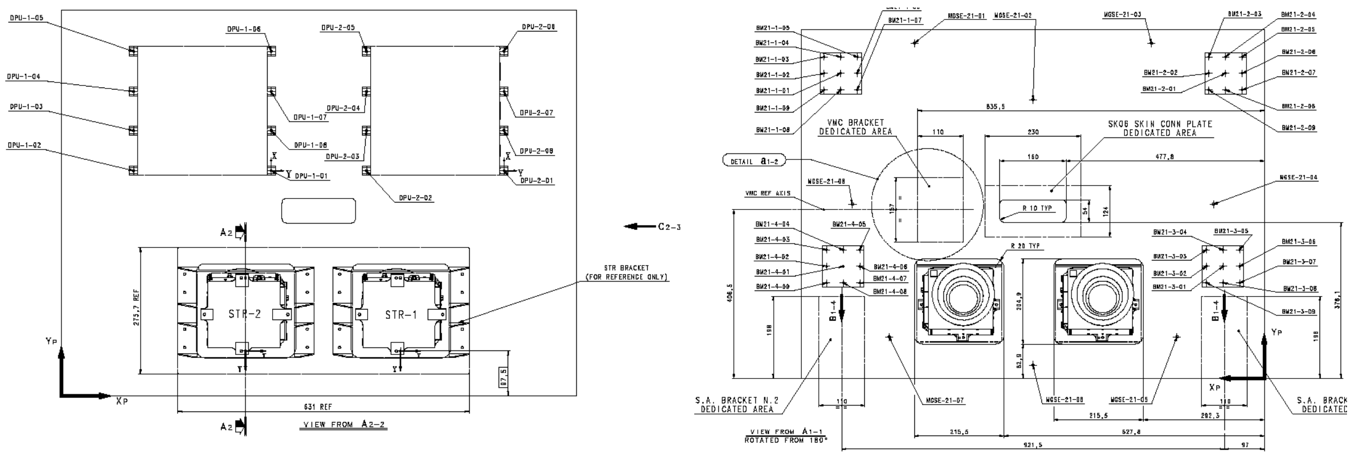


Figure 6.2.5-3 Star Trackers accommodation

Instruments update and layout

General

Changes from Instruments seen in the course of the phase C were less important than in previous phase in terms of growing and dimensions. Nevertheless, some units have been finally defined quite late in this phase, for instance LFI instrument with the BEU unit that has been split in 3 boxes and led the Lower Support structure to interface with the sub-platform. The RAA MGSE design is also not frozen.

The other evolution mainly concerned refinement of interfaces : fixation feet definition, base-plate contact type, update of external dimensions and mostly connectors move penalising harness routing stabilisation.

The interconnection diagram and complete information about harness characteristics were as well not always easy to recover and also changed.

Recall of SVM accommodation constraints

This paragraph intends to explain the different accommodation constraints that come from SVM design.

<u>Accommodation area</u>

1. Small panels

   The small panels are linked on their four edges to 2 large lateral panels and lower and upper platforms. Their global area is 1115.5*840 mm. The consideration of structural links between the panel and the SVM results in an effective area for units accommodation of 1000x750mm.

2. Large panels

   The large panels are linked on their four edges to 2 small lateral panels and lower and upper platforms. Their global area is 1731.2*840 mm.

   The panels are divided in three parts, a main centred one in-between shear webs and two small lateral zones outside shear webs. Main area measures 1185*840 mm. Small areas measure 243.1*840 mm.

   The consideration of structural links between the panel and the SVM results in effective areas for units accommodation of 1150x750mm for the central part, and 150x750mm for the lateral sides.

Panel tilting

SVM configuration must ensure that accessibility to the warm unit is possible after integration in case of emergency (replacing of a unit, connector, cable …).

At the difference of Herschel, the upper platforms are removable, providing an easy access for Instruments maintenance. Anyway, in case of heavier maintenance operations, SVM panels could be tilted as well but need platform removal before for WU disconnection.

The access by panel tilting is not possible for SCC panels which are integrated as a block, and that should be dismounted in the same way if more access is required.

The principle of panel tilting is recalled hereafter: (upper platform is removed).

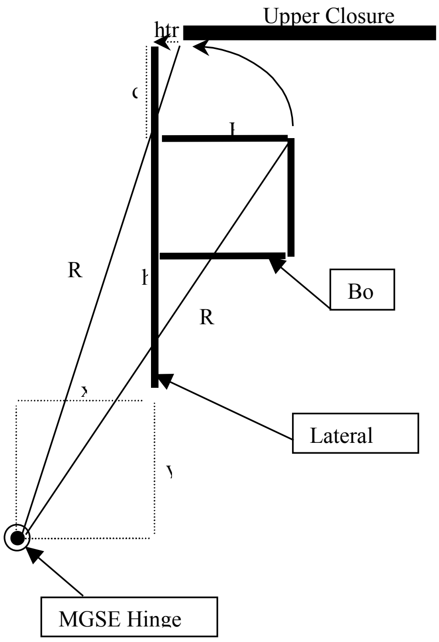


Figure 6.2.5-4 Panel tilting MGSE concept

SVM connector bracket

SVM harness (from PCDU, CDMU to warm units) is routed on the lower platform via interfacing connecting bracket set in each equipment/instrument partition in order to allow a disconnection before dismounting a lateral panel.

This interface-connecting bracket is set on the lower platform, 100 mm away from the lateral panel, its length varies (depending on the number of connectors needed) from 50 mm to 250 mm.

It can be set anywhere along the length of the panel, but it leads to keep an area free at the bottom of the panel corresponding to this bracket's area.

SVM layout description

The SVM configuration presented below is based upon all hypotheses from these Convergence Meetings, which took place during March/April 2002, even if some of them still needs official confirmation from Instruments. This hypothesis has been however introduced in IID-B Issue 02 rev.1 (HFI and LFI).

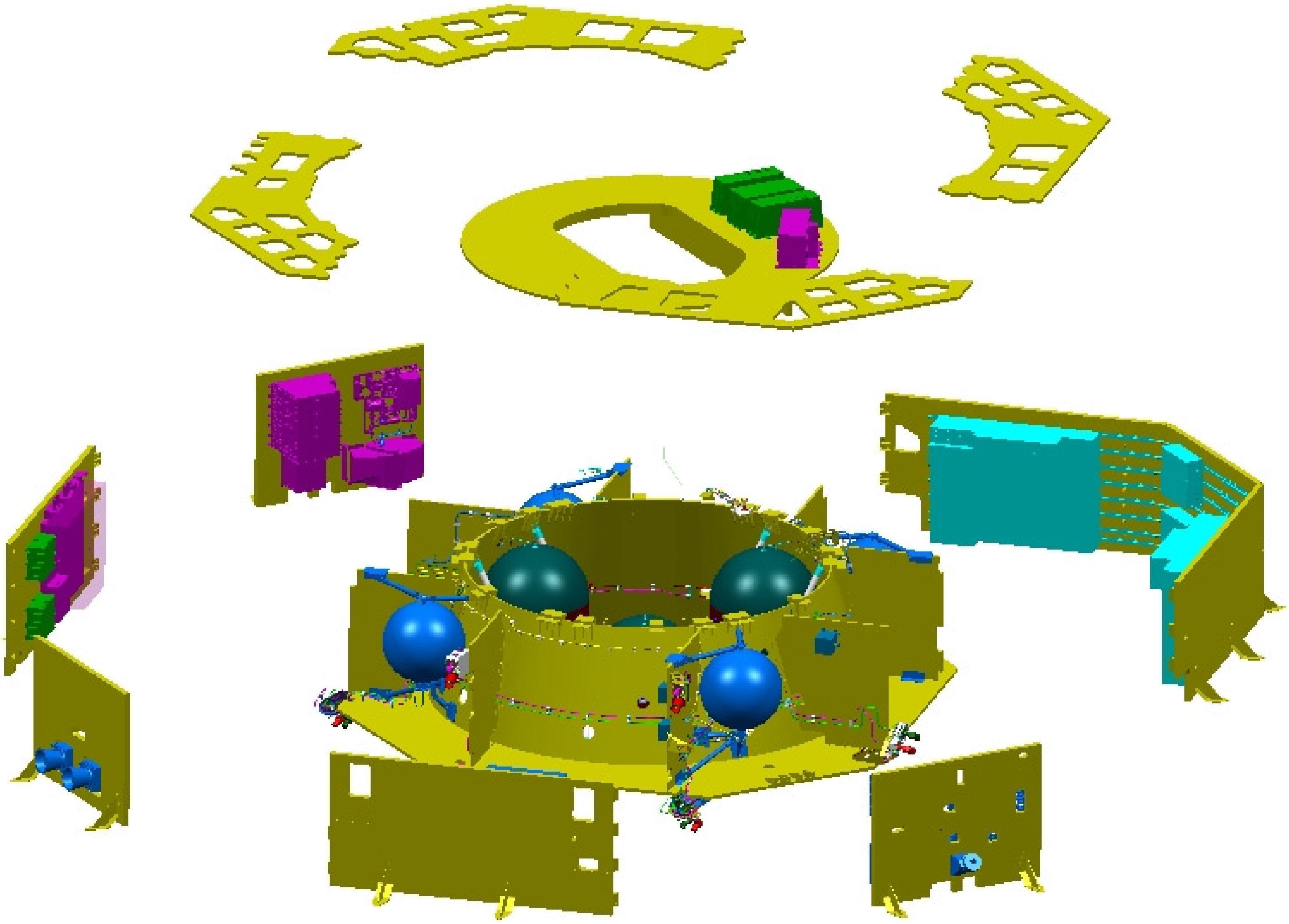


Figure 6.2.5-5a Planck SVM exploded view

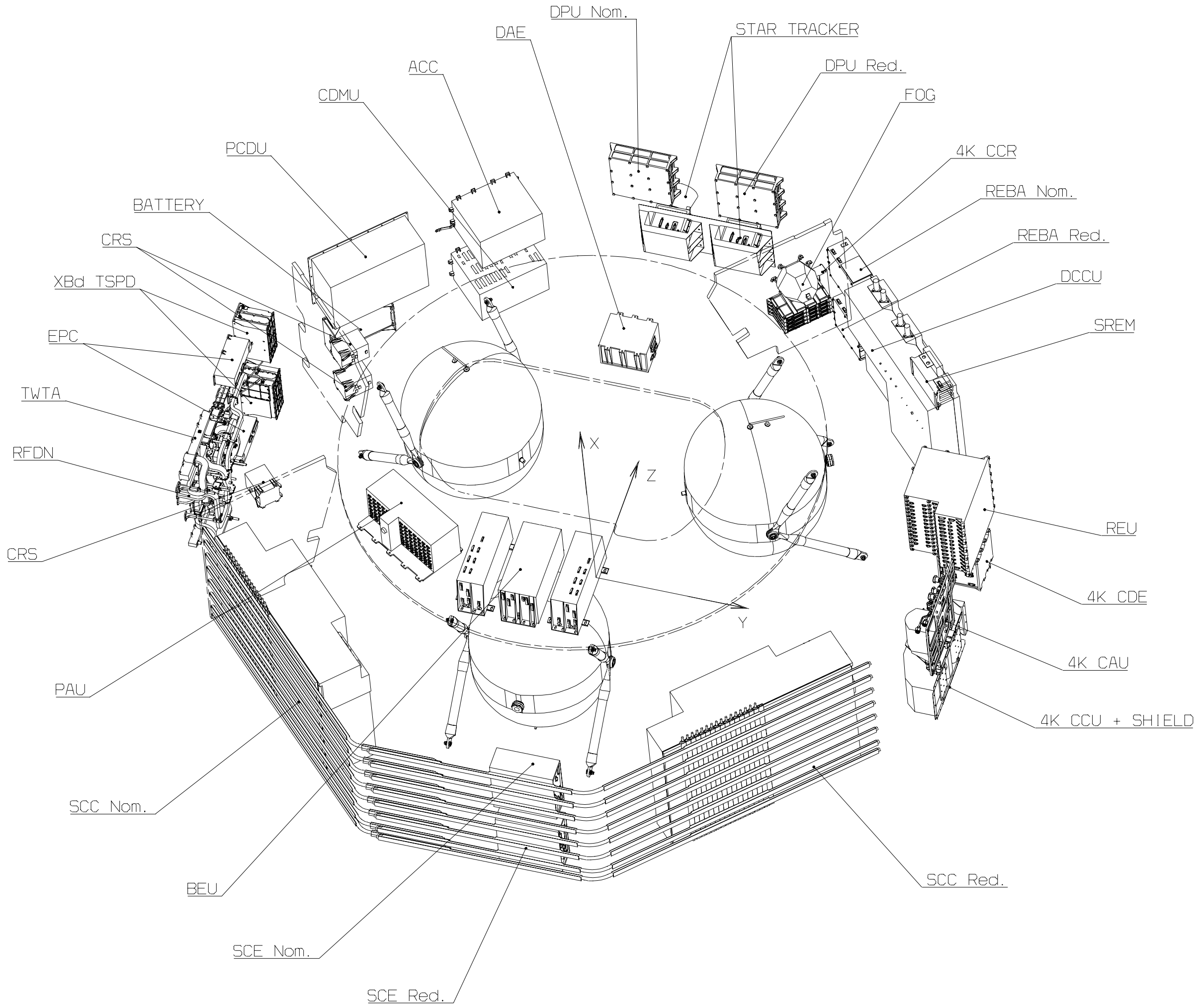


Figure 6.2.5-5b Planck SVM general layout

HFI/0.1K Assembly

Panel accommodation

The DCCU allocated volume has been respected by instrument, allowing keeping its accommodation on the panel.

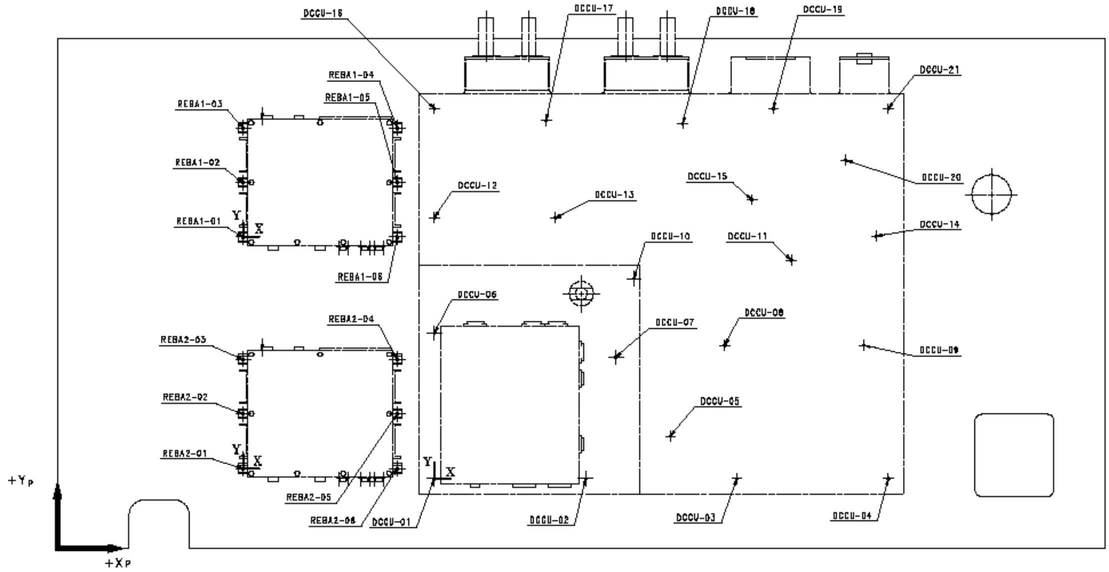


Figure 6.2.5-6 0.1K panel layout

Helium tanks supporting concept has been refined, they are set in-between a tripod on lower part (linked to brackets on cone, shear web and lower panel) and a bipod on upper part (linked to brackets on cone and shear web). The beams on top are removable to allow pipes integration. An anti-rotation device has been implemented on tank lower part to prevent from any rotation of the tank along its longitudinal axis, and consequently any torsional stress on the pipe.

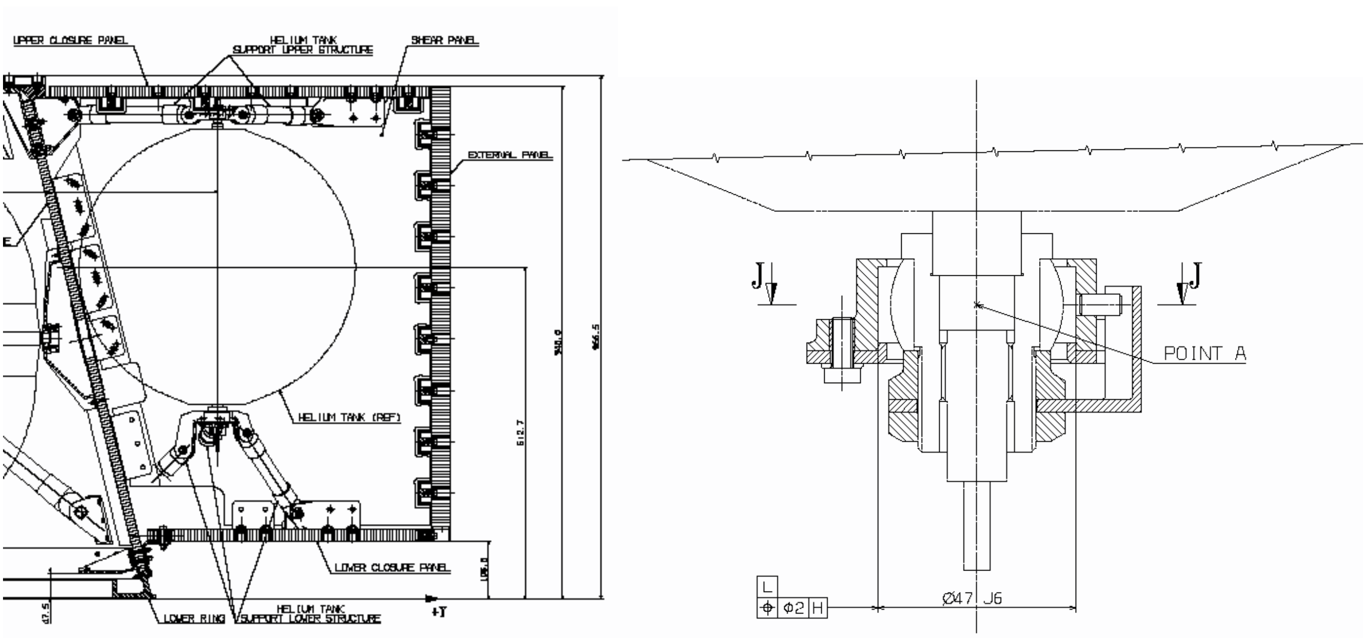


Figure 6.2.5-7 He tank accommodation and anti-rotation device

Pipe routing from DCCU to Helium tanks

Pipes interconnecting the DCCU and the tanks start from one side of the DCCU and join the different tanks by routing around SVM cone. They are connected on He tanks valves which are oriented vertically toward bottom of the SVM.

Pipe routing from DCCU to PLM

Five pipes interconnect DCCU and PLM, they interface with the PLM through a connecting bracket located on the sub-platform between PAU and BEU in -Y -Z area.

This bracket consists in an assembly of 5 independent valves on which pipes connect on both sides.

The principle is that the pipes start from one side of the DCCU, emerge from SVM through a groove along the cone between upper panel and sub-platform, then route around this one to go and connect to the Interface Connecting Bracket. They are routed gathered with a harness going to a connector either on the same bracket or on an additional one.

Refer to Planck SVM pipes general configuration in next pages for illustrations.

Exhaust pipe

A pipe is used for Helium exhausting outside the Satellite. In order to limit the reaction loads induced on the Satellite, it is foreseen to use a T-branch (100 mm length each branch) shape exit which is set along the vertical axis of the Satellite (launcher axis) to avoid any torque generation. It is accommodated at the centre of the DCCU panel going out through it with the Helium exit direction horizontal (to avoid blowing toward the Telescope). Refer to Figure 6.2.3.2.5.

It has been checked that this excrescence does not perturb SA shadowing.

This T complies with under fairing available volume, does not change the Satellite container design and is also compatible with allocated vacuum chamber volume.

To ease these operations it is also envisaged to have it dismountable (unscrew-able) at the panel outer border plane, thus having a very limited additional volume.

Accesses to DCCU

This instrument unit requires accommodation of several accesses during integration, tests in vacuum chamber and on the launch site. These are intended to fluid operations, like filling, purging of tanks and lines, leak tests.

As these accesses are needed even when SVM would be closed, it is preferable to do simple manoeuvres to perform the operations, then it shall be avoided to dismount part of SVM (like upper platform). There are 6 Fill and Drain Valves and 2 VCR. An access to connectors has been foreseen, but is finally unemployed by instrument. Brackets set on DCCU itself support these elements. Cut-outs have been implemented in upper closure panel to let valves go out and allow lateral panel tilting.

Finally to avoid disturbing V-groove effect, the 2 brackets with FDV will be capped with 2 enveloping MLI structures while 2 pieces of MLI would cover the connectors and encircle the VCR.

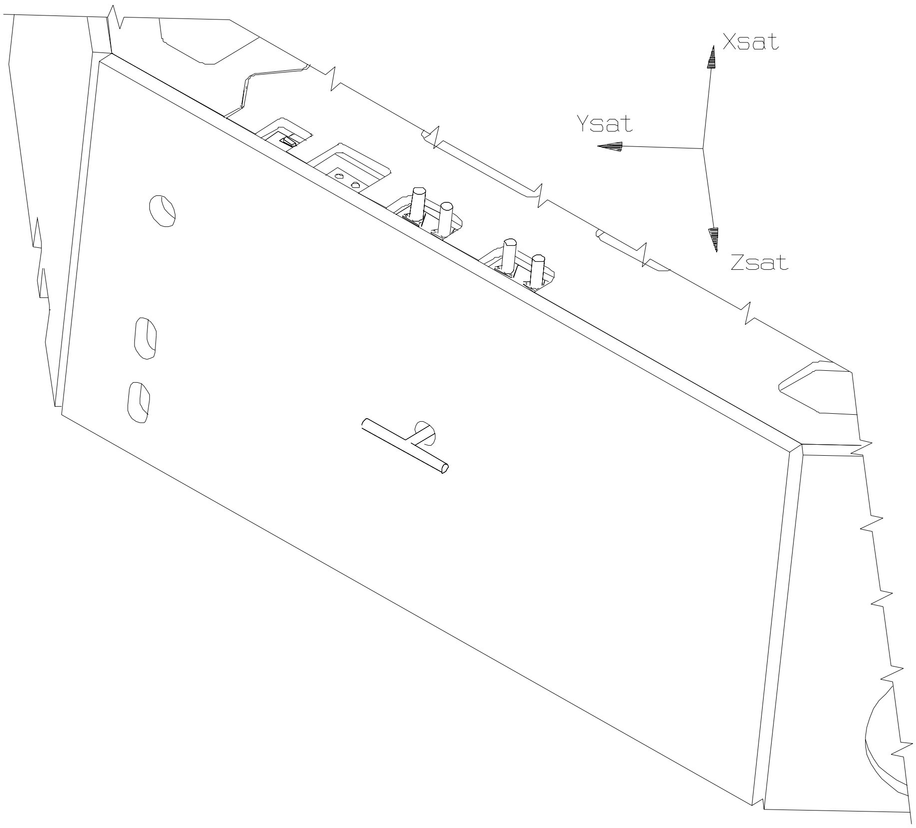


Figure 6.2.5-8 0.1 K accesses and exhaust pipe

HFI/4K assembly

Accommodation

Refinement of 4K CAU, 4K CEU and 4K CCU designs by Instruments giving CAU and CCU pipe interconnection layout. Due to these pipes CAU and CCU cannot be accommodated independently.

This panel now houses the REU, previously on +Z panel and relocated for SVM and Satellite balancing reason. It has been set on top left part of the panel leading to shift 4KCDE downward. As a direct access to 2 connectors was foreseen for 4KCCU stroke locking, an additional harness deports the connection to a bracket set on top of the panel.

The sensitiveness to EMC of REU and its new proximity with EMC polluting 4KCCU leads to develop an EMC protective shield surrounding this last unit. Inserts have been added on the panel to fix this shield, of which necessity is not confirmed yet.

The 4K CRU lately defined has been relocated several times to finally be accommodated on +Y+Z (+Z) shear web behind the FOG, in DPU and Star Trackers zone. It help reducing high thermal load in +Y panel area as well as the mechanical environment on the unit (random loads) because it is placed on a more loaded structure (FOG behind).

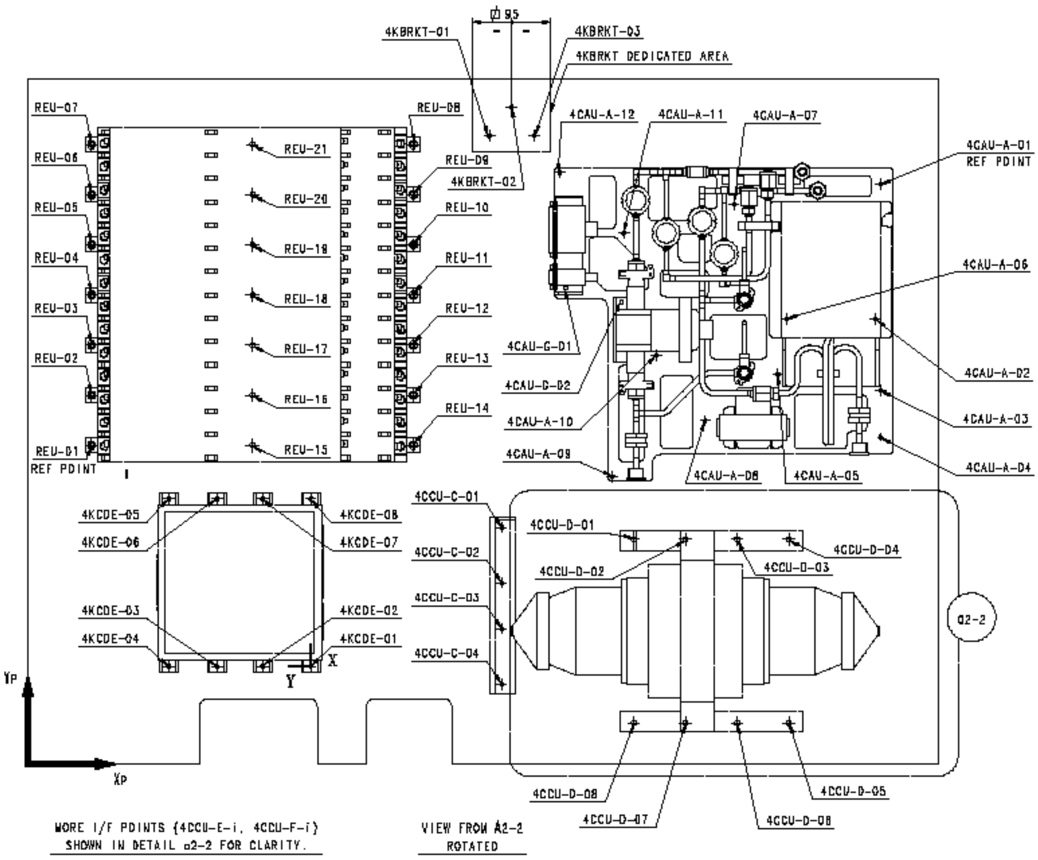


Figure 6.2.5-9 4K panel layout

Pipe routing

Two pipes and a harness start from 4K CAU and go toward PLM. Pipes exit from right side of CAU and harness from its left side (when considering a person located inside SVM and looking to 4K panel) but is routed gathered with the pipes. They route from upper right side of CAU going to next shear web via lateral panel, then route along the cone and emerge from SVM through a cut-out between upper platform and sub-platform to join the PLM interface. They interface with PLM through a connecting located on the sub-platform near BEU in +Y-Z area (in fact opposed to the 0.1K I/F bracket with regard to BEU). This bracket consists in an assembly of 2 independent valves on which pipes connect on both sides. A connector is also foreseen to be set either on the same bracket or on a dedicated one.

Refer to Planck SVM pipes general configuration in next pages for illustrations.

HFI/DPU panel

The 2 DPU are now accommodated on +Z lateral panel above Star Trackers, because the area has been freed by REU move. They supply all other HFI units, via connector brackets set on lower closure panel in right side of the panel.

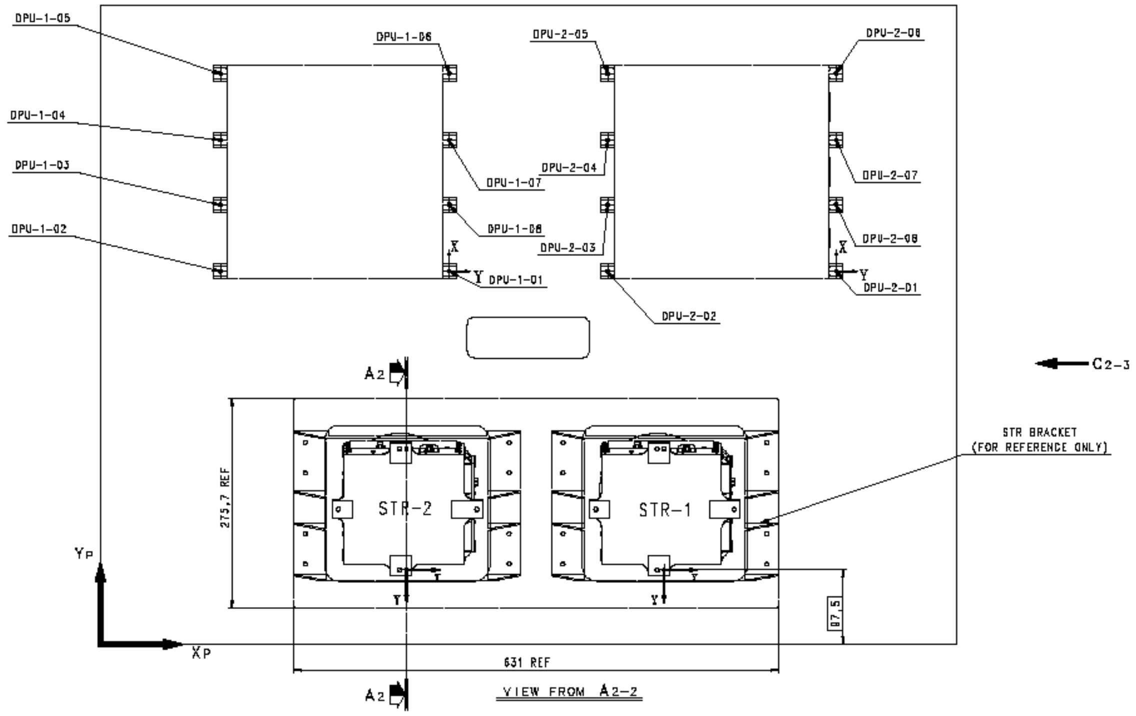


Figure 6.2.5-10 Star Trackers, REU and DPUs layout

HFI/sub-platform PAU

The PAU part of the detection chain is accommodated on top of the sub-platform in –Y+Z area aside BEU.

The PAU is connected to JFET on PLM part via the bellow routing on upward via a cryo. structure strut. It is then connected to REU through a huge harness.

LFI/REBA panel

The 2 REBAs which have slightly growing have been kept on +Y+Z panel with DCCU.

The are electrically connected to BEU unit on sub-platform. The harness routes on the next shear web (with FOG) up to a disconnection bracket. Then it goes to the sub-platform exiting the SVM through a cut-out in upper closure panel.

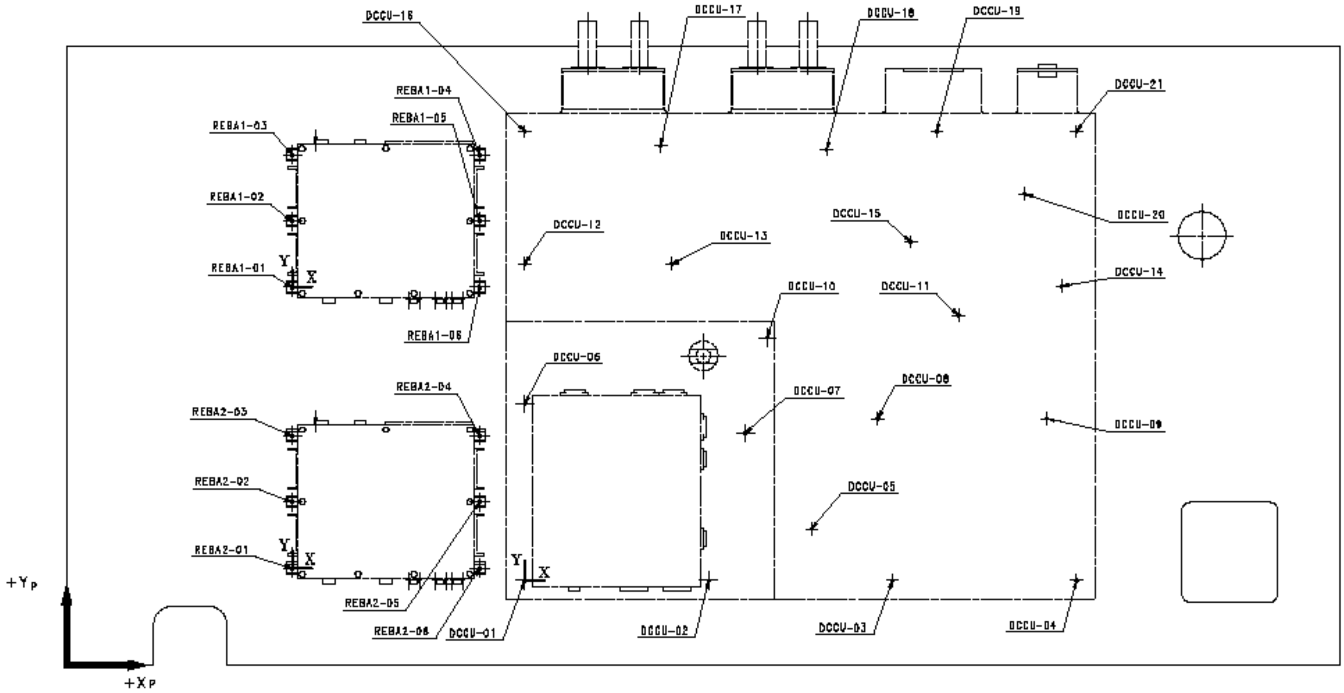


Figure 6.2.5-11 REBA accommodation

LFI/sub-platform accommodation

The sub-platform houses the BEU on its top and the DAE Power Box on its bottom. The units are interconnected with harness routing below the platform, the REBA are also connected with BEU. The routing on sub-platform has been lastly redefined because of removal of stiffeners.

The routing on sub-platform is shown below (PAU-REU/BEU-DAE/BEU-REBA)

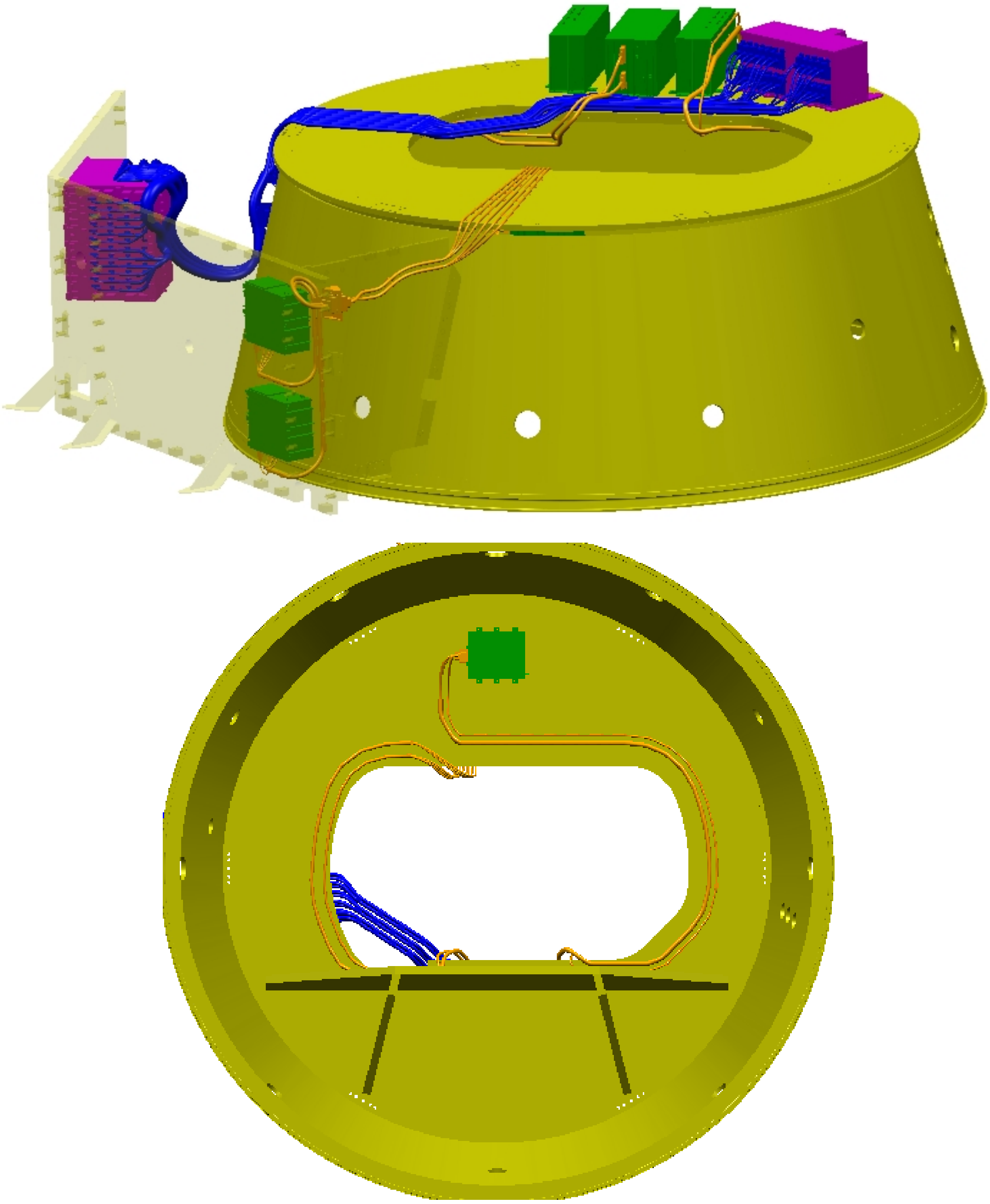


Figure 6.2.5-12 LFI units layout

BEU design

The design of the BEU came very late, and for mass saving reason has been split in 3 units. It added a new interface between the sub-platform and the waveguides Lower Support Structure formerly atop of BEU. This last element joins the Upper Structure linked to the PLM.

The RAA MGSE concept is being optimised with LFI instrument to make it stiffer at the basis with objective to uniformly spread IF loads with the subplatform.

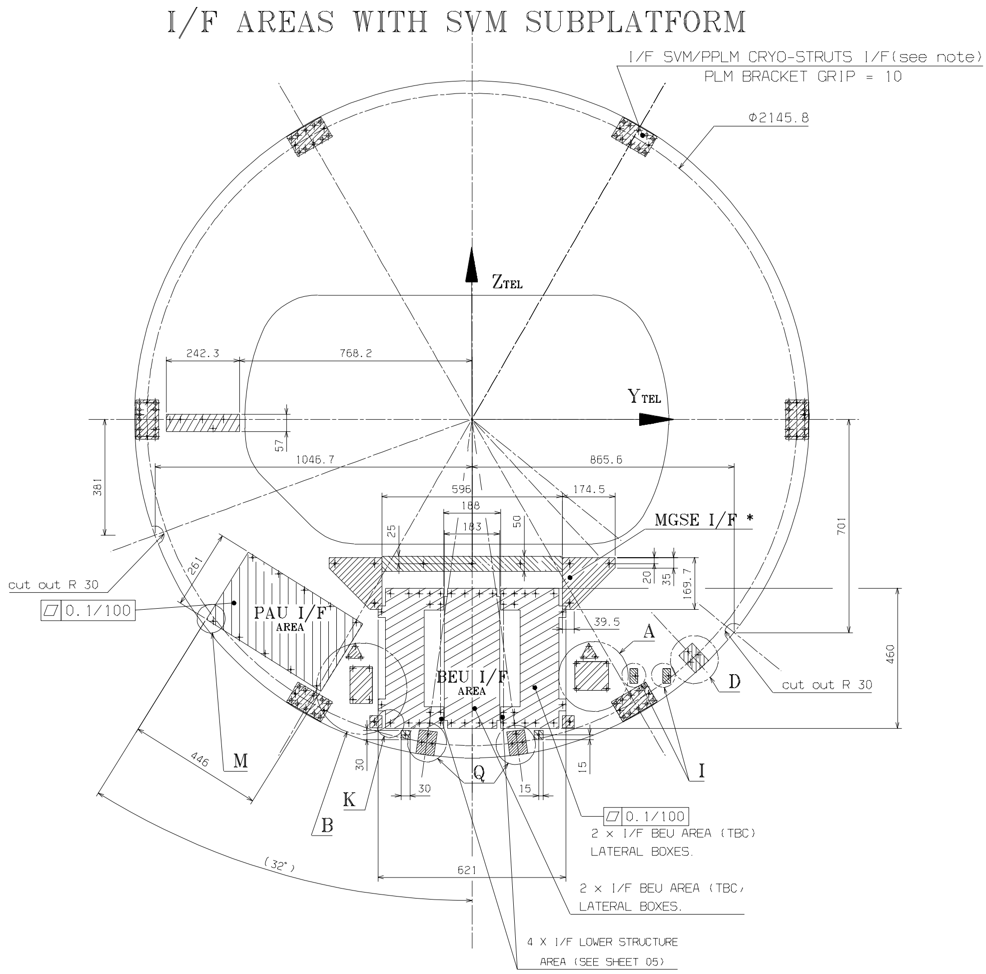


Figure 6.2.5-13 BEU interface

LFI/SCC panels

The SCC have been reversed top-down so that the pipe outlet is now upward. This goes in the right way as it reduces pipes length.

The heat-pipes network has been lastly refined to cope with final detail definition of SVM elements.

The SCE have been accommodated in a vertical position for clearance with He tank reason.

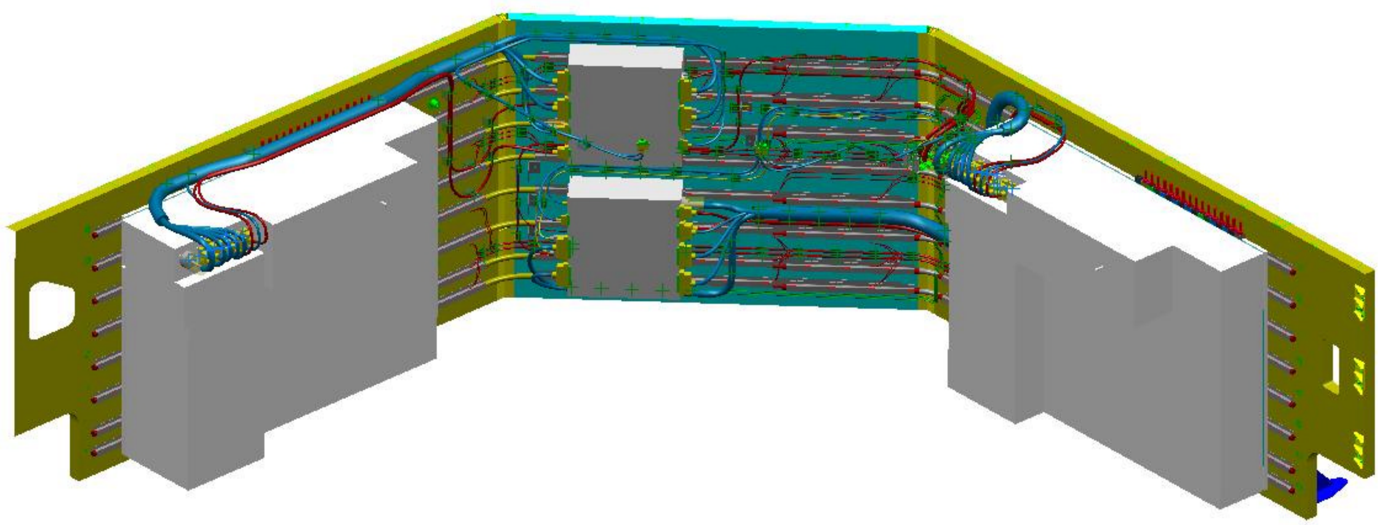


Figure 6.2.5-14 SCC accommodation

Pipe routing

One pipe goes out from each SCC top and goes directly to the cone. They run locally on it and go to the first V-groove above. A harness routes along the pipes up to the cold end.

Refer to Planck pipes general configuration hereafter for illustrations.

Planck SVM Pipes configuration

Several pipes are part of the cooling loop of the PLM instruments, 20K (2 pipes coming out of SCCs nominal and redundant), 4K (composed of 2 pipes routing together going out of 4KCAU) and 0.1K (4 pipes from DCCU to He tanks and 5 pipes from DCCU going to PLM).

The 4K and 0.1K pipes are split between SVM part from SVM units (4KCAU, DCCU) to physical disconnection (bracket) on sub-platform, and P-PLM part starting from this point to cold instruments.

The 20 K pipes are not interrupted and go directly from SVM units (SCC) to P-PLM grooves for thermalisation.

The general concept is that the pipes leave the units on lateral panels and join the cone (by routing eventually via the shear web). They run along the cone up to the SVM/PLM interface where they disconnect, or join the He tanks. To allow them crossing the shear webs, some cut-outs have been foreseen.

From AIT point of view, the 0.1K pipes deserving He tanks and PLM are firstly integrated to the SVM equipped cone (with shear webs), then the He tanks are mounted and connected to the pipes.

The PLM comes with the sub-platform and Sorption Cooler Sub-system assembled on its 3 lateral panels. The 20K pipes are mounted on SVM cone during the mating of PLM with SVM.

After all, the 4K pipes are mounted on the SVM.

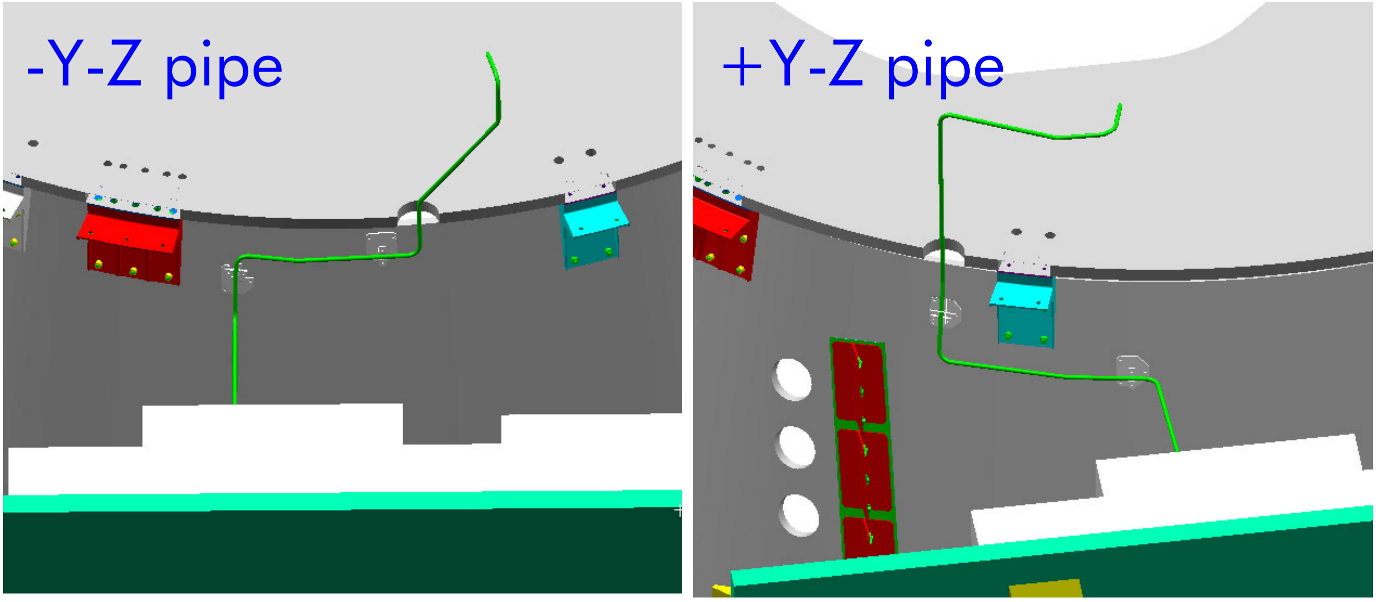


Figure 6.2.5-15 20K pipes routing –SVM part-

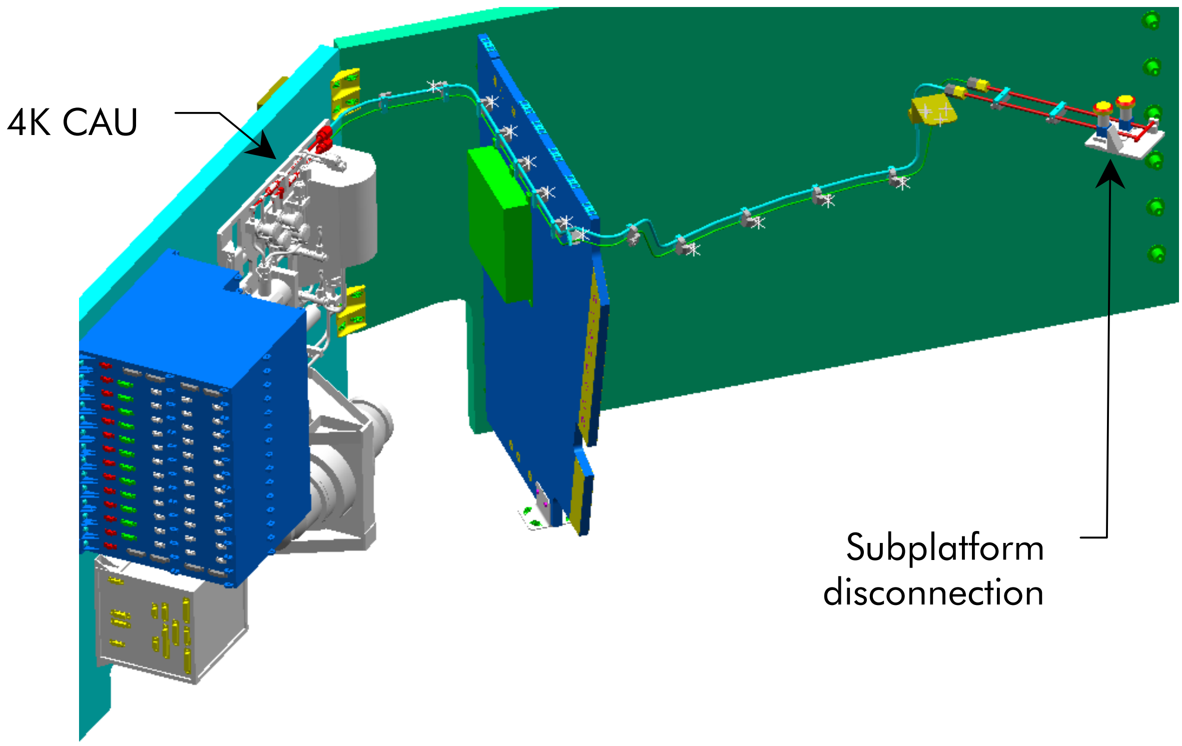


Figure 6.2.5-16 4K pipes routing –SVM part-

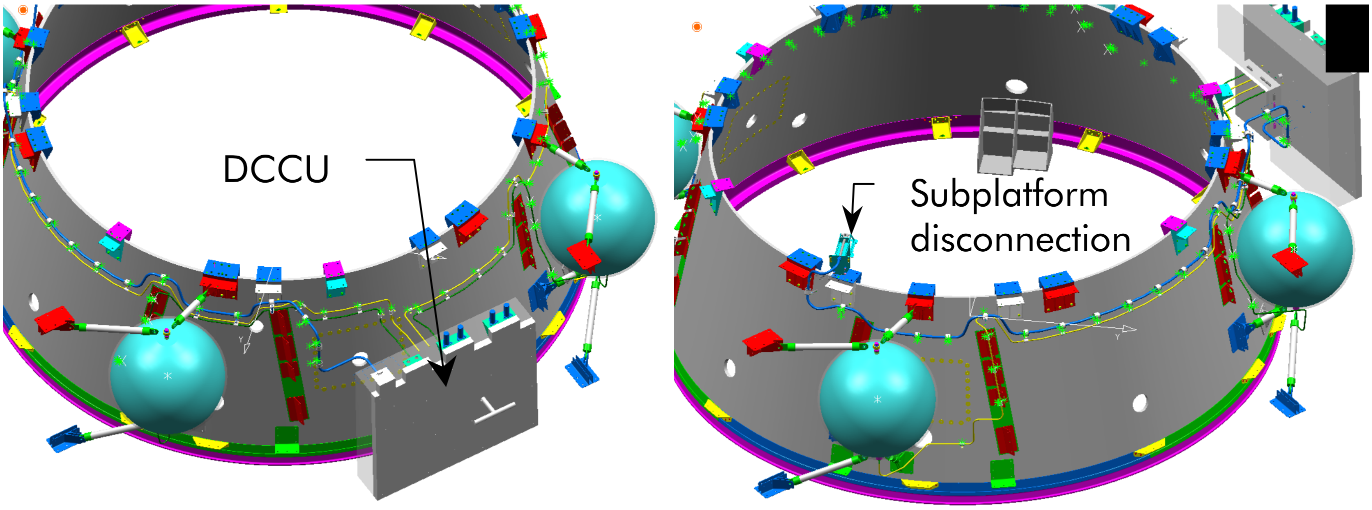


Figure 6.2.5-17 0.1K pipes routing –SVM part-

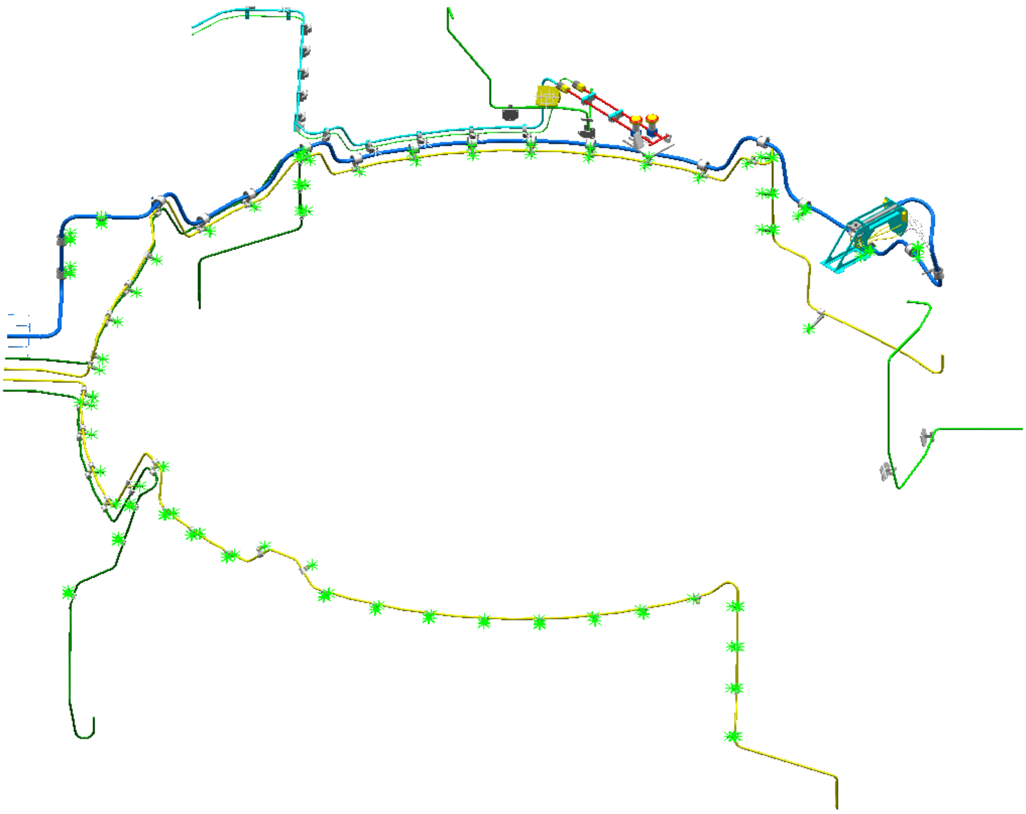


Figure 6.2.5-18 All pipes routing –SVM part-

The routings of the different pipes have been frozen by issue of drawings:

- PLS.A140.S.101SA for 0.1K pipes
- PLS.A140.S.102SA for 20K pipes
- PLS.A140.S.104SA for 4K pipes.

The pipes analyses regarding the specified mechanical environment are still on-going, which may lead to refinement of the design. The supports have also not been completely defined by all instruments.

Conclusion on SVM warm units accommodation

The present Instruments layouts displayed in this report has agreed between and Industry, and is therefore considered as baseline for CDR and subsequent phase. It is in general a consolidation of PDR definition with implementation of detailed definition of units, pipes and harness routing freezing.

Sensors accommodation

Herschel and Planck ACMS configurations share the below listed common features:

- the Coarse Rate Sensors (CRS) are mounted on the Shear Panels (2 are on -Y+Z (-Y) web and 1 is on –Y-Z (-Y) web), with their reference axis parallel to the X_S axis
- concerning the Sun Acquisition Sensors (SAS), one has been set under the cone inside the ring, the second one is set on a bracket on +Y panel at the limit of the 12° shadowing cone. Its field of view has been carefully studied with regard to PLM in-orbit allocated volume. The full space coverage is then ensured (with Planck spinning).
- the Attitude Anomaly Detector (AAD) is mounted under the cone inside the ring. It is set on a secondary structure supporting also a SAS and internal Solar Array connectors.

Antennae configuration

The Medium and 1 Low Gain Antennae are mounted to the cone inside it. They have been shifted upward to stay in SVM allocated volume. The second LGA is mounted on +Y panel ensuring the relevant fields of view. The RF connection between Low/Medium Gain Antennae and the TT&C panel is then realised by means of Wave Guides, which are mainly routed around/through the cone and on the Shear Panels. Both Herschel and Planck share the same Wave Guides routing concept, so that the highest possible level of commonality is achieved.

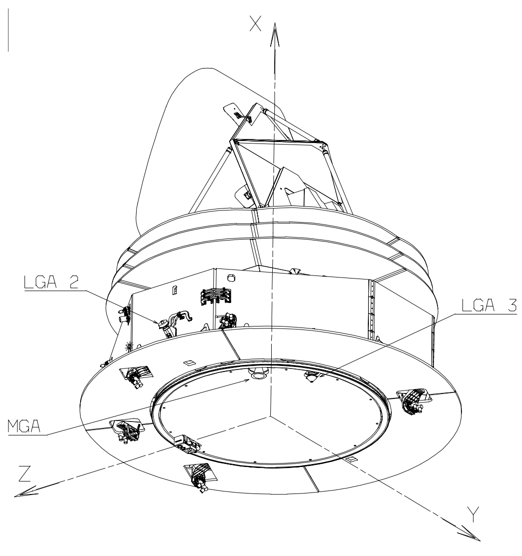


Figure 6.2.5-19 Antennae configuration

RCS accommodation

The RCS components/piping accommodation shall be organised as follows:

- components that do not need frequent accessibility (e.g.: Propellant Filter, Pressure Transducer, and Latch Valves) are accommodated on the RCS Support Panel (shear panel +Y+Z (+Z))
- components that need external accessibility (e.g. Fill & Drain, Fill & Vent Valves, and Test Ports) are accommodated on shear webs and accessible through the Lateral Panels
- main distribution loop is routed along the external and internal surface of the cone, approximately at the same height as the Venting Holes
- the SVM structure provides the mechanical interfaces to the pipes which distribute propellant from the main loop to the Thrusters and from the Fill and Drain valves to the Propellant Tanks
- the thrusters are carried by brackets connected to lower closure panels and shear webs.

Refer to ALS SVM Design report for details about RCT's accommodation.

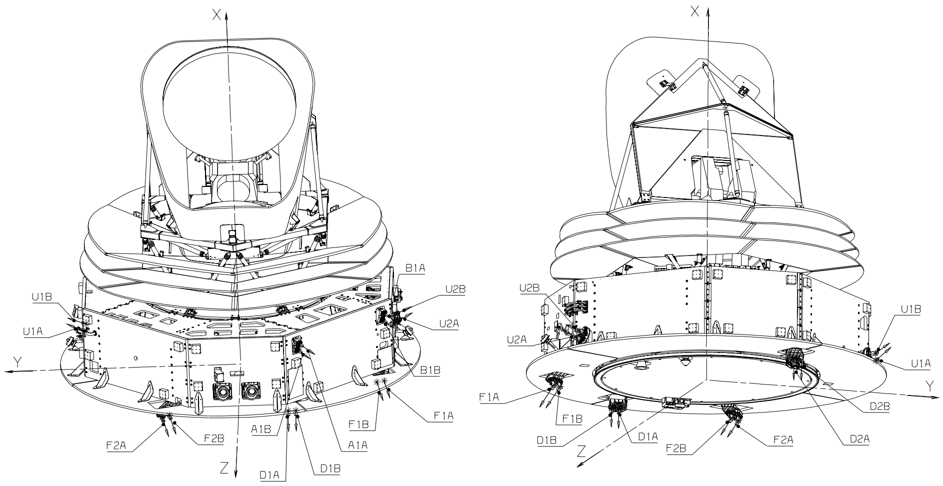


Figure 6.2.5-20 Thrusters accommodation

SVM harness

The SVM Harness is mainly routed over the Lower Closure Panel. Because of integration/test reasons, all Lateral Panels (with an exception for the three SCC Panels of Planck) must be tiltable/removable when fully equipped.

Therefore, dedicated Connectors (and relevant Connector Brackets) are accommodated around the Lower Closure Panel to interrupt the Harness bundles before jumping to the Lateral Panels.

The SVM structure will provide the mechanical interfaces for the fixation of all Harness items, as appropriate.

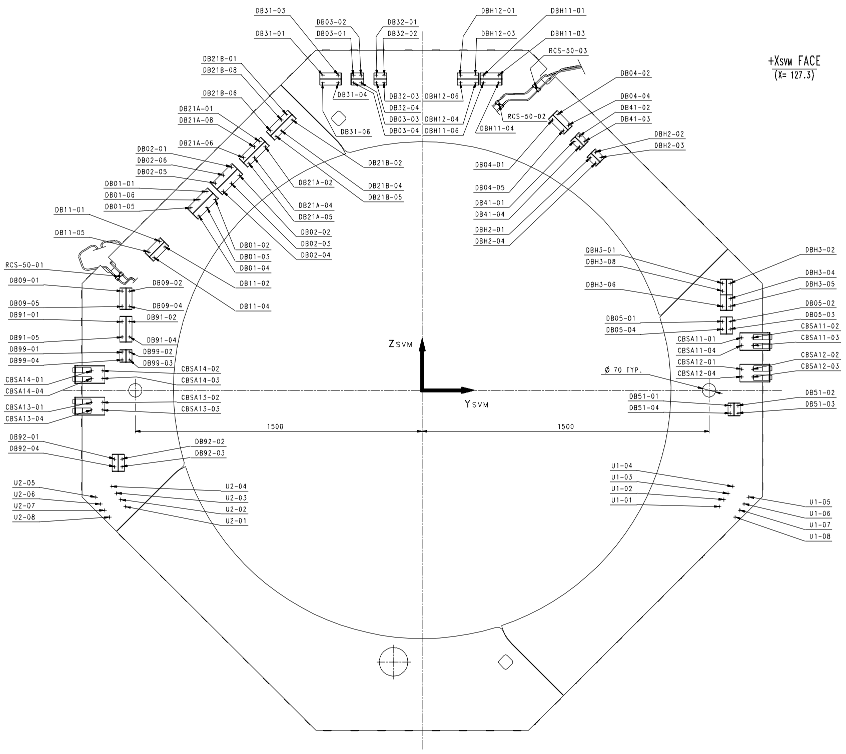


Figure 6.2.5-21 Lower closure panel

Thermal control concept

The Thermal Control Subsystem (TCS) hardware is mainly comprised of Multi-Layer Insulation (MLI), Black Paint and Fillers. The external surface of Herschel Lateral Panels is partly covered with Optical Solar Reflectors (OSR), where necessary. All TCS items are attached to the Primary Structure by means dedicated interfaces.

Solar Array

Planck Solar Array, mounted on the sun-looking face of Planck SVM (-X) is divided in two main parts:

- the Central Solar Array, which covers the entire internal area of the Central Cone. It is cut around MGA, LGA, SAS, AAD and SA connectors.
- the External Solar Array, which covers remaining area between the Central Cone and the AR5 Launcher allowable envelope (4220mm), and is segmented in four 90 degrees quadrants. Several cut-outs have been implemented to allow umbilical connectors and thrusters assembly passing through it.
- The solar arrays are fixed to the SVM structure (cone, lateral, lower closure panels) by means of secondary structures (brackets). A MLI cover is inserted between the top side of solar arrays and SVM and connections are using insulating thermal washers in order to reduce the heat transferred to the SVM.

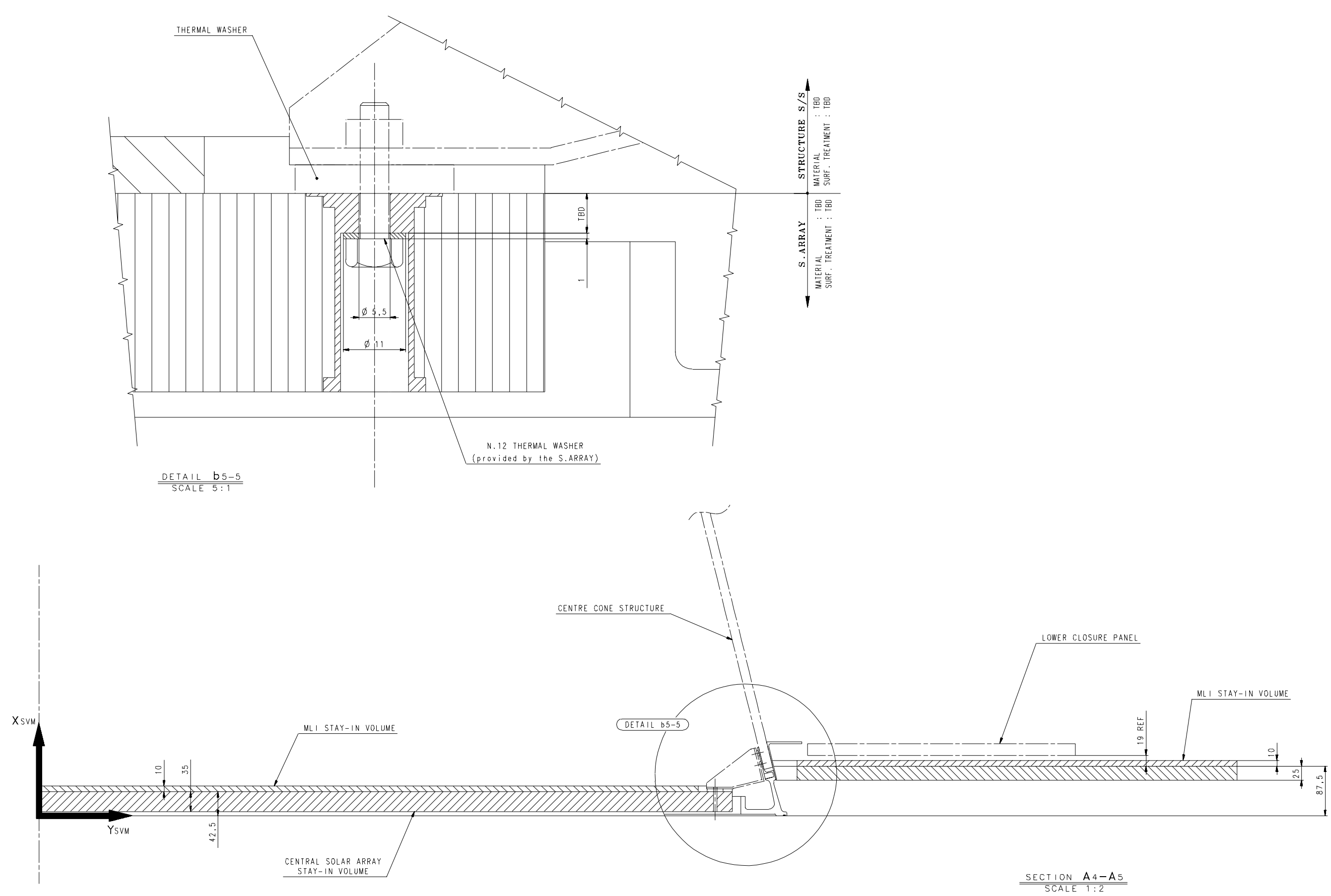


Figure 6.2.5-22 Solar Array mounting

6.2.6 Planck thermal design

6.2.6.1 Spacecraft general thermal architecture

6.2.6.1.1 Main mission characteristics

In this chapter, we will recall the main mission characteristics impacting the thermal concept of the Plank spacecraft.

In a general manner, Planck is not sensitive to the thermal environment experienced during the launch phase as it is protected by SYLDA 5 until launcher separation.

However, Planck shall sustain the net heat flux radiated by Sylda 5 during the ~1500 sec aboard the launcher. The 1000 W/m2 (AD05.2 ENVM-165) specified by ARIANESPACE corresponds to a 90° C black body. Withstanding a 90° C black body environment during 1500 min would lead to probably unacceptable temperature elevation of some of the spacecraft components. The RAMP analysis are being performed. No criticality is expected on Planck during this phase.

From launcher separation to the end of the mission, Planck attitude is constrained so the Sun direction remains below 10° from Xs spacecraft axis as depicted on Figure 6.2.6-1 (AD05.2 ENVM-310).

The overall Planck thermal design can consequently benefit at best from the cold environment at L2 to fulfil the thermal requirements during the scientific timeline.

Planck is a spun satellite at 1 Round Per Minute. During Planck mission, the spin axis (Xs) can be de-pointed by 10° off Sun. This however will be done such that the Earth Aspect Angle (angle between the -Xs and the Earth direction) remains below 15° (AD05.2 ENVM-320).

Definition of spacecraft axes is shown on Figure 6.2.6-1.

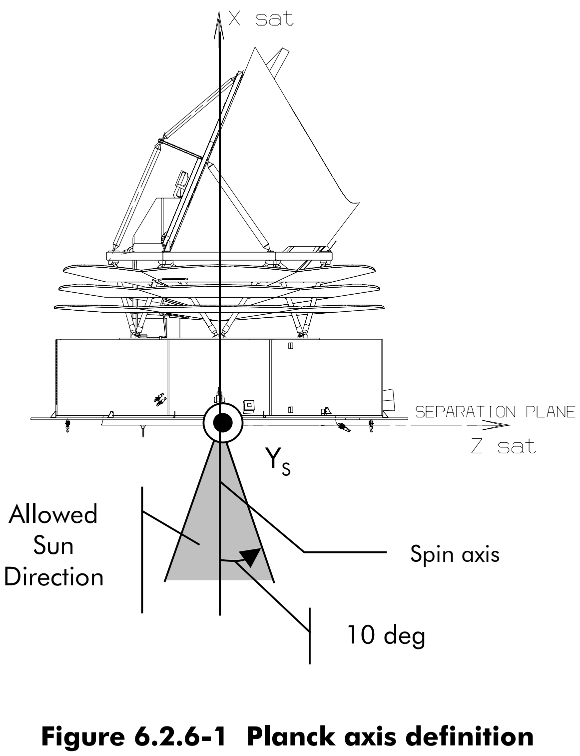


Figure 6.2.6-1 Planck axis definition

6.2.6.1.2 *Spacecraft design description*

Planck spacecraft is made of the Planck SerVice Module (P-SVM), and the Planck PayLoad Module (P-PLM). The spacecraft configuration is depicted on Figure 6.2.6-2.

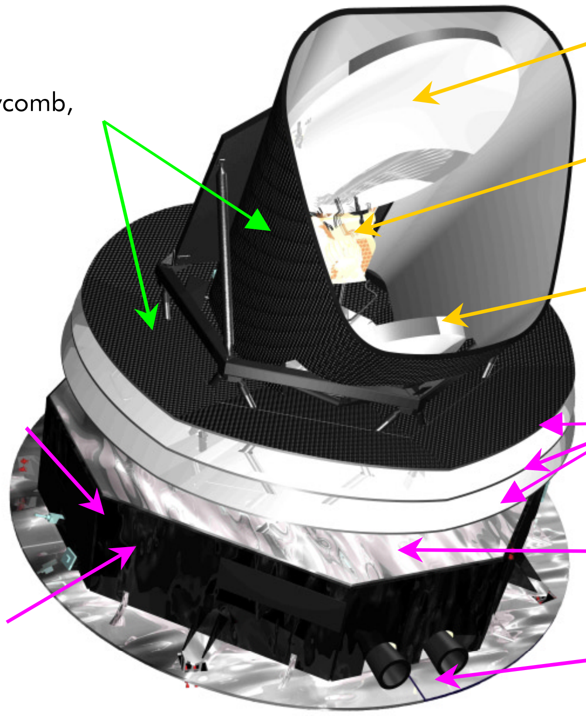


Figure 6.2.6-2 Planck overall configuration

The SVM houses the spacecraft units as well as the instruments warm units. Planck SVM shares with Herschel SVM common design features for the thermal control. The P-SVM thermal concept is a "classical" one compared to P-PLM, and aims at maintaining the equipment within conventional design temperature ranges. Passive thermal control is extensively used thanks to adequate coatings, MLI blankets, heat sinks… P-SVM also supports the As-Ga Solar Generator. The Solar Array is located on –X side of the satellite, always sun oriented. The solar array is the hottest part of the spacecraft (~ 120° C). It is conductively and radiatively insulated from the SVM, at around ambient temperature.

The P-PLM is a cryogenic payload operating between ~ 150 K and 0.1 K at its coldest point. The Payload is made of the main following components:

- an optical baffle, which also serves as a cryogenic radiator on its external side,
- a set of three so-called "V-groove" shields, which provides the high level of radiative insulation between the warm SVM and the cryogenic radiator. The shield temperatures range from around 150 K (Shield 1) down to between 50 K and 60 K (Shield 3). Part of shield 3 +X side is also used as a cryogenic radiator,
- a cryo-structure, which supports the different shields and radiator while providing conductive thermal insulation from the SVM,
- a telescope, made of a primary (1.5 m) and secondary reflector,

- a Focal Plane Unit (FPU) which houses the instruments detectors as well as the cold ends of the cryogenic chain,
- a cryogenic chain composed of three coolers, 20K sorption cooler, 4 K mechanical cooler and 0.1 K dilution cooler. The coolers units are spread over SVM and PLM.

The overall configuration of the spacecraft is optimised to achieve the low temperatures required by the Payload. The concept is based on a gradual temperature decrease between the hottest part, which is the Solar Generator down to the coldest part, the payload.

The optimisation of the spacecraft configuration has been made keeping in mind the need of thermal insulation between each level. For this purpose, each shield/"temperature level" receives a radiate flux only from the next most other temperature level. This is however not respected for the warmest "V-groove" shield, which presents a view factor to the backside of the Solar Array. The optimisation at this level was not possible due to volume and mass constraint (weight of an additional shield). Nevertheless, the impact of this flux on the temperature level of the shield has been reduced at a minimum value by insulating the backside of the Solar Array with an MLI blanket.

6.2.6.2 Review of main thermal requirements

In this chapter, we will recall only the main and more critical requirements, especially those having an impact at system level. Other requirements are investigated in details whether in the P-SVM or P-PLM documentation.

6.2.6.2.1 Temperature Levels

Service Module

The SVM shall ensure the required thermal environment to maintain the spacecraft warm units as well as the instruments warm units within their temperature design range. For the LFI and HFI instruments, unit requirements are described in their respective Instruments Interfaces Documents IID-B (AD04.05 and AD04.06).

Some instruments thermal specifications are challenging. It concerns the units mounted on the P-PLM sub-platform. This platform is not a radiative panel, and hardly evacuates the heat received to the other SVM panels. The units concerned are recalled hereafter as well as their thermal specifications.

UNIT	**Design Operating Temperature**	**Temperature fluctuation**	**Dissipation**
Power Amplifier Unit (PAU from HFI instrument)	[-10 °C , +30 °C]	+/-1,1 K/hour	15 W
Back End Unit / Data Acquisition Electronics (BEU/DAE from LFI instrument)	[-10 °C , +30 °C]	± 0.2 K/hour	31.8 W
Data Acquisition Electronics Power box (DAE power box from LFI instrument)	[-20 °C , +50 °C]	NA	13.1 W

Table 6.2.6-1 Main requirements on P-PLM sub-platform

The thermal solutions to meet these requirements have an impact on the P-PLM thermal performances, and need to be carefully controlled.

Besides the temperature levels difficult to achieve given the total heat loads on the P-PLM sub-platform, temperature stability performances are required for two of the three units.

The second critical item is linked to operation of the Sorption Cooler Sub-system, the 20 K cooler of the instruments cryogenic chain. The overall thermal specification is basically the need to evacuate:

- 470 W average thermal dissipation at Beginning of Life
- 520 W average thermal dissipation at End of Life
- 1200 W peak thermal dissipation

while maintaining a SCC interface temperature in the range [260 K, 280 K].

In addition to the above requirement, very stringent temperature stability levels were demanded by the cooler responsible in order to minimise the temperature oscillations at 20 K stage. The requested stability ranges from ± 3 K down to ± 0.5 K at the interfaces with the spacecraft, depending on operating mode of SCC elements.

Such unusual and drastic requirements have of course a deep impact on the overall Planck SVM configuration. Thermal aspects are discussed in Section 6.2.6.5.1.

PayLoad Module

The PLM have stringent thermal requirements for the proper operation of the instruments.

The exhaustive description of the P-PLM requirements can be found in the Planck PLM thermal analysis (RD06.10).

6.2.6.2.2 *Straylight induced Temperature fluctuations*

One of the challenging characteristics of Planck is linked to the very low level of Stray-light allowed to achieve the scientific mission.

The head specification is given in the System Requirement Specification (AD01.1 SPER-065 P), which defines the maximum allowable power at a given detector frequency due to spacecraft self-emission. Basically, signals at spin (1/60 Hz) or multiple of spin frequency in the [0.01 Hz, 100 Hz] range are to be minimised (spin-synchronous signal). These maximum acceptable SIN values have been declined in temperature maximum fluctuation levels on the SVM elements, expressed by an Amplitude Spectral Density (ASD) in K/Hz1/.

The figures included in the last issue of the SVM Interface Specification (AD07.1) are the following:

- at the SVM-PLM I/F truss point, at any frequency in the range [1/5000 Hz, 1/60 Hz], the fluctuation shall not exceed +/- 0.02K (reqmt ITP-220-P)
- on each SVM radiative panel: component at 1/60 Hz < 0.01 K/Hz ½ (reqmt ITP-230-P).

The first requirement is fulfilled. For the second requirement, the maximum ASD is $0.11 K/Hz^{1/2}$ at 1/60 Hz on –Z panel (see RD06.12). This out of specification is covered at system level as $0.128 K/Hz^{1/2}$ has been taken for input for <u>all</u> SVM lateral panels (see RD04.18).

6.2.6.3 Overall Thermal design description

The main feature of the overall Planck spacecraft thermal design lies in high level of thermal insulation required between the two modules forming the spacecraft. This feature is mandatory to achieve the low temperature requirements on the payload and also to minimise the level of stray-light generated by the SVM onto the instrument detectors.

Planck overall thermal design is depicted on Figure 6.2.6-3.

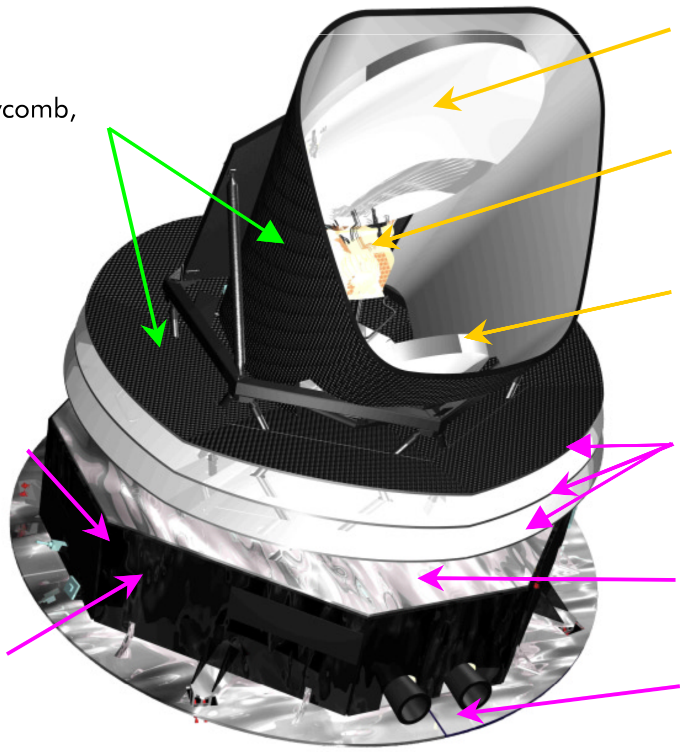


Figure 6.2.6-3 Planck overall thermal design

Thermal insulation between P-SVM and P-PLM is implemented at the following levels:

- PLM supporting truss. This truss is made of 12 GFRP struts for conductive thermal de-coupling. The inner volume of struts is filled with ECCOFOAM foam in order to avoid radiative exchange between hot and cold ends,
- top of SVM, including SVM upper closure panel, P-PLM sub-platform and instruments warm units mounted onto the sub-platform (BEU/DAE and PAU),
- back side of the external Solar Array.

High efficiency MLI blankets are installed on the elements described above in order to minimise the radiative loads onto the P-PLM. To enhance the radiative insulation, MLI external layers are aluminium coated as for Herschel.

6.2.6.4 Interfaces specifications

6.2.6.4.1 Temperature Levels and Heat fluxes

Thermal interfaces specification between the two modules (P-SVM and P-PLM) are gathered in their respective Interface Specification document (AD07.1 and AD07.3).

For the SVM, the requirements deal with radiative constraints to be fulfilled by the Thermal Control Sub-system on one side and boundary temperature constraints on the other side. The requirements are briefly recalled hereafter.

A first kind of specifications limit the radiative heat fluxes from the warm SVM onto the cold P-PLM. They are expressed by design specifications associated to maximum radiative temperature requirements:

– use of low emissive MLI external layer onto the SVM part with view factor with the P-PLM: $\varepsilon < 0.05$.

– requirement on the external layer MLI temperature:

  - < 220 K for MLI on top of SVM and upper closure panel,
  - < 235 K for MLI on SVM sub platform instruments units,
  - < 300 K for MLI on back side of external Solar Array.

The above requirements are in fact equivalent to a limitation on the radiative heat fluxes onto the P-PLM, and could be expressed in term of maximum allowable radiative fluxes (see § 4.2.3.2. of RD04.2).

Concerning the warm units onto the sub-platform, the total flux of the BEU and PAU towards the first "V-groove" shield shall not exceed 2.3 W. This requirement is necessary in order to constrain the heat loads within the allowable range to achieve the P-PLM thermal performances.

The second kind of specifications is related to boundary temperature constraints:

Temperature of the P-PLM attachment truss onto the SVM shall be lower than 310 K. The purpose of the specification is to limit the conductive heat loads onto the P-PLM via the supporting truss.

A compilation of the interface requirements between the modules as well as Alenia results for the CDR analyses are presented in Table 6.2.6-2

Object	Requirement	Alenia result	Comment
SVM/PLM truss interface	ITP-210-P, <310 K	<304 K	C
MLI SVM on upper closure panels	ITP-150-P, <220 K	<233 K	NC
MLI on top of SVM	ITP-150-P, <220 K	<247 K	NC
MLI on SVM sub platform instruments units	ITP-180-P, <235 K	<250 K	NC
MLI on back side of external Solar Array	ITP-200-P, <300 K	<314 K	NC
BEU/PAU radiative flux on Groove 1	ITP-170-P, <2.3 W	<2.25 W	C

Table 6.2.6-2 SVM/PLM interface requirement assessment

The non compliance are treated in § 4.2.3.2.2. of RD04.2. It is shown that P-PLM assumptions are conservative versus overall system TMM results and the performances are met at P-PLM level.

6.2.6.4.2 Temperature Stability requirements

The derivation of spacecraft temperature fluctuation is described in the PPLM thermal report, RD06.10.

The sources of perturbation are the following:

– SVM temperature fluctuation

– Sorption cooler dissipation on grooves.

This derivation takes as inputs the SVM fluctuation values of the CDR SVM thermal report (RD06.12) magnified by a factor ten.

The results for PLM are presented in Table 6.2.6-3 and are compared to requirements derived from straylight analysis. All the stability requirements are met.

PPLM thermal stability		Computed max amplitude at 1/60 Hz (µK)	Requirement (µK)
Primary reflector	Circular central part	0.2	1
	Moon illuminated part	1.3	15
	Circular outer part	1.1	3
Secondary reflector		<<0.1	1
Baffle		30	100
Shield 3 (internal)		4.7	100
Shield 3 (external)		1.3	13

Table 6.2.6-3 P-PLM Temperature fluctuation and comparison to requirement

6.2.6.5 Instruments critical thermal Interfaces

The thermal interfaces with HFI and LFI instruments are extensively described in SVM as well as P-PLM documentation. We will focus in this section only on critical interfaces with regards to the thermal requirements.

6.2.6.5.1 Sorption Cooler Sub-system

The Sorption Cooler Sub-system is a key component for the instruments operation. It provides the necessary cooling power to maintain the LFI detectors at their operating temperature (20 K) and pre-cool the 4 K and 0.1 K coolers dedicated to the HFI instrument.

The Sorption Cooler Subsystem (SCS) comprises the main following elements:

- Sorption Cooler Compressor (SCC), mounted on the SVM
- Sorption Cooler Electronics (SCE), mounted also on the SVM
- Sorption Cooler Cold End (SCCE), located inside the instruments Focal Plane Unit
- Sorption Cooler Piping (SCP), running from the SCC to the Focal Plane Unit.

Two SCS are accommodated in the SVM, and operate in cold redundancy.

The Sorption Cooler Compressor exhibits very stringent and unusual thermal requirements, which are related to the operation mode of this type of cooling device. The 20 K SCS is a Joule –Thomson (JT) cooler, which provides cooling power thanks to the expansion of Hydrogen from 5 MPa down to 0.03 MPa. The high pressure and low pressure are obtained tuning the temperature of Hydride sorbent beds. Six beds for each cooler are cycled alternatively in order to provide a continuous gas flow and therefore a continuous cooling power. The beds are part of the SCC. Their temperature ranges from around 260 K in hydrogen adsorption phase up to 460 K when releasing the Hydrogen. De-sorption phase is obtained heating each bed with several hundred of watts. As there is always at the same time a bed being in adsorption phase, i.e. at 260 K, the heated bed must be insulated from the other part of the SCC. This is achieved thanks to a gas-gap heat-switch maintained in open position. After all hydrogen is released, the bed must be cool down to 260 K before entering in adsorption phase. The heat-switch is therefore closed, and provides a thermal link between a radiator and the hot bed which is progressively cooled down to 260 K. The Sorption cooler Compressor is depicted in Figure 6.2.6-4. We have also reported in (*) proposed in iss 3.0 of AD04.6

Table 6.2.6-4 the main thermal requirements at SVM level.

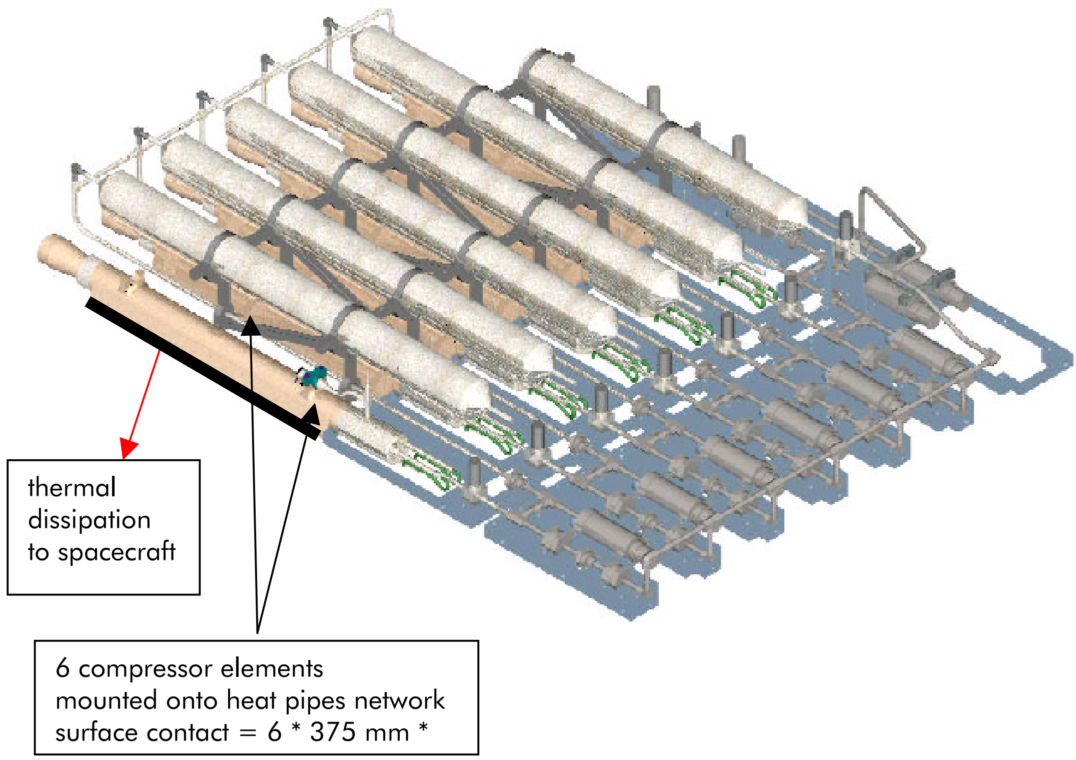


Figure 6.2.6-4 Compressor physical assembly (JPL drawing)

	Thermal requirement
SCC average dissipation	Max: 470 W
SCC peak dissipation	1200 W
Single bed peak dissipation	1020 W
Adsorbing bed operating temperature range (S/C side)	[260 K, 280 K]
Thermal gradient between S/C and adsorbing beds	< 2 K
Temperature fluctuation level between under adsorbing beds	[7 K, 4.7 K, 4.7 K] peak to peak (*)

(*) proposed in iss 3.0 of AD04.6

Table 6.2.6-4 SCS main thermal requirements (SVM level)

The above thermal requirements have deep impact on the SVM overall design. First of all, the octagonal shaped SVM box had been optimised in order to provide enough radiative area on a minimum number of adjacent panels in order to evacuate the average SCC and SCE dissipation. The necessity to transport the heat dissipated by the SCC and SCE all over the three panels dictate the use of a heat pipes network. The overall configuration is depicted on Figure 6.2.6-5.

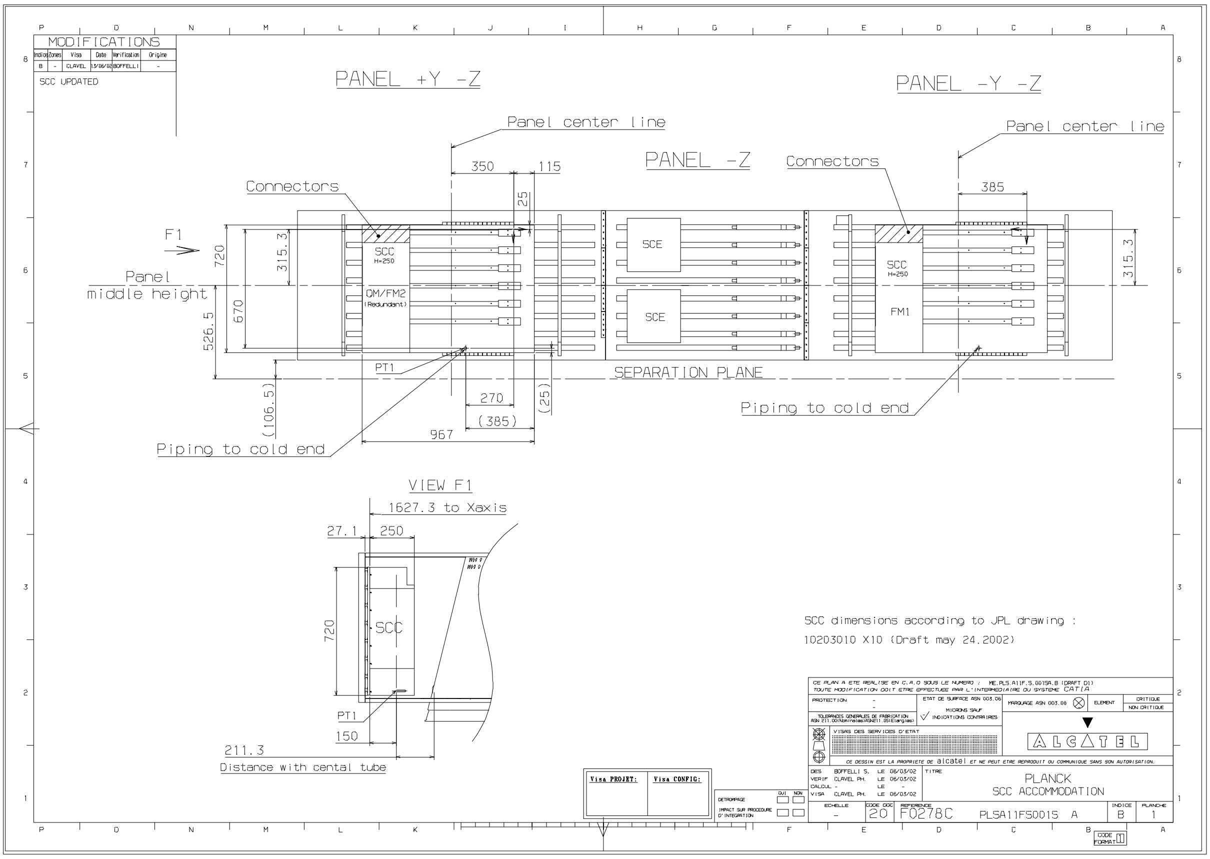


Figure 6.2.6-5 SCS accommodation in SVM

The SCC dissipative elements (the 6 beds) are mounted directly onto a first network of crossing pipes. A stringent requirement on these heat pipes is to sustain a heat power density onto their flange up to 6 W/cm2, occurring when thermal conductance between a hot bed and the radiator is restored. Heat is then transmitted to a network of longitudinal pipes, which distribute it all over the panels. Sizing of this network is driven by the heat transport capacity requirement, since they have to evacuate up to 1200 W on a total length of ~4 m. In order to optimise the heat capacity need, the longitudinal network has been broken into two short network.

The operating design temperature range of the SCC is a critical parameter given the very high heat dissipation of the SCC. This has lead to require a thermal insulation between the SCS panels and the remaining warmer SVM. This need of insulation is also justified by the fact that the high dissipation fluctuations induce large temperature fluctuations. The transmission of these fluctuations by conduction through the whole SVM, and at least to the P-PLM are not in line with the need of thermal stability for straylight purpose.

The most difficult aspect linked to the heat pipes network is related to the on-ground thermal test configuration. First of all, the heat pipes will operate in the so-called "reflux mode", which is not conventional even if more and more adopted especially for Telecommunications satellite. Besides this aspect, the test configuration is such that the first unit to be switched ON during tests is the Sorption Cooler Electronics, located in a "dry area" of the heat pipes when not yet started. The baseline to initiate the fluid circulation is to use implemented heaters as “start heaters” on relevant location of the longitudinal network.

Finally, acceleration levels during orbit are considered and taken into account for the elaboration of the procurement specifications. Acceleration level due to the spin is not a sizing case.

Results obtained by Alenia for on-orbit conditions and End Of Life case for the thermal analyses, are gathered in the next table:

	ALENIA RESULTS	REQUIREMENT
maximum T SCC/Spacecraft interface (adsorption phase)	280 K	280 K
Temperature stability at Spacecraft interface	[±7.9 K, ±2.2 K, ±2.2 K]	[±7K, ±4.7K, ±4.7K]*

* Proposed in iss 3.0 of AD04.6

Table 6.2.6-5 SCS thermal requirements assessment

RFD for the stability of the first adjacent bed will be issued and discussed with JPL.

6.2.6.5.2 4K Units

The 4K units are installed on the +Y panel, expect CRU which have been moved from 4K enclosure to the +Y+Z shear web (along with FOG units) in order to reduce dissipation in this enclosure.

The thermal requirements for these units are gathered in Table 6.2.6-6.

Unit	Operating temperature		ALENIA results		Dissipated power (W)
	Min (°C)	Max (°C)	Min (°C)	Max (°C)	
4K CRU	-10	+40	+1.7	+41.7	21
4K CAU	-10	+40	-5.9	+4.9	15
4K CEU	-10	+40	+17.0	+39.8	43
REU	-10	+40	+11.9	+34.7	92
4K CCU at bracket level	-10	+40	-0.8 at -X -7.1 at +X	+20.8 at -X +13.2 at +X	60
4K CCU at strap level	-10	+40	+17.6 at –Z +15.9 at +Z	+40.6 at –Z -38.7 at +Z	

Table 6.2.6-6 SCS thermal requirements assessment

Despite the move of the CRU unit, CRU and CCU are still not within requirements. Recovery action are presented in § 8.2.

6.2.6.5.3 P-PLM warm units equipment on sub platform

Three warm units are installed on the P-PLM sub-platform due to layout constraints with regards to the P-PLM. The concerned boxes are the BEU/DAE control box and DAE power box from LFI instrument and PAU box from HFI instrument.

A satisfactory solution has been found for the DAE power box, which conventional design temperature range (50° C maximum) enables its location at the –X side of the P-PLM sub-platform. This situation is not possible for the BEU/DAE control box as well as for the PAU box. The only way to reduce their temperature is to allow thermal radiation of these units towards cold Space. The drawback is an increase of the heat loads onto the warmest "V-groove" shield. This heat flux has been in turn used as an input data for the P-PLM thermal budget. The total allowable heat flux for BEU/PAU is 2.3 W.

The BEU and PAU warm units are thermally controlled by the use of an aluminium doublers to enhance conductance towards dedicated remote radiators.

The thermal requirements for these units are gathered in Table 6.2.6-7.

Unit	Operating temperature		ALENIA results		Dissipated power (W)
	Min (°C)	Max (°C)	Min (°C)	Max (°C)	
DAE power box	-20	+50	+3.9	+38.8	13.09
BEU	-20	+40	-16.3	+34.9	31.76
PAU	-10	+30	-12.8	+30.9	15

Table 6.2.6-7 Thermal requirements for sub platform equipments

Requirements are met on DAE, BEU. PAU is out of specification. Recovery action is proposed in §8.2.

6.2.6.5.4 Planck during launch

The computations, made by AE in the frame of the RAMP, are still in progress. The results are foreseen for end of august 2004. They will be discussed during the system CDR collocation.

The clocking of Planck with respect to the Sylda has been chosen in order to prevent sun illumination of the optical cavity during the BBQ phases (holes in the conical part of Sylda) and of the star trackers (holes in the cylindrical part of Sylda) (see §4.3.4.).

6.2.6.5.5 CFE equipments

FOG

The FOG (GEU+ICU) is installed on the +Z side of the +Y+Z shear web. Both units are black painted (Z306).

The GEU is mounted on a filler whereas the ICU is bolted on the web with a metal/metal contact.

SREM

The SREM is installed externally on the +Y+Z panel. This unit is black painted and mounted without filler on the panel.

The requirements and results for these units are presented in Table 6.2.6-8:

Unit	Operating temperature		ALENIA'S results	
	Min (°C)	Max (°C)	Min (°C)	Max (°C)
FOG (GEU)	0	+40	+8.7	+40.0
FOG (ICU)	0	+40	-2.8	+23.7
SREM	-10	+50	+5.1	+29.5

Table 6.2.6-8 FOG and SREM thermal requirements and results

The FOG GEU and the SREM are compliant with their temperature specification. The Fog ICU is exceeding its minimal operational temperature by 2.8 °C. Recovery actions are proposed in § 8.2.

6.3 Electrical and functional systems design

This section describes the way each of the main Herschel and Planck spacecraft's functionality's are implemented via hardware or software. A functional approach is used first, then the implementation is described through a breakdown into subsystems with a focus on the system related issues, and the EMC constraints on the design are provided. It shall be pointed out that the detailed description of each subsystem shall be found in the relevant section of the Service Module Design Report (RD01.01). Emphasise will be made on the design evolution since the Preliminary Design Review.

6.3.1 Electrical design overview

Before describing the different functions and their main design features, the major drivers retained are recalled hereafter, covering the overall system design, development and validation aspects.

- compliance to technical and fault tolerance requirements
- commonality between Herschel and Planck designs; this is one of the programme challenge
- optimisation of the hardware towards minimisation of the mass and cost aspects
- favour software based solutions to make the design more flexible in the development and mainly validation phases
- match the industrial development and validation constraints.

The overall electrical architecture is conceived to satisfy both the instruments and spacecraft mission needs.

The baseline is presented in Figure 6.3.1-1 for Herschel and Figure 6.3.1-2 for Planck. In line with the above drivers it is:

- decentralised, with the Data Handling tasks and the Attitude Control tasks running on 2 distinct computers
- high centralised within each Data Handling and Attitude Control computers, and a single Power Conditioning and Distribution Unit
- basically identical for both spacecraft's.

The electrical design changes since PDR are minimum:

- the Visual Monitoring Camera has been removed from Planck spacecraft, basically because it was impossible to get any picture of interest for media purpose from it
- Fiber Optics Gyroscopes have been added on Planck as CFE's. These units are connected on the ACMS data Bus. Their data is collected and formatted by the ACC and ACMS SW but is not used within the ACMS processing. A very basic FDIR is applied.

This design will be commented in the next sections but beforehand a functional level description is proposed, including functions related to spacecraft and instruments, and insight in the implementation is given. The main functions which will be discussed in the following are:

- the power generation
- the power protection and distribution
- the ground interface

- the telemetry acquisition and command and telecommand distribution
- the time management,
- the thermal control,
- the attitude and orbit control,
- the fault protection,
- the data storage,
- the instruments and Payload Modules Interfaces
- the interface with the non SVM units.

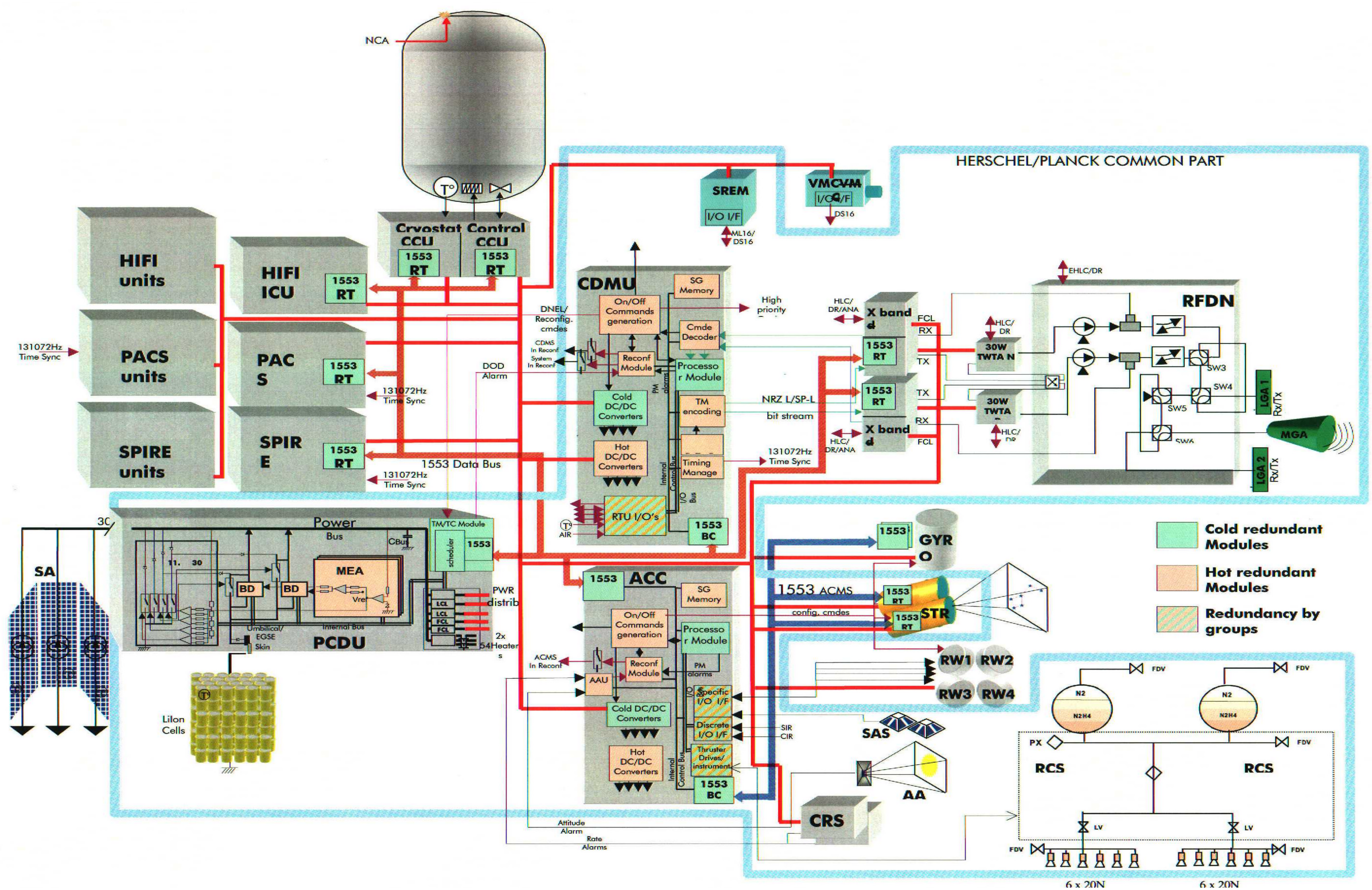


Figure 6.3.1-1 Herschel electrical architecture

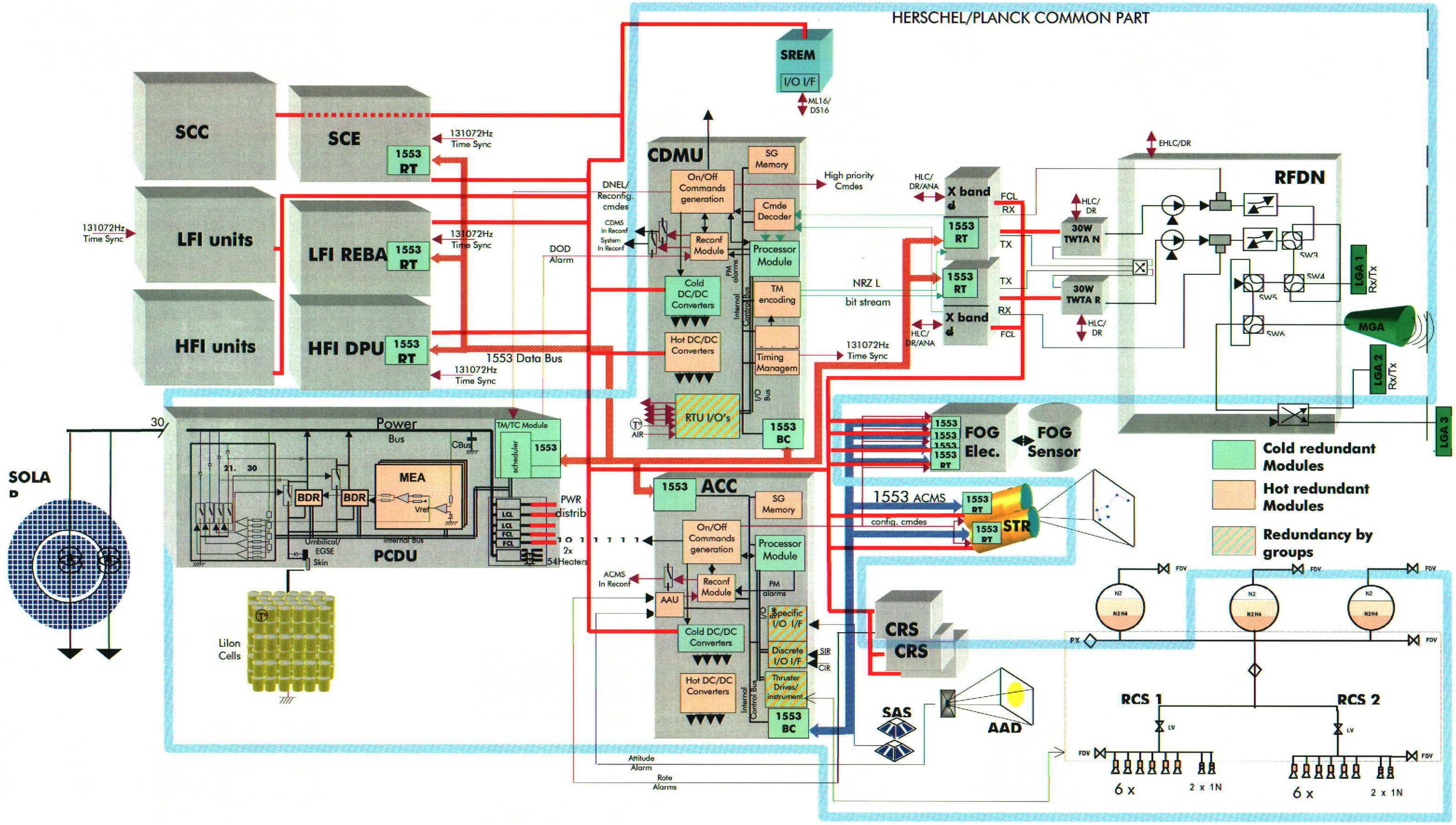


Figure 6.3.1-2 Planck electrical architecture

Power Generation

High-power Solar Arrays provide the necessary power to a 28V regulated bus. They are capable to sustain the high temperatures induced by the Mission requirements: indeed, the rear faces of the arrays must be blocked for Herschel and for Planck to minimise the thermal leakage towards the cold Payload Modules. The performances are guaranteed in these conditions.

Due to the stable temperature and Sun illumination conditions which characterise both Herschel and Planck missions, a power bus regulated by the S3R technique has been found optimum is implemented.

Another common feature is that both missions are eclipse free; however, because of:

- the need to power ON the spacecraft during launch in order to have the spacecraft ready for fast and safe post separation activities
- the need to be robust to a loss of nominal Sun pointing in case of unexpected multiple-sources failure.

An additional energy source is implemented consisting in a single, SPF tolerant, Lithium-Ion secondary battery. This battery is sized to cover the launch case, while the recharge rate is set high enough to take profit of the minimum illumination which could result from an attitude loss failure (SOHO lesson learnt).

The power generation function, essential to the satellites survival, is entirely hardware based. It is thus fully autonomous, especially for the solar array conditioning and battery charge/ discharge control, and is active as soon as energy is available from one of the sources.

Power distribution and Protection

The 28V regulated power is distributed to the power bus users, spacecraft and instruments units, via Latched Current Limiters (LCL) and Fold Back Current Limiters (FCL). The FCL's allow an automatic turn ON of the units as soon as sufficient power is available. They are allocated to the elementary functions which are considered as critical for the mission safety and control, and which shall not be affected by a reconfiguration:

- RF receiver
- TC decoder
- Reconfiguration electronics
- On board Time.

The other functions and units are supplied via switchable current limiters. These LCL's are nominally controlled by the data handling (CDMU) software via the 1553 data handling bus. For most of these LCL's, this commanding can however be overridden by High Level Commands issued by the CDMU reconfiguration electronics, and by direct ground TC's. A DNEL-like function, performed as part of a major recovery action allows to minimise the number of necessary HLC's, each of them suitably applies to groups of LCL's.

Both LCL's and FCL's also implement a protection function which ensure that any power problem in a unit does not propagate to the other units or functions.

Some LCL's feature a double switching mechanism to protect the user against failed ON conditions; these are:

- the LCL's for which the instruments have stated that they could not accept simultaneous ON of both nominal and redundant units,
- the LCL's which failure in ON status would cause critical impact to the spacecraft (e.g. Sorption Cooler Compressor)

The heater lines are organised into groups, each group being protected by a LCL while the elementary lines are activated via individual electronic switch devices. Specific FCL's are also provided to support the heating of the spacecraft in emergency situations (see later, thermal control function).

Ground Interface

As far as ground link is concerned, the Herschel and Planck missions are characterised by:

- X-Band links for up and downlinks and the same modulation scheme. Frequencies allocations however are specific for each spacecraft
- the Earth to spacecraft distances during operation are very comparable for both spacecraft: 1.8 Mkm for Herschel (large Lissajous), 1.6 Mkm for Planck (small Lissajous).
- the spacecraft to Earth aspects angles from telecommunication point of view are similar for both spacecraft: 15° maximum for Planck and 0° for Herschel
- the uplink and downlink rates requirements, mainly driven by the science data, are identical

which calls for an obvious hardware commonality for both up and down links.

Downlink:

The data collected by the CDMU is both transmitted in real time to one of the 2 cold redundant RF transmitter, and stored on board in the CDMU mass memory (see later) in case the RF link is not established. Each spacecraft will benefit from typically 3 hours of Daily Telecom Communication Periods (DTCP) during which it will be possible to establish the real time link, and download the stored data. 2 sets of antennae are provided:

- one Medium Gain Antenna permits to achieve the highest rate, but with a limited angular coverage; this is the nominal antenna for downlink and uplink during nominal operation
- 2 Low Gain Antennae on Herschel, and 3 Low Gain Antennae on Planck are implemented to make possible the transmission of data, though at a limited rate, in any spacecraft orientation; these are the nominal uplink and downlink antennae in spacecraft Sun Acquisition Mode and spacecraft Survival Mode.

Depending on the ground station (New Norcia or Kourou), and on the transmitting antenna, 4 downlink rates can be programmed:

- 500bps with both stations on LGA's
- 5kbps with New Norcia on LGA's
- 150kbps with both stations on MGA
- 1.5Mbps with New Norcia on MGA.

The optimisation of the available telecom bandwidth and the proper share between real time and stored data is guaranteed by an extensive use of the Virtual Channel mechanism; among 8 VC available, 6 are allocated with a defined priority scheme which ensures that both:

the spacecraft HK and critical instruments HK data have priority over the science data

the real time data has priority over the stored data.

This is then achieved by the following detailed allocation, from the highest to the lowest priority:

- VC0: real time essential spacecraft HK + essential instruments HK + Non periodic HK
- VC4: real time routine spacecraft HK + routine instruments HK (periodic)
- VC2: stored spacecraft HK (incl. non periodic HK+ stored instruments HK
- VC1: real time science data

– VC3: stored science data

– VC7: idle frames.

Where a transfer frame from VCn will be transmitted only if no transfer frame from higher priority Virtual Channels is ready to be transmitted, and if the downlink rate permits it.

The instruments data rates allocations and the spacecraft HK rate current allocations are:

– spacecraft real time HK = 9 kbps, composed of 3 kbps of essential spacecraft HK and 6kbps of routine spacecraft HK (this mainly comprises data for attitude reconstruction on ground when the spacecraft in Nominal Mode of operation)

– instruments real time HK = 2 kbps/instrument, composed of 300 bps of essential HK and 1.7 kbps of routine instrument HK

– real time science data = 130 kbps for all instruments together.

They are defined such that:

– the 5kbps downlink rate allows

  - when the S/C is in Sun Acq Mode at Launcher separation to transmit all the VC0 frames plus a few VC2 frames since no critical instrument HK (instruments are OFF), and no VC4 frames are present
  - when the S/C is in Sun Acq Mode, and when the link with New Norcia can be established, to transmit all the VC0 frames.
  - the 500bps downlink rate permits to transmit via VC0, when the S/C has transitioned to Sun Acq Mode or Survival Mode, a subsampling (1 packet over 11) of the essential TM packets plus the non periodic TM packets.

– the 150 kbps downlink rate permits to transmit all the VC0, VC4, VC2 then VC1 frames; this rate allows nominal real time operations of the spacecraft and instruments even if the spacecraft is in visibility of only Kourou station,

– the 1.5Mbps downlink rate permits to transmit all the VC0, VC4, VC2, VC1 & VC3 frames in a Daily Telecommunication Period (DTCP), with New Norcia.

The down link modulation scheme is NRZ-L/BPSK/PM for low rates, SP-L/PM for medium rate and GMSK for medium for high rate.

The downlink rates, corresponding modulation scheme as well as the antennae configurations are set by software commands, depending on the current satellite mode (see later for the definition of the spacecraft modes); a safe configuration is however selected at initialisation (typically 500bps on LGA). Similarly the RF transmitter and the TWTA to be used for downlink are turned on at start of the DTCP, and then nominally turned off and - on Planck - replaced by compensation heaters not to disturb the scientific observations.

The CDMU outputs Reed Solomon and Convolutionaly encoded, pseudo randomised for the high data rate, NRZ-L telemetry signals, leaving the whole modulation process into the TTC function (transponder): this approach allows to have the responsibility of the whole modulation performance within one single subsystem with the associated technical and interface cleanliness benefit. The pseudo randomisation is mandatory on the GMSK modulated signal to be able to guarantee a bit transition density consistent in all cases with the ground station performance

Uplink

The signal transmitted from ground is acquired by one of the 2 antenna sets:

- The Medium Gain Antenna in S/C Nominal Mode and Earth Acq Mode (see later for the definition of the S/C modes)
- the LGA's, oriented towards the +Z direction for Herschel and -X direction for Planck in S/C Sun Acq Mode and Survival Mode. The other LGA's would be solicited only in case failure leading to an attitude loss. All LGA's together ensure an omnidirectional coverage.

Depending on the ground station (New Norcia or Kourou), 2 uplink rates can be used:

- 125bps with Kourou
- 4kbps with New Norcia.

The demodulation of the X-band up stream is performed by one and possibly the 2 hot redundant Rx receivers, the signal on one of the receivers being in nominal much stronger than the other one. The demodulated data is then forwarded to the two hot redundant TC decoders which determine the best stream to lock on. Note that a priority scheme is implemented to avoid an erroneous lock on the weaker signal (lesson learnt from XMM: TC rejection anomaly).

Once decoded by the addressed decoder, the TC packets are either sent to the Command Priority Distribution Unit for direct commanding of e.g. the PCDU current limiters, or to the CDMU Processor Module in order to be processed by the software (Basic SW or Application SW).

Since the telecommand chain is basically in hot redundancy, only the receiving antenna and the uplink rate have to be selected by software.

Data acquisition/commands distribution

This function deals with the collection of telemetry data on board, and with the distribution of commands and telecommands.

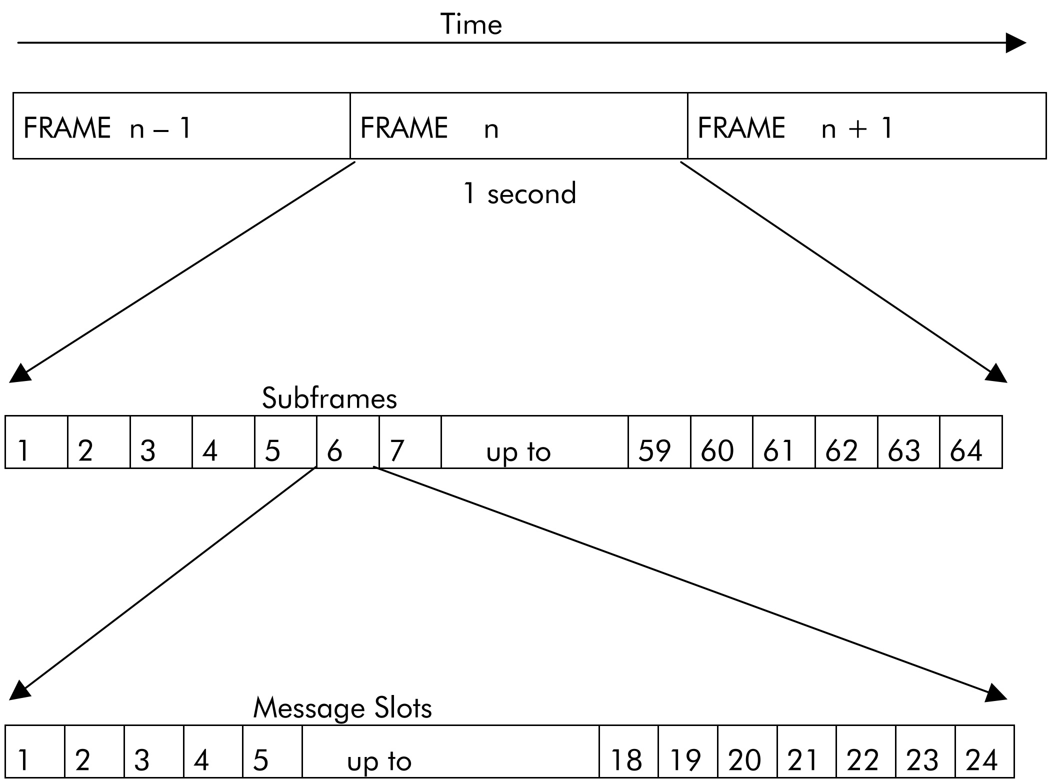
The communication on board the 2 spacecraft's is organised around a redundant 1553 data bus, to which most of the units are connected. This permits a straightforward interfaces implementation since all the science data and most of the housekeeping collection as well as the instruments and most of the units commanding will be via 1553 messages.

The main contributors to the load of this bus, the instruments and the ACMS computer, feature a packet level interface. The other units,

- either have a 1553 bus interface without packet I/F, i.e. the communication is at message level (PCDU, CCU for Herschel, Transponders). These are called "non intelligent users")
- or have standard point to point interfaces (Transponders receiver part, TWTA, RFDN, SREM, VMC, thermal control): DS16/ML16, Bilevels, Relay Status, Analog, Temperatures, on/off commands.

In these 2 cases, the telemetry packets are built by the CDMU software.

The bus protocol implemented to ensure an efficient and robust transfer of data is based on a cyclic structure, synchronised to the On Board Time (see Figure 6.3.1-3). The bus time is split into 1s frames comprising 64 subframes. Each of these subframes is itself composed of 24 elementary, well defined, slots where each slot contains a 1553 Bus message. The content of the subframes specifies the RT addresses and the subaddresses to be polled or to command; it is defined by a so called Bus Profile. The Bus Profile in use depends on the current spacecraft configuration and on the current instruments operation. A set of 16 Bus Profiles can currently be pre-defined and the switch from one profile to another one is performed upon telecommand. Each of the pre defined profiles can also be modified by telecommand.



Definition: 1 FRAME = 64 SUBFRAMES; 1 SUBFRAME = 24 MESSAGE SLOTS

Duration: 1 FRAME = 1 second: 1 SUBFRAME = 1/64 second .

Figure 6.3.1-3 Data Bus Protocol principles

Rules have been defined such that:

- One subframe is allocated to one single TM packet transfer. The maximum TM packet size (1kbyte) is such that it can be transferred in one subframe only
- Up to 3 TC packets can be transferred in one subframe, but each packet user shall only receive one TC per subframe.
- A complete subframe shall not necessarily be allocated to the transfer of non packetised 1553 messages: these messages can be interleaved in already allocated subframes.

Based on these rules, maximum subframes allocations have been specified in accordance with the instruments data rates and spacecraft subsystems data rates (see TN Data Rates & Downlink rates RD03.11). The current allocations are shown in Figure 6.3.1-4 & Figure 6.3.1-5 for Planck and Herschel as a function of the satellites modes (see §6.3.3 for description of the Satellite Modes). It shall be pointed out that the protocol capability in term of bandwidth, i.e. the maximum amount of useful data which be exchanged on the Bus, in some specific conditions, can be higher than 440 kbps, thus well in excess of the required performance.

PLANCK SUBFRAME ALLOCATION	Launch Mode	S/C Sun Acquisition	Nominal Normal	S/C Earth Acquisition	Survival
LFI TM	0	3	15	3	0
HFI TM	0	3	15	3	0
Sorption Cooler HK TM	0	2	2	2	0
AOCS TM	4	4	4	4	4
PCDU TM	1	1	1	1	1
AOCS TC receipt Report TM	2	2	2	2	2
Subframes allocated to TC sending	4	4	4	4	4
FOG TM/TC	0	1	1	1	0
Total number of subframes allocated	**11**	**20**	**44**	**20**	**11**
Number of spare subframes	**53**	**44**	**20**	**44**	**53**
Max theoretical equivalent bit rate (bps)	90112	163840	360448	163840	90112
Actual equivalent bit rate (bps)	65024	130560	327168	130560	65024

Figure 6.3.1-4 Planck Subframes allocation

HERSCHEL SUBFRAME ALLOCATION	Launch Mode	S/C Sun Acquisition	Nominal		S/C Earth Acquisition	Survival
			Normal	Burst Mode		
Prime Instrument TM	0	3	27	40	3	0
Non-Prime1 Instrument TM	0	3	3	3	3	0
Non-Prime2 Instrument TM	0	3	3	3	3	0
AOCS TM	4	4	4	4	4	4
PCDU TM	1	1	1	1	1	1
CCU-Nominal TM	1	1	1	1	1	1
CCU-Redundant TM	1	1	1	1	1	1
AOCS TC receipt Report TM	2	2	2	2	2	2
Subframes allocated to TC sending	4	4	4	4	4	4
Total number of subframes allocated	**13**	**22**	**46**	**59**	**22**	**13**
Number of spare subframes	**51**	**42**	**18**	**5**	**42**	**51**
Max theoretical equivalent bit rate (bps)	106496	180224	376832	483328	180224	106496
Actual equivalent bit rate (bps)	69120	142848	339456	445952	142848	69120

Figure 6.3.1-5 Time Management

An essential parameter in the scientific data processing for both Herschel and Planck missions is the time accuracy, and especially the time synchronisation between science and attitude data.

This function is basically implemented in hot redundancy within the CDMU which manages the On Board Central Time Reference and distributes synchronisation signals. More precisely, this CTR is:

– Used to synchronise the time based on board operations

– Distributed to the 1553 data handling Bus Remote Terminals at the subframe 33. This datation mechanism permits a relative accuracy of less than 50µs between the CTR and a given RT, i.e. a datation accuracy between the Attitude data packets and the science packets which can be far better than the specified 500µs,

– Distributed within the Packet Structure ICD service 9 to the packet users which can accept it, upon TC,

– Used to generated the 131072Hz synchronisation signals to the instruments units.

This function is implemented in hot redundancy, such that:

– the CTR reliability is improved: no single failure can stop/corrupt the On Board time.

The mechanism to synchronise the on board time with the ground Temps Atomic International (TAI) is provided in compliance with the Packet Telecommand standard, however no need is expressed for such an on board correlation. On the contrary, the instruments, if they look for an accurate on board synchronisation of all the events with a Central Reference Time, do not expect any jump in time, such as the ones which would result from the CTR synchronisation with the ground time. Eventually the baseline operation principle is to let the on board time "free running", and to perform on ground the necessary TAI correlation, on a daily basis. This offers the benefit to significantly relax the constraints on the long term stability of the on board oscillators.

In order to increase the accuracy of the on ground time correlation, a change in the Time TM packet sampling interval from 1 every 256 VC0 frame to 1 every 64 VC0 frame has been implemented.

Active Thermal control

As a result of the drivers announced at the beginning of the chapter, the nominal thermal control function is essentially implemented via software, as illustrated in Figure 6.3.1-6, which allows to remain flexible in the setting of the different parameters until late in the development of the spacecraft's.

The temperature of each controlled interface point is monitored by 3 hot redundant sensors acquired by the CDMU I/O system. After a majority voting on these 3 measurements is computed the result is entered in either a Proportional-Integral regulation loop (fine regulation) or a simple min/max algorithm, depending on the interface point to regulate (fine regulation is currently applied to HIFI and STR units). As a result the corresponding nominal heater line is commanded in the PCDU via 1553 messages.

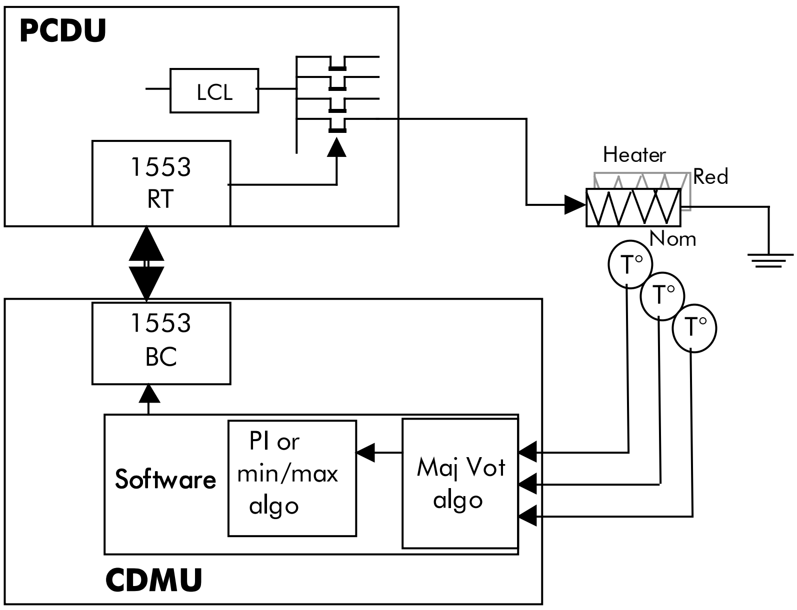


Figure 6.3.1-6 Nominal active Thermal Control

In order to cover the case of a critical failure ultimately leading to the loss of both CDMU's processor module, a survival thermal control is implemented, entirely relying on thermostats connected on permanent, FCL protected lines in the PCDU. This back up mode design is basically based on the following requirements:

- the thermostated control shall not interfere with the nominal operating mode: the survival temperatures thresholds shall be set such that there is no risk of overlap with the nominal thermal control thresholds
- the survival heating function does not aim to keep all the units within their operating or non operating ranges. Its purpose is to guarantee a minimum temperature level to the units essential for the spacecraft survival and to support it in the recovery from a dramatic SOHO-like failure case.

It has actually been shown that Herschel and Planck thermal design were such that no part of the spacecraft would reach temperatures below the qualification levels in any failure condition. Thermostats are therefore only used on the battery to ease SOHO-like failure cases recovery by maintaining it within temperature ranges for which the charge efficiency is optimum.

Attitude and orbit control

This function deals with all the monitoring and control necessary to keep the spacecraft in a pointing attitude in line with the satellites modes (see §6.3.5) and targeting requirements . It is characterised by:

- a fully autonomous implementation based on a dedicated computer, the ACC, and a full control of the subsystem units configuration
- a high commonality between Herschel and Planck designs: in terms of hardware and in terms of operating modes.

The Attitude and Orbit Control function, in standby during launch, becomes active upon sensing of the launcher separation strap status . In parallel, at separation, all nominal and redundant ACMS sensors and actuators LCL's are turned on in the PCDU from CDMS commanding; the configuration of the ACMS units is then managed autonomously by the ACMS computer (the ACC) which acts in baseline directly at the level of ON/OFF switch implemented within each unit. Exceptions, apart from the Sun Acquisition Sensors and Attitude Anomaly Detectors are the Coarse Rate Sensors: their status is only controlled by the turn ON/OFF of the PCDU LCL's; they will nominally be switched ON before launch, and never by switched OFF during the mission.

It shall be pointed out that the LCL's role as far as ACMS units power lines are concerned is limited to the protection function. No recovery action at CDMS level will modify the configuration which remains in all cases under full control of the ACMS; as it will be discussed later, a failure upstream an ACMS unit (especially in a LCL) will simply be seen as a unit failure by the ACMS, and handled within the ACMS FDIR.

After separation, then, the ACMS automatically enters a Sun acquisition mode relying on a limited and reliable set of sensors/actuators. From this state the transition to normal mode and the associated pointing targets are received as CDMS telecommands wherever they are originated from (ground, mission timeline, FDIR). A feature of the design is that although the ACMS, in normal pointing mode, is basically slaved to the CDMS once the sun acquisition is achieved, its commanding is performed via high level pointing commands which are decoded locally and realised autonomously in the ACMS.

In parallel to the normal mode of operation, the FDIR task is performed and has priority over all other tasks. In case of failure, ultimately, as it is addressed briefly in the following, and in a more detailed way in section 6.3.3, the survival mode is engaged.

Apart from the design features directly derived from the performance requirements, the overall Attitude and Orbit Control function implementation is strongly driven by a small number of FDIR related rules:

- the survival mode is based on a specific, different set of sensors and actuators and does not rely on reaction wheels (on Herschel),

– the survival mode is triggered by units which do not participate to the normal mode nor to the survival mode itself.

The different satellites mode and their relationships with ACMS modes and FDIR are be detailed later in Section 6.3.3.

Fault protection

The fault protection function first aims to protect the spacecraft safety, including the instruments, in case of any single failure, and second in the cases where this is feasible, to optimise the mission scientific return.

It is basically distributed between hardware and software features on the one hand, and between the CDMS and the ACMS on the other hand.

The fault protection system is basically always active from the separation with the launcher, and runs in parallel to the other tasks which it interrupts in case of failure, with actions depending on:

– the failure critically

– the FDIR current mode.

The failure criticality is identified by 5 levels, from the less critical level 0 which has no noticeable impact on operation to the system level 4 which leads to initiate a survival mode. The implementation of the detection and of the recovery mechanisms fully depends on this failure criticality: software based for levels 1 & 2, and hardware based for levels 3 & 4, potentially both for the level 0. The levels 3 & 4 are supported by a reconfiguration electronics included in the CDMU and the ACC, hot redundant, supplied via FCL's and capable to detect the selected alarms, and as a result to start specific reconfiguration sequences.

There exist two FDIR modes:

The Autonomous Fail Safe (AFS) mode actually implements the Failure Detection function, but not the Isolation nor the Recovery. The AFS mode is automatically engaged at launcher separation and is proposed to remain valid until each spacecraft is commissioned. It is designed to limit the consequences of the spurious raising of numerous false alarms which may happen before all the failure detection thresholds are properly adjusted. The AFS mode ultimately relies on the survival mode triggering to recover from a real failure.

The Autonomous Fail Operational (AFO) mode implements the full FDIR function, with hierarchical recoveries following the failure criticality to optimise the use of the available hardware. The AFO mode is basically the operational mode which should be engaged once the spacecraft's commissioning is completed. The recovery actions are designed to minimise the impact on the scientific mission as long as spacecraft safety is not considered endangered.

These 2 modes and 5 criticality levels are applied to both ACMS and CDMS. It is intended to have the 2 subsystems run in the same FDIR mode. The interface between ACMS and CDMS as far as fault protection is concerned is kept simple: both sides report to the other one only the failures levels 3 & 4 via status lines, but the current FDIR status is totally independent from one subsystem to the other. Especially a level 4 failure recovery in one subsystem does not lead to trigger a level 4 alarm in the other subsystem.

Data storage

Most of the mission time happens out of ground station visibility. The data storage function purpose is to offer hardware and associated software mechanisms to temporarily store the acquired science or housekeeping telemetry before they can be downloaded to ground.

The storage medium is constituted by a hot redundant Solid State Mass Memory (SSMM). Its size of 25Gbits EOL per redundancy allows the storage of all the data generated on board plus the storage of the Mission Timeline for more than 48 hours. In order to increase the reliability of the storage process, (the acquired data is stored in parallel into the 2 SSMM.

The data in each SSMM is organised in stores which number and size are fixed by command. By design, each store must be allocated to a single virtual channel and fulfill the following constraints:

- remain consistent with the virtual channels allocation on the one hand
- be in line with the Herschel and Planck missions characteristics and instruments specific requirements
- ensure a good protection of the stored data
- The packet stores allocation and breakdown between Science data, HK data, each instrument is controlled by specific software services and remains essentially an operational issue (with the subsequent need to minimise the daily number of operations). Scenarios are proposed by ESOC, however the baseline approach is under consolidation.

The storage function is always active: during launch, all the acquired HK is stored, then is started to be downloaded when the RF link permits it. The storage is never interrupted, which guarantees a permanent access to the spacecraft configuration and status during the non visibility periods.

Instruments and PLM interfaces

Interfaces with the instruments have been kept as simple as possible.

From an Hardware point of view,

- the power is distributed via a set of dedicated LCL lines, some implementing the "double switches" feature. The instruments do not internally control the switching ON/OFF of these power lines; only some secondary power switching may be performed at instrument level,
- the telecommand and telemetry interface is only via the CDMS 1553 data bus
- individual 131072Hz clock, synchronised with the On Board Master Clock are distributed to some instruments for synchronisation purpose. HFI and LFI (Planck) use these lines for the precise datation of the science data. It is to be noticed that the standard procedure implemented to time synchronise the science samples with the spacecraft telemetry uses the 1553 data bus protocol, which distribute the CTR (Central Time Reference) with every second.

From a software point of view, the instruments interface is mainly restricted to the telemetry packets collection and telemetry packets distribution in accordance to the data bus protocol addressed beforehand (see Figure 6.3.1-3). The packet data interface mechanism is driven by Bus Profiles established for each Mission configuration (and which can be changed in flight). Few additional functions also appeared necessary, these are:

- the procedures to turn ON/OFF a complete instrument,
- the procedures to support the recovery of an instrument in case of failure of the instrument itself, or of the 1553 data Bus interface.

These procedures are under detailed definition, however, to limit the impact on the on board software process, the baseline is to go through an implementation using On Board Control Procedures (see §6.3.3).

The PLM interface somewhat differs between Herschel and Planck.

On Herschel it consists in:

- the control of the CVV valves and the temperature monitoring; this is performed via the Cryostat Control Unit (CCU)
- the monitoring and control of the telescope temperatures in order to implement a decontamination algorithm. The temperature sensors are acquired by the CDMU via the CCU, the Herschel specific control law is performed within the CDMU ASW and the telescope heaters are commanded via the PCDU.

On Planck it consists in:

- the monitoring and control of the telescope reflectors and Focal Plane Unit temperatures in order to implement a decontamination algorithm. The temperature sensors are acquired directly by the CDMU, the Planck specific control law is performed within the CDMU ASW and the telescope and FPU heaters are commanded via the PCDU.

Non SVM units interfaces

Some Herschel and Planck units are not part of the actual Service Module definition; these are the Cryostat Control Unit, the Visual Monitoring Camera, the Standard Radiation Environment Monitor and the Fiber Optics Gyroscopes.

CCU:

This unit acts as a "RTU" in charge of the Herschel PLM interface as addressed in the previous paragraph. It is made of 2 strictly identical halves, operating in active hot redundancy. The hardware interfaces are simple: 2 power lines are distributed to the 2 CCU halves via 2 LCL's, and the data interface is via 2 CCU 1553 data bus connections, one for each half.

The CCU is in the "non intelligent" user category and receives/transmits non packetised messages. The specific software interfaces to communicate with the CCU are detailed in the Section 6.3.4.

Visual Monitoring Camera:

This media-purpose camera is only installed on Herschel. The hardware interfaces are very basic: 1 power line is distributed via one LCL, and the image and telemetry data is acquired via a standard DS16 serial interface.

Its mission and mode of operation are by steps:

1. the VMC is turned ON by the CDMU SW as part of the post separation sequence,
2. after 5s of warm up, it automatically starts to acquire images which integration time and acquisition period can be selected before launch via jumpers, among a set of pre defined values; integration time can be chosen between 0.7 and 5ms depending on the calculated illumination of the scene to capture, and the images acquisition rate can be every 1s to every 1.75s,
3. A maximum of 15 512x512x8bits images are stored in the VMC RAM. Once the VMC memory is full, it stops acquiring images, and the data remains stored until switch OFF,
4. Upon dedicated TC, the raw images are acquired by the CDMU, packetized, then transferred to a CDMU SSMM packet store. The specific software process is addressed in section 6.3.4,
5. The packet store containing the VMC packets are transferred to ground, via VC0 virtual channel, upon telecommand,
6. The VMC can be turned OFF …

SREM

This unit is a CFE installed on Herschel and on Planck which aims to continuously collect data on the radiation environment seen by the spacecraft over the mission. The hardware interfaces are: 1 power line is distributed via a single LCL, the housekeeping data is acquired via a standard DS16 serial interface while the commands are sent via a standard ML16 I/F.

The software interface is through a dedicated function and is detailed in Section 6.3.4.

FOG

The Fiber optics gyroscopes are CFE's installed on the Planck ACMS 1553 Bus. The FOG is actually constituted by 4 identical blocks (1 per measurement axis), each of them supplied by an individual power line via LCL and featuring an independent 1553 Remote Terminal. Each of the blocks can be commanded in ON/OFF state by the ACC which therefore controls the FOG configuration.

The FOG is not involved in the ACMS processing and a very basic FDIR is applied; the acquired telemetry is simply packetized then sent to the CDMU as part of the normal ACMS TM. One additional subframe is allocated to Planck ACC in the Bus profile for FOG packets acquisition (see Figure 6.3.1-3).

Details on the FOG functional implementation are provided in H-P-4-DS-TN-011.

6.3.2 Avionics electrical design

6.3.2.1 CDMS

6.3.2.1.1 General Overview

The Command and Data Management Subsystem performs the following general tasks:

- Telemetry acquisition and formatting

  To perform the Spacecraft monitoring and manage the emission of transfer frames as defined in the Packet TM Standard from the assembling into a frame to the encoding.

- Telecommand acquisition, decoding validation and distribution

  To manage the reception of TC segment as defined in the Packet TC Standard from their acquisition to the routing towards the corresponding user.

- Data storage

  To manage the saving of data to insure their integrity until dump to ground.

- Time distribution and time tagging

  To generate the required synchronisation signals, on board datation and its distribution especially to manage time tagging.

- Autonomy supervision and management

  To monitor that the others functions are running without failure. In that case, it manages the corresponding reconfiguration to bypass this failure.

In order to perform these functions, the CDMS interfaces with the payload instruments, the ACMS, the Power Control System and the Telemetry and TeleCommand subsystem. It is composed of a computer named CDMU for Control Data and Management Unit and a 1553 bus interface to communicate with the others sub-systems and instruments, the System Data Bus SDB. The CDMU is basically a router which receives data from a user (ground, instrument, other unit) and transmits them to another user (mass memory, telemetry encoder, …). This representation allows to clearly identify each data flow within the CDMS in order to define the processing capability that has to be fulfilled by the CDMS. The diagram hereafter shows such a representation of the CDMS regarding data flow aspects.

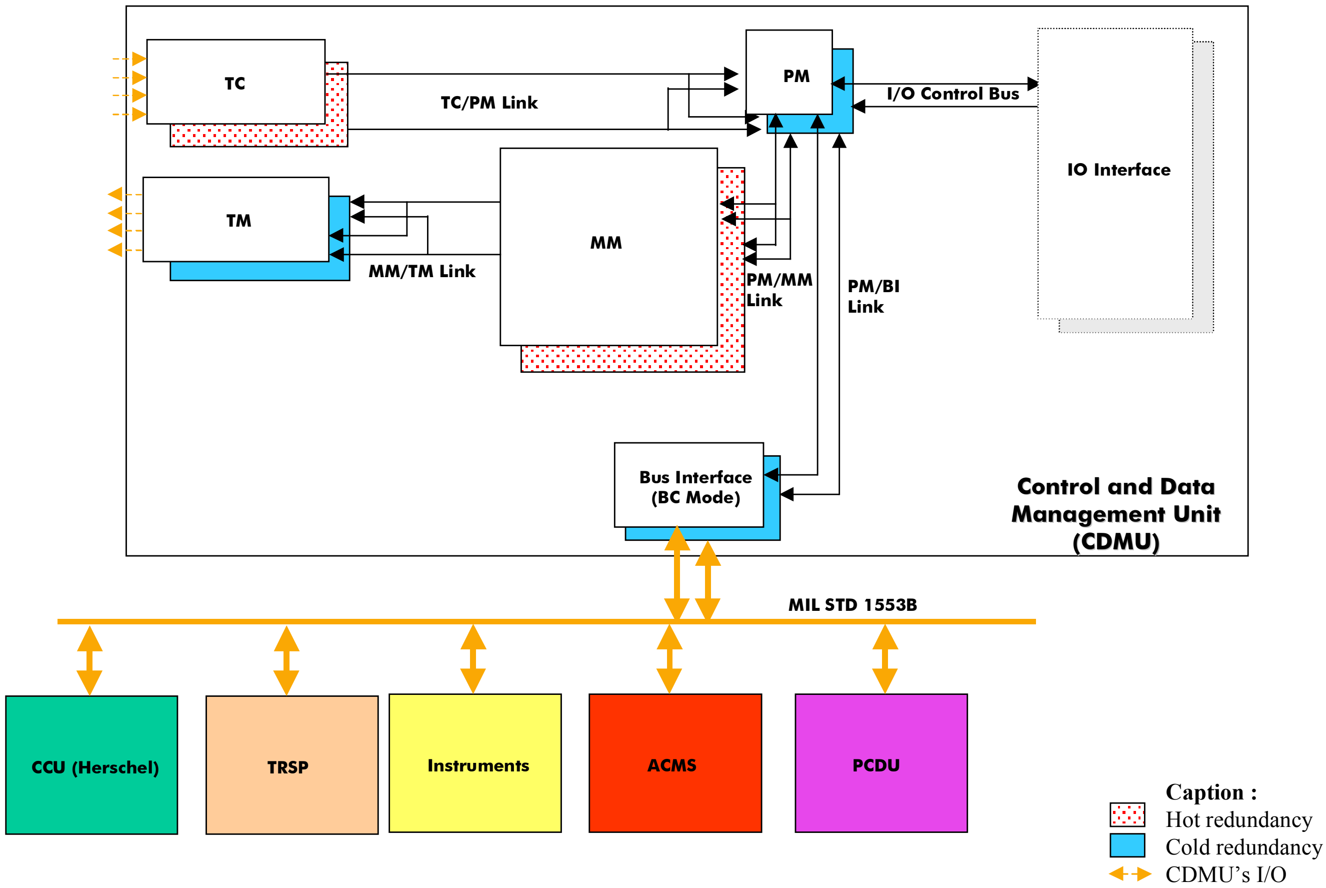


Figure 6.3.2-1 CDMS data flow

6.3.2.1.2 *CDMS Breakdown*

As mentioned above, the CDMS is composed of a CDMU and a 1553 interface which are further detailed hereafter.

Communication between the CDMU and the others sub-system/modules is done through the communication interfaces. To handle all communication (read/write/execution) within the computer, the communication interfaces has to provide a certain processing capability: the computer must be able to perform real time read/write accesses on each communication interface it has to manage.

Also, the Herschel and Planck CDMU's have to run several processing tasks in addition to these read/write accesses such as:

- FDIR monitoring, isolation and recovery
- Mission Time Line management
- On Board Control Procedures execution
- Storage of data (science data, instruments and platform housekeeping) into a 25 Gbits EOL mass memory
- On Board Time management.

The CDMU then offers a set of functionalities described in Figure 6.3.2-2 that allow to reach the necessary performance.

In a first part, each main CDMU internal function is described. Subsequently, a brief description of each CDMU's communication interface is given.

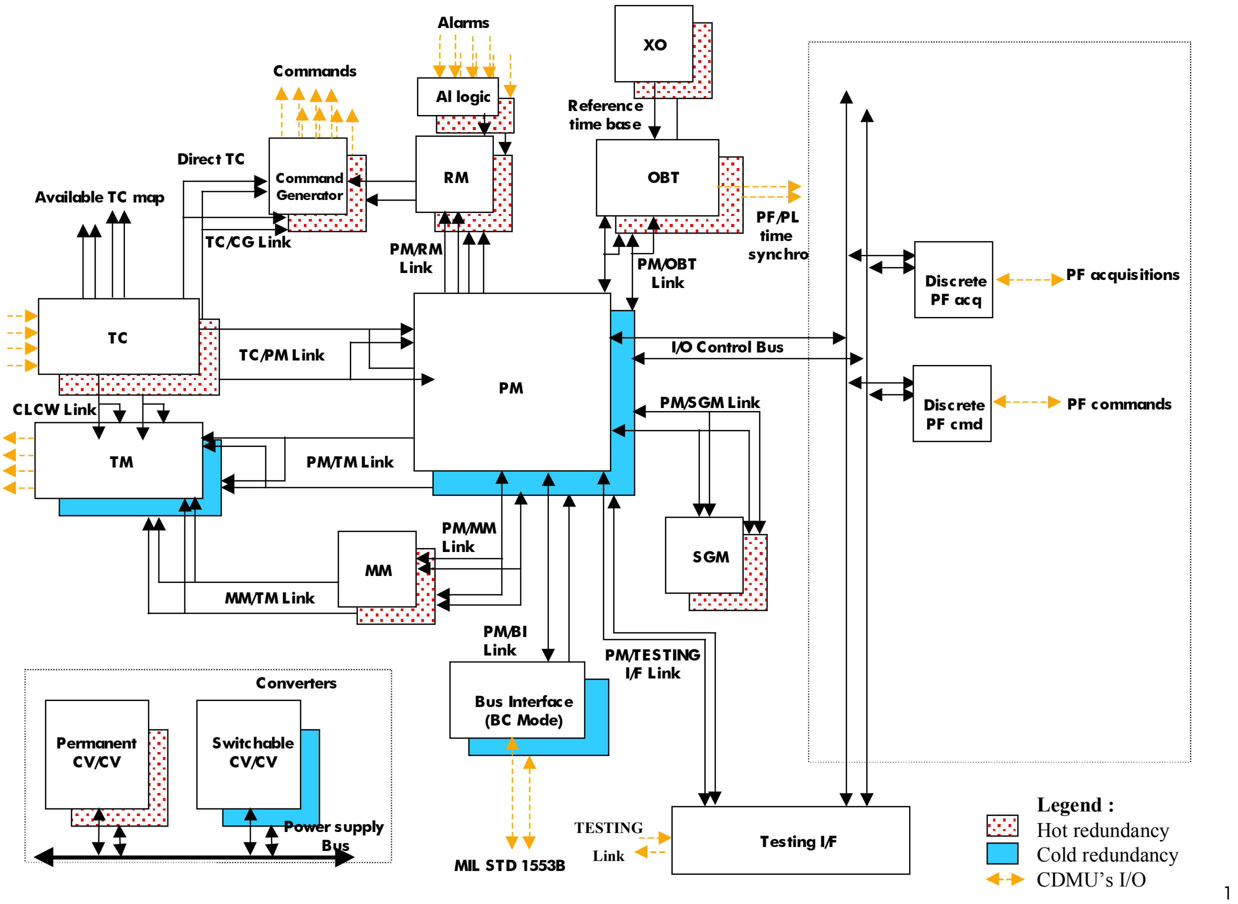


Figure 6.3.2-2 CDMU functional breakdown

6.3.2.1.2.1 *TC Function*

This function provides means to decode and route each TC packet received from ground either to be Processed by the PM function or to be directly executed by the command generator, one MAP Link interface from the TC Decoder being dedicated to connect the active PM and an other one for one CPDU. It must be noted also that two additional MAP Links are used. The first one is used basically to restart the complete CROME ASIC that include TM/TC/RM/OBT/SGM functions, the second one being used to disable, temporarely, the access from PM and RM to the command generator.

The commands processed by the PM are essentially time tagged commands, their execution being managed by the Mission Time Line service. It can also be a specific command request for a particular software user or a request for activating an OBCP.

[1] Functions depicted as a red dotted box are connected to a permanently powered ON converter (hot redunded) when the other ones are connected to a switchable power converter (cold redunded).

The TC packet decoder is sized to support a rate of 4 kbits/s and a rate of 125 bits/s. In addition, according to the PS-ICD, the size of a TC packet is variable from 12 bytes to 248 bytes. This leads the CDMU, actually the CDMU Basic Software (see §6.3.4) to be able to manage per second, up to14 TC packets from ground with minimum length and 2 TC packets with maximum length when the maximum bit rate is used for the TC Uplink (i.e. 4 kbits/s). The related processing load constraints are detailed in the CDMU Basic software documentation.

6.3.2.1.2.2 TM Function

The TM Function will provide means to encode and multiplex TM Packets before to downlink them.

The telemetry data stream is encoded as a concatenated code composed of a Reed Solomon and Convolutional code. This encoding permits to achieve a minimum signal to noise ratio (E_b/N_0) of 2.8 dB for a frame loss probability of 10^{-5}. The frame structure complies with the Packet Telemetry Standard.

As far as the downlink telemetry is concerned, the data rates are identical for the 2 spacecraft. Four data rates are then considered:

- 500 bits/s (with Kourou and New Norcia)
- 5 kbits/s (with New Norcia only) on LGAs
- 150 kbits/s on MGA with Kourou and New Norcia
- 1.5 Mbit/s on MGA with New Norcia only.

The downlink modulation scheme is NRZ-L/BPSK/PM for low rates and NRZ-L/SPL and NRZ-L/GMSK for medium and high rates. The CDMU outputs a simple NRZ-L data stream while the modulation is performed at the level of the TTC transponder (see § 6.3.8.).

TM packets are organised in:

- housekeeping packets
- science packets
- TC report packets
- Event report packets
- Memory dump packets
- context packets (TBC).

6.3.2.1.2.3 Processing Function

The Processing function is organised mainly around a microprocessor, RAM and a companion chip to manage more efficiently the processor interfaces (TM, TC, 1553 interface, …).

The processor has a direct access to 4 Mbytes of RAM (i.e. with 0 wait state for both a read or write access) and the companion chip (named COCOS according to the designer wording) handles 2 more Mbytes of RAM used as read and write buffer with the processor module interfaces.

Due to the high criticality of this function, some protection mechanisms are provided to ensure the integrity of the data transmitted to the processor over the processor bus by an on-the-fly detection (single and double error) and correction (only for single error) EDAC mechanism (Error Detection And Correction). Besides, by associating this EDAC with a scrubbing software service it is possible to prevent the occurrence of double error in RAM by periodically clearing the single errors.

During a boot sequence, the processor is driven by a boot software saved in a dedicated PROM (of about 64 kbytes). Especially, this boot software handles the loading of the On Board Software from the 2 Mbytes program memory of EEPROM to the RAM.

6.3.2.1.2.4 OBT Function

The On board Time function implemented in the CDMU maintains the central reference time which is regularly broadcasted to all users via the 1553 communication link. The CDMU will regularly broadcast the time reference to each 1553 users including the ACC. An ACC OBT function also exists, but it is synchronised to the CDMU one, and is updated with the time information received via the 1553 messages.

The OBT function comprises at least a clock counter driven by a reference oscillator. The performances of the OBT function depends mainly on the features of this reference oscillator (mainly short and long time stability).

The main specific features of the reference oscillator used to drive the clock shall be:

- 1 ppm over 100 sec. and
- 1 ppm over 30 days including all parameters influencing the stability.

To avoid the loss of the time on board, on a single failure occurrence, the OBT function is implemented with two identical module, in hot redundancy.

The OBT date format follows the CCSDS Unsegmented binary time Code (CUC) format using 2 bytes to define the sub-seconds resulting in a resolution of about 15.3 μs ($1/2^{16}$ s) and using a user selectable epoch.

6.3.2.1.2.5 RM Function

The CDMU, as well as the ACC, features hot redundant reconfiguration modules basically consisting in a state machine capable to issue sequences of pre-programmed CPDU packets to generate ON/OFF commands to external units, and for internal purpose.

The RM function is associated with a 2 x 512 kbytes safeguard memory for the storage of the spacecraft context, to be used in case of reconfiguration after a failure and for post failure analysis. The SGM is divided into 2 toggling areas, where one area is write protected (and supposed to contain the last valid data) while the other area is written.

This reconfiguration module is dedicated to high level FDIR recovery tasks (i.e. system level and computer level, see § 6.3.3.).

The Reconfiguration Module also acquires the Launcher separation straps status and initiates certain post separation activities.

The RM is able to react to an alarm occurrence by generating the associated reconfiguration sequence, without any OBSW support. A reconfiguration sequence is a series of command requests (CPDU packets), the command generator being in charge of decoding each command request and generate the associated ON, OFF or Reset elementary command (see the CG Function part) via the command interface. In addition, during a reconfiguration sequence due to a FDIR Level 3 alarm situation, the RM will send an interrupt to the active PM before to reset it after a delay of about 200 ms. This delay is intended to give a sufficient amount of time to the active PM to perform some sontext saving in SGM prior to the reset command.

6.3.2.1.2.6 Command Generator Function

Both CDMU and ACC comprise a command generator (CPDU) issuing ON/OFF commands (or reset) individually to equipments.

A command request to both ACC & CDMU command generator can be originated from either the reconfiguration module (see above), the OBSW (via the PM) or, for CDMU only, the ground (via the TC decoder). It is however possible to drive some ACC functions from ground. This is done by sending ground commands directly to the CDMU command generator. Indeed, some output of the CDMU Command Generator are routed to the ACC. This is especially the case for ACC PM A&B ON/OFF, ACC RM A&B Enable/Disable, ACC WD A&B Enable/Disable, …

6.3.2.1.2.7 Storage Function

This function is made necessary to store on board up to 48 hours of science and housekeeping data. Indeed, the communication link with the ground can be unavailable for up to 48 consecutive hours.

This autonomy requirement is the driver for the memory sizing. Consequently, a memory area with 25 Gbits End Of Life is provided. It is composed of 4 banks of 8 Gbits each such that the design is tolerant to the loss of a complete bank. Moreover, for reliability reasons the mass memory will be managed in hot redundancy.

More precisely, the present mass memory capacity will be sufficient to store during 48 consecutive hours the following type of data:

- Spacecraft HK: 1.52 Gbits (9 kbits/s)
- Instrument Data (science + HK): 22.46 Gbits (130 kbits/s)
- MTL: 35 Mbits (100 sets per day of 100 max length TC's per day that is 100 x 100 x 2 days x 226 bytes)
- OBCP: 200x64kbytes is considered as negligible regarding other data flows
- visual monitoring camera: 180 Mbits, the VMC operation being out of the science payload operation phase.

This amount being slightly less than 25 Gbits (see budget report).

A more detailed analysis is provided in the technical note RD03.11 "Data Rates & Downlink Rates”.

To manage it in an efficient way, the mass memory is divided in buffers, associated to packets stores, according to the PS-ICD. The mass memory is intended to receive all housekeeping and mainly science data generated on board.

Several ways are possible to handle the mass memory. For example, for each instrument, a packet store may be allocated for science and housekeeping data and another one for the platform housekeeping data. A second way may be to use a new packet store for each 24 consecutive hours to save all spacecraft data (science and housekeeping instrument data and all platform housekeeping data). A third way to use packet stores definition is to have a packet store for each instrument to store their science data and another one to collect all instrument housekeeping data+lower priority spacecraft HK, a last one being used to save essential platform housekeeping data and critical “quick look” instrument data.

The baseline is however an operation decision, still to be finalised, also considering the fact that, by design of the CDMU, each packet store must be associated to one single virtual channel.

The following figure depicts a synthesis of main data flows to/from the mass memory controller; note the VMC data flow cannot, by specification, be simultaneous with the instruments flow.

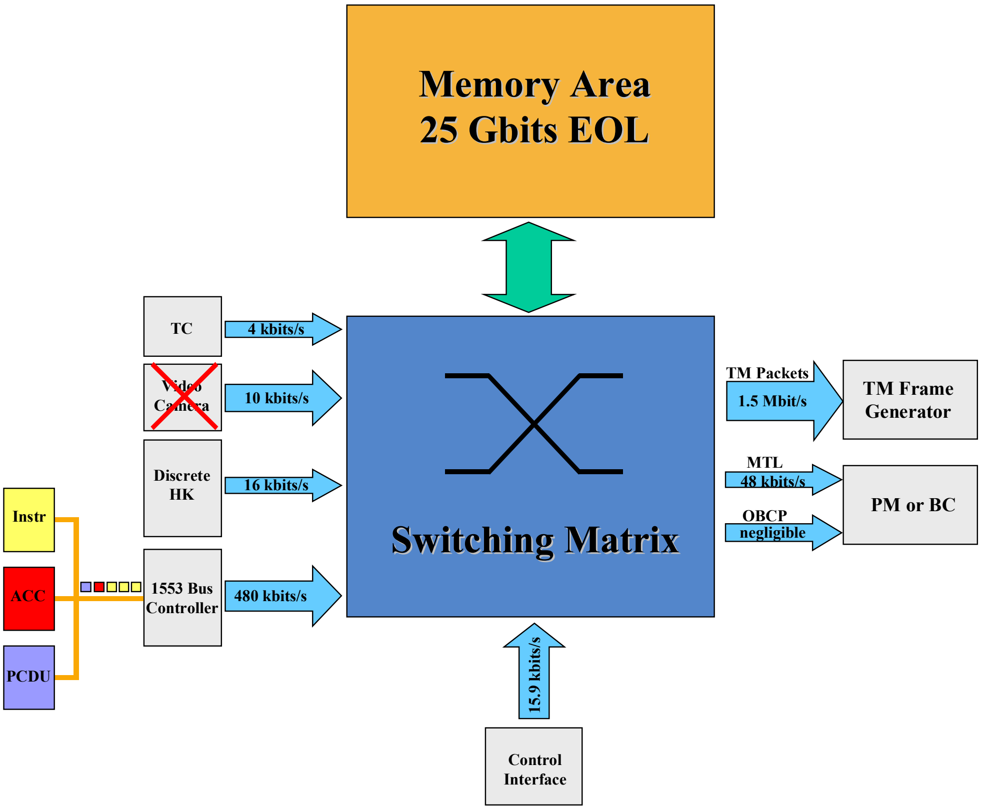


Figure 6.3.2-3 Data Flows within the mass memory

6.3.2.1.2.8 CDMU Interfaces

The present section addresses the CDMU communication interfaces.

6.3.2.1.2.8.1 TM Interface

The TM interface allows the CDMU to downlink housekeeping and science data from all the users according to the Packet Telemetry Standard. This downlink will be performed at 4 selectable data rates:

- 500 bits/s
- 5 kbits/s
- 150kbps
- 1.5 Mbit/s.

Depending on the satellite mode (see § 6.3.3.) and on the achievable link performance. This interface will provide TM data to the Tx transponder then to either a Low Gain Antenna or a Medium Gain Antenna depending on the mode of operation of the satellite.

6.3.2.1.2.8.2 TC Interface

The TC interface receives telecommands of different types from ground:

- direct CPDU telecommands (e.g. ON/OFF command request)
- commands for the Mission Time Line Service or other PSICD services
- memory patches
- command on MAP ID 5 or 6 to restart the CROME ASIC or to put the CROME command selector in a mode where only TC from ground are allowed to be sent to the command generator.

6.3.2.1.2.8.3 Subsystem and Instruments 1553 Interface

The Satellite Data Bus (SDB) is the main communication link between the CDMS and the other sub-systems. It is implemented by using the 1553 standard for the electrical and functional interface. The protocol over this communication link is based on the rules specified in the Packet Structure - Interface Control Document which defines a time division protocol into frames, sub-frames (64 sub-frames per frame) and slots (a slot can contain up to one complete 1553 message), a frame period being 1 second. Each user, according to the amount of data it has to transmit, has been allocated a number of sub-frames. A sub-frame allows to transmit up to a maximum length (1 Kbyte) Telemetry Packet or to send up to 3 TC packets.

6.3.2.1.2.8.4 I/O Interface

This is the serial link between the CDMU processor module PM and the board responsible for the individual I/O acquisition/distribution channel. A channel could be especially an ON/OFF command, a Memory Load command, a Digital Serial acquisition, a Digital Relay acquisition, an Analog acquisition or a temperature acquisition. This link is implemented through an internal OBDH bus.

Herschel Planck avionics design has been made such that most of the commanding and telemetry housekeeping acquisition are performed via messages on the external 1553 serial data bus. Consequently, the traffic on the I/O link will be, by design, limited.

As a sizing figure, one can consider that the number of transaction (i.e. one command issuing or one housekeeping acquisition) on this link will never exceed 1000 transactions per second.

6.3.2.1.2.8.5 Alarm Interface

This interface is part of the CDMS reconfiguration module and is used to acquire external, system level and internal, CDMU level, alarms.

Through this interface the RM monitors, independently from SW, the Power status of the satellite by the mean of a Depth Of Discharge system alarm signal (see § 6.5.4.).

When an activity is detected on an alarm input, the status of all alarm inputs are acquired to form a pattern, this pattern being compared with a set of stored alarm patterns (the PAP's). In case the acquired alarm pattern matches with one PAP, the RM triggers the suitable reconfiguration sequence. This sequence issues CPDU TC packets towards the command generator (CPDU). A series of ON/OFF commands, PM reset or PM save context interrupt are then sent to put the spacecraft in a mode as defined in § 6.3.3., and also to allow investigation later.

6.3.2.1.2.8.6 Command Interface

This is the interface to generate High Level Commands (ON/OFF commands, reset commands) inside or outside the computer. The command is issued on request from either the On Board Software or the ground (via the TC Decoder) or the reconfiguration module.

6.3.2.1.2.8.7 Synchronisation Interface

The CDMS provides SBDL synchronisation signals and timing signals as required by the science instruments (AD-05.1 to 05.6): 131072 Hz synchronisation lines are generated and distributed in hot redundancy. These signals are synchronised with the CDMU On Board Time clock.

In addition, the Users connected to the 1553, basically instruments and ACC bus are also synchronised through 1553 synchronisation messages, which, together with the periodic distribution of the Central Time Reference authorise an accurate datation of the science measurement and attitude data from ACMS.

6.3.2.1.2.8.8 Video Camera Interface

To support Public Relation activities, Herschel spacecraft integrates a video camera, the VMC, directly connected to the CDMU I/O interface (DS16 line) to acquire and store image sequences.

For the video camera interface bandwidth a data rate 10 kbits/s during few minutes has been defined. It shall be pointed out that the camera operation is specified not to interfere with science ones.

6.3.2.1.2.8.9 SREM Interface

A standard payload is installed on board Herschel and Planck spacecraft's: the Standard Radiation Environment Monitor. This equipment, from a data handling point of view, interfaces the CDMU via standard ML16/DS16 I/O links. The SREM will operate continuously during the Missions, however, the related data production rates will be low.

6.3.3 Satellite autonomy concept

After having defined the boundaries of the autonomy concept on Herschel/Planck, derived from the operation concept (see details in Section 6.5.1), this chapter will address the main mechanisms implemented to ensure the autonomous operation of the satellites. These are:

- the operation scheduling mechanism in charge of the management of the programmed operations of the spacecraft
- the fault protection system, and mainly the FDIR mechanism, which guarantees the safe operation of the spacecraft in case of failure.

6.3.3.1 Operation concept overview

The Herschel and Planck satellites are operated from one single ground station (nominally New Norcia). This leads to a ground contact of typically 3 hours per day for each spacecraft (DTCP: Daily Telecommunication Period). When ground contact is not available (OP: Observation Period), the spacecraft's are fully autonomous, performing science observation according to a pre-defined schedule uploaded during a previous DTCP. The spacecraft's are designed to cope with this autonomy requirement, allowing operation without ground contact for 48 hours. The objective of the autonomy implementation is twice: to maximise the scientific return and to ensure the spacecraft safety in any condition.

The basic concept of operation of the satellites is that all activities will be performed according to the on-board Mission TimeLine (MTL) during nominal operations, even if the spacecraft is in ground visibility, while the context of operation of the satellites is defined by the current Satellite Mode. Autonomy functions allowing spacecraft reconfiguration in order to maintain scientific activities are active on-board and do not require inputs from ground. Actions from ground are limited to receiving telemetry (real time and stored in the mass memory) and sending commands to update the Mission Timeline. The Timeline is sized to support 48 hours of autonomous operations.

Real time commanding of the spacecraft is also possible. In the meantime fault protection functions and possibly MTL are still active on-board, and ground commands are not required to maintain spacecraft safety. This is in accordance with the requirement that ground reaction shall not be required within less than 3 minutes (OIRD, CTRL-1). Protection mechanisms (definition of priorities based on the source of the telecommands) are implemented to manage possible conflicts between commands originated on board and on ground.

6.3.3.2 Operations scheduling

6.3.3.2.1 On-board scheduling

This service defines the functionalities, and the way to interface them, of the on Board Mission TimeLine. The MTL basically allows to execute autonomously, even during spacecraft visibility, any type of telecommands which have been loaded from ground during DTCP. This facility is centralised inside the CDMS which distributes the telecommands to the different users as soon as they should be executed, with the following characteristics:

- time resolution is 1s
- up to 4 TC's per second can be distributed
- between 5682 and 34200 TC's can be stored in the MTL, depending on the size of the telecommands. This size is consistent with:
    - the mission operational need driven by the instruments needs and the corresponding spacecraft commanding. Herschel is the sizing case here,

- the spacecraft visibility constraints such that the MTL can be entirely uploaded in a DTCP,
- the CDMU OBSW performance

In order to allow for a certain functional breakdown of the MTL activities and for a parallel execution of several independent activities, the On board Scheduling service supports the concept of sub-schedules. It permits different subsets of the MTL, identified by a specific subschedule ID, to be managed independently (enable, disable, report …). Note that it is also possible that some MTL commands are not attached to any sub-schedule (sub-schedule identifier = 0).

In case of anomaly, the FDIR mechanism has then the capability to stop one or several sub-schedule executions at anomaly detection time and to block the triggering of one or several sub-schedules during recovery, the other sub-schedules or independent MTL TC continue their nominal execution or triggering. Due to the fact that any sub-schedule can be stopped by the FDIR, each sub-schedule shall be self contained and must not be dependant of a previous sub-schedule, i.e. the expected configuration could be the wrong one if a previous sub-schedule has been stopped by the FDIR. Such as to have the possibility to create the link between MTL and FDIR

- the subschedule concept has been further refined (see RD03.26) by the introduction of 2 categories of subschedules:
  - permanent subschedules, defined by the fact that they are always enabled at the start or re-start of the MTL (when the MTL gets enabled)
  - transient subschedule is defined by the fact that they are always disabled at the start or re-start of the MTL (when the MTL gets enabled).

  This permits by suitably allocating the MTL commands to a subschedule type, to specify which activity will be restarted or not after a failure leading to a complete MTL disabling occurs.
- Proposal for the subschedules operational implementation rules has been made (see RD03.27). It goes through the design of "meta-subschedules", i.e. subschedules which task is only to enable their associated subschedules or set of suschedules at times when it make sense, from a functional point of view to restart the activities commanded from the associated subschedule(s).

The Figure 6.3.3-1 illustrates the operation from MTL with the occurrence of a failure affecting a unit (e.g. instrument) involved in the current operations. The execution result is in the second diagram.

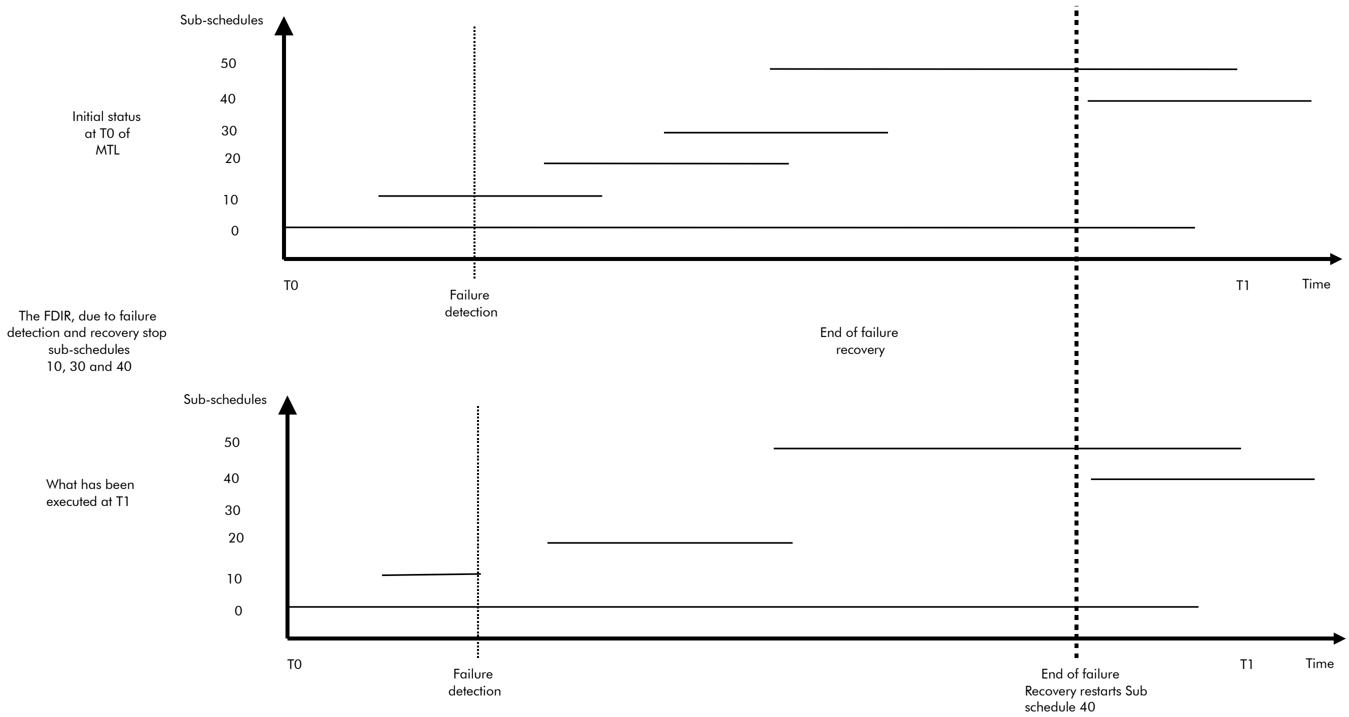


Figure 6.3.3-1 Operations from MTL after a failure

Only ground can update the MTL.

As mentioned, the MTL consists in a sequence of time tagged commands. Any command is allowed, and especially, if the activities to be started are of a complex nature, these commands can activate a specific software function, or an On Board Control Procedure (OBCP). This feature is the second service available as part of the On board scheduling mechanism and is described below.

6.3.3.2.2 On-Board Control Procedure

The other functionality available to support the nominal operation of the spacecraft will be by execution of pre-defined on-board control procedures (OBCP's).

OBCP's can be activated by:

- MTL (Mission Time Line)
- Ground command
- On-board event, automatically (e.g. FDIR)
- Other OBCP’s.

OBCP's are flight procedures, developed and validated on ground, which are uploaded on-board of the Herschel or Planck satellite, stored in Mass Memory until they are started, i.e. interpreted. They are written using a Spacecraft Control Language (SCL).

After activation they are executed in the on-board system. They are essentially implemented within the CDMS; PACS instrument is the only other on board entity which implements also this service. The intended use is for controlling processes, which may be active for an extended period of time and which may involve the (conditional) execution of a (longer) sequence of commands. These on-board Telecommands may affect one or several application processes or functions. More than one on-board unit can be involved. A feature of the OBCP's is that, because they are translated by an on board interpreter, have a low – say not guaranteed – timing performance.

In the way they are implemented within Herschel/Planck CDMU OBSW, OBCP's are actually able to issue any type of telecommand, and can consequently perform any action. However, some rules for the "good usage of OBCP's" have been established:

- the maximum number of active OBCP's is 16. This –relatively low – limit has 2 consequences:
  - the OBCP shall not be designed as "background tasks", but rather as limited-life actions, such that the risk to have more than 16 OBCP's active together is kept minimum,
  - the total number of on board procedures implemented shall be minimised.
- In order that OBCP's which would be designed for critical functions (e.g. FDIR) be started even though 16 OBCP's would already be active, 2 OBCP categories have been created, the critical ones and the others. If made necessary (because the 16 OBCP slots are used), a non critical OBCP will be stopped, and its slot will be used by the activated critical OBCP.
- in order to retain predictable, robust and safe behaviour of the spacecraft, OBCP service shall not be used, before launch, to code any of the activity related to the satellites operations. Current baseline is to retract the pre-launch usage of OBCP's to the coding of actions related to instruments operations: Turn ON, Turn OFF, FDIR procedures.

6.3.3.2.3 Priority Management

The nominal autonomous operation of the spacecraft is based on the 2 mechanisms which have been described in the previous chapters: the On Board Scheduling and the On Board Control Procedures.

The task of these 2 mechanisms is mainly to issue telecommands, based on the spacecraft time for the MTL, and after some processing for the OBCP's. However, other telecommands sources exist: the Ground, the FDIR and the OBSW functions. Because the CDMS is basically unable to comply with a composite worst case, i.e. the maximum commanding rate from all the sources together (should it be possible to define it !), and considering the essentially different nature of all the telecommands sources, a priority order based on their respective criticality in the frame of the baseline operation principles is established. This permits to guarantee:

- a safe spacecraft behaviour in any circumstance,
- an optimised science instruments operation, and thus science return,
- the most efficient usage of the bandwidth of the on board communication links.

It is applicable to all onboard systems, where meaningful.

The identified TC sources and the retained priority order is:

(0) High Priority Ground commands: this source has been artificially created in order to provide to the Ground the highest priority access to the S/C commanding resources in very exceptional conditions. The CDMS design is not supposed to take into account the occurrence of these priority 0 TC's in routine mode of operation, but is required to execute them with the highest priority whenever they occur.

(1) FDIR commands: they are by definition critical and need to be executed first, whenever such commands occur. A specific allocation for these commands is implemented in the commanding task.

(2) **MTL Commands**: These commands are, by definition, On Board Time related within a second and all the communications protocol must guarantee their execution. A specific allocation for these commands is therefore implemented in the commanding task.

(3) **Ground commands**: due to the limited ground visibility, and the spacecraft distance, the real time commanding by ground is not entirely possible, and nominal (by opposition to the High Priority ones above) ground commands must be considered as not time critical compared to above sources.

(4) **SW routine Functions commands**: these are the commands issued by routine SW functions (e.g. Thermal control). Their time criticality is lower than the time criticality of the commands directly issued by the previous sources. Note that these do not comprise specific, and well identified FDIR SW functions which have the FDIR priority as mentioned in (1).

(5) **OBCP's commands**: the OBCP mechanism is per principle and due to a priori poor timing performances, reserved to those on board operations which are not considered as time critical within few seconds.

6.3.3.3 Spacecraft system modes

The satellite modes aim to predefine a spacecraft configuration for a given life phase of the mission in order to structure the design cases and simplify the testing. They are therefore closely linked to the operation of the spacecraft, which will essentially transition from one Satellite Mode to the other one and to the FDIR strategy detailed in the next chapter.

They have been established following the definitions given in the SRS (AD01.1). The list of modes and the correspondence with the various phases of the mission are presented hereafter; this shows that all the mission phases are properly covered. The main drivers for definition of the spacecraft modes have been the following:

- to provide the instruments with the required observation modes for their scientific objectives
- to provide the necessary modes logically sequenced to ensure efficient and inherently safe operations of the satellite when an unplanned event may endanger the instrument detectors, the optical components, the lifetime of the spacecraft on-board equipment
- to minimise the number of modes and maximise commonality between Herschel and Planck, in order to simplify on-ground operations.

Satellite Life Phase		System mode
Launch Phase		Launch Mode
Transfer Phase	Initial Orientation Phase	Sun Acq Mode
	Platform Commissioning and Performance Verification Phases	Nominal Mode
Routine Scientific Phase	Science Commissioning Phase	Nominal Mode
Recovery Phase	CDMS computer level failure	Earth Acq Mode
	CDMS system failure	S/C Survival Mode
Attitude Recovery Phase	ACMS failure	Sun Acq Mode

6.3.3.3.1 Pre-Launch/Launch Mode

This mode corresponds to a kind of standby mode of the spacecraft up to the spacecraft separation from ARIANE. It ends after the post separation activities have set the spacecraft in Sun Acquisition Mode. Separation is detected upon sensing of separation straps simultaneously by the CDMU Reconfiguration Module, the ACC Reconfiguration Module (see Chapter 6.3.3.4.), the CDMU S/W and the ACC S/W such that the safety constraints (independent barriers) related to the RCS and TTC operation can be satisfied.

During this mode:

- TC reception and processing (both for ACMS and CDMS) are active
- TM collection and storage are performed
- Power is autonomously generated and distributed
- Herschel PLM monitoring and control is performed (CCU nominal + redundant is ON)
- The spacecraft is configured such that the attitude control system can be operational 20s after separation and in compliance with the attitude domain restrictions
- The spacecraft shall be configured such that the telemetry can be downloaded 20s after separation.

During launch mode, power will be provided by the battery. After fairing separation, orientation of the launcher will be such that the Herschel Sun Aspect Angle requirements will be fulfilled (i.e. Herschel Solar Array will be exposed to Sun allowing battery charging). This is not the case on Planck as its Solar Array will not be exposed to the Sun.

During launch, instrument are all switched off, except HFI, which is in launch mode to provide power to the 4 K cooler for launch lock.

When the separation is detected at CDMS level, the Visual Monitoring Camera is turned ON and the Satellite Sun Acquisition Mode is engaged.

6.3.3.3.2 Sun Acquisition mode

In this mode the spacecraft reaches and maintains a safe sun-pointed attitude.

Launcher separation detection initiates the separation sequence program running in the CDMU and ACC which commands all activities to perform Sun acquisition and acquire the data link.

More exhaustively, The Sun Acquisition Mode is entered in any of the following conditions:

1. At separation from the Launcher, after all immediate post separation On Board activities.
2. Upon dedicated Ground command.
3. Upon ACMS attitude alarm triggering: Sun Pointing alarm or Rate alarm (see § 6.3.3.4.).
4. Upon ACMS computer reset.
5. Upon ACMS computer switch over.

In Sun Acquisition Mode, the spacecraft is in Sun-pointed attitude and power is generated from the Solar Array.

The satellite Sun Acquisition Mode makes use of:

- The nominal set of ACMS sensors/actuators when the Mode is triggered by the Conditions 1, 2 and 4 (separation, ground commands or ACMS computer reset)
- A set of sensors/actuators (including thrusters) which are not used in any other modes when the Sun Acq Mode is triggered by the conditions 3 and 5 (ACMS System alarms or by an ACMS computer switchover).

When it is reached from the condition 1 (separation from the Launcher), communication with Earth for TC is performed using omni-directional coverage provided by the LGA. By default, the Telecommand Nominal rate (4kbps) is selected. The downlink TM uses the omni directional antennae at the rate of 5kbps.

When it is reached from any other condition (2, 3, 4 & 5), communication with Earth for TC shall be performed using omni-directional coverage provided by the LGA. By default, the TC low rate (125bps) is selected. The downlink TM uses the omni directional antennae at the rate of 500kbps.

In Sun Acquisition Mode, the payload instruments are:

- OFF except power to the HFI 4K cooler for launch lock if the Mode is entered at separation from the Launcher
- In standby or OFF if the Mode is entered from the other conditions (2, 3, 4 & 5).

Configuration of the spacecraft subsystems and instruments at entry into the Sun Acq Mode is summarised in Table 6.3.3-1 & Table 6.3.3-2.

6.3.3.3.3 Nominal Mode

Nominal mode is the mode of operation of the spacecraft during commissioning and performance verification phases and during scientific mission, including DTCP's.

Transition to Nominal mode is performed only upon telecommand.

Although configuration at entry into the Mode is specified (this is actually the definition of the Satellite Mode …), combinations of most of the subsystem modes are available, upon dedicated TC. Especially.

Subsystem & Instruments	Possible modes
ACMS	Nominal (SCM and HCM for Planck) Orbit Control Modes
CDMS	TTR in Full mode Processor Module Off for the non active computer Processor Module Nominal Operation for the active computer Mass Memory nominal I/O System ON
TTC	Any
PCS	Any
Thermal Control	Any
Instruments	Any

Configuration of the spacecraft subsystems and instruments at entry into the Nominal Mode is summarised in Table 6.3.3-1 & Table 6.3.3-2.

During non visibility periods, Herschel spacecraft will be in operational pointing mode, 3-axis stabilised.

During non visibility periods, Planck will remain in operational pointing mode with the spin axis oriented in the Sun direction. Spin axis re-orientation manoeuvres are periodically commanded in order to maintain the S/C Sun pointed.

All Housekeeping and science data acquired from the instruments (if switched ON) and Housekeeping from the spacecraft is stored in the mass memory, and simultaneously sent to ground during DTCP's.

The operations on both Herschel and Planck are nominally commanded via the Mission Timeline, as detailed in § 6.3.3.2.

6.3.3.3.4 Survival Modes

Survival mode is reached in case of major on-board failures (i.e. system failures) detected by the CDMS.

More exhaustively, transition to survival mode from any System mode can only be initiated:

- from a ground command
- after a Depth of Discharge alarm, detected by CDMS (CDMS Level 4, see § 6.3.3.4.).

The spacecraft is then put into **safe conditions** where it is able to survive, without ground contact, for a period of time a priori only limited by the consumable.

Safe conditions are defined by:

- a Spacecraft safe state: It is a configuration of ACMS, thermal S/S, Power S/S and communications states, which allow the spacecraft to be safe
- **and** an instrument state (i.e. OFF).

As these could result in the loss of a significant mission time (e.g. to bring back the Planck cooling system to the right temperature), spacecraft is designed to switch to Survival Mode only in case of major power loss (CDMS level 4 failure, as described in § 6.3.3.4.

Detailed configuration of the spacecraft subsystems and instruments at entry into the Survival Mode is summarised in Table 6.3.3-1 & Table 6.3.3-2.

Survival Mode relies, as much as possible, on a set of equipment which are not used in other modes. This set of equipment list is stored in a protected - fail safe - memory area, which can only be changed by ground Telecommand.

Satellite Survival Mode can only be exit on ground TC.

6.3.3.3.5 Modes transition Logic

The mode transition logic is shown on the following figure. The main modes have been defined for Herschel and Planck, allowing to have the same transition logic for the two spacecraft. Detailed explanation on the transition conditions shall be found in the next chapter.

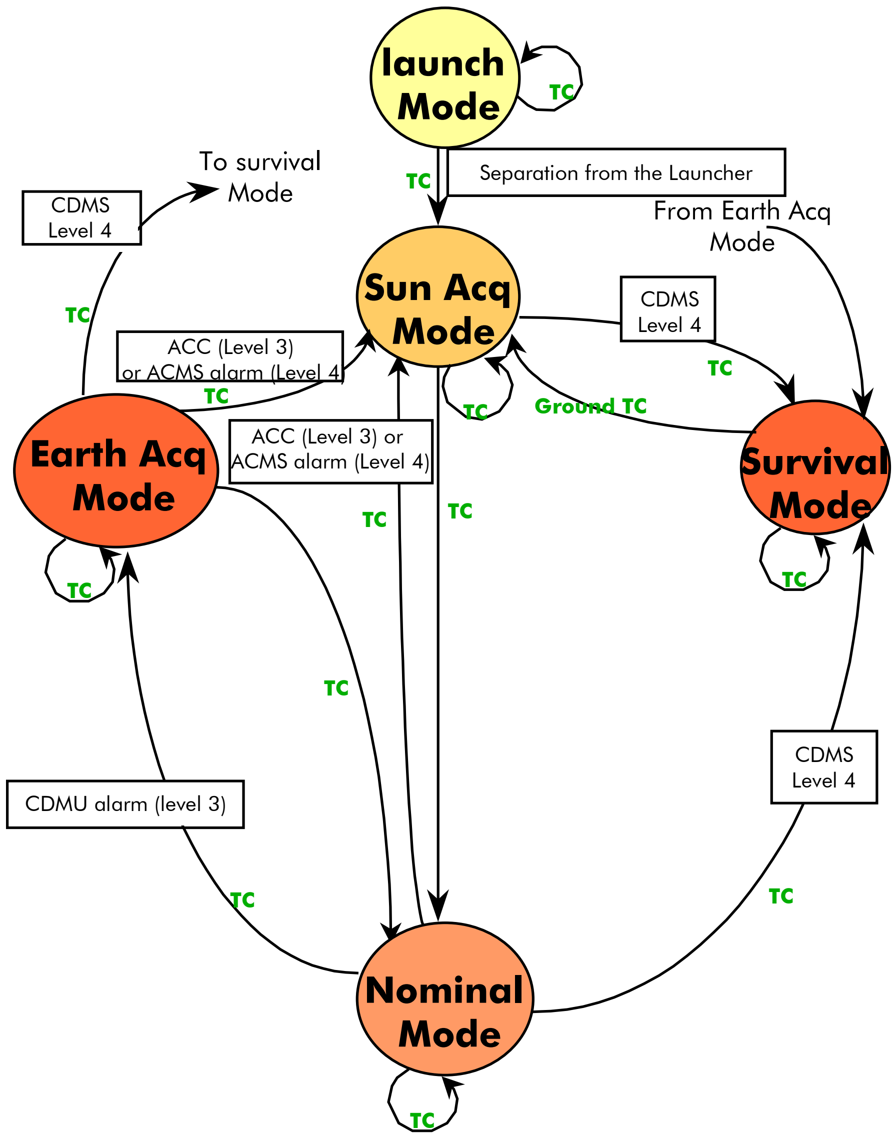


Figure 6.3.3-2 System modes transition logic

6.3.3.3.6 Modes definition

The following table summarises the **Herschel** operational modes. For each of them, the TM/TC mode is driven by the downlink rate and the virtual channels allocation and prioritisation. It shall be pointed out that the table here below specifies the status at entry or re-entry into the mode. It shall remain possible, via subsequent relevant telecommand, to individually change each of the subsystem and functional mode while in any of the S/C mode.

Spacecraft Mode	TTC MODE: Antennae Configuration: Nominal branch (*backup branch*)	TTC MODE: TM/TC Configuration	MTL Mode	ACMS Mode	EPS Mode	Instruments Mode
Launch Mode	Rx: LGA +Z (*MGA*)	Low rate	Disabled	SBM	Battery Discharge	OFF
	Tx: LGA +Z	OFF				
Sun Acquisition Mode	Rx: LGA +Z (*LGA –Z* when initiated by separation) (*MGA* otherwise)	Low rate (Nominal rate after separation)	Disabled	SAM or SM	Battery Charge or SA	OFF or Standby
	Tx: LGA +Z	Low2 Rate (5kbps) when initiated by separation Low1 Rate (500bps) otherwise				
Nominal Mode	Rx: MGA (*LGA+Z*)	Nominal rate	Enabled	NOM,OCM	Battery Charge/ discharge or SA	OFF, standby or Science
	Tx: MGA	Medium Bit Rate (transition to High Bit Rate by TC)				
Earth Acquisition Mode	- Rx MGA (*LGA+Z*)	Nominal rate	Disabled	NOM	Battery Charge/discharge or SA	OFF or Standby
	- Tx MGA	Medium Bit Rate				
Survival Mode	- Rx: LGA+Z (*LGA-Z*)	Low rate	Disabled	SAM, SM	Battery Charge/discharge or SA	OFF
	- Tx: LGA+Z	Low1 rate (500bps)				

NOM: Normal Mode – SAM: Sun Acquisition Mode – SM: Survival Mode – SBM: Stand By Mode – OCM: Orbit Correction Mode.

Table 6.3.3-1 Herschel satellite Modes

The following table summarises the **Planck** operational modes. For each of them, the TM/TC mode is driven by the downlink rate and the virtual channels allocation and prioritisation. It shall be pointed out that the table here below specifies the status at entry or re-entry into the mode. It shall remain possible, via subsequent relevant telecommand, to individually change each of the subsystem and functional mode while in any of the S/C mode.

Spacecraft Mode	**TTC mode**		**MTL Mode**	**ACMS Mode**	**EPS Mode**	**Instruments Mode**
	Antennae Configuration: Nominal branch (*backup branch*)	**TM/TC Configuration**				
Launch Mode	Rx: LGA –X (MGA)	Low rate	Disabled	SBM	Battery Discharge	OFF except 4K cooler in Launch Lock
	Tx: LGA -X	OFF				
Sun Acquisition Mode	Rx: LGA -X (*LGA* –Z/+Z when initiated by separation) (*MGA* otherwise)	Low rate (Nominal rate after separation)	Disabled	SAM or SM	Battery Charge or SA	OFF or Standby
	Tx: LGA -X	Low2 Rate (5kbps) when initiated by separation Low1 Rate (500bps) otherwise				
Nominal Mode	Rx: MGA (LGA -X)	Nominal rate	Enabled	SCM, HCM, OCM	Battery Charge/ discharge or SA	OFF, standby or Science
	Tx: MGA	Medium Bit rate (transition to High Bit Rate by TC)				
Earth Acquisition Mode	Rx: MGA (LGA -X)	Nominal rate	Disabled	OCM, HCM, SAM	Battery Charge/discharge or SA	OFF or Standby
	Tx: MGA	Medium rate				
Survival Mode	Rx: LGA –X (LGA +Z/-Z)	Low rate	Disabled	SAM, SM, OCM, HCM	Battery Charge/discharge or SA	OFF
	Tx: LGA -X	Low rate (500bps)				

SCM: Science Mode – SAM: Sun Acquisition Mode – SM: Survival Mode – SBM: Stand By Mode – OCM: Orbit Correction Mode – HCM: Angular Momentum Correction Mode

Table 6.3.3-2 Planck satellite Modes

6.3.3.4 FDIR

We have just reviewed the mechanism implemented to perform autonomously, as constrained by the operation conditions, the Herschel and Planck missions. The present section addresses the mechanism, called FDIR, designed to support the autonomous execution of the mission in case of failure, or to ensure a proper recovery if the mission execution cannot be pursued in safe conditions.

6.3.3.4.1 High level requirements

The main drivers for the FDIR strategy are the Herschel/Planck overall autonomy and safety requirements:

- The mission shall be nominally maintained without ground contact for any 48 hours period during the operational life, assuming no major failure condition. Mission shall be maintained as far as possible on the main cases of single failures
- The spacecraft shall survive without ground contact for any 1 week period during the operational life when switched to survival mode
- Satellite life shall be preserved: fuel consumption shall be optimised, Herschel cryostat Helium shall be preserved, and reconfiguration and equipment loss shall be minimised.

This imposes the need to have any failure likely to induce a loss of the mission, or a damage to the spacecraft safety, autonomously detected, isolated and recovered. The requirements are identical for both Herschel and Planck, and, considering that the baseline Avionics architecture is also identical for both spacecraft, the FDIR philosophy is unique while the alarms definition and processing, and the details of the reconfiguration actions obviously differ from one spacecraft to the other one.

The strategy to apply in order to detect, isolate and recover failures is basically dependent on the spacecraft life phases, or more precisely on the current spacecraft mode. The spacecraft modes are detailed in the previous Chapter 6.3.3.4.

6.3.3.4.1.1 FDIR concept

Herschel and Planck share a number of commonalties (orbit in L2, use of common ground stations, common design for electrical subsystem, identical data rates to ground…), which leads to a reduction of the operational costs by implementing the same FDIR concept for both spacecraft.

As the consequence of the main FDIR requirements, The FDIR strategy is based on a breakdown into level. Each level is defined according to:

- the severity of the failure
- the functions involved on the failure detection (H/W or S/W).

In addition to this, the levels are managed together in a hierarchical way, each level being identified by its functional application. The highest level is the System level.

The next sections will provide a description of each level with its associated strategy.

6.3.3.4.1.2 Failure Classification

According to potential effects on equipment units, function, computers (CDMU and ACC) or system performance, several failure levels are defined. The different levels are detailed in the following sections, while the overall breakdown is summarised in Table 6.3.3-3.

Level 4	Level 3	Level 2	Level 1	Level 0
SYSTEM	ACC	Spacecraft positioning function	Eqpt 1 Eqpt 2 Eqpt 3	⋮
	CDMU	Thermal monitoring and control function	Eqpt 1 Eqpt 2 Eqpt 3	⋮
		Power supply function	Eqpt 1 Eqpt 2 Eqpt 3	⋮
		Spacecraft monitoring and control function	Eqpt 1 Eqpt 2 Eqpt 3	⋮
			Eqpt 1 Eqpt 2 Eqpt 3	⋮
		Payload Management function	Eqpt 1 Eqpt 2 Eqpt 3	⋮

Table 6.3.3-3 Failure classification principles

Failure types have been split into **5 main levels** (Level 0 to Level 4) characterised by:

- the failure severity
- the recovery sequence
- functions involved in the detection (H/W or S/W functions).

The different levels are detailed hereafter.

6.3.3.4.1.2.1 Level 0

Level 0 failure is associated to an internal single failure in one equipment unit (including ACC, CDMU and PCDU) which can be automatically recovered by the unit itself without any impact on the rest of the system (H/W devices or S/W applications). Level 0 failures and their handling are typically described in the units FMECA.

Level 0 failures are typically:

- EDAC single bit error. EDAC device can detect and correct one bit flip in data read from RAM memory. There is no impact in data reading operation when the corrupted data in RAM is re-written locally in a background function.

Multiple (number selectable by ground) occurrences of Level 0 failure could lead to higher level recovery actions (unit/coupler/computer reconfiguration). Then, level 0 failures will be reported to the higher level.

6.3.3.4.1.2.2 Level 1

A **Level 1** failure is a failure, as seen by the ACMS computer (ACC) or the Data handling one (CDMU), in a unit connected to either computer via the data bus (1553 bus), or dedicated acquisition lines and which can not be autonomously recovered by the unit itself. The monitoring of the unit is performed by the appropriate ACMS S/W or CDMS S/W via simple health check, and recovery actions are ordered by the same software depending on the failure status. In case of failure, the ACMS or the CDMS, depending on the failed equipment unit, provides the necessary actions to recover from the detected failure. Note that CDMS and ACMS have to be understood here as the CDMU and ACC Processor Modules (PM), what is outside being considered as “unit”; especially, failures in the peripherals and in the I/O system of the computers are identified as level 1 failures if they can be recovered by the CDMS or ACMS S/W.

Two sub levels are identified, depending on the failure origin:

- Level 1a for unit failures
- Level 1b for communication unit failures.

Level 1a relates to failure which can be attributed to the unit level:

Currently identified level 1a failures are:

Unit	**Identified level 1a failures**
PCDU	Failure of distribution circuit (FCL, LCL, HPS, HCS)
CDMU	PM board M1553C Interrupt: Internal Control Bus SSMM RT COCOS failure (level is TBC) OBDH Interrupt: DMA error OBDH Interrupt: MARS ASIC error PM board PacketWire handling: TTR A/B CROME PDEC failure PM board SpaceWire Interrupt: with TTR/RM PM board SpaceWire Interrupt: with SSMM (level is TBC) PM board SpaceWire Timeout: with TTR/RM PM board SpaceWire Timeout: with SSMM (level is TBC) MM Board: MM Interrupt (level is TBC) MM Board: NUT command TTR/RM Board: CROME Handling Status Monitor Invoked Command error
ACC	PM board M1553C Interrupt: Internal Control Bus TTR/RM Board RT COCOS failure OBDH Interrupt: DMA error OBDH Interrupt: MARS ASIC error PM board SpaceWire Interrupt: with TTR/RM PM board PacketWire handling: TTR A/B CROME failure (level is TBC) PM board SpaceWire Timeout: with TTR/RM TTR/RM Board: CROME Handling Status Monitor Invoked Command error
STR	Power status error Health error (STR Housekeeping data error, continuity error, Loss of tracked star error, Covariance error, “initial quaternion” error)
RWL	Power status error Health error (Continuity error, Accumulation error)
CRS	Health error (range error, continuity error, static value error)
Gyros	Power status error Health error (Individual Gyro HK data error, Continuity error)
SAS	Health error (range error, continuity error, static value error)
RCS	RCS error from HK (catbed temperature out of range, Thruster ON time error, FCV status wrong)
XPND	Tx wrong ON/OFF status and wrong output power
RFDN	Switches 1 & 3 failures
Thermal Control	Unit_switch_off_HIGH and Unit_switch_off_LOW limits exceeded for a unit
Instruments	All failures identified by instruments to be recovered - See IID B’s

Failure of these equipment units are detected by ACC or CDMU software applications.

Level 1b relates to failures at communication units level, and as such can be considered as multi-application related.

Level 1b failures are:

Unit	**Identified level 1b failures**
CDMU	Failures in 1553 Data Bus (see SOFDIR Appendix 1)
ACC	Failures in 1553 ACMS Bus

Every bus coupler will be checked by the mean of:

- specific internal health status depending on coupler design
- 1553 protocol errors including I/O timeouts.

As detailed in the appendix 1 of SOFDIR applicable to the 1553 Data Bus, the MIL Bus FDIR has the capability to manage the bus redundancy switch-over. This function collects the data necessary to monitor the status of the communications on the bus, isolates bus medium failure, and performs an automatic reconfiguration of the bus.

6.3.3.4.1.2.3 Level 2

A **Level 2** failure is related to an anomaly of one of the satellite functions. The objective is to detect failures which have not/cannot be flagged at Level 1 by simple unit/communication health check, and, if possible, to process them before they may turn into a more severe (i.e. more mission impacting) system alarm.

For each function, depending on the current System mode, observed performances are compared to non ambiguous thresholds and in case of failure a recovery strategy is engaged, possibly leading to the reconfiguration of the whole functional chain. The level 2 failure detection and recovery are performed, depending on the function involved in, by either of the two CDMS or ACMS on-board Software.

Currently identified level 2 failures are:

Unit	**Identified Level 2 failures**
TTC	RF Switches 1 or 3 blocked into intermediate position
Thermal Control	Temperature is outside ranges [FDIR Low NOP, FDIR High NOP] or [FDIR Low OP, FDIR High OP]
CDMS	Loss of RF Signal during 60 hours
ACMS	Gyro/STR inconsistency Command error Gyro Sum check error

6.3.3.4.1.2.4 Level 3

A level 3 failure is an internal computer unit (CDMU or ACC) failure, more severe than Level 0, such that the computer unit cannot neutralise it autonomously.

FDIR Level 3 errors are detected either by Hardware or Software while the recovery is performed by H/W, via the relevant reconfiguration module (i.e. CDM_RM or the ACC_RM).

Currently identified level 3 failures are:

Unit	Identified level 3 failures
CDMU	PM board M1553C Interrupt: Internal Control Bus BC failure PM board M1553C Interrupt: Internal Control Bus Send List interrupted & not completed PM board M1553C Interrupt: Internal Control Bus timeout PM board M1553C Interrupt: Internal Control Bus TTR/RM RT COCOS failure OBDH Interrupt: Identified OBDH error OBDH Timeout 1553 Data Bus BC failure CDMU internal alarm: PM System Error, PM Alarm all (internal COCOS alarm, PM undervoltage alarm, RM watchdog toggle
ACC	PM board M1553C Interrupt: Internal Control Bus BC failure PM board M1553C Interrupt: Internal Control Bus Send List interrupted & not completed PM board M1553C Interrupt: Internal Control Bus timeout PM board M1553C Interrupt: Internal Control Bus TTR/RM RT COCOS failure OBDH Interrupt: Identified OBDH error OBDH Timeout 1553 ACMS Bus BC failure (TBC) ACC internal alarm: PM System Error, PM Alarm all (internal COCOS alarm), PM undervoltage alarm, RM watchdog toggle

The first occurrence of these alarms corresponds to the **Level 3a**, and the second occurrence to the **Level 3b**.

Depending on the computer alarm sub-level (3a or 3b), the reconfiguration sequence is different: computer reset for a 3a alarm or computer switch over to the redundant unit for a 3b alarm.

6.3.3.4.1.2.5 Level 4

A level 4 failure is defined as a major on-board failure which has not been able to be detected or recovered by lower level FDIR procedures. Each Level 4 failure is be detected by dedicated independent system alarms and directly hardwired to the relevant reconfiguration module (ACC_RM or CDM_RM).

Level 4 recovery action are be performed by the proper reconfiguration module (CDM_RM or ACC_RM).

The following Table 6.3.3-4 lists the failure cases which are detected and recovered by FDIR at system level (via reconfiguration or change to safe mode). Those potential failures result from an analysis describing system feared events considered for each operational satellite life phase.

Function	Potential failure
Spacecraft positioning and control function (including propulsion management)	Sun out of specified pointing range
	Excessive angular velocity
Power supply function	Bus undervoltage
	Power loss

Table 6.3.3-4 System feared failures

From this list of system potential failures, 3 system alarms are considered:

- Loss of proper Sun Pointing **(SP)**
- Depth of Discharge **(DOD)**
- Rate Anomaly **(RA)**.

SP, and RA alarms are handled by the ACC_RM.

DOD alarm is handled by the CDM_RM.

It shall pointed out that the failures ultimately leading to the listed alarms may be first processed by lower level reconfigurations.

When a level 4 alarm is activated on ACC, it is instantaneously taken into account and satellite directly goes to *Sun Acq Mode* with ACMS in Survival Mode (use of the "survival set" of equipment and the redundant ACC Processor Module).

When a level 4 alarm is activated on CDMU, it is instantaneously taken into account and satellite directly goes to S/C *Survival Mode*.

6.3.3.4.1.3 FDIR Modes

To comply with the mission requirements, FDIR concept is organised around two main points:

- The failure classification, which has been exposed in the previous sections and is summarised in Table 6.3.3-5 hereafter,
- The FDIR Modes.

Failure Level	Failed Unit or function	Detection principle
0	All	N/A
1a	Equipment failure	Detected by OBSW Acquisition of the health status and critical parameters
1b	Communication interfaces failure	Detected by OBSW Communication protocol and bus couplers monitoring
2	Vital satellite function performance anomaly Main function failure	Detected by OBSW Function performance monitoring
3a	CDMU or ACC failure ***First occurrence***	Nominal processor module H/W alarm, S/W alarm or Watch Dog
3b	CDMU or ACC failure ***Second occurrence***	Nominal processor module H/W alarm, S/W alarm or Watch Dog
4	Global satellite malfunction	System alarms

Table 6.3.3-5 Failures classification summary

FDIR Modes are associated to Satellite Modes and aim to support the science mission. In fact this has been set up to define two reconfiguration strategies depending on the mission life phase.

FDIR strategy is defined according to the 2 current status of the mission (i.e. satellite is doing scientific observations and acquisitions or not), each one being associated with one of the two FDIR autonomy modes:

- autonomous fail operational (AFO), when the satellite is doing scientific observations and acquisitions
- autonomous fail safe (AFS), the rest of the time.

Each Spacecraft Mode entry configuration includes one of these FDIR autonomy modes.

Note: As a matter of completeness, it shall be precised that transition of one FDIR Mode to the other actually occurs upon a dedicated TC. It is therefore practically possible to trigger any FDIR Mode in any Satellite Mode.

6.3.3.4.1.3.1 Autonomous Fail Safe (AFS)

Autonomous Fail Safe (AFS) mode is the first FDIR autonomy mode. It is required to answer to physical (e.g. possible RF link unavailability…) or operational constraints of the mission. It is typically applicable to the early phases of the Herschel & Planck mission, when the spacecraft subsystems in flight calibration is not done, the scientific observations are not yet entered and the main concern is to preserve the spacecraft safety while minimising the risks and avoiding erroneous, spurious reconfiguration actions. The AFS mode basically assumes that the spacecraft in flight status is not sufficiently known to rely on complex reconfiguration strategies.

In AFS mode, the flight program, uploaded during ground contact, is autonomously executed. On alarm occurrence, the spacecraft safety is given more importance than to the mission continuation: the related failure is not isolated nor recovered by low levels FDIR processes, and the spacecraft safety is eventually based on level 4 recovery.

6.3.3.4.1.3.2 Autonomous Fail Operational (AFO)

Autonomous Fail Operational (AFO) mode is the second autonomy mode and it directly answers to the system requirements to maintain the continuity of the autonomous mission and performance as long as healthy alternative functional path exists. It essentially applies for both spacecraft, to the scientific observation modes, including the ground communications periods.

In AFO mode, on level 0 to 2 alarm occurrence, the continuation of the mission is favored by suitable, elementary recoveries. On level 3 or 4 alarm occurrence, priority is given to spacecraft safety over mission continuation.

6.3.3.4.1.3.3 Relation between Satellite modes and FDIR modes

A FDIR strategy is applied according to the current Satellite Mode (see § 6.3.3.3.), this FDIR strategy being defined by an adapted FDIR mode (i.e. AFO or AFS).

For each Satellite Mode (see § 6.3.3.3.), the corresponding FDIR modes shall be as described in the Table 6.3.3-6 hereafter. For each Satellite Mode, the authorised FDIR Modes are marked by a X. The FDIR mode at entry into the satellite mode is marked ❑.

Satellite Modes	AFS	AFO
Launch Mode	(1)	
Sun Acq Mode	❐ **X**	**X**
Survival Mode	(1)	
Nominal Mode	X	❐ **X**
Earth Acq Mode	❐ **X**	**X**

Table 6.3.3-6 Relation between satellite et FDIR modes

(1): Launch Mode and Survival Mode are specific cases; the reconfiguration strategy associated to these Modes is strongly linked to the satellites configuration; details about the Launch Mode and Survival Modes configurations and recovery strategies shall be found in RD03.20.

6.3.3.4.2 Overall FDIR Implementation

ACMS Management is carried out by the ACC and the ACMS S/W. In the same way, management of the CDMS is done by the CDMU and the CDMS S/W.

Each function is managed by either the ACMS or the CDMS. This means that they run independently.

Symmetrically, the FDIR function is divided into CDMS FDIR part and ACMS FDIR part, with simple interfaces between them. **Each** FDIR subset (i.e. CDMS FDIR and ACMS FDIR) comprises, for hardware monitoring:

- A hardware reconfiguration module with direct hard-wired links from critical units, for alarm inputs. The CDMS reconfiguration module is called CDM_RM, while the ACMS reconfiguration module is called ACC_RM
- An associated non-volatile safeguard memory, respectively the CDM_SGM for the CDMS safeguard memory, and the ACC_SGM for the ACMS safeguard memory.

Each hardware reconfiguration module (i.e. ACC_RM and CDM_RM) is independently powered from the rest of the computer (respectively the rest of the ACC and the rest of the CDMU). The context of the satellite is saved, each time a change in the configuration occurs, in the suitable non-volatile safeguard memory (i.e. ACC_SGM or CDM_SGM depending on the considered set of equipment units). Suitable toggling mechanism protects the critical data (the context) stored in SGM from being corrupted in case of OBSW failure:

The context is saved every T seconds. The SGM is split into two areas A and B; when the context is written in A every 2T, B is write protected and when the context is written in B every 2T+1, A is write protected. In that way an OBSW failure cannot corrupt both areas, and the valid context to restart from is always, at a given time, the write protected one.

Basically, the CDM_SGM and ACC_SGM memorise all the system and units configuration necessary to ensure autonomous failure recovery, and to save the failure context for later analysis (e.g. attitude data). Note that the design of the CDMU is such that the Central time reference, distributed to all intelligent users keeps running in case of computer reconfiguration.

The CDMS S/W and the ACC S/W detect low level alarms (i.e. Levels 1 and 2 alarms), while the CDM_RM and the ACC_RM detect high level alarms in input and order any reconfiguration by means CPDU telecommand packets issuing High Priority Commands called HPC_CDM when originated from the CDM_RM, and HPC_ACC when generated from the ACC_RM.

An important feature is that any software failure detection isolation and recovery procedure can be individually enabled or disabled by ground commands, whatever the FDIR Mode.

The CDMS is in charge of the management of the Mission TimeLine and specific mechanisms have been put in place to ensure the mission continuation, i.e. a consistent MTL commanding continuity, in case of levels 0 to 2 failures when the spacecraft is in AFO Mode. The main mechanism is the "logical commanding" of the units. It consists in creating telecommands which are basically independent from the physical unit redundancy in use ("logical commands"); this physical unit is autonomously identified on board from a configuration table which is updated when a level CDMS level 1 or 2 recovery occurs and leads to switch over units. A second mechanism is provided by the implementation of the 1553 Bus FDIR (see RD03.20, Annex 1). The Bus profile driving the 1553 send list indeed comprises for each Bus user, the nominal and redundant RT address, and the Bus FDIR has the capability to autonomously update the RT address, should a Bus user unit switch over happen.

The MTL also sends dedicated time-tagged commands to the ACMS. Because:

- the ACMS FDIR, and therefore the ACMS units status, including ACC, is independent from the CDMS one,
- the Satellites Mode management is centralised within the CDMS,

specific interfaces have been designed to ensure a consistent satellite behavior, in line with the Satellite Modes defined in §6.3.3.3, including the case of failure of the CDMS-ACMS communication link. The following paragraphs address the way these 3 cases are handled from a system point of view: ACMS is not available, CDMS is not available, CDMS – ACMS communication is not available.

It shall be noticed that ACMS and CDMS are considered as unavailable only in case of levels 3 and level 4 failures (see before). Analysis and recommendations partly driving the present implementation are detailed in RD03.20.

ACMS unavailability

When the ACMS is unavailable (i.e. the ACC Processor Module is involved in the reconfiguration processes)°, it shall report this status to the CDMS such that the proper Satellite Mode transition (see Figure 6.3.3-3) can be initiated.

To this purposen the ACC_RM reports a status signal to the CDMS, via a reliable status link called AIR[2], to inform of its unavailability. For failure tolerance reason the status link is hardware and independent from the communication link: AIR is a relay set by the ACC_RM, acquired by the CDMU I/O system and reset by the ACMS S/W as part of the ACMS S/W Init.

CDMS unavailability

During the CDMS unavailability (the CDMU Processor Module is involved in the reconfiguration processes), Herschel and Planck spacecraft have to be maintained in a safe mode, and the spacecraft shall be put in a safe attitude by the ACMS.

In that purpose, the CDMU_RM sends a status signal to the ACMS, via reliable links. Depending on the unavailability reason (i.e. alarm level), two different status are sent to the ACMS:

The reconfiguration is due to a CDMU level 3 failure

The CIR[3] status signal is set to request ACMS to put the spacecraft in Earth Pointing Mode in order to be able to download data at a high rate and allow a fast failure analysis and recovery by the ground when in visibility; CIR is a relay set by the CDMU_RM, acquired by the ACC I/O system and reset by the CDMU S/W as part of the CDMU S/W Init.

The recovery strategy has been simplified wrt PDR: the baseline is to not restart the MTL. The failure 3 recovery sequence is such that the spacecraft transitions into Earth Acquisition Mode (see § 6.3.3.3.):

- the CDMS and related units are in a stable "safe mode", defined by the reconfiguration sequence stored in SGM

[2] AIR: ACMS in Reconfiguration
[3] CIR: CDMS In Reconfiguration

– the ACMS is requested to initiate an Earth Acquisition in ACMS normal mode via the setting of the CIR relay,

– the instruments are put in a defined "Standby Mode", which they have defined wrt specified system constraints.

The reconfiguration is due to a CDMS level 4 failure

The SIR[4] status signal is set to request ACMS to put the spacecraft in an attitude, safe w.r.t. power generation, in Sun Pointing Mode (see § 6.3.3.3.); SIR is a relay set by the CDMU_RM, acquired by the ACC I/O system and reset by the CDMU S/W as part of the CDMU S/W Init.

A CDMS level 4 leads to a complete CDMS level reconfiguration with a switch over to redundant units, including the processor module. Level 4 failures are system level "critical" failures and the current recovery baseline is to not restart the MTL.

The failure 4 recovery sequence is such that the spacecraft transitions into Survival Mode (see § 6.3.3.3.):

– the CDMS and related units are in a stable "safe mode", defined by the reconfiguration sequence stored in Survival register,

– the ACMS is requested to initiate a Sun Acquisition via the setting of the SIR relay,

– the instruments are turned OFF.

Communication link unavailability

Some information (e.g. synchronisation messages, On Board Time) have to be transmitted periodically from the CDMU to the ACC over the communication link. The implemented communication link is a 1553 data bus (composed of a nominal bus – *BUS A* and a redundant bus – *BUS B*) where CDMU is the bus controller and ACC a remote terminal.

In the same way, some information (e.g. housekeeping data) is transmitted periodically from the ACC to the CDMU.

Anomalies in the CDMU<->ACC communication are fully handled at the 1553 data Bus FDIR (level 1b failures), detailed in RD03.20, Annex 1. The failure recovery can ultimately lead to a CDMU Level 3 failure triggering.

[4] SIR: Satellite in Reconfiguration

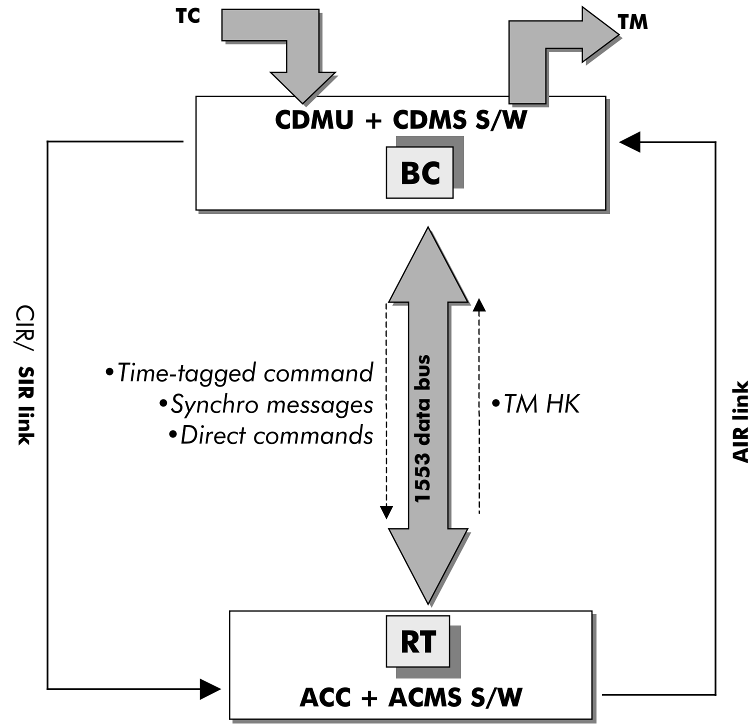


Figure 6.3.3-3 CDMS/ACMS Interface

6.3.3.4.3 FDIR Strategy

The FDIR strategy, from a system point of view is unique for both spacecraft: each phase, from an autonomy and FDIR point of view is declared as AFS or AFO. For each Satellite Mode, depending on the operational life phase, the top level requirements (AFO, AFS) are declined at lower levels. These notions of Satellite Modes and FDIR Modes are however unknown to the instruments, and the next paragraphs first address the 2 strategies and the articulation between them. Then the overall recovery strategy is summarised

6.3.3.4.3.1 Service Module level

The strategy, as far as Service Module is concerned, has been widely discussed in the previous sections; in summary:

- The hierarchical failure detection identification and recovery architecture allows to satisfy the top level requirement to have a mission interruption only in case of a major, high level failure, the equipment level failures being possibly processed and recovered autonomously at lower levels.
- The failure processing essentially depends on the current Satellite Mode (see § 6.3.3.3.), and the reconfiguration actions, in AFO mainly, is graduated with regards to failure severity. As already explained, each computing subsystem, CDMS and ACMS, applies a similar strategy to recover from a single failure:
  - Software monitoring for the surveillance of low level failures, associated to a reconfiguration managed by S/W
  - Hardware monitoring for the surveillance of high level failures, then a hardware based reconfiguration.

- Major failures which can endanger the spacecraft safety are detected by dedicated hardware alarms and handled independently from on-board software tasks (by the mean of high level commands issuing).
- For other failure categories, software monitoring and recovery procedures are implemented via specific FDIR functions within the ACC or CDMU S/W, depending on their respective control.

6.3.3.4.3.2 Instrument level

The instruments FDIR implementation from a spacecraft point of view, and its interfaces with the SVM level FDIR have been kept very simple. Its principles are:

- Most of the FDIR tasks are handled internally to the instruments; they can be considered as level 0 failures as seen from the spacecraft side.
- Few internal instruments isolation and/or recovery activities need the spacecraft support, and are considered as level 1a failures. This support will be requested by the instruments via the generation of dedicated events. These events will typically trigger specific OBCP's, specified by the instruments, which will perform the requested isolation and/or recovery actions. Especially, these OBCP's may:
  - turn OFF instrument units
  - disable commanding from MTL for the instrument APID
  - disable commanding from the MTL Subschedule dedicated to the failed instrument operation, e.g. using the meta subschedule feature described in Section 6.3.3.2.1.
  - resume instrument activity (subschedule, APID) after the instrument has notified the failure recovery, nominally at the start of the next subschedule for the instrument.

  It shall be underlined that the actions with regard to a failed instrument commanding are strongly dependent upon the MTL organisation into subschedules, meta-subschedules.

An independent monitoring of the instrument behaviour is performed via the 1553 data Bus FDIR (see RD03.20, Annex 1), and especially the TFL FDIR (via a monitoring of the amount of data delivered by the instruments). The actions to be taken in case an anomaly is found are defined by the instruments and will typically consist in the start of a dedicated OBCP, as per above case.

6.3.3.4.3.3 Failure recovery strategy

The following table illustrate the CDMS and ACMS failure recovery strategy for the FDIR Levels 1 and 2.

Depending on the failure level and the active FDIR mode, a recovery sequence is defined.

FAILURE LEVEL		**DETECTION PROCEDURE**	**FAILURE RECOVERY**	
			AFS Mode	**AFO Mode**
1a	Equipment failure	OBSW acquisition of unit health check status	Detect failure only. Isolation and recovery will be performed if levels 3 or 4 are triggered On a case by case basis, deviations could be accepted to authorize the isolation and recovery of well identified level 1a failures in AFS	Stop boost if boost and depending on the failed ACMS equipment unit Save failure context Triigger unit recovery procedure (eg. Switch over to the redundant unit using SGM configuration) Resume operations
1b	Communication I/F failure	Monitoring of communication protocol and bus couplers	Detect failure only. Isolation and recovery will be performed if levels 3 or 4 are triggered. Requirements for 1553 data bus failure detection are specified in Annex 1. On a case by case basis, deviations could be accepted to authorize the isolation and recovery of well identified level 1b failures in AFS	Stop boost if boost and depending on the failed equipment unit (TBC) Save failure context Switch over to the redundant bus coupler or direct interface using SGM configuration. Requirements for 1553 data bus failure detection isolation and recovery are specified in SOFDIR Annex 1. Resume operations
2	Main function failure	OBSW performance check	Detect failure only. Isolation and recovery will be performed if levels 3 or 4 are triggered On a case by case basis, deviations could be accepted to authorize the isolation and recovery of well identified level 2 failures in AFS	Stop boost if boost Save failure context Identify the failed unit by a consistency cross check or possibly switch over to the redundant functional chain using SGM configuration. Resume operations

Table 6.3.3-7 Level 1 & 2 Failures recovery strategy

The two next tables illustrate the FDIR Level 3 failure recovery strategy. Each computer is treated on its own. First is presented the ACC Level 3 failure recovery strategy, then the CDMU one. Again, depending on the failure level and the active FDIR mode, a recovery sequence is defined.

FAILURE LEVEL		DETECTION PROCEDURE	FAILURE RECOVERY	
			AFS Mode	**AFO Mode**
3a	**ACC** internal failure – first occurrence	Nominal processor module HW alarm or SW watch dog	Stop boost if boost In case of ACC internal alarm: Set the AIR signal, to inform the ACMS about the ACC reconfiguration Save Failure context Reset the nominal processor module. Re-Load SGM context Transition the S/C into the Mode specified in Fig 6.3.3-2 : S/C is switched to Sun Acquisition Mode. if it runs from S/C Nominal Mode or Earth Acq Mode	
3b	**ACC** internal failure – second occurrence	Nominal processor module HW alarm or SW watch dog	Stop boost if boost In case of ACC internal alarm: Set the AIR signal, to inform the CDMS about the ACC reconfiguration Save failure context Switch over to the redundant processor module Load context from Survival Context memory Transition the S/C into the Mode specified in Fig 6.3.3-2: S/C is switched to Sun Acquisition Mode if it runs from S/C Nominal Mode or Earth Acq Mode	

Table 6.3.3-8 ACC Level 3 failure recovery strategy

<table>
<tr><th colspan="2">FAILURE LEVEL</th><th>DETECTION PROCEDURE</th><th colspan="2">FAILURE RECOVERY</th></tr>
<tr><th></th><th></th><th></th><th>AFS Mode</th><th>AFO Mode</th></tr>
<tr><td>3a</td><td>**CDMU** internal failure – first occurrence</td><td>Nominal processor module HW alarm or SW watch dog</td><td colspan="2">In case of CDMU internal alarm : Set a CIR signal to be acquired by the ACMS,
Save failure context
Reset the nominal processor module.
Re Load SGM context
Disable MTL service execution and wait for TC to re-start full MTL execution
Transition the S/C into the Mode specified in Fig 6.3.3-2: S/C is switched to Earth Acquisition Mode. if it runs from S/C Nominal Mode</td></tr>
<tr><td>3b</td><td>**CDMU** internal failure – second occurrence</td><td>Nominal processor module HW alarm or SW watch dog</td><td>In case of CDMU internal alarm : Set a CIR signal to be acquired by the ACMS,
Save failure context
Switch over to the redundant processor module</td><td>Re Load SGM context
Disable MTL service execution and wait for TC to re-start full MTL execution
Transition the S/C into the Mode specified in Fig 6.3.3-2 : S/C is switched to Earth Acquisition Mode. if it runs from S/C Nominal Mode</td></tr>
</table>

Table 6.3.3-9 CDMU Level 3 failure recovery strategy

This last table illustrate the FDIR Level 4 failure recovery strategy.

There is a common strategy for both FDIR modes (i.e. AFS and AFO), but the recovery sequence is sensitively different depending on the alarmed computer (i.e. ACMS level 4 failures or CDMS level 4 failures).

FAILURE LEVEL		DETECTION PROCEDURE	FAILURE RECOVERY	
			AFS Mode	**AFO Mode**
4	Global satellite malfunction	System Alarm : DOD (CDMS), RA & SP (ACMS)	Stop boost if boost Disconnect non essential loads In case of CDMS Level 4 alarm : Set SIR signal to be acquired by ACMS In case of ACMS Level 4 alarm : Set AIR signal to be acquired by CDMS, to inform about ACMS reconfiguration Save failure context Switch over to the redundant processor module and re-start from Survival Context memory In case of CDMS level 4 alarm, see Fig 6.3.3-2: spacecraft is switched to Survival Mode (exception is from Launch Mode) In case of ACMS level 4 alarm, see Fig 6.3.3-2: spacecraft is switched to Sun Acq Mode with ACMS in SM (exception is Launch Mode) Disable MTL Service and wait for TC to re-engage full MTL service execution	

Table 6.3.3-10 Level 4 failure recovery strategy

6.3.4 Avionics software architecture

High level principles have been retained for the Herschel/Planck avionics On-Board Software (OBSW) design, development, verification and validation activities. These principles are listed here under, then explained and expanded in dedicated sections:

- The commonality between the different software products has been favoured based on a standard functional architecture and largely common hardware targets.
- Common software design, development and test means have been specified.
- The use of Herschel/Planck System Database (HPSDB) compatible bridge files (XML format) for the OBSW generation and HPSDB population has been required.
- Independent Software Verification and Validation (ISVV) activities have been specified. The validation tasks will be performed using a common Software Validation Facility (SVF) for a minimum of two versions for each identified software product.

Other issues which are specific to the satellite level, e.g. the interface with non SVM units and instruments, the flight OBCP's development, are also discussed in the following.

6.3.4.1 On-board software design description

The OBSW is part of the following SVM subsystems:

- the Command and Data Management Subsystem (CDMS), under Alenia Spazio (ALS) responsibility
- the Attitude Control and Measurement Subsystem (ACMS), under Dutch Space responsibility.

Both CDMS and ACMS include one computer based on ERC-32 microprocessor, respectively the Central Data Management Unit (CDMU) and the Attitude Control Computer (ACC), connected together by the mean of a 1553 B bus. Each computer implements its own dedicated software.

As far as the ACMS is concerned, this subsystem is also composed of equipment which includes software:

- Star Tracker SW
- Gyro SW.

The whole CDMU/ACC OBSW architecture has been conceived in order to fulfil the commonality requirement. For instance:

- Herschel and Planck CDMU and ACC OBSW will be developed using the same standard Software Development Environment (SDE)
- CDMU OBSW for Planck and for Herschel will be identical. They will only differ by the satellite database they are compiled with (the database is mainly used to load predefined tables and all messages definition) and mission specific functions (e.g. payload management and decontamination heating)
- Bootstrap Software, I/O drivers (when the used hardware is common), and scheduler (namely RTEMS) of CDMU and ACC OBSW will be the same.

Even if CDMU and ACC OBSW will be different, they will be designed according to the same software breakdown. Each of these OBSW is composed of the Application Software (ASW) and the Basic Software (BSW), as described in Figure 6.3.4-1.

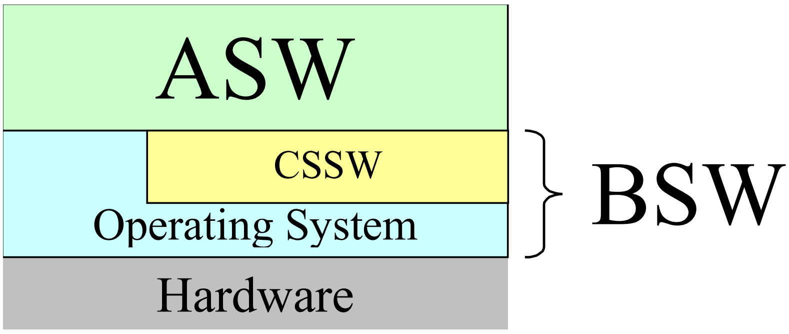


Figure 6.3.4-1 Herschel/Planck CDMU/ACC OBSW breakdown

The ASW is the highest layer.

The BSW is essentially common to CDMU and ACC OBSW (although not strictly identical in the two cases). It supplies services to the ASW. These services are either basic ones to interface hardware devices included in the Operating System (OS) layer:

- Task scheduling capabilities
- Time management
- Events
- Inter-task-communication services
- I/O drivers
- Bootstrap

or common services to CDMU and ACC included in the Common Service Software (CSSW) layer:

- TC dispatching
- Event Management
- Functions Management
- TM Management
- Bus Management (1553).

The BSW also performs important functionality by itself, i.e.:

- Memory Management (patch/dump)
- On-Board Storage and Retrieval Service (SSMM Management)
- Low level FDIR (e.g. for S/C 1553 bus and hardware failures).

The CDMU ASW supports the following main functionality:

- Relevant Packet Services
- Mission specific functions
- Satellite mode management

- Power distribution management
- Thermal control
- Failure Detection Isolation and Recovery (FDIR)
- Mission Timeline (MTL) Management
- On-Board Control Procedure (OBCP) management.

The ACC ASW supports the following main functionality:

- Relevant Packet services
- FDIR
- ACMS Mode Management
- Sensors Data processing and actuators commanding
- Control law.

Herschel and Planck ACMS specificity leads to the design of two distinct ACC ASW associated with two distinct ACC BSW. However, for commonality purpose, a Common Application Software (CASW) service layer has been identified, responsible e.g. for the basic communication with the ACMS units and the CDMU (through BSW services), and ACC Packet Services not supported by the BSW. Both ACC ASW will only differ by their respective Satellite Dependent Application Software (SDASW) layer, as described in Figure 6.3.4-2:

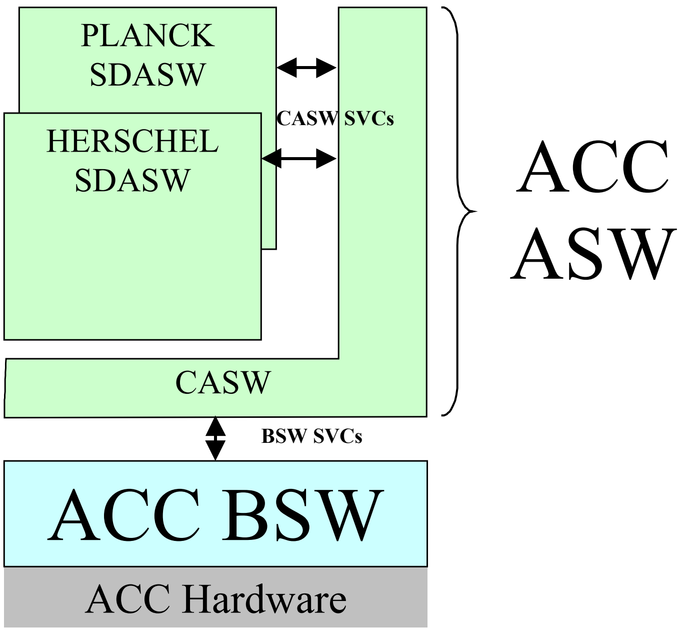


Figure 6.3.4-2 Herschel/Planck ACC ASW breakdown

As far as packet services (as required in PS-ICD) are concerned, their implementation has been also dispatched between BSW and ASW as described in Table 6.3.4-1 below:

Service Type	Service Name	Services supported by			
		CDMS		ACMS	
		BSW	ASW	BSW	ASW
1	Telecommand Verification	Yes	Yes	Yes	Yes
2	Device Command Distribution Service	No	Yes	No	Yes
3	Housekeeping and Diagnostic Data Reporting	Yes	No	Yes	No
4	Not Used	No	No	No	No
5	Event Reporting	Yes	Yes	Yes	Yes
6	Memory Management	Yes	No	Yes	No
7	Not Used	No	No	No	No
8	Function Management	Yes	Yes	Yes	Yes
9	Time Management Service	No	Yes	No	Yes
10	Not Used	No	No	No	No
11	On-board Operations Scheduling Service	No	Yes	No	No
12	On-board Monitoring Service	No	Yes	No	No
13	Not Used	No	No	No	No
14	Packet Transmission Control Service	Yes	No	Yes	No
15	On-board Storage and Retrieval Service	Yes	No	No	No
16	On-board Traffic Management	Yes	No	No	No
17	Test Service	Yes	No	Yes	No
18	On-board Control Procedure Service	No	Yes	No	No
19	Event/Action Service	No	Yes	No	No
20	Not Used	No	No	No	No
21	Science Data Transfer Service	No	No	No	No
22	Not Used	No	No	No	No

Table 6.3.4-1 Herschel/Planck Packet Services Supported by SVM OBSW

Note:

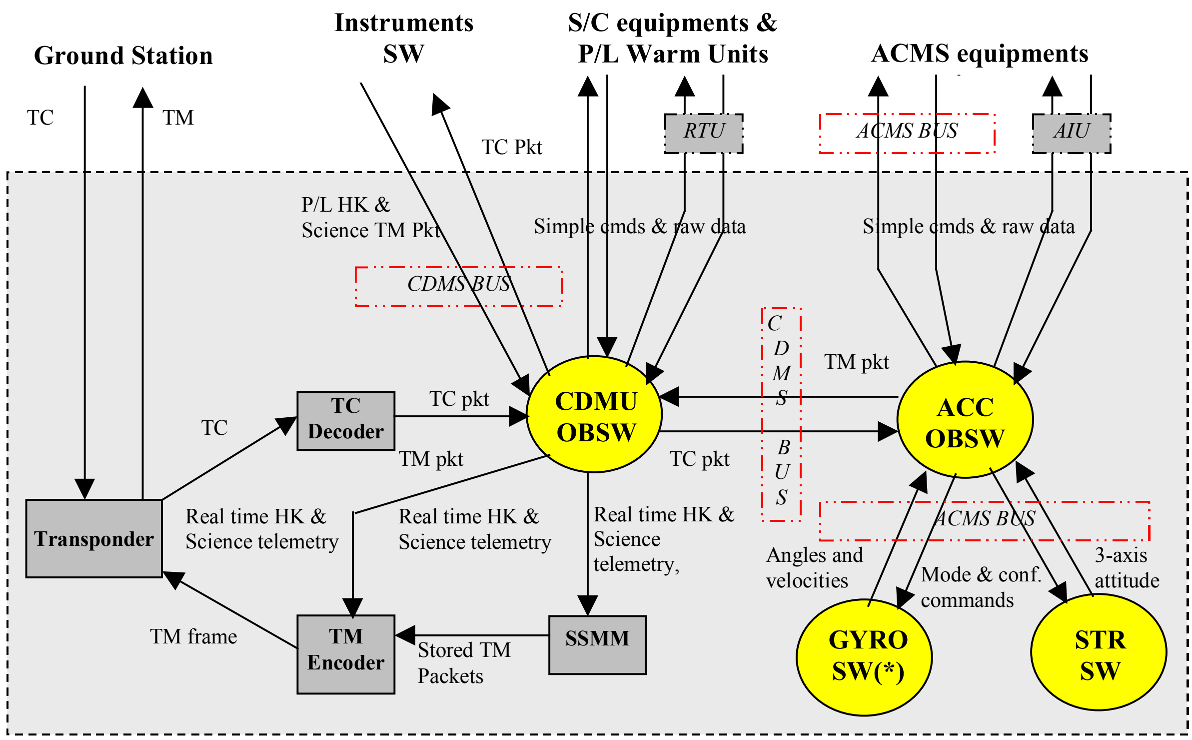
– Service#1 & #5:
  - ASW generates verification and event reports by using services provided by the BSW. Note that this is applicable to telemetry packets generation in general.

– Service#2:
  - Though BSW does not implement service#2, it provides all the necessary low level services to communicate with related devices (e.g. CPDU and OBDH access)
  - As far as ACMS is concerned, only mission specific CPDU commands are supported (see PS-ICD for more details)

- Service#9:
  - On receipt of a Synchronise User request (TC[9,3]), the CDMU ASW will send the Enable Time Synchronisation request to the specified user (TC[9,4]) followed or not by the Time Code (TC[9,5]) according to the specific implementation of the Service#9 performed by the intelligent end-user (see PS-ICD for more details). E.g., TC[9,5] is not supported by ACMS OBSW and thus will not be sent by CDMS OBSW.
- Service#16:
  - No specific Service #16 TM/TC packet has been defined for the On-Board Traffic Management. The CDMS OBSW will report anomalies related to TM/TC packet routing and distribution. Then, in order to control the generation and transmission of individual packet (e.g. enabling/disabling of real-time down-linking and/or SSMM storage), it has been decided to expand the Packet Transmission Control Service #14 instead (see PS-ICD for more details).
- Service#21:
  - This services is only supported by Instruments.

6.3.4.2 On-board Software Interfaces

The Figure 6.3.4-3 shows the interfaces between OBSW products and with the hardware addressed in § 6.3.1. and § 6.3.2.



(*) HERSCHEL Only

Figure 6.3.4-3 Satellite Software architecture and interfaces

The SVM section of the CDR design report details the OBSW functions specific to the SVM units. The following chapters describe the OBSW contribution to the management of units which are not part of the SVM (see § 6.3.1.); these are, as far as the CDMU OBSW is concerned, the instruments, the VMC, the SREM and the CCU (Herschel).

6.3.4.2.1 VMC Management

6.3.4.2.1.1 VMC Overview

The Visual Monitoring Camera (VMC) aims to film on request and during a short duration the spacecraft neighbourhood in a certain fixed direction, the baseline being to watch the separation from the launcher. It is part of the SVM CDMS to which it communicates via standard serial links (only DS16, no ML16).

There is only one VMC on Herschel (no redundancy). The VMC on Planck has been removed on ESA request.

The VMC operating modes are:

- OFF_MODE: this mode is entered when the VMC is switched OFF via a dedicated PCDU command (VMC_OFF_CMD). This will also be the mode at launch.
- ACQUISITION_MODE: this mode is entered when the VMC is switch ON via a dedicated PCDU command (VMC_ON_CMD). Then, the VMC autonomously performs the following sequence of actions:
  - It warms up during VMC_WARM_UP_DELAY (5 ±2 seconds)
  - Then, it acquires 15 images of 263176 bytes (512x512 8-bits pixels + few bits for additional information like image and line identifiers) and store them in its internal buffer. The total amount of data for the 15 images is thus 3947640 bytes.
  - When the 15 images have been acquired, the VMC stops its acquisition activity. The delay between 2 images is HW configurable by setting the “System Status” pin connector. This delay can be from 1s to 1.75s.

Note that these modes are independent from any other S/C mode.

Switching OFF, then ON the VMC will start the acquisition of 15 new images.

All VMC data is sent through the image frames structure; no specific VMC HK telemetry is identified.

6.3.4.2.1.2 OBSW VMC Management

- <u>CDMU ASW:</u>

  The separation strap condition is detected by the ASW that will then start the separation sequence by switching ON the VMC (VMC LCL closure). Then, as stated previously, the VMC will autonomously acquire 15 images.

  Of course, at any time VMC can be switched ON/OFF by sending command to the PCDU using Packet Service #8 Telecommand (PCDU Management function handled by ASW or raw 1553 message handled by BSW).

- <u>CDMU BSW:</u>

  On receipt of a dedicated Telecommand (Packet Service#8 used for VMC management function), the BSW starts the transfer of the data stored in the VMC internal buffer to the CDMS. This acquisition is done by sending a sequence of the same specific DS16 on the OBDH bus (625/second).

Once acquired, the BSW packetises the VMC data in dedicated TM(8,8) packets of maximum size (the last packet size being according to number of remaining data to be stored). These packets are handled as any other TM packets, i.e. sent to a selected VMC Packet Store in the SSMM and/or real time Virtual Channel zero according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…]. At launch, the value for the transmit and storage flags of these packets are to be set to respectively disabled and enabled, i.e. VMC packets are stored in SSMM but not sent in real-time to avoid bandwidth saturation.

According to the amount of data to be transferred, the transfer of one image will last about 3min30s [263176*8bits/(625*16bits)=210,5 s], i.e. 52min38s for the 15 images [3158,112 s].

Before the completion of the VMC data transfer, a dedicated Telecommand (Packet Service#8 used for VMC management function) can be sent to the BSW in order to stop the acquisition of the data stored in the VMC internal buffer. Whenever requested, the stop of the VMC data acquisition will be effective only after the completion of the in progress VMC packet building (to allow efficient data retrieval).

Note also that if any error linked to VMC data acquisition is detected (e.g. OBDH error), the VMC acquisition process will be stopped and an event report indicating the failure sent.

Finally, the acquisition of the VMC data is considered as a low priority process and will thus not interfere with other OBDH bus traffic.

6.3.4.2.2 SREM Management

6.3.4.2.2.1 SREM Overview

The Standard Radiation Environment Monitor (SREM) is a monitor-class instrument intended for space radiation environment characterisation and radiation housekeeping purposes. It will provide continuous directional, temporal and spectral data of high-energy electron, proton and cosmic ray fluxes encountered along the orbit of the spacecraft, as well as measurements of the total accumulated radiation dose absorbed by the SREM itself.

The SREM is connected to the CDMS to which it communicates via standard serial links (DS16 and ML16).

There is only one SREM per spacecraft (no redundancy).

6.3.4.2.2.2 OBSW SREM Management

Apart from the switching ON/OFF of the SREM, the complete SREM Management is handled by the CDMU BSW. Dedicated SREM function has been designed (via Packet Service#8). This function is responsible for:

- Verification and execution of SREM telecommands by translating requests into SREM-commands on the ML-line,
- Acquisition of SREM accumulation data and packetisation in dedicated TM(8,7) packets. These packets are handled as any other TM packets, i.e. sent to a selected SREM Packet Store in the SSMM and/or real time Virtual Channel zero according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…].

By telecommand, it is possible to perform the following activities:

- Start/Stop Cyclical SREM Data Accumulation
- Dump SREM Memory
- Load SREM patch

– Set/Get SREM Registers.

The execution of these TC is done according to the following state machine:

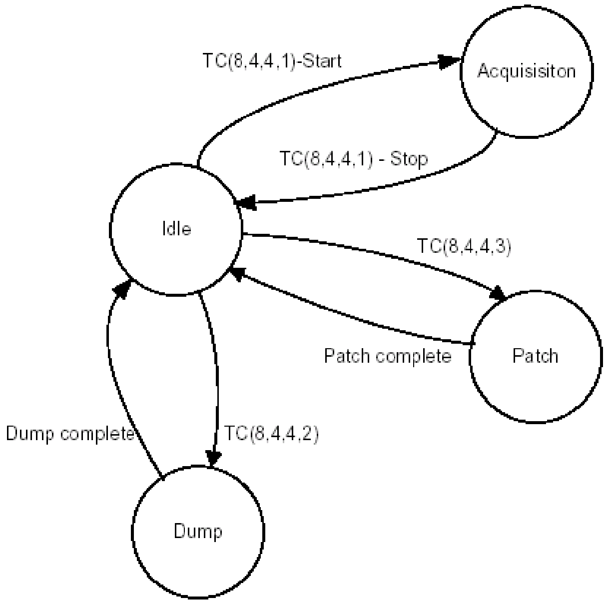


Figure 6.3.4-4 OBSW SREM states

– Idle, when no acquisition, load or dump is ongoing.

– Acquisition, when SREM accumulation and total dose data is acquired and delivered.

– Patch, when a patch received by TC(8,4,4,3) is loaded into SREM memory.

– Dump, when a requested SREM memory area is read from the SREM and reported in TM.

In any of the states above, SREM register read or write access may be performed in parallel. Acquisition, Patch and Dump are mutually exclusive.

6.3.4.2.3 CCU Management

6.3.4.2.3.1 CCU Overview

The Cryostat Control Unit (CCU) will be physically mounted on the Herschel spacecraft's Service Module (SVM) and will interface with the cryogenic cooling system for cold units of scientific instruments in Extended Payload Module (EPLM).

The CCU will be powered via a LCL by the PCDU and operated by the CDMU via MIL-Std 1553B bus interface.

The CCU will provide operational access to the cryostat instrumentation as well as to the telescope temperature sensors. Through its user interface the CCU will monitor the cryostat status by acquisition of the pressure and temperature sensor readings, will operate and monitor the helium contact measurement system and will operate the cryogenic-valves as well as to acquire their status indicators.

There are two CCU (A/B) on Herschel, operated in hot redundancy.

6.3.4.2.3.2 OBSW CCU Management

The CDMU OBSW is responsible for the acquisition of the CCU telemetry via the S/C 1553 bus according to Bus profile definition and current CCU mode.

In flight, each CCU redundancy can be asked to enter into the following main modes:

- Monitoring (nominal mode)
- DLCM (foreseen only twice per year).

On request to perform CCU mode transition (for each CCU half) via a dedicated Service#8 TC, the CDMU OBSW sends the related 1553 messages to the CCU in order to acquire the complete set of data associated to each CCU mode. The full set of data will only be available after a certain time from the request (up to 4s), depending on the requested number of parameters. New set of data is only acquired upon request initiated from the CDMU SW

When commanded in DLCM mode, nominally via a dedicated CCU_DLCM TC originated from ground, the CDMU OBSW has to packetise all the received data into dedicated telemetry packets. These packets are handled as any other TM packets, i.e. sent to a selected Packet Store in the SSMM and/or real time Virtual Channel zero (VC0) according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…]. The data in that mode is only for ground purpose and is not supposed to be processed on-board.

When commanded in Monitoring mode via a dedicated CCU_Monitoring TC originated from ground, the CCU is cyclically be commanded by the CDMU SW to initiate Monitoring measurement sequences. The acquired data is stored in the CDMS datapool from which it can be extracted and put in Housekeeping packets and monitored. E.g. some data acquired in Monitoring mode (telescope temperatures) are used by the Decontamination Heating algorithm (the Decontamination algorithm will check that the CCU is in Monitoring Mode before starting). The baseline is to periodically send a Monitoring Mode request to the CCU in accordance with the mission monitoring needs (typically between 4s and 3600s), and in parallel transfer the monitoring parameters to the CDMS datapool at a rate consistent with the 1553 Bus profile period, i.e. nominally every 1s.

In parallel with the 2 above modes, the CCU Housekeeping data is routinely acquired (period is 1s) and stored in the datapool.

Very simple FDIR will be applied to the CCU: the CCU will be checked to be in the Mode it has been commanded in (this is mainly to avoid DLCM to be triggered when not requested, upon CCU failure; this would indeed impact Herschel cryostat lifetime).

6.3.4.2.4 Instruments Management

The CDMU OBSW is responsible for the following main activities related to Instruments management:

- <u>TC routing</u>: any telecommand addressed to Instruments are first partly verified (Packet ID, length, Error control and Sequence Control) at CDMU BSW level before routing according to its APID via the S/C 1553 bus and according to Bus profile definition.
- <u>TM acquisition, storage and down-linking</u>: All the telemetry packets generated by Instruments are acquired on the S/C 1553 Bus according to Bus Profile definition by the CDMU BSW. Then, they are stored in dedicated packet stores in SSMM and/or down-linking to ground on request.

- TM processing: the CDMU OBSW is able to process on-board specific telemetry coming from instruments like:
  - HK packets: on request they can be stored in the CDMS datapool for parameters extraction by On-Board Control Procedures. Currently no such procedure is planned,
  - Events packets: each Instrument event packet (TM(5,x)) reception can linked to an action to be performed by the CDMU ASW. Additionally, an OBCP can be asked to wait for the receipt of events generated by Instruments (either TM(5,x) or TM(1,x))
- Central Time Reference (CTR) broadcasting: every second the CDMU BSW sends on the S/C 1553 the CTR according to the bus protocol. The CTR is to be used by Instruments for synchronisation purpose. Note also, that the synchronisation procedure can be started on request by using service #9.
- Failure Detection Isolation & Recovery (FDIR): The CDMU OBSW performs health monitoring of the Instruments as any other intelligent users connected on the S/C 1553 bus (e.g. TFL FDIR and check that amount of generated TM is as expected). In case of anomaly, an event is generated and associated recovery actions are performed. In case of anomaly detected by the Instrument itself and whenever it needs CDMS support to recover, the Instrument has also to generate an event. As far as Instruments are concerned, the recovery procedures will be implemented via OBCP.
- Peak-Up (Herschel only): On receipt of a dedicated peak-up event from the instrument, the CDMU ASW will issue toward the ACC a Peak-up Telecommand containing the relevant parameters acquired by the instruments (HIFI and SPIRE only) in peak-up mode. In peak-up mode the instrument establishes a pointing correction to be performed by the S/C in order to accomplish the observation. This information issued toward the ACC will allow fixing of the necessary pointing.
- Decontamination Heating.

6.3.4.3 On-board Software Organisation

The high level architecture presented here above, together with the constraints of the industrial organisation in the framework of Herschel/Planck project, eventually lead to complex share of responsibility and interfaces. Therefore, for clarity, homogeneity and coherency reasons in order to:

- lessen risk of misunderstanding
- ease requirements traceability and compliance checking
- ease interfaces management and definition
- avoid interface gaps.

it is requested that all involved subcontractors shall deliver the same software documentation package defined by ASP and compliant with ESA standard requirements (ECSS-E-40B and ECSS-Q-80B).

For the same purpose, the list of the requested OBSW reviews and associated documentation package has also been defined. All these reviews take place during the software life cycle as described in Figure 6.3.4-5.

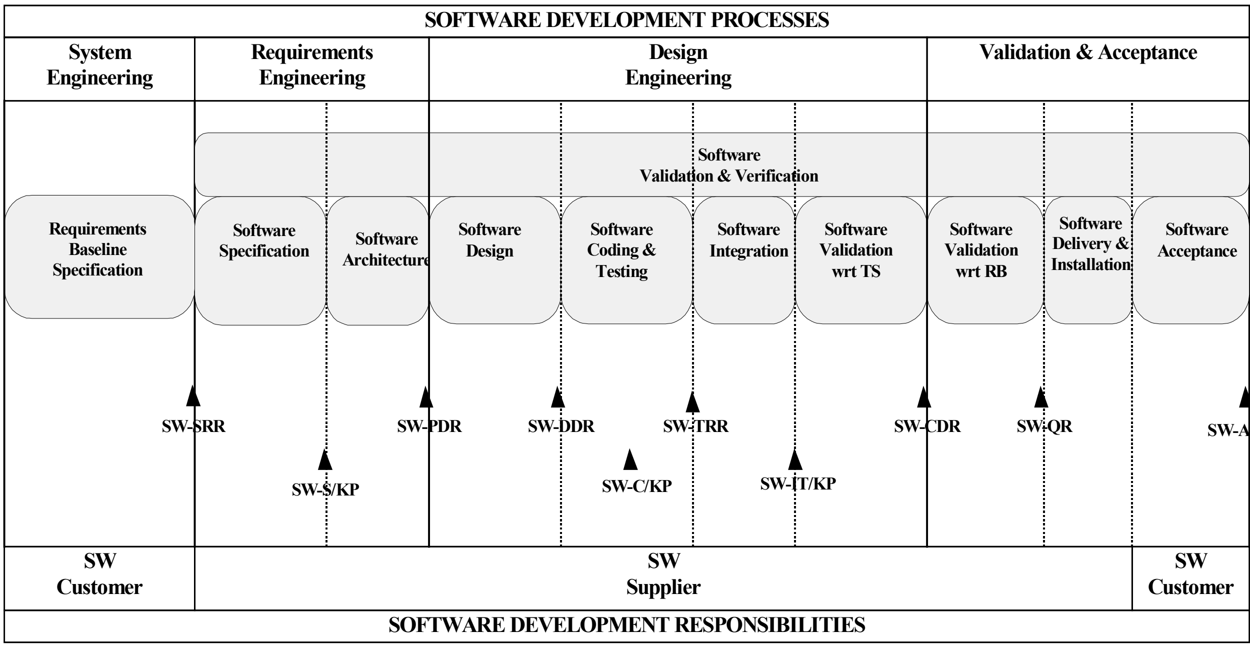


Figure 6.3.4-5 OBSW Reviews and Key-Points

The Figure 6.3.4-6 sums up the Herschel/Planck OBSW product tree in line with the functional breakdown presented in the previous section, and introduces:

- The responsibility sharing among the industrial team
- The document set to be exchanged between the different levels: Requirement Baseline (RB), Technical Specification (TS), Design Definition File (DDF) and Design Justification File (DJF).

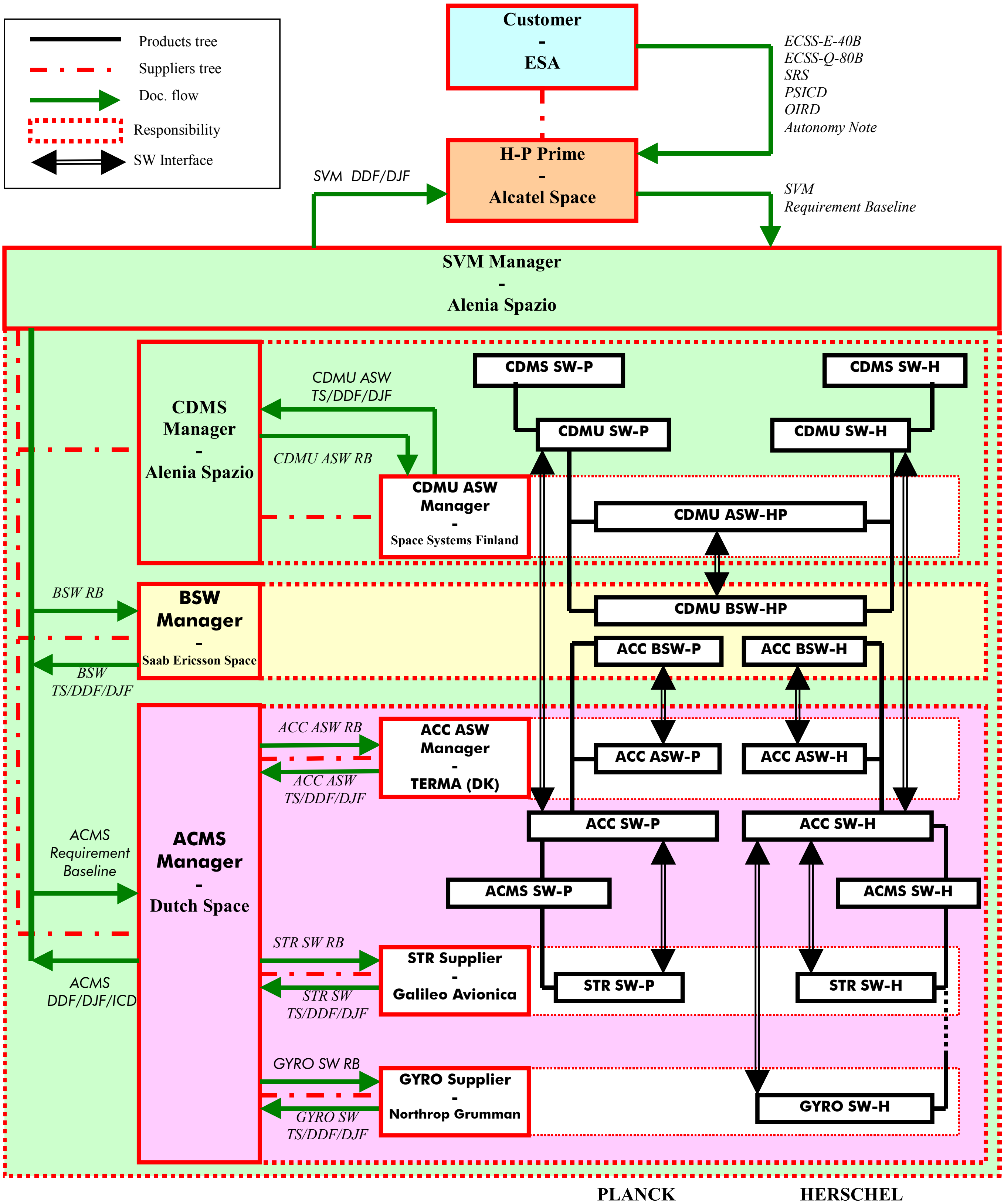


Figure 6.3.4-6 Herschel/Planck OBSW Products/Suppliers/Specifications' Trees

6.3.4.4 Software Development Environment

In order to optimise the OBSW design, development and test tools to be used within the Software Maintenance at ESOC, a standard Software Development Environment (SDE) has been specified to be utilised at a minimum by the CDMU and ACC BSW and ASW contractors, and possibly by any other OBSW product supplier. Even if not exactly similar, the STR SDE is largely common.

The definition of this SDE is given in Table 6.3.4-2:

	ACC/CDMU BSW/ASW	STR SW
Requirements management tool	DOORS[5]	-
Processor	ERC-32	ERC-32
Design language	UML	OOA/OOD/OOP
CASE Tool	Rational ROSE	-
Host computer	Sun Workstation	Sun Workstation
Host OS	Solaris 8.0	Solaris 8.0
Programming language	C/Assembly	C/Assembly
Compiler/Debugger	GCC/GDB	GCC/GDB
Target operating system	RTEMS 4.5.0	None. Interrupt driven SW
Cross compilation system	LECCS	ERC32CCS 2.0.6 (ERC32 GNU cross compiler)
Software testing tool[6]	CANTATA	CANTATA
Configuration management tool	CLEARCASE	mks
ERC-32 simulator	TSIM	SIS

Table 6.3.4-2 Software Development Environment Definition

6.3.4.5 Software Validation Facility

6.3.4.5.1 SVF Purpose

The Software Validation Facility (SVF) is a facility which offers the possibility to maintain, to test and to verify Herschel/Planck OBSW without having the target system available. For this purpose, the SVF creates an environment, which simulates the functionality and the performances of the devices which interface the OBSW. Consequently, the OBSW sees its environment exactly as it will see it on-board. The SVF also enables testing the OBSW robustness in representative failure cases.

The SVF will be capable to handle both Herschel and Planck configurations.

At first dedicated to OBSW maintenance during the operation phase at ESOC premises, the SVF will also be used to perform the Independent Software Verification and Validation (ISVV) activities described in Chapter 6.3.4.7. As a consequence, ISVV will also be devoted to demonstrate the suitability of the SVF design with the OBSW maintenance needs.

[5] This is only an ASP recommendation
[6] Used for Static analysis, Unit tests and Dynamic analysis

6.3.4.5.2 SVF for the ACC/CDMU OBSW

6.3.4.5.2.1 ACC/CDMU SVF Overview

The SVF for both ACC and CDMU OBSW (BSW+ASW) will be a pure software numerical simulator (using the TSIM ERC-32 simulator from Gaisler Research) that is developed by TERMA (DK).

In order to consolidate the specification, design and testing activities of the SVF, the following contribution is foreseen:

- CAPTEC (ISVV contractor) participation to the review of the SVF specifications both to ensure the adequacy between SVF design and ISVV needs, and anticipate/optimise ISVV contractor's understanding of the SVF definition and use
- Saab Ericsson Space (Computer and BSW supplier) support for the understanding of the ACC/CDMU architecture and BSW design driving the hardware
- Dutch Space (ACMS designer) assistance on the validation of the ACC flight dynamics models.

The driving requirements for the design of the SVF are:

- Use of 'true' OBSW (cross-compiled binaries for ERC32 target), i.e. no instrumentation of the OBSW code shall be needed
- Representativeness down to the bus traffic and simulation of ASICS
- Real time performance.

Three copies of the ACC/CDMU SVF will be developed. The first one is to be delivered to ISVV contractor to start the validation of the OBSW. Any SVF problems discovered during this validation phase will be corrected before delivering the second SVF release to ESOC and finally SVF contractor will keep at their premises a third copy for maintenance purpose.

6.3.4.5.2.2 ACC/CDMU SVF Architecture

The Figure 6.3.4-7 describes the overall ACC/CDMU SVF architecture.

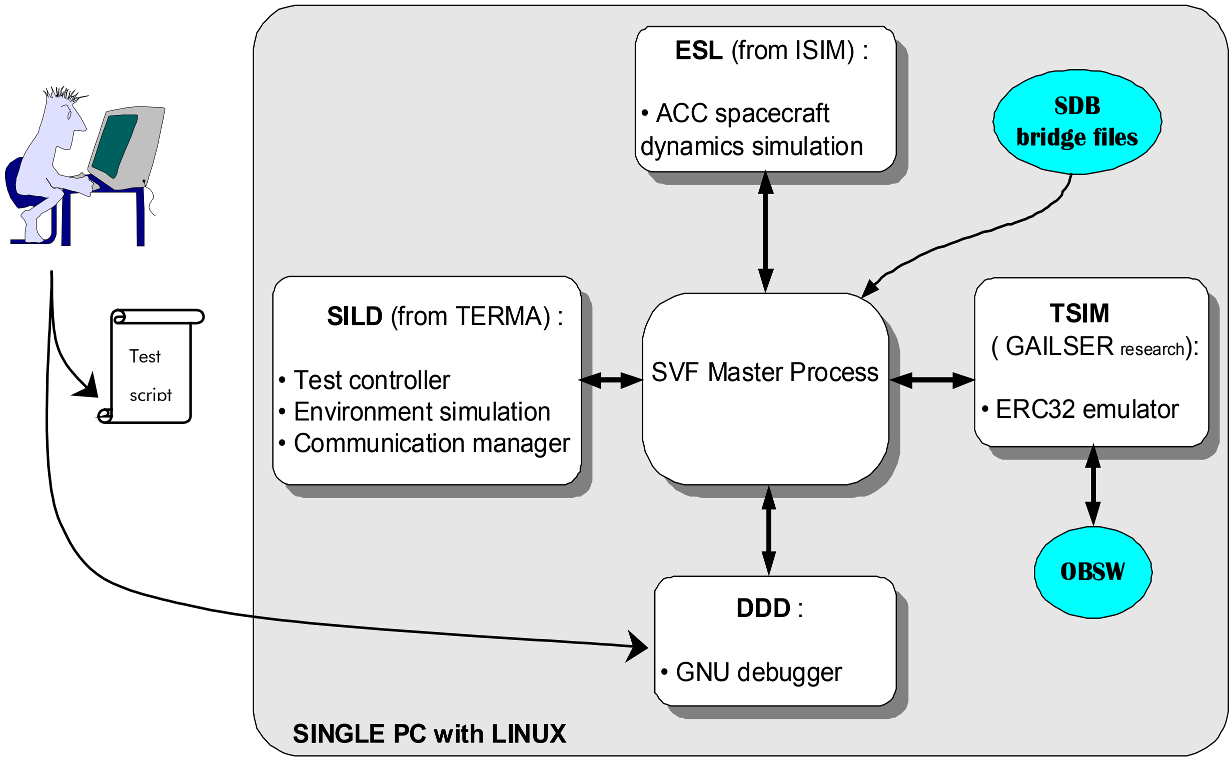


Figure 6.3.4-7 ACC/CDMU SVF Architecture

The SVF will run on one Single PC (powerful 3MHz bi-processor with Linux) equipped with full SVF software and tools, printers (Black & White and Colour) and networking capability.

The major SVF SW components are described here after:

– SILD

Test script input language as well as environment simulation programming language. Note that this language has already been used by the ISVV team and ESOC on previous projects (e.g. ROSETTA, ENVISAT).

– ESL

Simulation language, used for the spacecraft dynamics and ACC subsystems simulation. It is developed by ISIM/Salford University for ESA.

– TSIM

ERC32 chipset software emulator from Gaisler Research. It allows the use of real OBSW compiled for ERC32 processors.

– DDD

Data Display Debugger, based on GNU debugger GDB. Graphical User Interface to trace and breakpoint OBSW real-time source code execution, examine/assign/display any OBSW internal data.

– <u>SVF Master Process</u>

  SILD process designed to manage the different dialogs from the SVF components (synchronisation, data transfers, time stamping) and replies to the user interactive inputs.

– <u>External interfaces</u>

  Test script, interactive inputs, SDB bridge files, OBSW file.

6.3.4.5.3 SVF for the Star Tracker OBSW

Initially, the SVF for the Star Tracker OBSW was planned to be part of the contract with TERMA and thus based on the same architecture as the ACC/CDMU SVF described previously.

However, in order to develop a representative pure software simulator, information related to STR HW design (mainly interface with the SW) and performance were to be disclosed to the SVF contractor. As TERMA (SVF contractor) is a direct competitor of Galileo Avionica (STR supplier), GA did not authorise ALCATEL SPACE to disclose the needed STR information/documentation. As a consequence, it was decided to remove the development of the STR SVF from TERMA Statement Of Work, and investigate the feasibility to get adequate STR SW test facility directly from GA.

Finally, the retained architecture for the STR SVF is as follows:

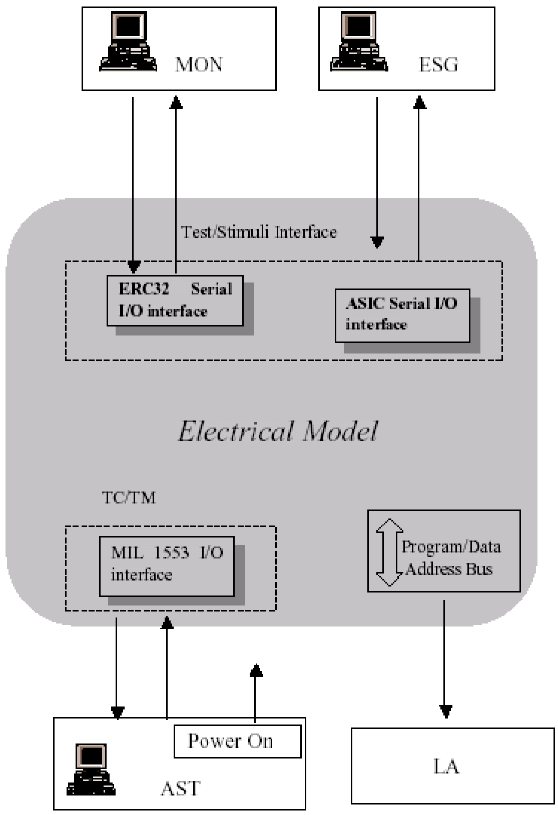


Figure 6.3.4-8 STR SVF Architecture

This architecture is based on the use of:

- **One Star Tracker Electrical Model**: The Electrical Model is constituted of a standard 19 inch rack containing the digital electronics representative of the digital section of the STR flight unit. In particular, the same microprocessor (ERC32), ASIC and 1553-B interface are implemented in this model. This model can be therefore used to run the STR SW on the real target and to perform SW verification as well as integration tests of the STR with the AOCS. It is possible to stimulate the EM with a stream of data simulating the AD converter output, so that the data processing and corresponding pattern recognition and attitude measurement algorithms can be verified.
- **One "light" Unit Checkout Equipment (UCE)**: The main components of this "light" UCE being:
  - **One Electrical Stimuli Generator (ESG):** The main scope of the ESG is the generation of an electrical signal reproducing the digitised video output of the STR detector in a simulated operational environment, for functional testing purposes. This signal is sent as input to the STR through a dedicated connector that directly interfaces with the ASIC of STR. This signal reproduces the video signal immediately after the A/D conversion at the end of the analogue chain, corresponding to the image produced on the CCD (pixel by pixel) in different conditions of celestial sphere pointing, simulating the effect of real sky.
  - **One ASTR unit Tester (AST):** The AST SW is the control and data handling SW of the STR UCE dedicated to STR commanding via 1553 bus, TM acquisition and monitoring and to perform dedicated procedures for test and Check-out. The AST is thus used to drive all test operations and for the verification of the external interface. Specially, it includes the following functionality:
    - Manage the communications with the STR
    - Record all exchanged data and messages in log file(s)
    - Verify the communication protocol according to 1553 standard.
    - Send TCs to STR and receive TMs from STR
    - Allow to command all STR operating modes and verify current operating mode, current health check status and current TC acceptance/execution by STR.
- **One Monitor (MON)**: The MON (SUN work station with debugger GDB linked to MON_SW on STR via serial line) is to be used whenever it is not possible to inspect data not exposed to external interface or to simulate non-nominal behaviour. This resource allows to set breakpoints and to check and modify SW variables.
- **One Logic Analyser (LA)**: The LA (Logic Analyser) is to be used for verifying the accesses of single chip microprocessor to RAM, PROM and EEPROM address spaces. Furthermore, it is to be used, if necessary, for checking digital signals from and to the STR. Note that for SVF/ISVV purpose, the use of this LA is still to be confirmed.

6.3.4.6 Herschel/Planck System Database use in OBSW development process

In order to be compliant with ESA requirements about the HPSDB to be the only repository for all the data needed by the different users (engineering, OBSW, AIT, flight operations, …) and therefore to ensure their consistency, the baseline consists in using directly the Bridge Files generated from the HPSDB in the final building and validation process of any OBSW.

The selected medium between HPSDB and OBSW (known as "OBSW-Bridge-Files") is expressed in XML format according to dedicated XML schema. It allows import/export operations of the complete HPSDB contents (including the boxes hierarchical structure) or of any of HPSDB box.

HPSDB-OBSW Bridge Files will be the unique data interface, used as a bi-directional medium, between HPSDB and OBSW. HPSDB facilities provide tools for:

- Generation of OBSW-Bridge-Files from the HPSDB.
- Input of data defined in OBSW-Bridge-Files into HPSDB.

To avoid any discrepancy between HPSDB stored data and OBSW code, the OBSW-Bridge-Files are part of OBSW Interface Control Document and the final OBSW code is build using automated tools from data present in OBSW-Bridge-Files.

For automated OBSW building purpose, the HPSDB stored items are identified by an OBSW dedicated ID (known as "mnemonic") that is also used in OBSW source files. For HPSDB-OBSW interface concern, mnemonic is an alias of the HPSDB identifier defined according to Naming Convention.

From OBSW point of view, the following categories can be distinguished among data present in OBSW-Bridge-Files:

- **IN/OUT** data: These data reflect high level requirement (such as packet structure or values for packet Type and Subtype defined in PS-ICD) to OBSW. Modification of their value may have a significant impact on OBSW and in other parts of spacecraft environment. Link between such data and the OBSW code (by means of mnemonic and automated tool for OBSW building) is not required.
- **OUT** data: These data are defined by OBSW development team (their value reflect the implementation retained in response to OBSW specification) and are present in HPSDB for use during the spacecraft validation and operations. Calibration curves or value of identifiers for on-board functions (as parameters of operational significance) are typical example of such data. A mnemonic is attached to these data, since they are OBSW development output, it is not required to use them for OBSW code building.

  It is supposed that other parts of spacecraft environment (typically validation and operation) are flexible to modification of these data.
- **IN** data: These data are identified by a mnemonic in OBSW-Bridge-Files and their value is part of the OBSW detailed specification. The automated tool for OBSW code building shall take into account the value defined in OBSW-Bridge-Files for these data. The definition of default HouseKeeping packets or Spacecraft Data Bus Profile are typical example of such data.

  The OBSW validation shall demonstrate robustness (or show its limitation that shall be specifically pointed out) against modification of these data.
- **INFO** data: These data do not affect the OBSW code.

This approach increases OBSW flexibility and adaptability to functional parameters definition for which refinement can occur rather late in the project (typically after completion of AIT phase). Such parameters will be part of the OBSW-Bridge-Files "IN data" category. It applies in particular to the definition of:

- Data-Pool contents and association with Parameter-ID
- Default (i.e.: EEPROM stored) HK TM content
- FDIR threshold and monitored parameters identification (Default contents for Monitoring and Event/Action tables)
- Default definition of Spacecraft Data Bus Profiles
- Thermal lines configuration and thresholds
- AOCS adjustment parameters of control laws
- AOCS equipment calibration parameters
- …

Note that the same automatic mechanism must also be used to configure the OBSW validation tools (Benches, …).

OBSW development process shall not be dependent on this refinement but shall be capable to deliver a correct configured release on request in a short delay. This allows:

- To increase OBSW quality and reliability, e.g. avoiding human error while taking into account modification of HPSDB values.
- To minimise the impacts of functional parameters definition refinement.
- To decrease time to build and validate a new version of OBSW due to the only modification of HPSDB. Once the automatic mechanism is itself validated, only a small subset of validation tests to check the correct "injection" of the values from the HPSDB and to check correct behaviour of the OBSW are required (mainly initialisation and performance/robustness tests).
- To ease OBSW maintenance, as e.g. knowledge about OBSW Design is not necessary as dispatching of modification is automatically performed.
- To ease configuration management and validation for CDMU OBSW, as Herschel and Planck CDMU OBSW shall only differ by their respective configuration extracted from HPSDB. Indeed, only one set of OBSW Core source files (generic) is necessary for both satellites, and is to be validated only once. Then, a subset of specific validation test is needed to complete the verification process.
- To ease ACC OBSW development as AOCS functional parameters to be taken into account are numerous and are subject to several refinements.

Nevertheless, to prevent any OBSW development to be disturbed by numerous modifications of the HPSDB contents that could impact the OBSW, it is acceptable to use apart configuration files during OBSW development and validation phases.

Moreover, in order to ensure the consistency/coherency of these OBSW databases content, avoiding e.g. a big gap between the values of the data inside the OBSW databases and the HPSDB, it is requested to any subsystem contractor (respectively ACMS and CDMS) to approve the content of these OBSW databases used by their respective subcontractors to validate and qualify their OBSW.

6.3.4.7 Independent Software Verification and Validation

The Independent Software Verification and Validation (ISVV) is a verification and validation process performed by an organisation independent from the supplier of the OBSW to be verified and/or validated. The ISVV team performs verification activities such as conducting reviews, inspections, testing, auditing…

ISVV activities include two parts, namely:

- Independent Software Verification
- Independent Software Validation.

These two activities are not obligatory performed for all the OBSW products, as depending on the degrees of criticality and/or reusability of each OBSW, only one or both processes are to be performed on the entire OBSW or only on part of it.

The objectives of the Independent Software Verification are mainly:

- to verify OBSW requirements against Herschel/Planck system functional requirements, including interface requirements
- to verify OBSW architectural and detailed design against OBSW Requirement and Interface Control Document

- to perform OBSW Code analysis against OBSW design, requirements and coding standards
- to perform run-time error detection.

The objectives of the Independent Software Validation are mainly:

- to check exhaustively that the OBSW behaviour is operationally correct regarding the operational modes of the satellite
- to validate exhaustively that the software capabilities are available in nominal and contingency situations
- to validate exhaustively the software performances with regard to worst case operational conditions.

In the frame of Herschel/Planck project, the following OBSW will be subject to a complete ISVV:

- CDMU SW
- ACC SW
- Start Tracker SW.

The associated list of critical functions (when relevant) to be especially verified is:

- Bootstrap
- Failure Detection Isolation and Recovery (FDIR)
- Survival Mode
- Memory Management
- Telecommand Management.

ISVV will nominally be performed in two steps for each OBSW:

- First ISVV on the OBSW release delivered by the supplier after its respective Qualification Review
- Final ISVV on the final release of the OBSW (if different from the previous one).

Moreover, once delivered to ISVV contractor, OBSW updates resulting from the findings of the ISVV team or the Avionics validation activities, or from the normal progress of the OBSW development will also be subject to an ISVV.

The ISVV will be performed on the Software Validation Facility (SVF) delivered by ASP and installed at ISVV contractor's premises. The SVF is described in Chapter 6.3.4.5.

6.3.4.8 On-Board Control Procedures Generation and Validation

6.3.4.8.1 Responsibility for OBCP generation and validation:

The baseline is not to have any OBCP at launch time. The only identified deviation from this baseline is related to the implementation of the Instruments FDIR. Indeed, as the specification of these FDIR procedures is likely to be known very late in the development process, it was decided to use OBCP for that purpose.

Like any other in-flight functional OBCP that could be identified later on, it is considered that ASP are in charge of their specification, generation and validation. It is anyhow envisaged to make use of already foreseen ISVV activities on OBCP for that purpose when Software Validation Facility (SVF) capabilities allow it.

As far as other potential OBCP are concerned (e.g. for testing or monitoring purpose during AVM or AIT activities or even at ESOC) it is considered that the user of these OBCP is in charge of their specification, generation and validation.

6.3.4.8.2 Facility for OBCP generation and validation:

6.3.4.8.2.1 OBCP Generation and Debugging:

The OBCP are generated on the OBCP Development Environment (OBCP-DE) that is developed and delivered by the CDMU ASW contractor (namely Space System Finland). Moreover, this OBCP-DE allows to perform preliminary testing/debugging of the generated OBCP in a native environment.

The OBCP-DE is only a SW tool. It has to be installed on the SUN SPARC Workstation with Solaris 8.0.

Four OBCP-DE will be delivered by SSF and distributed to ESA/ASP/ALS/CAPTEC(ISVV contractor). However, as it is a SW tool not linked to any license authorisation, there is in fact no limitation on the number of available copies.

The OBCP-DE is composed of:

- an On-Board Control Language (OCL) compiler to generate the OBCP code from OBCP source ascii files and HPSDB bridge files. Three output formats are currently foreseen for the OBCP token code:
  - Binary: to be used as input for the OBCP test tool
  - ASCII for export to SCOS2000
  - TC for validation and uplink.
- An OBCP Test tool, itself composed of:
- An OCL interpreter (identical to the one in the CDMU ASW)
- A command-line User interface that provides testing/debugging functionality (e.g. stepping execution, breakpoints setting, display of memory content and variable/parameter values, OBCP token code coverage analysis)
- A Run-Time Library (RTL) to interface with the CDMU ASW functions via the OCL interpreter.

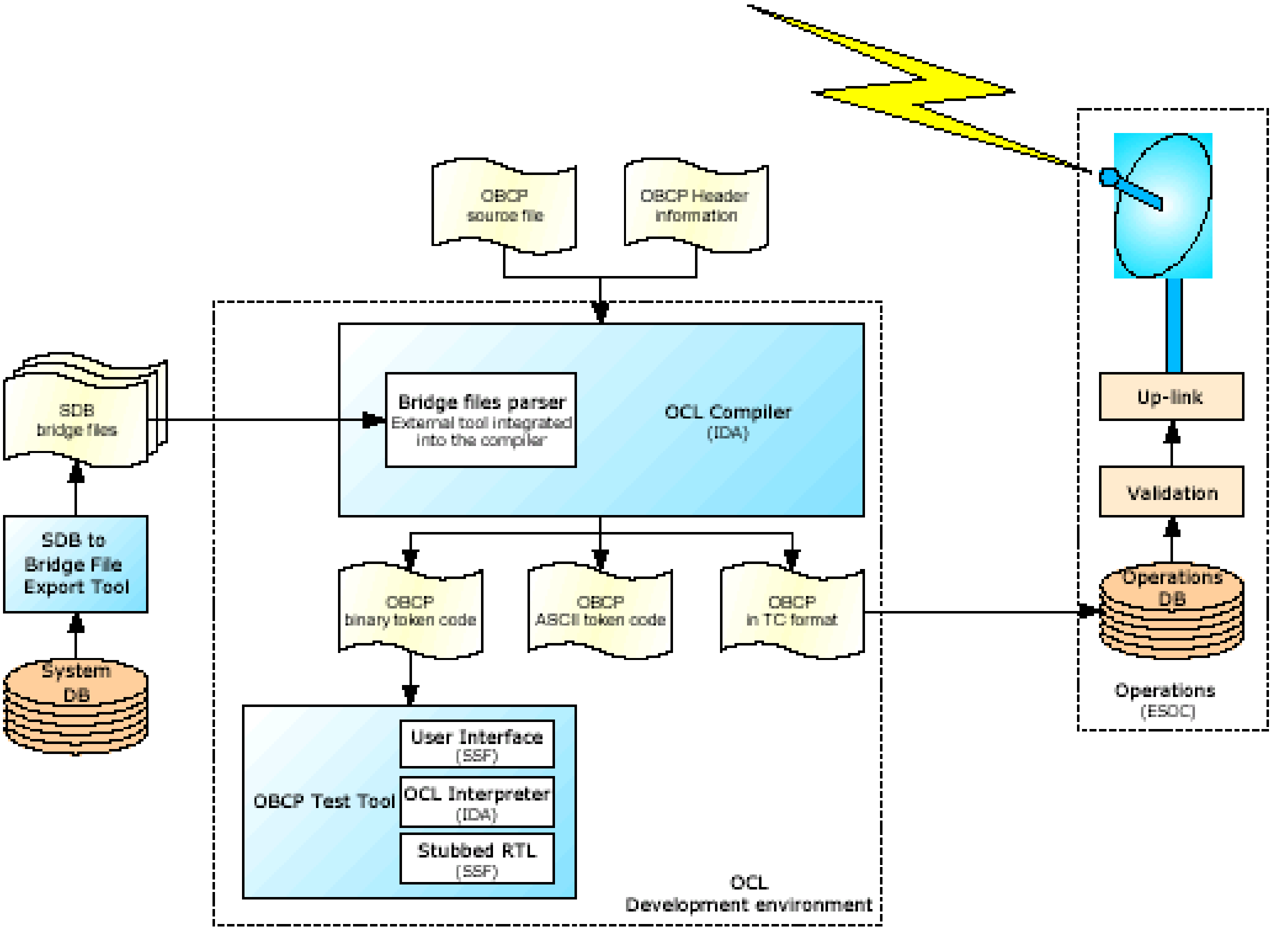


Figure 6.3.4-9 OBCP Development Environment Overview

6.3.4.8.2.2 OBCP Functional Validation:

Once an OBCP is generated and pre-validated on the OBCP-DE, it has to be formally validated with the CDMS OBSW.

As stated previously, any in-flight functional OBCP will be validated as far as possible on the SVF by the ISVV contractor. If needed, complementary tests could be run on the AVM or during AIT phase if a more representative environment is requested.

As far as the other OBCP are concerned, they will be validated by their user on its own facility running the CDMS OBSW (e.g. AVM/EM/FM/SVF/other simulators). It is recalled that OBCP loading and commanding is simply done by TC.

6.3.4.8.3 OBCP generation planning:

The following milestones are considered for the OBCP generation planning:

- The OBCP-DE will be delivered by SSF with the CDMU ASW V2, currently foreseen in end 12/2004. This means that the generation and validation of the OBCP can not start before 01/2005. Of course, this does not prevent from starting the specification of the OBCP. E.g. specification of the in-flight OBCP to be used for Instruments FDIR will be finalised by ASP in collaboration with ESA & Instruments during Data Management Working Group meetings.
- Start of IST on the AVM is currently foreseen in mid 05/2005. This date is considered as the due date for the availability of validated in-flight OBCP.

6.3.5 ACMS Design

6.3.5.1 Main system "Pointing" Requirements

Satellites shall be able to be pointed according to the requirements given in System Requirement Specification (SRS). Three main groups of requirements related to pointing are identified.

6.3.5.1.1 Functional pointing requirements

The satellite attitude control requirements are expressed in section 6.9 of SRS. Main function of ACMS is to point the instruments (SMAC-050) according to science observation modes defined in annex 1 (Herschel pointing modes) and annex 2 (Planck Scanning Strategy) to SRS.

One of the key requirement for ACMS design is SMAC-015 which asks ACMS to be able to perform first orbit correction manoeuvre 6 hours after launch. The orbit correction performance requirement (SPER-045) is very stringent and current design of ACMS cannot fulfil it: a deviation is issued to this requirement.

6.3.5.1.2 Performance pointing requirements

The Herschel and Planck instrument LOS shall be pointed according to performance required in MOOF-030 & MOOF-040 (SRPE) for Herschel and MOOF-045 for Planck.

These system requirements have been allocated to the different modules as explained in details in “Herschel and Planck pointing budget module” allocation reference H-P-1-ASPI-BT-0176.

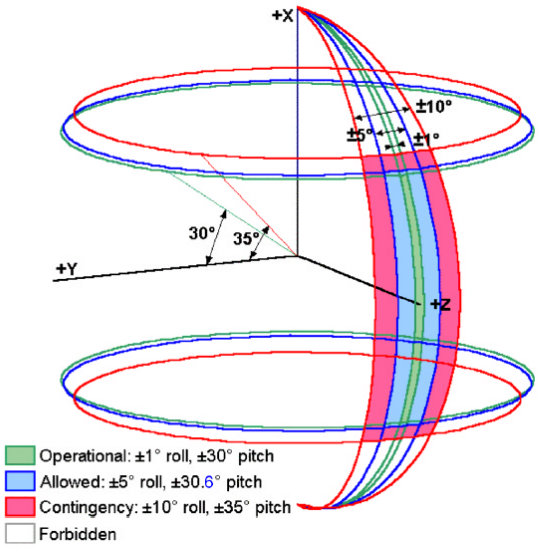
To fulfill these requirements and to satisfy the communality requirement, the design uses a star tracker as main sensor. In order to minimise the cross term effect of around LOS star sensor performance on LOS performance, Star tracker boresights are accommodated parallel (Planck) or antiparallel (Herschel) to the instrument line of sight. Then, in order to minimise thermo elastic effects, several iterations have been necessary to accommodate the star tracker on Herschel. Finally, it is now put on the STR assembly platform which is directly attached to the CVV.

Based on the current ACMS design performances and mechanical/thermal analysis, the obtained system pointing performances are given in “Herschel Planck system pointing budget for CDR” reference H-P-1-ASP-BT-0813. Major non compliance is Herschel SRPE for which a Request For Deviation has been raised.

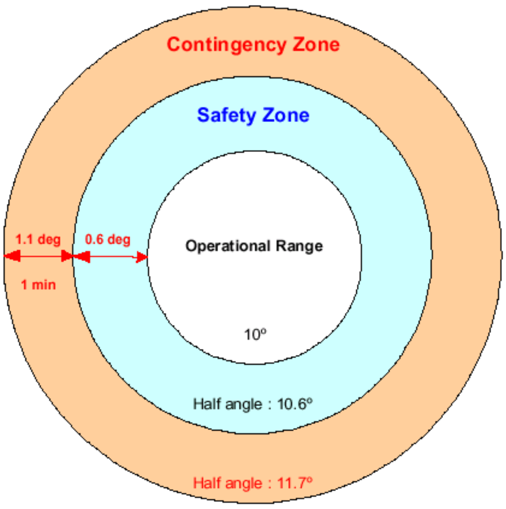
Herschel and Planck missions also require the spacecraft to perform several manoeuvres. Associated slew requirement are given in MOOF 70 to 125. The more critical Planck angular momentum slew manoeuvre requirement (MOOF-110) is also assessed in H-P-ASP-BT-5010.

6.3.5.1.3 *FDIR requirements*

The ACMS shall prevent safe attitude that could endanger or degrade instrument performances (SMAC-065). The ACMS will be compatible with the operational attitude domain required in MISS-110 (Herschel) and MISS-120 (Planck). In addition, two zones have been defined at system level: the allowed zone also called safety zone which is a zone around the operational to allow attitude control clearance (e.g. necessary for unit reconfiguration) and the contingency zone which a zone around the allowed zone. It is allowed to go in that zone during a limited duration only in case of contingency (PM reconfiguration). The allowed and contingency zone are specified in SVM requirement specification (requirements ACP-010-H & ACP-015-H for Herschel and requirements ACP-020-P & ACP-022-P for Planck). At HPLM level, these requirements are introduced in the HSS design to ensure adequate protection of the PLM.



Herschel Sun pointing zones



Planck Sun pointing zones

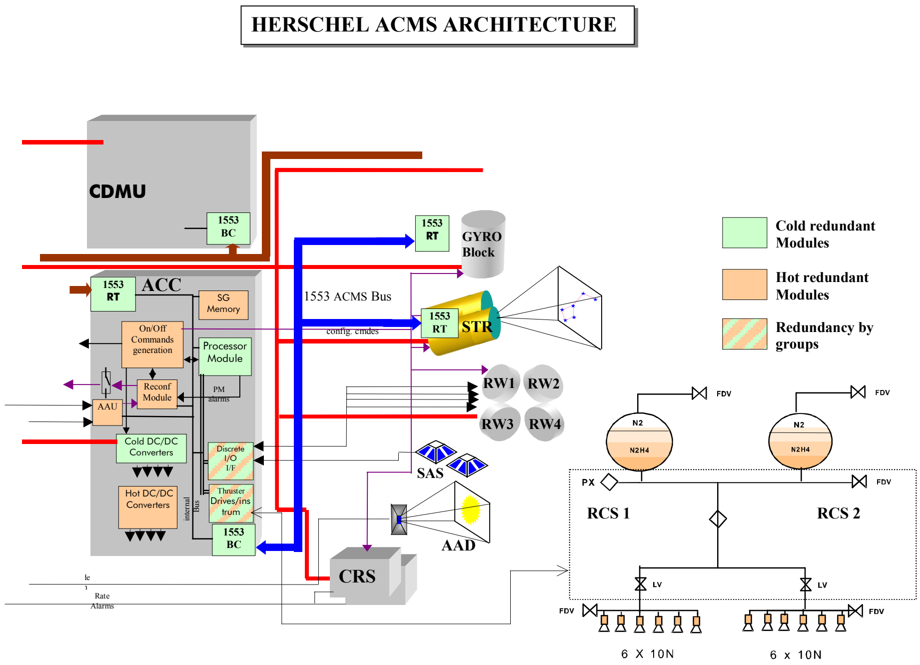
The other main fault management requirements which drive the ACMS design are MOFM-050 (no single failure in the on board protection system shall cause the spacecraft to go into survival mode) and SPER-115 (no single point failure). The design which copes with these requirements is such that there is independence between sensor/actuator of the nominal modes, sensor/actuator of the survival modes and fault detection sensor(exception is the ARAD design for which the deviation reference H-P-4-D-RFD-001 has been submitted and accepted).

6.3.5.2 Architecture

The following ACMS architecture has been designed in order to fulfil the Herschel and Planck pointing requirements. Herschel and Planck share the same computer (ACC), Star Tracker Hardware, Coarse Rate Sensor (CRS) equipment, Sun Acquisition Sensor (SAS) equipment, Attitude Anomaly Detector (AAD) principle.

This section only draws the high level architecture of the ACMS. The details (modes, algorithm…) of the ACMS design are given in "ACMS design report" reference H-P-4-DS-TN-011.

6.3.5.2.1 Herschel Architecture



Herschel architecture

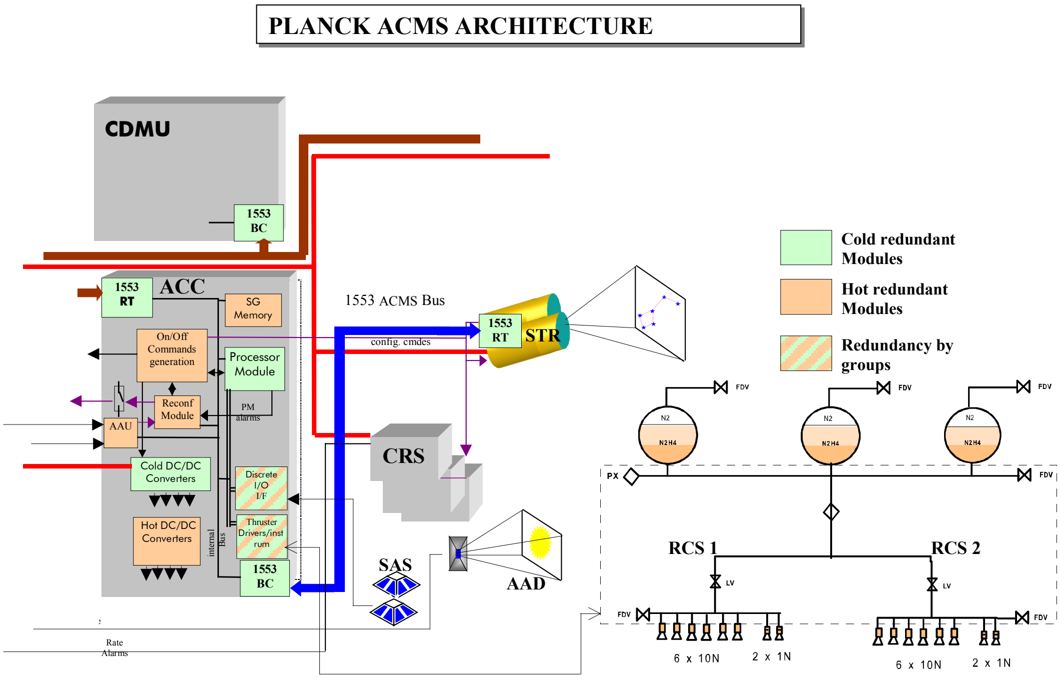
RCS has been depicted for information

The associated equipment list is:

COMPONENT	NUMBER	SUPPLIER	ELECTRICAL I/F	COMMENT
AAD	2	TNO/TPD	Analog Cross strapped to ARAD	Internally redundant
CRS	2	LABEN	Analog 2 are cross strapped to ARAD Powered and activated (ON/OFF) by CDMU	3 axis information for each component Same component as Planck
SAS	4	TNO/TPD	Analog Cross strapped to AIU Located on –Z and + Z sc faces	Same component as Planck (internally redundant)
STR	2	GALILEO AVIONICA	MIL 1553B	Cold redundancy Same HW as Planck
GYR	4	NORTHROP GRUMMAN	MIL 1553B	4 sensors in hot redundancy, redundant electronic
RWS	4	TELDIX	Analog/single ended Cross strapped to AIU	
ACC	1	SES	See dedicated section	
THR 20 N	12	ASTRIUM	See RCS section	

Herschel equipment list and I/F

6.3.5.2.2 Planck Architecture



Planck architecture

The associated equipment list is:

COMPONENT	NUMBER	REDUNDANCY	ELECTRICAL I/F	COMMENT
AAD	2	TNO/TPD	Analog Cross strapped to ARAD	Internally redundant
CRS	3	LABEN	Analog 2 are cross strapped to ARAD Powered and activated (ON/OFF) by CDMU	Same component as Herschel
SAS	4	TNO/TPD	Analog Cross strapped to AIU Located on –X and +Y sc faces	Same component as Herschel (internally redundant)
STR	2	GALILEO AVIONICA	MIL 1553B	Same HW as Herschel Cold redundancy
ACC	1	SES	See dedicated section	
THR 1N	4	ASTRIUM	See RCS section	
THR 20 N	12	ASTRIUM	See RCS section	

Planck equipment list and I/F

NOTE: FOG (Fiber Optic Gyro) is connected to ACC via MIL1553. The FOG is a passenger and is not used in Planck ACMS control algorithm.

6.3.5.3 ACMS external interfaces

The ACMS has interfaces with CDMS and RCS. CDMS and ACMS are communicated via the satellite data management bus. Interface with RCS is done thanks to the THR board of the ACC.

6.3.5.4 ACMS Modes

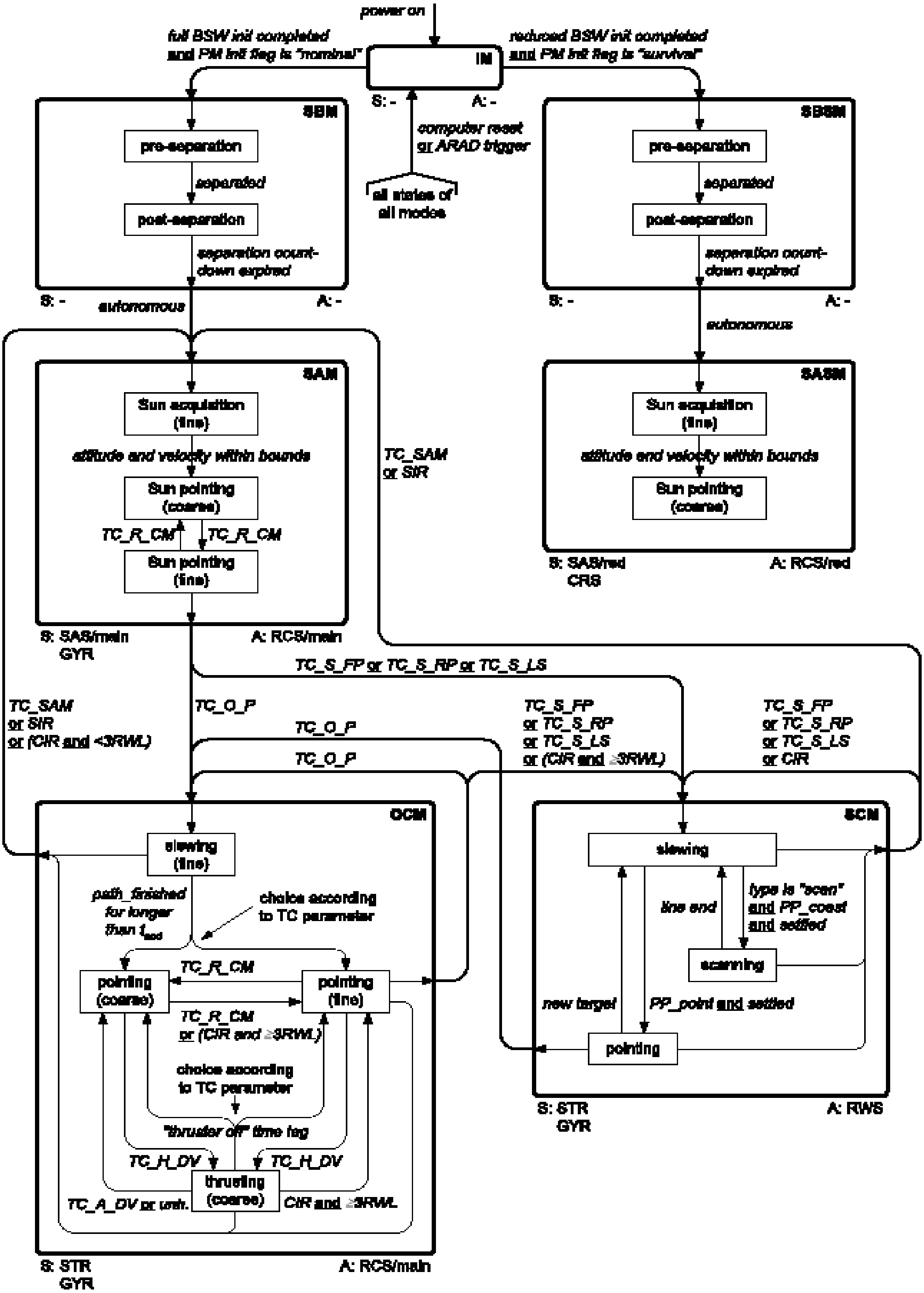
Under nominal conditions, the ACMS operates in the so-called nominal modes. In case of level 3b or 4 failure, the ACMS switch to Survival mode.

6.3.5.4.1 Herschel modes

Herschel has 4 nominal modes (Stand By, Sun Acquisition Mode, Science Mode and Orbit Correction Mode) and 2 survival modes (Stand By and Sun Acquisition Survival Mode).

- Standby Mode (SBM): it provides basic communication with the CDMU and monitors the separation status. It initialises the ACMS for SAM and handles the twenty seconds separation delay.
- Sun Acquisition mode (SAM): The Sun Acquisition Mode is the mode that the spacecraft uses to acquire the Sun and to maintain an anti-Sun pointing for the spacecraft Z axis.
- Science Mode (SCM): Science Mode (SCM) provides the control functions needed to perform science operations (fine pointing, raster pointing, line scanning, solar system object tracking, small attitude adjustments (peak-up))
- Orbit Correction Mode (OCM): The Orbit Control Mode is the ACMS mode that the spacecraft uses to perform all the foreseen delta-V manoeuvres, namely dispersion correction manoeuvres (after separation from the launcher and during the transfer to L2), injection into L2 orbit manoeuvre, and periodic station keeping manoeuvres at L2.
- Standby Survival Mode (SBSM): has the same role as SBM but initialise the SASM.
- Sun Acquisition Survival Mode (SASM): is the ACMS recovery mode in case of level 3b or 4 failure putting the Satellite Z axis towards the sun.

The Herschel mode transition logic is:


power on
full BSW init completed
and PM init flag is "nominal"
IN
reduced BSW init completed
and PM init flag is "survival"
S: -
A: -
computer reset
or ARAD trigger
all states of
all modes
SBM
pre-separation
separated
post-separation
separation count-
down expired
S: -
A: -
autonomous
SBSM
pre-separation
separated
post-separation
separation count-
down expired
S: -
A: -
autonomous
SAM
Sun acquisition
(fine)
attitude and velocity within bounds
Sun pointing
(coarse)
TC_R_CM
TC_R_CM
Sun pointing
(fine)
S: SAS/main
GYR
A: RCS/main
TC_SAM
or SIR
SASM
Sun acquisition
(fine)
attitude and velocity within bounds
Sun pointing
(coarse)
S: SAS/red
CRS
A: RCS/red
TC_S_FP or TC_S_RP or TC_S_LS
TC_SAM
or SIR
or (CIR and <3RWL)
TC_O_P
TC_O_P
TC_O_P
TC_S_FP
or TC_S_RP
or TC_S_LS
or (CIR and ≥3RWL)
TC_S_FP
or TC_S_RP
or TC_S_LS
or CIR
OCM
slewing
(fine)
path_finished
for longer
than t_{end}
choice according
to TC parameter
pointing
(coarse)
TC_R_CM
pointing
(fine)
TC_R_CM
or (CIR and ≥3RWL)
choice according
to TC parameter
"thruster off" time tag
TC_H_DV
TC_H_DV
thrusting
(coarse)
TC_A_DV or unh.
CIR and ≥3RWL
S: STR
GYR
A: RCS/main
SCM
slewing
line end
type is "scan"
and PP_coast
and settled
scanning
new target
PP_point and settled
pointing
S: STR
GYR
A: RWS

In addition to the nominal mode necessary for nominal scientific operations and orbit aspects, non nominal transitions occurs when ACMS receives external alarms or when ARAD triggers. As required in SOFDIR,

- In Case of reconfiguration of the CDMU computer (signal CIR raised), the ACMS shall put the Spacecraft in an earth pointing attitude permitting to have the optimum downlink rate. So if ACMS is in Science mode when CIR is raised or in OCM, ACMS will go to a new Science Mode with a predefined (earth pointing) target if the number of operational wheels allows it (more than 3). If ACMS is in OCM and number of wheel is not sufficient to go to SCM, it will go to SAM. Finally, ACMS will stay in SAM if already in SAM.

- In case of reconfiguration of the system (signal SIR raised), the ACMS will go from OCM or SCM to SAM.

The following table presents the nominal sensor/actuator configuration per mode and the possible/allowed redundancy. Sensors used for ARAD are also given:

Mode	ACMS units for control	Redundant sensor/actuator	Sensor for ARAD	Comments
Sun Acquisition mode (SAM)	SAS +Z - A SAS –Z - A GYR - ABC RCS - A 1553bus - 1	 GYR DBC/ADC/ABD 1553bus - 2	AAD CRS – A	No reconfiguration of RCS
Science Mode (SCM)	STR - A GYR - ABC RWL - 1234 1553bus - 1	STR - B GYR DBC/ADC/ABD RWL – 123/234/124/124 1553bus - 2	AAD CRS – A	
Orbit correction Mode (OCM)	STR - A GYR – ABC RCS – A 1553bus - 1	STR – B GYR DBC/ADC/ABD 1553bus - 2	AAD CRS – A	No reconfiguration of RCS
Sun Acquisition Survival mode (SASM)	CRS – B SAS +Z – B SAS –Z – B RCS - B	Not applicable	Not applicable	

6.3.5.4.2 *Planck modes*

Planck nominal modes are Standby mode, Sun Acquisition mode (SAM), Angular Momentum Control Mode (HCM), Science Mode (SCM) and Orbit Correction Mode (OCM). As per Herschel, a Survival standby (SBSM) and Sun Acquisition (SASM) Survival Mode are present:

- Sun Acquisition mode (SAM): The Sun Acquisition Mode is the mode that the spacecraft uses to acquire the Sun and to maintain an anti-Sun pointing for the spacecraft X axis. The attitude of the spacecraft in SAM is Sun pointing, with nominal spin rate and small nutation.

- Science Mode (SCM): The Science Mode is the ACMS mode that the spacecraft uses to gather the science data by the payload. It is a passive mode (no actuation).

- Angular momentum Control Mode (HCM): The Angular Momentum Control Mode is the ACMS mode that the spacecraft uses to perform the slew manoeuvres within the operational domain, aiming to acquire the different pointing needed for the science mode.

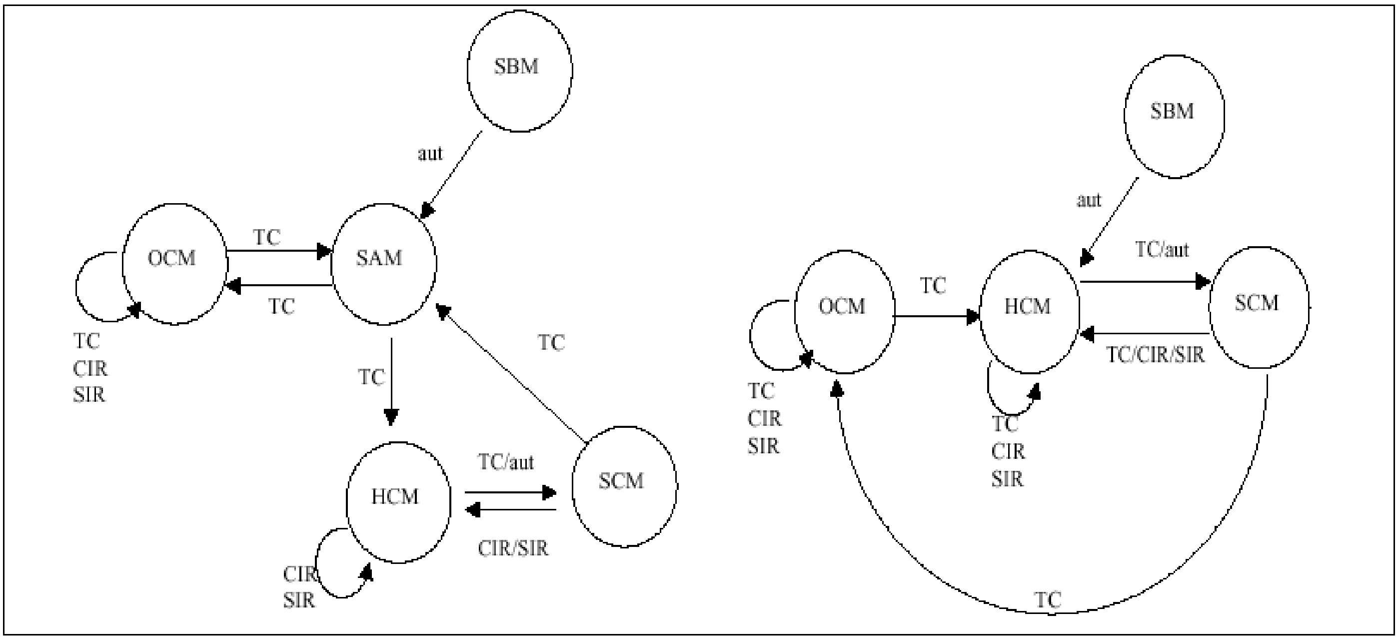
- Orbit Correction Mode (OCM): The Orbit Control Mode is the ACMS mode that the spacecraft uses to perform all the foreseen delta-V manoeuvres, namely dispersion correction manoeuvres (after separation from the launcher and during the transfer to L2), injection into L2 orbit manoeuvre, and periodic station keeping manoeuvres at L2.
- Survival mode: is the ACMS recovery mode in case of level 3b or 4 failure.

The mode transition is more complex than Herschel. The Planck mode transition logic depends on whether the ARAD thresholds for the CRS Y and Z channels (transversal angular velocity) are high or low. Indeed, Planck has two different sets of values (to be modified by ground and implying desactivation of RM) for the ARAD thresholds, depending on the phase of the mission. Planck high threshold phase and respectively low threshold phase are the phases where the transversal angular velocity thresholds are set to a high value and to a low value.

The idea behind the different thresholds is to limit the excursion out of the contingency zone in case of a thruster (1N or 20 N) failure. Detailed rationales are given in ACMS FDIR analysis reference H-P-4-DS-TN-010. HCM and SCM have to have a low threshold or otherwise may not recover from a worst case 1N thruster left-open failure at the edges of the operational domain. SAM (20 N actuator) has to have a high threshold, or otherwise would trigger Survival Mode in nominal operational conditions. OCM may have either high or low thresholds for the delta-V manoeuvres, depending on the typical mode of origin and destination.

Depending on whether the threshold is "low" or "high", some mode transitions are forbidden or allowed. For instance, it is not possible to go directly from SCM (low threshold) to SAM (high threshold) since Kinematics of SAM are not compatible with low threshold and automatically a transition to SASM will occur if the transition is allowed.

The transitions allowed in both high and low thresholding phases are:



Mode transition for Planck "high" threshold phase (left) and "low" threshold phase (right).

The ACMS handles all possible non nominal cases as follows:

- In case of Satellite in reconfiguration (SIR signal raised by the CDMU):
    - When the Planck ACMS is in OCM, the ACMS commands an auto-transition to OCM and initiates a manoeuvre with null target delta-V and pointing towards an anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir (refreshed by ground and nominally coïncident with Sun) stored in the SGM. The ARAD threshold value does not need to change.

  - When the Planck ACMS is in HCM or SCM, the ACMS commands a transition to HCM and initiates a slew manoeuvre towards a anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir stored in the SGM.
  - When the Planck ACMS is in SAM, the ACMS ignores the SIR.
- In case of CDMU is in reconfiguration (CIR signal raised by the CDMU): same philosophy as per SIR management with Hcir target.
- In case of level 3a failure, the ASW shall first detect the difference with a level 4 anomaly. This is done by reading the flag PM selection relay. If it says "nominal", this means a reset of the computer (and not a reconfiguration to the other PM). Then, the action of the ACMS is depending of the high or low threshold current selection. It then reads the associated RM threshold flag. If high, a transition to SAM is commanded and if low, HCM is entered with Hsir target.

The following table presents the nominal sensor/actuator configuration per mode and the possible/allowed redundancy. Sensors used for ARAD are also given:

Mode	ACMS units for control	Redundant sensor/actuator	Sensor for ARAD	Comments
Sun Acquisition mode (SAM)	SAS +Z - A SAS –Z - A CRS - A RCS - A 1553bus - 1	1553bus - 2	AAD CRS – B	No reconfiguration of RCS Reconfiguration of SAS under ground responsibility
Science Mode (SCM)	STR - A 1553bus - 1	STR - B 1553bus - 2	AAD CRS – B	
Angular Momentum Control Mode (HCM)	STR – A 1553bus – 1 RCS 1N - A		AAD CRS – B	No reconfiguration of RCS
Orbit correction Mode (OCM)	STR - A RCS 20 N – A 1553bus - 1	STR – B 1553bus - 2	AAD CRS – B	No reconfiguration of RCS
Sun Acquisition Survival mode (SASM)	CRS – C SAS +Z – B SAS –Z – B RCS 20 N – C	Not applicable	Not applicable	

6.3.5.5 Sensor/Actuator

The Herschel/Planck ACMS unit detailed design is presented in the following design reports:

UNIT	*SUPPLIER*	*DESIGN REPORT REFERENCE*
Star tracker	Galileo Avionica	H-P-4-GAF-RP-0002
Gyroscope	Northrop Grumman	899710
Sun Acquisition Sensor	TNO/TPD	H-P-4-TNO-RP-S004
Coarse Rate Sensor	LABEN	TL20107
Attitude Anomaly Detector	TNO/TPD	H-P-4-TNO-RP-A004
Reaction Wheel	Teldix	H-P-4-TX-RP-0001
Application Software	Terma	H-P-4-TASW-DS-0001

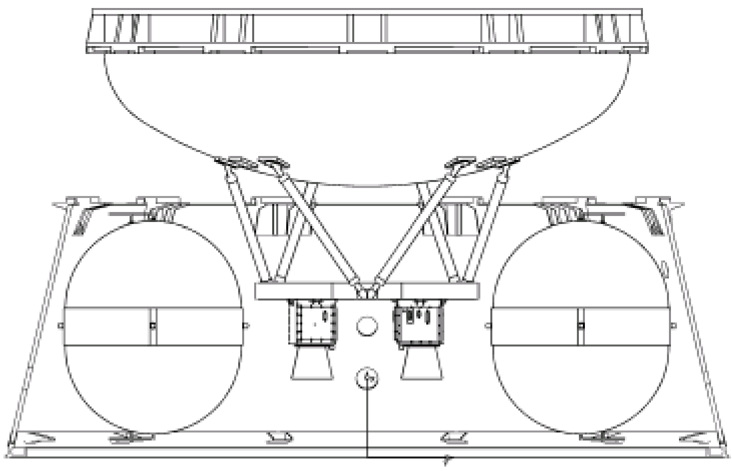
A short description of the unit and the associated performance requirements are presented in section 3.2.3 of ACMS design report.

The summary of the unit lay out and key performance is the following:

Star Tracker

It is a wide field of view optical star sensor unit performing 3-axis autonomous attitude determination. The hardware is common between Herschel and Planck. The software implements the interlacing function for Herschel and the Time Delay Integration (TDI) for Planck.

For Herschel, it is located on the STR assembly platform attached to the CVV. The maximum misalignment (including ground and orbital effects) between instrument and STR lines of sight is 0.4°. A fine control of the thermal gradient of the STR baseplate and of the gradient between the mounting feet is implemented by SVM thermal control.



Herschel Star Tracker Accommodation

The Herschel Star Tracker main performance are (taken form performance analysis reference H-P-4-GAF-RP-005):

Without interlacing

NEA (standstill)	0.6 arcsec (Pitch/Yaw)	6.5 arcsec (Roll)	68% confidence level
Bias	0.8 arcsec (Pitch/Yaw)	7.4 arcsec (Roll)	68% confidence level

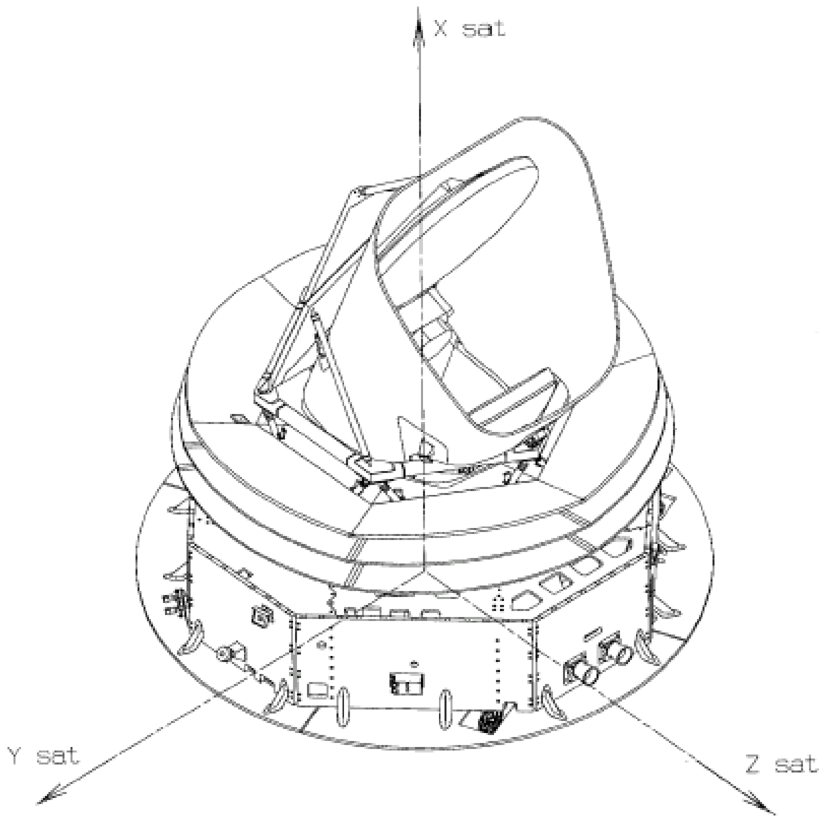
With interlacing (more than 18 stars)

NEA (standstill)	0.39 arcsec (Pitch/Yaw)	3.98 arcsec (Roll)	68% confidence level
Bias	0.56 arcsec (Pitch/Yaw)	3.7 arcsec (Roll)	68% confidence level

On Planck, the main performances are:

NEA (standstill)	2.3 arcsec (Pitch/Yaw)	23 arcsec (Roll)	68% confidence level
Bias	1.6 arcsec (Pitch/Yaw)	14 arcsec (Roll)	68% confidence level

The 2 cold redundant Planck star trackers are accommodated as presented in next figure. Boresight is in XZ plane and tilted of 5° so that to be parallel to telescope LOS. The maximum misalignment between telescope line of sight and STR boresight is 1.5°.



Planck Star Tracker Accommodation

The ASTR which is the basis for Herschel Planck STR will first fly on Messenger. There is no modification of hardware for Herschel/Planck but software modification (addition of interlacing and TDI).

Gyroscope

The gyroscope (Herschel IRU) is accommodated inside the SVM on a shear panel. 4 sensor heads (Hemispherical Resonator Gyros) are working in hot redundancy connected to 2 cold redundant electronics. The main performances are (taken from Herschel IRU Design report):

- Bias after 6 hours 0.2 deg/hr
- Angle random walk 0.00015 º/$\sqrt{hr}$
- Short term bias stability 0.0016 deg/hr 1hr
- Noise 0.014 arsec
- Scale factor 500 ppm
- Scale factor stability 0.01 over one month.

The SSIRU which is the basis of the Herschel IRU (mechanical modification done to withstand higher shock and sine levels) will fly on Deep impact and Messenger.

Reaction Wheels

The Herschel Wheel is an integrated electronic reaction wheel with a capacity of +/- 30 Nms, providing a maximum torque up to 20 Nms. A torque budget is presented in section 5.3 of Teldix budget report reference 15 175-742: the nominal motor torque is 0.235 Nm.

4 reaction wheels are accommodated in a skewed configuration allowing commanded torque in all directions. They are located on +Z/+Y SVM panel. The tilt angle is 70°.

This model of Teldix wheel is developed for a military German programme.

Sun Acquisition Sensors

On Herschel, two units are accommodated: 1 on +Z (internally redundant) and 1 on -Z face (internally redundant) of the spacecraft. Boresights are along respectively along +Z and -Z axis. It thus provides nearly a full coverage of the sky.

On Planck, two units internally redundant are accommodated: 1 on -X cone and 1 on +Y (slighlty tilted) face of the spacecraft.

Associated attitude accuracy is in the order of the degree (without albedo).

SAS have flown on several ESA missions.

Coarse Rate sensors

2 CRS are baselined on Herschel and 3 on Planck. They are located inside the SVM.

The performances are analysed in CRSA error budget reference TL19334: error is modelled linearly as a+b.t with:

- a < 0.04765 deg/s (value at 6°/s)
- b < 1.328.10-5 (deg/s)/h (value at 6°/s).

Unit is recurrent from Integral (with minor electronic tuning)

Attitude Anomaly detector

They are located on +Z face and +X faces respectively on Herschel and Planck. The FOV is 0.15° accurate.

AAD (with different FOV) have flown on different ESA mission as XMM.

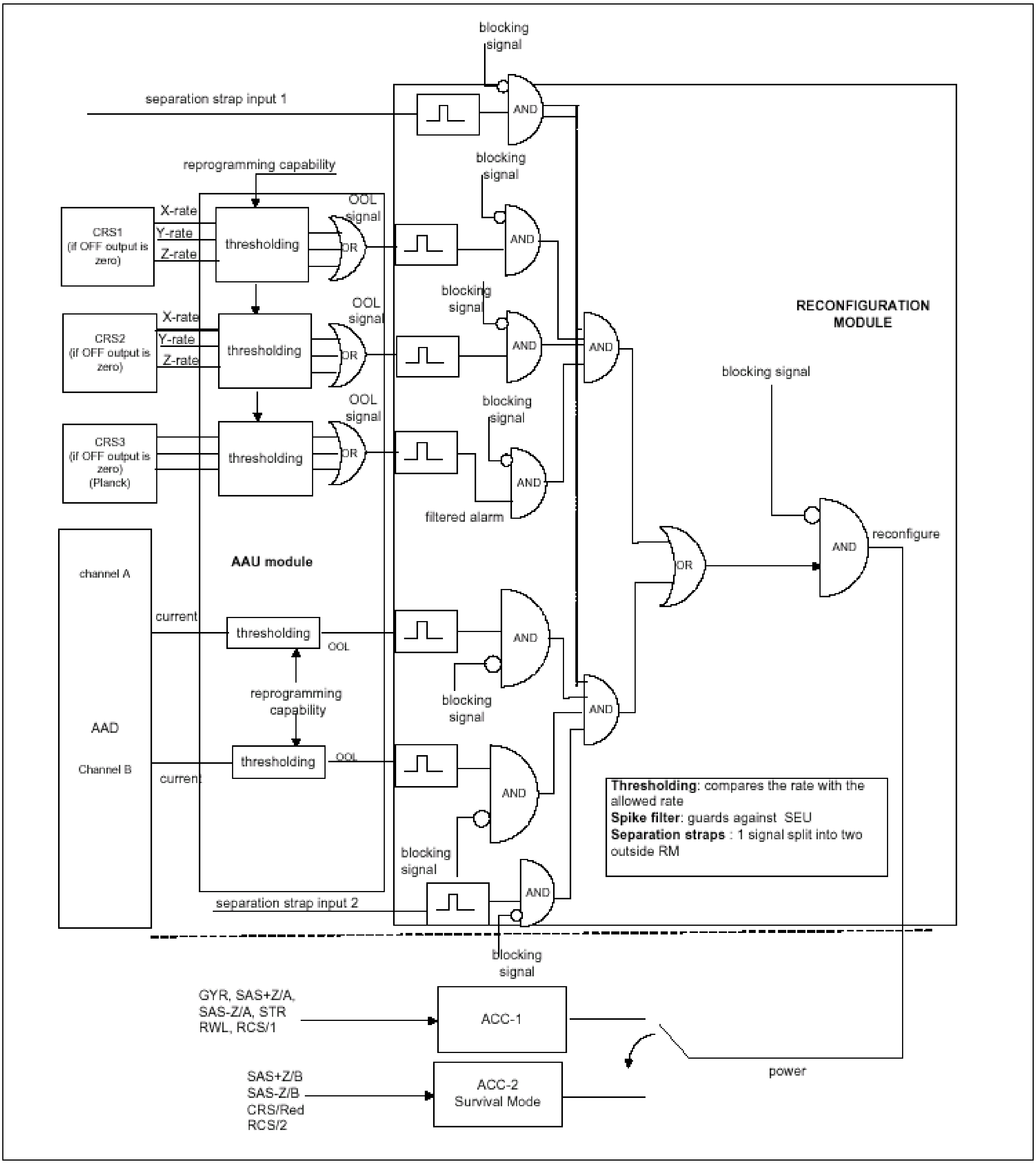
6.3.5.6 FDIR

The ACMS handles the five FDIR levels as defined in SOFDIR and the AFS/AFO FDIR modes.

The ACMS FDIR is presented in Alenia technical note "ACMS FDIR issues" reference H-P-4-TN-AI-0035. This note covers level 3 and 4 of FDIR. Other levels are addressed in ACMS FDIR analysis reference H-P-4-DS-TN-010.

In order to guarantee the compliance with the contingency zone requirements, a fully Hardware attitude and rate anomaly detection (ARAD) and recovery has been implemented as level 4. The idea is to sense any failure before the end of the allowed zone using an Attitude Anomaly Detector (AAD) and a Coarse Rate Sensor (CRS) so that to force a reconfiguration in survival more and to guarantee that the contingency domain are not exceeded. The different signals from AAD and CRS are mixed inside the ACC in a unit called ACMS auxiliary unit (AAU) connected to the reconfiguration module of the ACC.

The design of the ARAD is the following:



6.3.5.7 System pointing calibration

This section provides the basic operational concept for the system pointing calibration. It applies only to Herschel since Planck system pointing calibration is under instrument team responsibility as indicated in section 4.4.2 of SRS.

6.3.5.7.1 Principle of calibration

In order to achieve the best performances, the long term error between the instrument reference and the scientific mode attitude sensors has to be calibrated. The calibration phase aims mainly at the reduction of the bias errors.

The calibration will be performed such as to point both the instrument and the ACMS sensors (Star Tracker) toward targets with well known directions. The resulting ACMS attitude estimation will be compared with payload attitude data resulting in an estimation of the bias between instrument and ACMS sensors line of sight. The result of the calibration process is then used for adapting the pointing of the spacecraft (bias compensation).

This system calibration is mandatory mainly because of launch which will causes relative misalignment between instrument and ACMS LOS. So an extensive initial calibration (also called main calibration) will be necessary during the performance verification phase. Then periodic check (also called calibration check) and calibration parameter update will be performed. As indicated in SRS section 4.3.2, a ground facility will be provided to update, if necessary, the calibration values such that the pointing performances of the fine pointing mode can be improved during the next 24 hours. In all case, the calibration duration will be minimised.

The ACMS design foresee two Star trackers to be used in cold redundancy. So the bias to be applied will be different function of the Star tracker in use. Two different matrix are available at ACC ASW level to take into account two different bias suitable for each Star tracker. Ground has also the liberty to take into account different bias in the target attitude (but shall foresee a possible reconfiguration of star tracker). Different frames and associated misalignments are addressed in a next section.

6.3.5.7.2 System requirement specification requirement related to calibration discussion

Several requirements taken from SRS 3.0 apply for the Herschel calibration:

– MOOM-100: The spacecraft shall support a calibration mode, involving the execution of multiple calibrations in order to establish the angles between stellar reference and the instruments lines of sight such that the pointing requirements of the fine pointing mode can be met at all possible spacecraft attitudes satisfying the attitude constraints of Section 4.2.7. and for all possible spacecraft operational conditions.

  Since instrument fields of view are reduced, it is not possible to get every time attitude information around their line of sight. That's why calibration is foreseen only for LOS and not around LOS. There is no on board a specific “calibration mode” but the calibration which is managed by ground using available on board facilities.

  The nominal operational procedure which is in line with the pointing philosophy defined in AD04.1 and which assumes all healthy instruments, is:

  - First perform, using ground facilities, the calibration of the PACS LOS versus ACMS sensor LOS. PACS is chosen since it provides the highest resolution and secondly because an autonomous on board calibration is not possible since PACS doesn't own the peak up procedure.

    For that PACS calibration, several observations will be considered to minimise ACMS sensor & instrument measurement bias errors. And for each observation, a dedicated pointing profile will be considered to take into account Field of view constraints. It is discussed in next section.

With the ACMS & PACS raw telemetry acquired during these observations, the bias between PACS LOS and ACMS sensor LOS will be estimated at ground level.

- Then, based on the previous PACS calibration, on board SPIRE & HIFI calibration will be possible using peak up procedure (without using ground facilities). In order to justify it, let first recall the three SRS requirements which are relative to the peak up mode of the instruments:

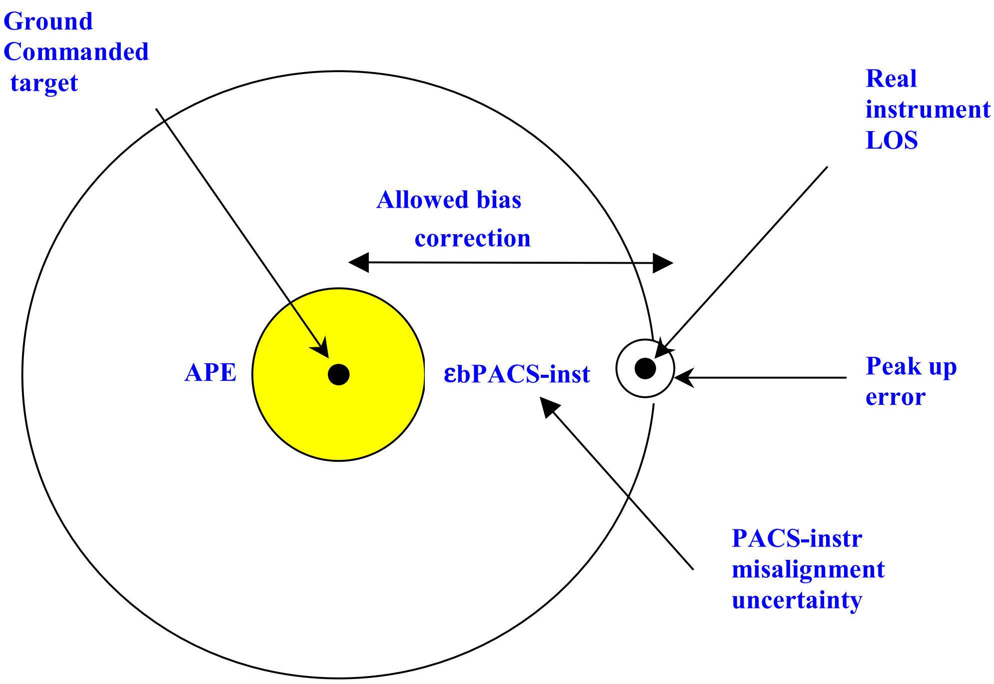
– MOOM-105: The spacecraft shall communicate, on-board and to ground, a request for pointing correction from the prime instrument per single observation.

– MOOM-110: After reception of the request for pointing correction from the instrument, the spacecraft shall autonomously readjust its attitude accordingly.

– MOOM-115: The correction shall only be allowed within predefined boundaries,<10 arcsec around Y and Z axes.

So based on previous estimation of the bias between ACMS sensor and PACS plus the ground knowledge of the misalignment between PACS and others instruments, ground will command peak up mode to SPIRE or HIFI.

This procedure will work if the sum of pointing error, error in the knowledge between instrument LOS and peak up bias estimation error falls into the allowed correction boundaries given in MOOM-115 (see next figure).



The current misalignment budget between PACS LOS and other instrument LOS is given in Herschel

System alignment budget reference ASP-03-ISIIO-28 issue 2 (included in system budget report RD02.3). It is less than 7.32 (2σ). So at 2 σ, the above constraints is respected.

In these conditions, peak up procedure should work and correction will be sent to ground (the possibility to discard the peak correction at ACMS level exits). The bias correction will be accurate according to the requirement of IID-A (less than 1 arcsec). It could be possible to use that correction for future pointing.

That procedure applies if PACS is healthy. If not, ground will perform the calibration for SPIRE and HIFI using the ground facilities which will/shall be, whatever happens, available. The applied procedure will be identical as nominal PACS one but taking into account instrument details (ex: FOV constraints). Note that the nominal procedure (described above) has been selected since it simplifies the SPIRE and HIFI calibration work for operation teams.

6.3.5.7.3 System calibration constraints

Of course, to perform calibration, both STR and instruments shall own objects in their field of view. This is naturally achieved for the STR because is a large FOV sensor.

But, for instance, PACS Field of view is 1.75' x 3.5' (= 0.0291°x0.0583°). Still, a maximum 0.3° misalignment between telescope LOS and ACMS sensor LOS is tolerated. That means, for first calibration only, the expected object may not be present in PACS FOV. In that case, a raster which covers the 0.3° with step of FOV size shall be commanded to find the object. A worst case of int(0.3^2/0.029°x0.058°) = 52 points shall be commanded. This is of course only valid for initial calibration.

It has to be noted that the FOV of others instruments is in the same order of PACS FOV. Same computation can be performed to determine the raster size for other instruments.

For initial calibration, a raster pointing (small rotation of field of view size) shall be initiated if expected object is not present in instruments FOV.

The duration of the initial calibration is different than the next ones because of the raster which has to be commanded to find object in instrument FOV.

100 samples are considered per observation. ACMS attitude estimation frequency is 4 Hz on Herschel. Instrument frequency is higher. It means that around 15 minutes for the first calibration (around 25s for each raster point) and around 25 s for the following calibrations per observation are necessary.

But the observation duration is not the driver here. Duration of slew between observation has to be considered and the time to reach thermal equilibrium of the payload (several days) and SVM (several hours) are the more time consumer. For each observation, both Star tracker has to be calibrated.

Duration of initial calibration will be around one week (TBC).

The determination of number of available sources for the system calibration is a running action at instrument level (calibration steering group activity).

6.3.5.7.4 Calibration periodicity

Daily calibration check

To be compliant with SRS, it is proposed to perform a daily check using nominal instrument and ACMS telemetry. As written in SRS, the OP will certainly begin by a small calibration period. In order to reduce that period, it is proposed to perform a single observation for the operational instrument (PACS, HIFI or SPIRE).

With the telemetry of this observation, the bias between ACMS sensor and instrument called "current bias" will be estimated at ground level.

The check will be to verify if the bias variation amplitude with respect to last calibration data is still in line with the pointing performance requirements.

New calibration

If the above check is positive, no new calibration will be requested. If not, a new calibration (procedure identical to the first one but with reduced duration since based on previous knowledge) will be necessary and shall be planned during one of the next visibility periods.

The variation of the bias between STR LOS and instrument LOS is mainly due to thermo-elastic effect. Large variation are typically at season period. That's why the typical time domain of the calibration is monthly.

Expected calibration period is one month (in line with stability requirements and analysis).

6.3.5.8 Moon in STR FoV

This section assesses possible impact of the presence of the Moon in Star tracker Field of view during Planck OCM. Mission analysis has shown that Moon can be in the Star FoV in the first days after launch. This of course depends of the launch date and the situation can last several days. This is critical since first orbit correction has to be performed in the first days of the mission.

The logic of the Planck OCM is described in section 5.5 of ACMS design report. Three states are present:

- Inhibit state: no actuation (neither attitude nor orbit correction) is done
- Delta V state: orbit correction is performed here. Depending of TAA (Thrust Aspect Angle) value, one or two sector(s) of the spin cycle are used to actuate. The size or angle of the sector (duty cycle) is tuneable in the OCM telecommand.
- Correct state: this is attitude correction part of the OCM. Attitude correction pulses can happen at any time during the spin cycle and are not predictable (depending of the correction to be done). After a delta V pulse, the logic detects if there is an attitude correction to be done, interrupts the delta V and performs the attitude correction in the next spin cycle. The delta V is resumed in the following spin cycle.

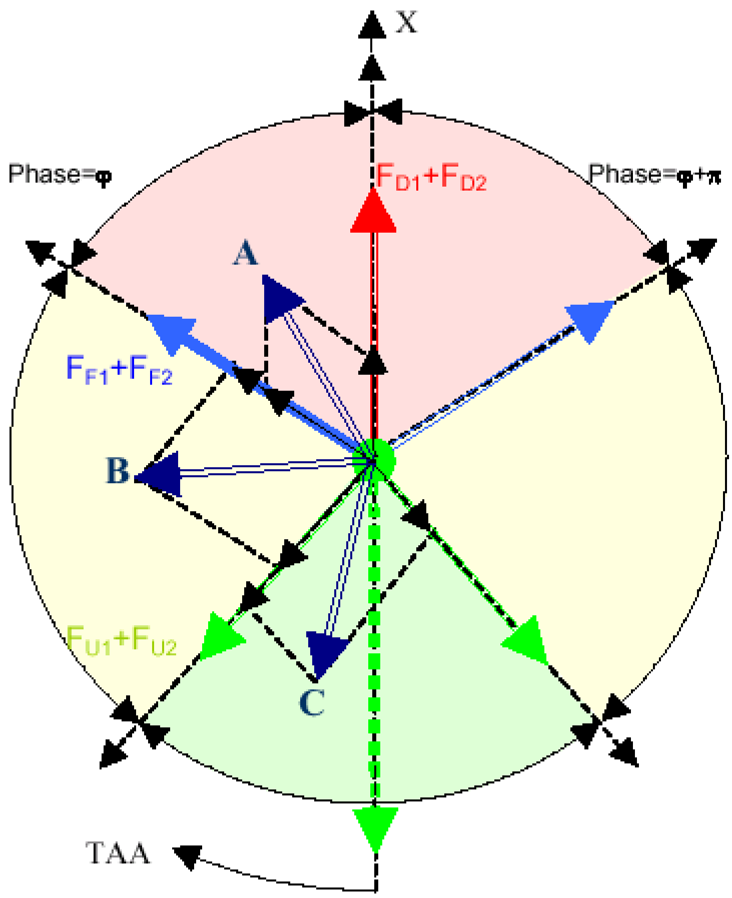
As soon as delta V or Correct State is ended, the attitude is estimated again. A certain duration is necessary so that attitude estimator converges. No actuation is thus possible during this time which is a fixed parameter (part of database). The duration allowed for attitude convergence is 10 seconds (current setting of database parameter).

The concern begins when the moon is in the Star tracker during the attitude estimation convergence. In that case, the ACMS design as reported in ACMS design report (H-P-4-TN-011) makes that any going or foreseen actuation is stopped. As soon as Star tracker is able to recover, the manoeuvre is executed as nominal. STR Probability to recover the attitude in 3 cycles is 99.73 % according to STR performance analysis. Duration of acquisition cycles is less than 2 seconds. It means that STR recovers in less than 6 seconds.

3 sectors are defined function of TAA value:

Sector A	128°<= TAA <=360 128=232°	1 pulse
Sector B	47,6°<= TAA <=128° or 232°<= TAA <=360 47,6=312,4°	1 pulse
Sector C	0°<= TAA <=47,6° or 312,4°<= TAA <=360°	2 pulses

The usage of thruster is sector dependent as depicted in next figure:



Thrust Aspect Angle sectors and combinations of thrusters for its acquisition.

So the current situation is the following:

Without considering the attitude correction,

For TAA in sector A and B, first pulse can be executed depending of the OCM telecommand arrival at ACMS level. Indeed, if attitude estimation has converged before the date of the first pulse, it will be performed. After the first pulse, if Moon is present in the STR FoV, actuation is inhibited. Thrust will be possible if moon leaves the STR FOV in time for attitude reacquisition and convergence. It means 6 seconds + 10 seconds before the foreseen date of actuation. Moon can stay in STR FoV during 6.95 s (Moon exclusion angle is +/-20° plus 0.5° moon size divided by minimum spin rate in OCM 5.9°/s).

If it happens that at OCM entrance, attitude has no time to converge before the foreseen date of first pulse, it is delayed of one spin cycle.

For Sector C, the situation is more difficult since there are 2 actuations per spin cycle (opposite in the cycle). So if Moon is present in the STR FoV in the 10 seconds after the first pulse, 6.95 seconds + 6 seconds + 10 seconds can be necessary to get a new attitude which is not sufficient for next actuation (greater than 30 s – duty cycle).

So without considering attitude correction, OCM with TAA in sector And B are feasible only in certain case when moon leaves the STR field of view at least 16 s before the foreseen actuation For TAA in sector A, OCM are not feasible if moon is in the STR FoV during the 10 s + mid duty after the STR boresight has been coincident with thrust direction (projection in YZ plane).

Considering the attitude correction

Due to the fact that attitude correction can happen any time in the cycle and the time of actuation is not repeatable one cycle to the other (due to nutation), the actuation will be suspended until the time between the availability of attitude and the needed attitude pulse is positive. This not deterministic.

In conclusion, with the current design, the behaviour of the OCM when the moon is present in the STR Field of View is not deterministic due to the necessity of attitude correction pulses.

Possible solutions to avoid this scenario are:

Orient spacecraft to avoid Moon in STR FoV but it can be done in a very limited range as mentioned in SENER RFD "attitude limitation for orbit maintenance".

Propagate attitude but would need to take into account/model the effect of Delta V thurst on attitude. The impact is complexity and loss of accuracy.

It is thus not recommended to perform Delta V with Moon in STR Field of view.

6.3.5.9 Herschel frames and transformations

This section presents the different frames and transformation used at ACMS level to point the Herschel instruments.

The definition of ACA frame (taken from ACMS implementation specification) is:

- The Herschel ACA-X axis shall coincide with the instrument axis, as defined as: The anti-direction of the boresight axis of the main STR
- The Herschel ACA-Z axis shall be as follows:
  - In case STR 1 is the main STR:
    - ZACA: Coincides with the rotated Z axis of STR 1, rotated by The nominal location on the SVM (-3.5°) about the STR boresight axis
  - In case STR 2 is the main STR:
    - ZACA: Coincides with the rotated Z axis of STR 2, rotated by rotated by The nominal location on the SVM (+100.0°) about the STR boresight axis.
- The Herschel ACA-Y axis shall complete the ACA right handed orthogonal co-ordinate frame

The Raw information (the one available on the 1553) from the STR is first converted in the right format: it represents the attitude of boresight reference frame in inertial frame. Then the attitude is transformed in a frame called ACA frame at ACMS level.

This transformation (called qACA/STRi i= 1,2) is star tracker dependent and is computed based on On Board Data Base parameters.

Then a misalignment correction/transformation is applied. This transformation could be sun aspect angle dependant and is star tracker dependant (for each star tracker, a table of 7 misalignment quaternion is available giving a 10° resolution for SAA dependence). This transformation (called qinst/ACAi i=1,2) represents the rotation between instrument frame and ACA frame. Note that it is currently not foreseen to use the SAA dependency.

The ACA frame has no flight existence since it cannot be measured. It exists on ground and could be measured with HPLM cube. But the ground knowledge is not sufficient to achieve the requested pointing performance due to launch and orbital misalignment effect. The system calibration gives directly the bias between STR boresight reference frame and instrument frame and allows to meet the requested performances.

It has to be considered that the ACMS can autonomously switch from one Star tracker to the other without ground intervention (level 2 FDIR). Moreover, ground cannot send attitude target command in a frame which is not calibrable in flight. And as STR configuration is not predictable (by nature of failure), ground has to command in instrument frame.

So the ACA frame will be made coincident with instrument frame. Transformation to take into account Gyroscope and Reaction wheel misalignment will be adjusted after system calibration. And ground will command directly instrument frame.

6.3.6 Power design

Power Subsystem Architecture

The Herschel Planck power subsystems have a very high degree of commonality, they both employ the same PCDU and battery, while the Solar Arrays are different but utilise a common solar cell type.

PCDU

The PCDU has been designed to interface with 30 sections of a solar array, provide a regulated 28V bus, distribute this power via protected outputs and to handle the battery charging/discharging.

The PCDU distributes the power to each user via either a Foldback Current Limiter (FCL) or a Latching Current Limiter (LCL). FCLs cannot be commanded OFF, they are reserved to supply essential loads. FCLs can be commanded OFF and ON via the 1553 bus and in addition for selected LCLs via discrete TC lines. LCLs are implemented in three classes depending upon the required limitation current. The LCL will start to limit the current after the LCL class current has been exceeded by 20 %, and once the limitation threshold has been achieved, will trip off after 10mS. The precise LCL current limitation can be anywhere in the range of 1.2x to 1.5x the LCL class current. All LCLs and FCLs provide status and current telemetry. The LCL classes are:

LCL Type	Iclass	$Ilimit_{min}$	$Ilimit_{max}$	Iovershoot	$Trip_{min}$	$Trip_{max}$
Class I	1A	1.2A	1.5A	2.25A	10mS	12mS
Class II	2.5A	3.0A	3.75A	5.63A	10mS	12mS
Class III	5A	6.0A	7.5A	11.25A	10mS	12mS
FCL	1A	0.25A*	1.5A	2.25A	-	-

* This value is achieved at the maximum fault condition, i.e. upon the application of an overload condition, the FCL will react to limit the current between Ilimitmax and Ilimitmin.

For applications which require more than 5A (Sorption Cooler and 4k Cooler) several Class III will be wired in parallel (4 for the Sorption Cooler and 2 for the 4k Cooler) to provide the required output current. The paralleling of the LCLs will be implemented in the PCDU harness with the ON/OFF commands to each LCL being sent in parallel to the group of LCLs, hence for the Herschel PCDU where these high loads LCLs are not required it will be possible to utilise these LCLs individually while still maintaining an identical PCDU for both Herschel and Planck.

One identified failure modes of LCLs which use FETs for the switching function is a gate-drain short circuit which leads that the FET cannot be switched OFF and will have a high dissipation. A survey of all the users have identified which LCLs must be protected against this failure mode, ones which cannot tolerate both the nominal and redundant units being ON at the same time, and a second series switch (FET) will be implemented within the LCL to ensure that it may always be switched OFF. To resolve the excess dissipation problem, all Class III LCLs will be implemented with series switches.

The essential loads are supplied via FCLs which do not trip off nor can they be powered off. All FCLs have the same characteristics. The problems associated with a re-triggerable LCL being constantly retriggered, usually at around 1Hz, and the possible sources of noise for the instruments, meant that FCLs were selected in preference to re-trigerable LCLs. The essential heaters are supplied by FCLs, redundant thermostats will be implemented to so that a single failure will not mean that the heaters are permanently powered.

The PCDU provides 10 FCLs and 62 LCLs, for a detailed breakdown and allocation please refer to RD01.1.

In addition to the FCL/LCL distribution, the PCDU will also provide protected switchable heater lines. For each group of heaters a LCL type device (called Heater-Group Protection Switch - HPS) will supply 6 heater switches (series FETs), in case of an overload situation the bus will always be protected since the current will be limited. Each heater line is specified to be able to provide 3.75 A, while the HPS is rated at 10A. The PCDU will provide a total of 54 nominal + 54 redundant heater lines.

The battery charging concept is that the last three sections of the array can be connected to the battery if the battery requires charging. The connection (and disconnection) of the array sections to the battery is managed in a sequential manner by the MEA in conjunction with the BCR and BDR, the maximum battery charge current will correspond to the current of 3 sections (nominal 9A total) and as the battery becomes charged then the a section is switched from the battery and made available to the mainbus as any other section. With a fully charged battery, the load on the last section is minimal (battery taper charging) and the current from the last section (less the battery taper current) is also made available to the mainbus.

The PCDU implements a 3 domain regulated power bus concept based upon the SR3 concept:

- Sunlight Domain - the power is supplied by the 30 solar array sections, the sections are either shunted or connected to the mainbus, the voltage regulation being achieved by having one section being switched at a high frequency (up to 3kHz) between shunt and mainbus.
- Battery Charge Domain - The last 3 sections of the array (designed to be normally shunted for the nominal power load) can be switched to the battery should the battery require charging. This assumes a battery recharge to be performed in a reasonable time. The complete recharge of the battery with the present conditions will be achieved in less than 4 hours after the separation from the launcher. The circuit controlling the domain ensures that the user load has priority over battery charging should there be insufficient power for both the bus users and battery charging. The control of the battery charging, autonomously performed by the PCDU, is managed by the MEA and by monitoring the battery voltage for the end of charge voltage (the end of charge voltage may be modified by software programming). There are no high current pulses applied to a battery with the implemented architecture and therefore the risk of damaging or degrading the battery performance is reduced.
- Battery Discharge Domain – Should the Mean Error Amplifier detect that the mainbus load exceeds the available solar array power then the battery will be discharged to provide the required power. The BDR is implemented as a push-pull PWM converter, the nominal power capability being 400 W each BDR, sufficient to supply the spacecraft in worst case launch conditions.

The Mainbus capacitor is implemented as both a central capacitor employing self healing capacitors and distributed capacitors on each module within the PCDU, therefore the mainbus capacitor is tolerant to a short circuited capacitor.

Battery

The battery proposed and selected for Herschel Planck will be from AEA, the technology is based upon a number of screened commercial low capacity cells arranged in a number of parallel strings (26 strings of 6 cell). The proposal from AEA has taken some pessimistic ageing and degradation factors into account, the sizing of the battery reflects these factors and lead to mass and volume penalties. Although the eclipse requirements at system level have been removed and the battery size could have been reduced, it was decided to maintain the baseline design to ensure generous battery power margins. The battery BOL energy capability is 777Wh with a capacity of 36 Ah (measured capacity on the EM gives 93 % capacity = 34.75Ah), the needs in the launch case are 330W for Planck and 254W for Herschel for 50 minutes under the worst case operating conditions. The battery sizing case is the launch phase, although the battery will be used during the mission to handle to peak power demands, this is well below the requirements of the launch condition.

Solar Array

The Solar Arrays are the main difference between Herschel and Planck. The power requirements of the instruments and the lifetime requirements are different for the two missions. The requirements and available power for the Solar Arrays are summarised:

- Herschel:
  - Requirement Available

	Requirement	Available	
– BOL	1700 W	SS 0° Inclination	1681 W
		WS 0° Inclination	1921 W
– EOL (3.5 Years)	1400W	SS 30° Inclination	1405 W
		WS 30° Inclination	1517 W.

The minor non-compliance for BOL is accounted for in the power budget.

- Planck:
  - Requirement Available

	Requirement	Available
– BOL	1900 W	1992 W
– 21 months	1900 W	1908 W
– 30 months	1700 W	1892 W.

While the shape and size of the arrays for Herschel and Planck are different, the type of cell, substrate, interconnects, wiring, and manufacturing procedures will be common to both arrays. Herschel will also have 1 section of 100 % European cells which are the same as the baseline RWE apart from a slight loss of efficiency.

Power distribution to instruments

The power to the instruments will be distributed as given in the following tables:

Herschel Allocation	To	Type	Protected	Class
HIFI HRH	**FHHRH**	LCL	YES	III
HIFI HRV	**FHHRV**	LCL	YES	III
HIFI ICU Nom	**FHICU**	LCL	YES	III
HIFI ICU Red	**FHICU**	LCL	YES	III
HIFI LCU Nom	**FHLCU**	LCL	YES	III
HIFI LCU Red	**FHLCU**	LCL	YES	III
HIFI WEH	**FHWEH**	LCL	NO	II
HIFI WEV	**FHWEV**	LCL	NO	II
PACS BOLC Nom	**FPBOLC**	LCL	YES	II
PACS BOLC Red	**FPBOLC**	LCL	YES	II
PACS DPU Nom	**FPDPU**	LCL	NO	II
PACS DPU Red	**FPDPU**	LCL	NO	II
PACS DEC/MEC1	**FPMEC1**	LCL	YES	III
PACS DEC/MEC2	**FPMEC2**	LCL	YES	III
PACS SPU Nom	**FPSPU1**	LCL	NO	II
PACS SPU Red	**FPSPU2**	LCL	NO	II
SPIRE HSDPU Nom	**FSDPU**	LCL	YES	I
SPIRE HSDPU Red	**FSDPU**	LCL	YES	I
SPIRE HSFCU Nom	**FSFCU**	LCL	YES	III
SPIRE HSFCU Red	**FSFCU**	LCL	YES	III

Planck Allocation	To	Type	Protected	Class
LFI DAE Nom	**PLBEU**	LCL	YES	III
LFI DAE Red	**PLBEU**	LCL	YES	III
LFI REBA Nom	**PLREN**	LCL	YES	II
LFI REBA Red	**PLRER**	LCL	YES	II
HFI DCE	**DCE**	LCL	NO	II
HFI DPU Nom (PHBA-N)	**PHBAN**	LCL	YES	II
HFI DPU Red (PHBA-R)	**PHBAR**	LCL	YES	II
HFI REU belts group 0&1	**PHBAR**	LCL	NO	II
HFI REU belts group 2&3	**PHBAR**	LCL	NO	II
HFI REU belts group 4&5	**PHBAR**	LCL	NO	II
HFI REU belts group 6&7	**PHBAN**	LCL	NO	II
HFI REU belts group 8&9	**PHBAN**	LCL	NO	II
HFI REU belts group 10&11	**PHBAN**	LCL	NO	II
HFI REU Proc Nom	**PHCBC**	LCL	YES	I
HFI REU Proc Red	**PHCBC**	LCL	YES	I
HFI 4KC Drive bus Nom	**PHDC**	LCL	YES	2 Class III in Parallel
HFI 4KC Drive bus Nom	**PHDC**	LCL	YES	2 Class III in Parallel
HFI 4KCDE Nom (PHDC)	**PHDC**	LCL	NO	II
HFI 4KCDE Red (PHDC)	**PHDC**	LCL	NO	II
Sorption Cooler Compressor Nom	**PSM4**	LCL	YES	4 Class III in Parallel
Sorption Cooler Compressor Red	**PSR4**	LCL	YES	4 Class III in Parallel
Sorption Cooler Electronics Nom	**PSM4**	LCL	YES	III
Sorption Cooler Electronics Red	**PSR4**	LCL	YES	III

DC/DC synchro

Previous ALCATEL experience with synchronised and non-synchronised power systems has shown that contrary to what may be expected, a synchronised system is not less noisy than a non-synchronised one. Early in the program, the instruments were requested to reconsider their need for a DC/DC synchronisation signal, with the intention to retain the DC/DC synchronisation only if a sound rationale could be provided. One instrument (LFI) had planned to use this DC/DC sync signal as an internal 131 kHz clock, not only for internal DC/DC synchronisation but for timing purposes. This was considered an inappropriate use of the signal since the quality of a DC/DC sync clock is generally inferior to a dedicated timing clock (accuracy, stability, duty cycle, jitter), so the DC/DC synchronisation signal has been removed and a 131072 Hz clock signal has been made available for each instrument.

Power FDIR

The power system is totally autonomous for the protection of the power bus and requires no additional inputs or control. However to support the overall spacecraft FDIR, a Dod (Depth of Discharge) signal is sent from the PCDU, which is generated depending upon the battery voltage. This threshold can be programmed to be between 18 and 20 volts, corresponding to a Dod of 90 % to 80 %.

A DNEL (Disconnect Non Essential Loads) input to the PCDU is also provided as a HL command input. Upon receipt of this command the PCDU switches off all LCLs which are attached to Non Essential Loads (payload units). This external DNEL input is supplied by the CDMU in response to a Dod alarm, hence when the battery is approaching the end of discharge, the non essential loads are shed and allowing adequate battery energy for additional FDIR activities. The DNEL signal is also generated internally to the PCDU in case of a power bus undervoltage of 25.5V.

The LCLs have a bus undervoltage detection and will latch off when this bus undervoltage is detected. For the LCLs connected to the non-essential loads the undervoltage threshold is 25.5V and for the LCLs connected to the essential loads the threshold is 21.5V

To protect the battery from excessive discharge, the BDR will be inhibited when a battery voltage of 15V is detected. The BDR will automatically switch ON only when the battery voltage is greater than 18V, this is to ensure that the BDR is enabled only when the battery is sufficiently charged (18V corresponds to a 6 % state of Charge)

6.3.7 Harness design

For detailed implementation of the harness design please refer to the SVM Design Report (RD01.1) for the warm harness description and the H-EPLM Design Description (RD01.2) for details of the cryo harness design. Warm Interconnecting Harness (WIH) is under instrument responsibility and described in the IID-B (AD04.2 to AD04.6). Routing has been performed under ASP responsibility and is described in Section 6.3.3.2. to 6.3.3.6.

6.3.7.1 Harness electrical design

Several critical areas have been identified for the harness design at system level, they are:

- Herschel Telescope Decontamination Heaters Harness (voltage drop)

  The Telescope heaters will have a resistance of 6.5 Ohm, considering a typical implementation harness resistance of 0.9Ohm this leads to a voltage drop of over 3 V over the harness. This means that the power at the heaters with the minimum PCDU output voltage is 85 W instead of the required 90 W, while at the maximum PCDU output voltage the heater power is 91 W. The length of the harness has been identified as being important, and care must be taken not to make the harness too short which will cause a “best case” situation with a current greater than the specified 3.75 A at maximum PCDU output voltage conditions. The PCDU supplier has confirmed that there is no problem to provide 4 A to the heater loads except that the derating of the connector pins will be slighty degraded.

- Herschel Telescope Decontamination temperature sensor (use of cryo harness and accuracy)

  To keep the thermal load to a minimum on the cryostat, Astrium have elected to implement all signal connections using stainless steel. The specified temperature sensor for the Telescope is a 2 kOhm Platinum Probe, and the required accuracy is ± 3 K at 313 K. A preliminary analysis assuming 10 meters of stainless steel harness (=1500 Ohms) shows that in order to achieve the required accuracy the variation of the harness resistance (due to temperature variation along it's length) must be less than 3 Ohms. The temperature sensor originally selected (PDR timeframe) was a 5 kOhm Platinum Probe, however due to technological problems with this device, the 2k Ohm thermistor has been selected which although offers less accuracy and is more critical to the harness resistance variation but is more mechanically robust and less prone to failure.

- Herschel Solar Array harness length (power loss)

  The initial specification for the Herschel Solar Array required an equal harness length of 1.5 m for all three panels. However after further design study and placement of the connector bracket, the harness for each solar array panel will be slightly different, the new lengths are estimated as 2 m, 3.5 m and 5 m. A study shows that even with the 5 m harness length the voltage drop will still be compatible with the PCDU and that the increase of harness lengths will lead to an additional 5 W of losses which is considered as within the nominal design margins of a 1500 W Solar Array.

– Safe and Arm plug connections

A study of inhibit and safety issues (see RD03.8) identified a need for the following safe and arm plugs:

- Between the PCDU and the Non-Contaminating Actuators
- Between the ACC and Thrusters
- Between the ACC and Latching Valve.

These connections will be implemented into the harness design as part of the normal work process, and do not pose any critical aspects.

6.3.7.2 SVM harness and WIH configuration

The SVM harness realises the connection between all SVM equipment and also from PCDU and CDMU to instruments warm units set on SVM panels (up to unit connector). It also includes the harnesses supplying heaters for ATC of panels.

The WIH gathers all harnesses interconnecting the different warm units.

On a lateral panel, the different harnesses start from an instrument/equipment then run between the different units and are fixed to the structure with simple tie-bases.

When connecting units on different lateral panels or on a shear web, the harness leaves the unit on the panel then goes to a disconnection bracket set on lower closure panel. Another bundle routes on lower closure panels and links this bracket to another one close to the other panel (lateral or shear), cut-outs in shear webs allows passing of harnesses. A final bundle connects the bracket to the units by routing on the panel.

A flexible loop (overlength) is added to the harnesses going to disconnection brackets to ensure lateral panels tiltability and dismountability.

6.3.7.3 General work and rules

At the PDR were presented conceptual paths dedicated to the different harnesses, SVM harness, WIH and Cryoharness (Herschel only).

The work done in this domain during phase C/D mainly consisted in full routing definition of the different harnesses allowing starting of manufacturing. The harness routing was defined with ALS/NXH for SVM harness and WIH and ASED for cryoharness (Herschel). The coherence between harnesses (interference) have been managed by ASP. The result of this work was also submitted to approval of instruments for warm units lateral panels.

It appears that physical separation between all these harnesses was difficult to achieve due to the lack of space on the structure (mainly lateral panels) and big size of units housed.

In general and when possible, all harnesses have been routed trying to separate nominal and redundant bundles.

The segregation between the different EMC classes was taken into account in a first step but then withdrawn because of a lack of space on panels. It results that part of SVM harness and WIH may route commonly. The instrument teams agreed on the final proposed routing.

6.3.7.4 Outputs to Instruments

Some warm units have connectors implemented on their top side. Because of the height and to minimise free length of harnesses, tie-bases need to be implemented on units to support the different bundles.

Location and dimensions of these supports have been defined for SVM harness, WIH and cryoharness purposes. They shall be used by instruments as the definition of paint-free areas in case the unit is painted.

WIH routing definition is under responsibility of Industry but manufacturing is Instrument task, consequently routing layouts and lengths definition have been provided. CAD models in STEP format (universal format) have also been provided so that Instruments can have the full 3D definition and allowing having a better understanding. Top view scale 1 paper drawings (print-out of the models) have been provided to ease harnesses manufacturing on jigs.

The routing has been established on the basis of the information available in IIDB's (geometrical characteristics). In general the bending radius of the cables used is equal to 5 times the diameter.

Hereafter is presented the situation for each instrument.

6.3.7.5 Herschel definition

As a general rule, WU are connected to SVM harness and WIH from the bottom part of the panel, and are connected to cryoharness from the top of the panel.

6.3.7.5.1 Cryoharness configuration

As introduced before, the Cryoharness links the cold units set in H-PLM CVV to warm units in SVM.

There are additional harnesses to monitor CVV valves, Telescope decontamination heaters and Cryo-cover opening. Part of these connections goes to CCU (on –Z SPIRE panel) and some directly interface with launcher because of needs during launch phase. A bracket on SVM cone is dedicated to H-PLM umbilical lines and is connected to Satellite umbilical connectors.

The H-PLM comes with the cryoharness running along the CVV and its supporting struts and joins the H-PLM/SVM brackets. During integration, the H-PLM is mated with these brackets on top of SVM.

In parallel, the "warm part" of the cryoharness is installed on each lateral panels from warm units connectors to top of panels (once other harnesses have been integrated), the remaining part going to H-PLM/SVM brackets is kept flying.

The lateral panels are brought one by one, connected horizontally to the SVM, electrical connections with disconnection brackets on lower closure panels are made. The panels are tilted upward to close the SVM. Some cut-outs in the edge of upper closure panels let go out the cryoharness flying part which is at the end connected to the H-PLM brackets.

Concerning segregation of EMC class, the cryoharness more sensitive in the principle is shielded and therefore less perturbed by EM noise when routing near other classes (WIH, SVM harness).

6.3.7.5.2 Harness configuration on HIFI panels

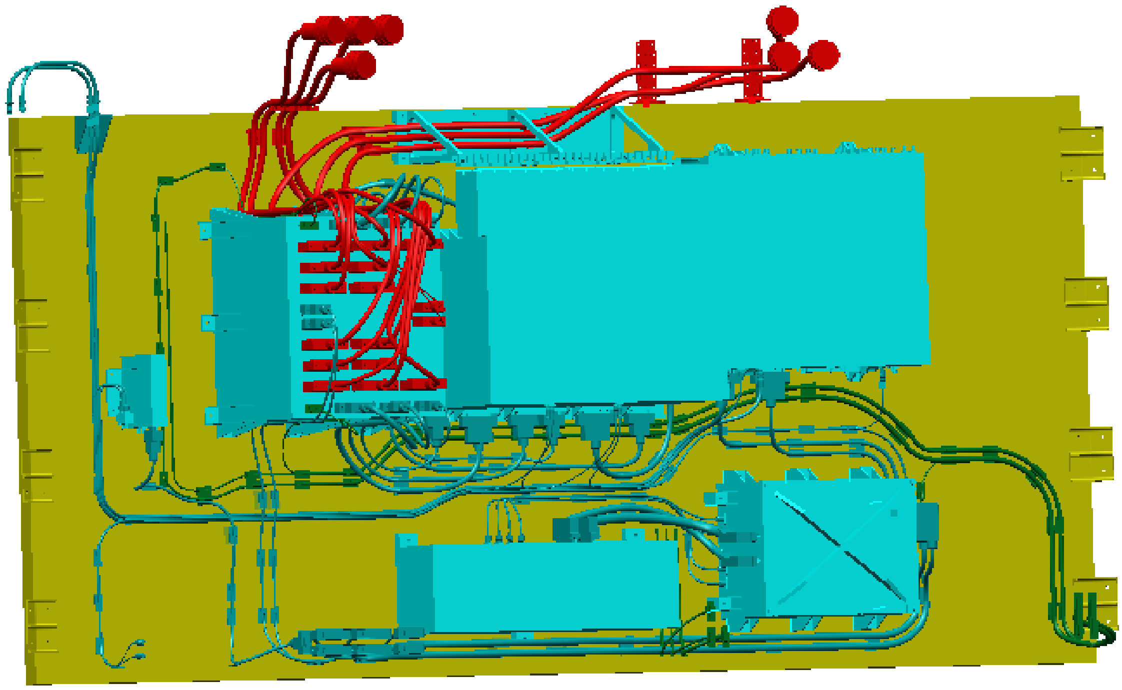
HIFI units are accommodated on 2 lateral panels (-Y and –Y-Z). The WIH routing on this panel was made difficult by the density of units and number of interconnections between units with flexible and semi-rigid cables for WIH composition.

The SVM harness and WIH are running all over the free place on the panels. Disconnection brackets on lower closure panel enables the panels' interconnection with flexible harnesses.

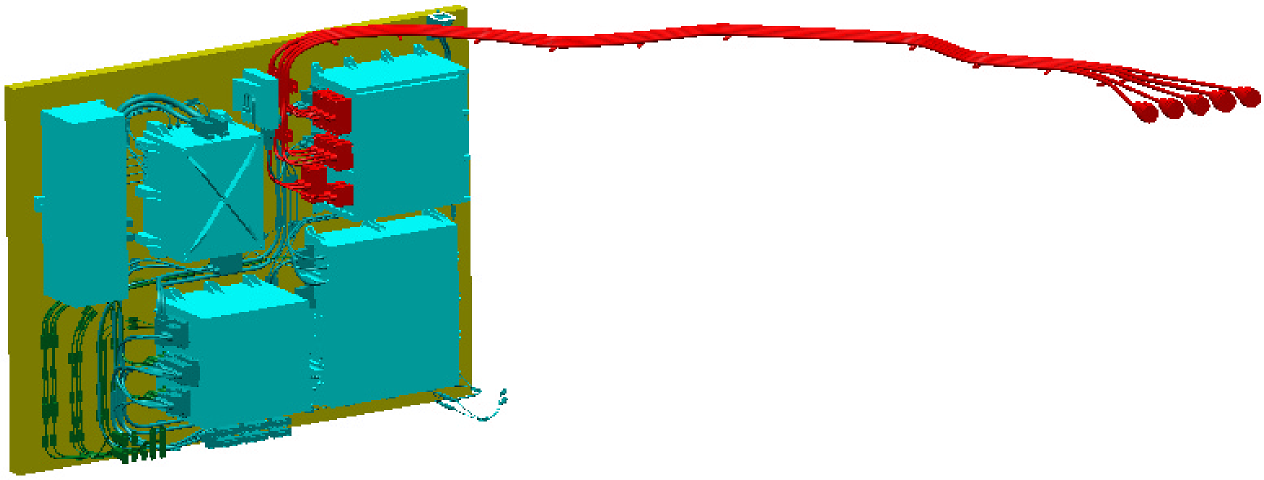
As there is another specific link between the 2 panels with semi-rigid cables and to make it compatible with integration constraints, disconnection brackets (accessible through upper panels) have been set on top of lateral panels and a flying jumper is brought after closure of SVM.

The cryo harness is connected to FHFCU and up-converter on –Y-Z panel and arrives from top of the units. Some space is kept for it. Concerning –Y panel, it is connected to FHLCU and enters in SVM via cut-outs above the units and also through the cut for LOU-LSU waveguides.

The routings of the different harnesses are geometrically fully compatible.



HIFI -Y panel harness layout



HIFI –Y-Z panel harness layout

The SIH cryoharness is represented in red color, the SVM harness is in dark green color and the WIH is in light blue. The HIFI warm units are in light blue.

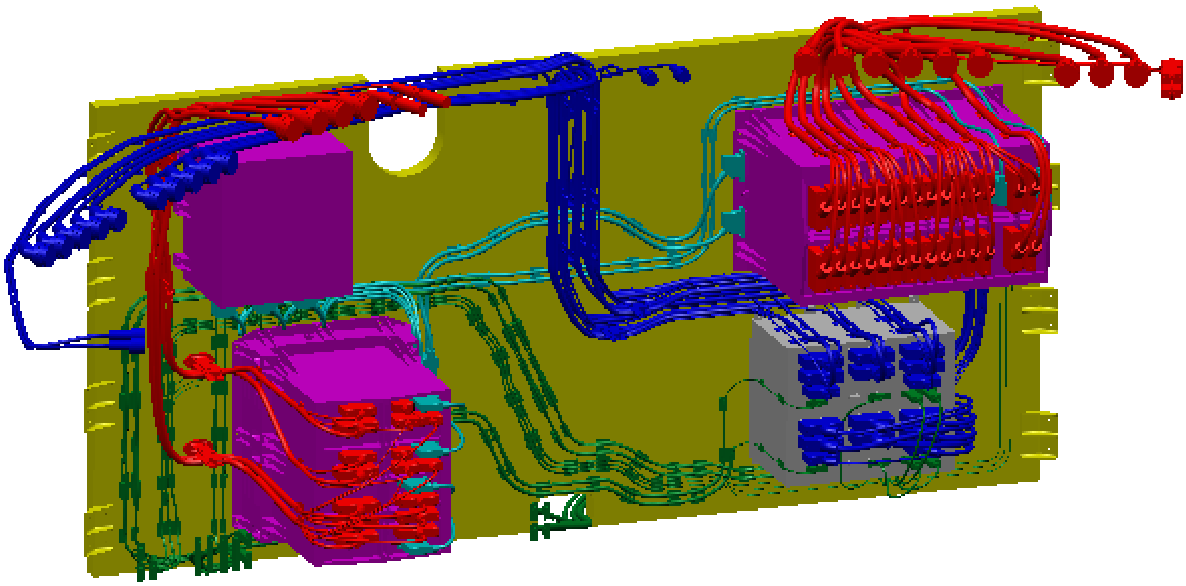
The WIH definition has been transmitted by document H-P-4-NXH-RP-0020 iss A2 with annotations.

6.3.7.5.3 SPIRE panel (-Z)

There are 3 SPIRE units and CCU monitoring H-PLM set on this panel. The big size of these leaves few space on panel but sufficient for harnesses accommodation.

The cryoharness routes to the CCU via space in-between shear walls and arrives from top to HSDCU and HSFCU.

The routings of the different harnesses are geometrically fully compatible.



SPIRE –Z panel harness layout

The SIH cryoharness is represented in red color and the CCH cryoharness in dark blue, the SVMharness is in dark green color and the WIH is in light blue. The SPIRE warm units are in purple and the CCH in grey.

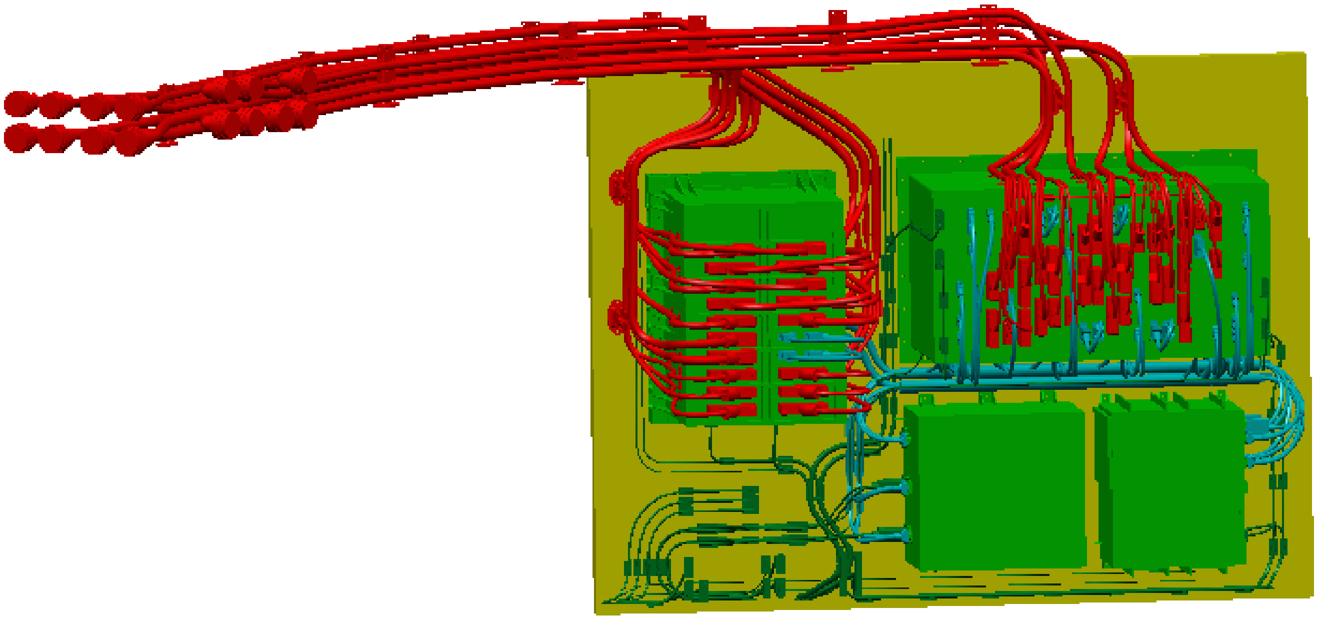
The WIH definition has been transmitted by document H-P-4-NXH-RP-0022 iss A1.

6.3.7.5.4 PACS panel (+Y-Z)

There are 4 PACS units set on this panel. As for other Instruments panels, the big size of these leaves few space on panel but sufficient for harnesses accommodation.

It has to be mentioned that routing is in line FPDECMEC configuration reflected in ASP drawing HES.114P.S.001SA issue B.

The routings of the different harnesses are geometrically fully compatible.



PACS +Y-Z panel harness layout

The SIH cryoharness is represented in red color, the SVMharness is in dark green color and the WIH is in light blue. The PACS warm units are in green.

The WIH definition has been transmitted by document H-P-4-NXH-RP-0021 iss A1.

6.3.7.6 Planck definition

The situation for the harness on Planck is more complex as the instruments have more units and that they are accommodated on several panels, shared with SVM equipment in some cases. This is reinforced by the fact that some units are set on sub-platform because they need to be as close as possible to the FPU (bellow for PAU and waveguides for BEU).

Moreover, the Sorption Cooler Subsystem imposes 2 huge units necessitating one panel for accommodation of each.

6.3.7.6.1 HFI subsystem

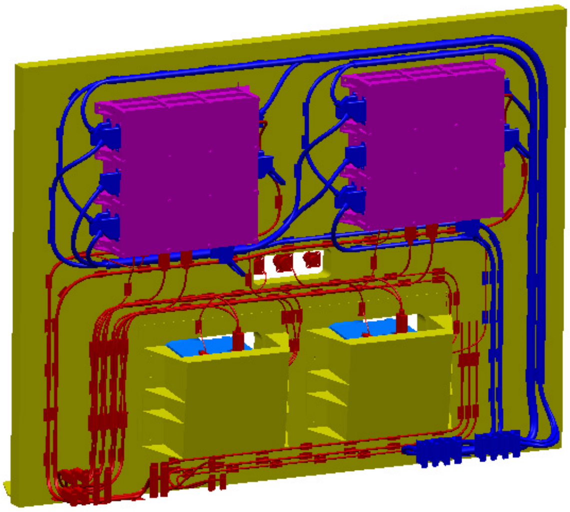
HFI units are spread over 3 lateral panels (DPU on +Z, DCCU on +Y+Z, 4K units and REU on +Y) and the sub-platform (PAU).

The DPUs (both on +Z panel) are interconnected and supply other HFI units (0.1K, 4K elements and REU except PAU) by routing via the lower closure panels and disconnection brackets to allow panels' tiltability and dismountability.

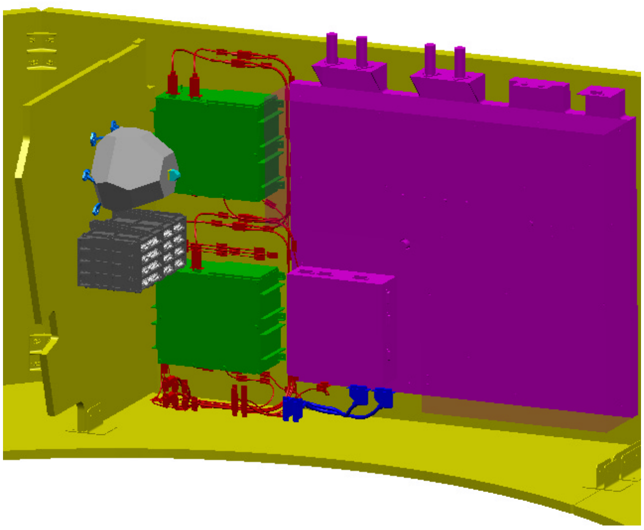
Regarding the 4K panel, in addition to the WIH linking directly the units on +Y lateral panel another bundle routes along the pipes to join the P-PLM (the SVM part stops at sub-platform level with pipes inter-connection).

Supplementary bundles, part of the SVM harness are used to realise all the connections with 4KCRU on one side. Another part links the 4KCDE to bracket on top of the panel ending with 2 connectors used during satellite transport and some tests to lock 4KCCU strokes.

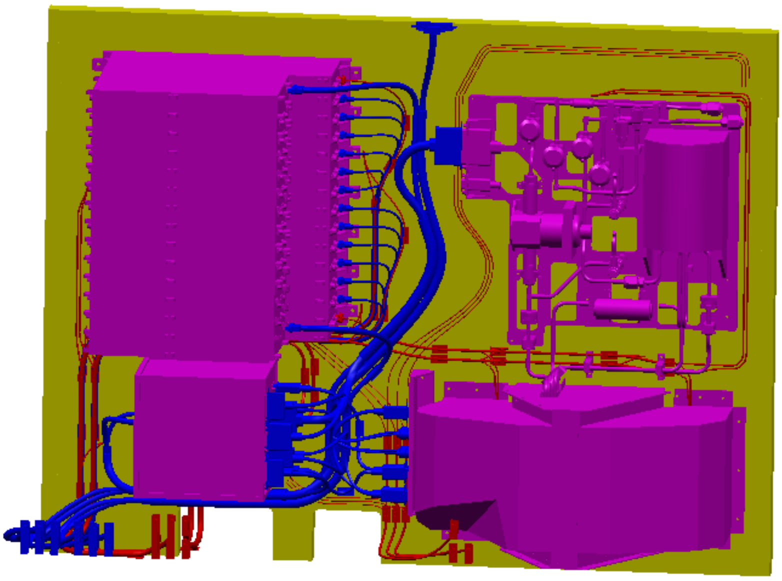
From the DCCU, part of 0.1K chain, go out additional harnesses running with the pipes, up to each He tank for temperature acquisition and to PLM as instrumentation (the SVM part stops on the sub-platform with the pipes inter-connection).



DPU +Z panel harness layout



DCCU +Y+Z panel harness layout



4K +Y panel harness layout

The WIH is represented in blue color, the SVMharness is in red color. The HFI warm units are in purple.

PAU-REU harness

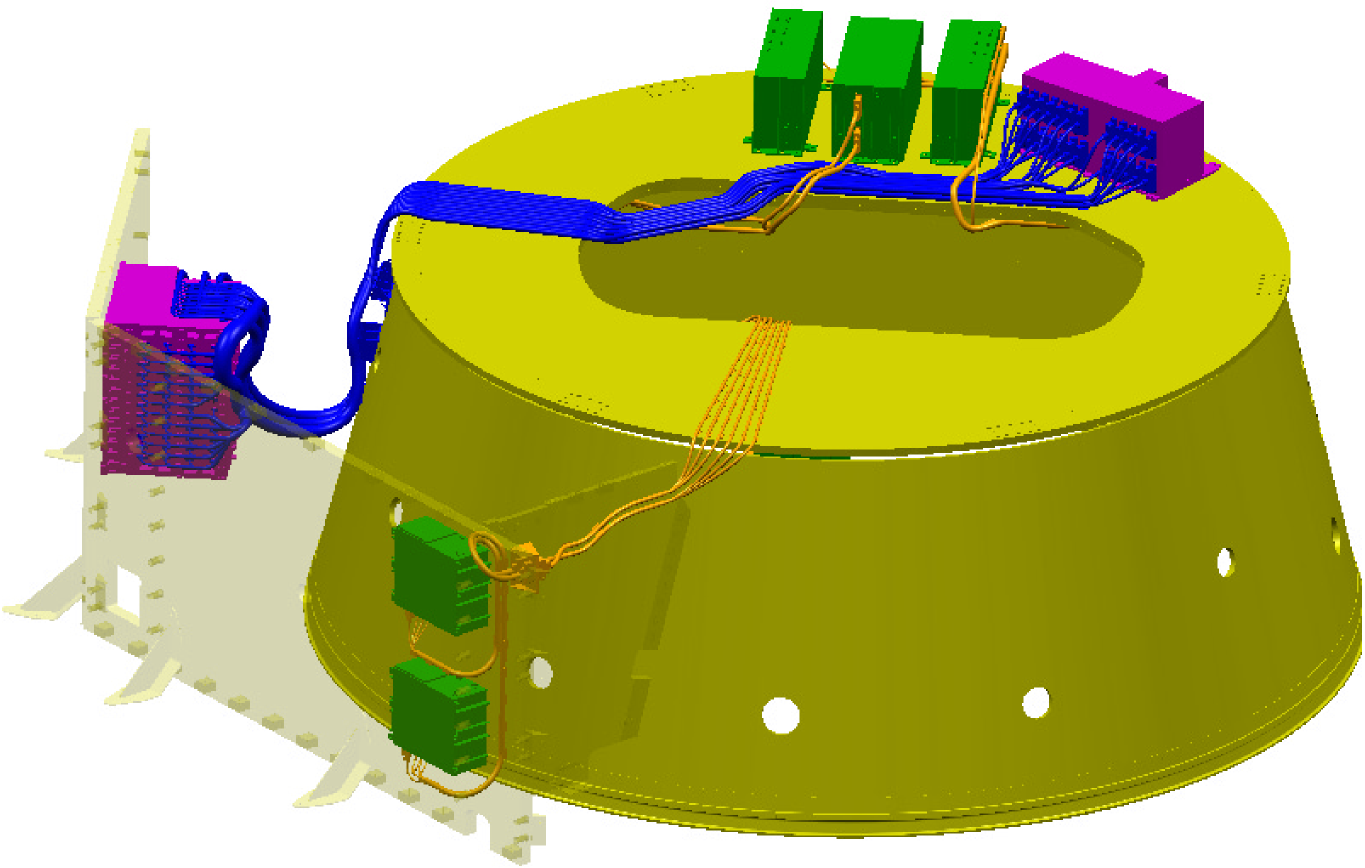
This harness is treated specifically because it is rather de-coupled from the rest of HFI WIH. Its routing has been difficult to define, because of the long harness path between these 2 units from sub-platform to lateral panel.

The main constraints coming from instruments is that this harness is composed of 12 bundles ∅15 mm each not interruptible and limited to a maximum length of 5m, the lengths of the 12 harnesses shall be standardised to 3 different lengths at the maximum. Moreover the REU has an internal harness blocking the arrival of the harness from several sides.

From the satellite point of view, the REU has been relocated from +Z to +Y panel (for centering reason), close to a shear web housing RCS equipment (latch valve, filter).

The PAU being on sub-platform, the harness is submitted to V-groove thermal effect; to avoid perturbing it the harness has to prevent any tangential barrier then shall route as far as possible below sub-platform level in free zones. This constraint imposes that the harness routes in the edge of the sub-platform as long as possible and then cross it radially (minimised disturbances).

Subsequently the harness enters in SVM runs under He tank support beam, over 0.1K pipes and jumps to REU. A flexible loop is here implemented to make possible the integration and tiltability of the lateral panel.



PAU-REU subplatform harness layout

The PAU-REU WIH is represented in blue color. The HFI warm units are in purple.

The LFI WIH is in gold color. The LFI warm units are in green.

The latest document providing HFI WIH characteristics is H-P-4-NXH-RP-0023 issue A2

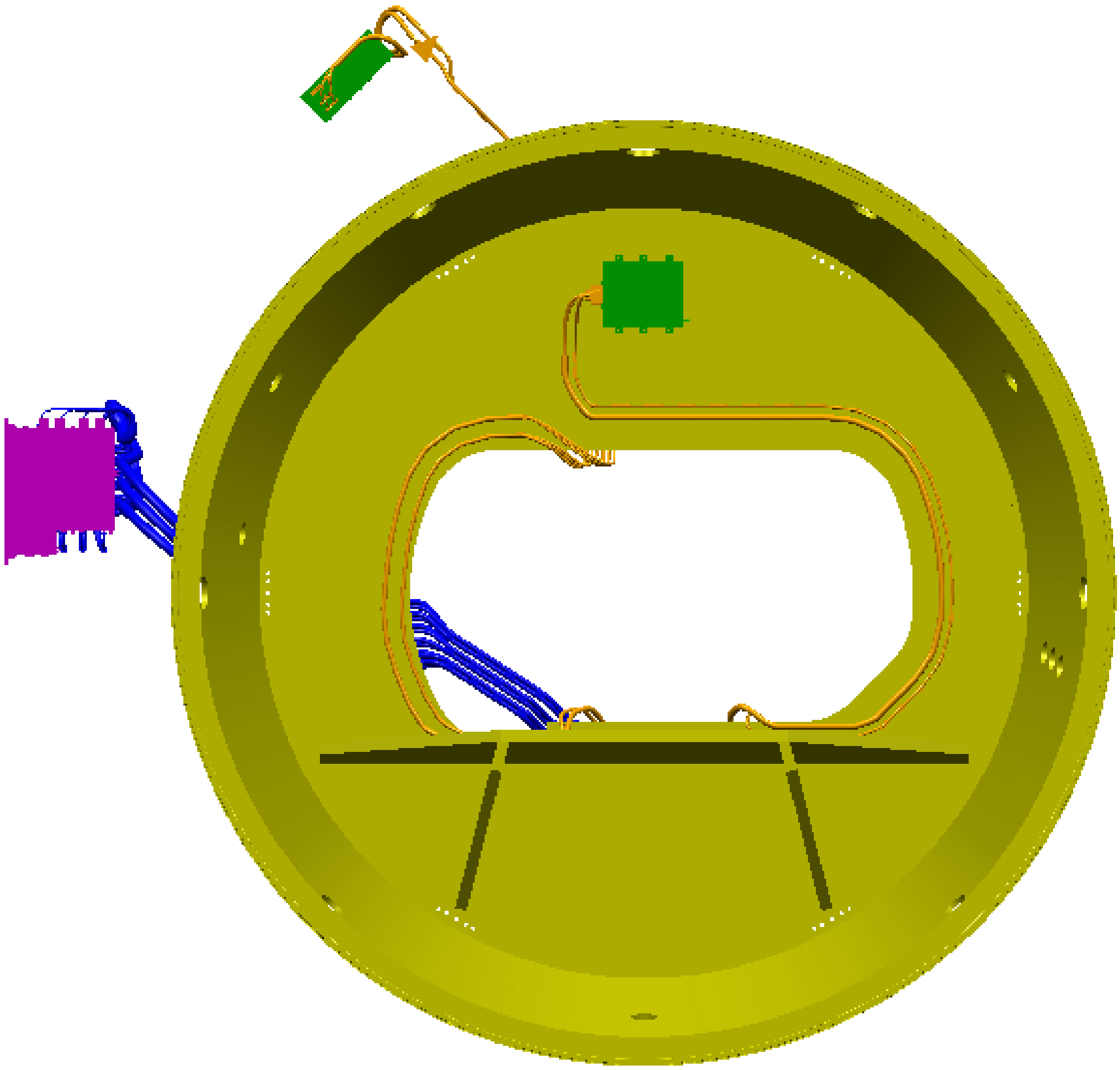
6.3.7.6.2 LFI subsystem

LFI units are accommodated on +Y+Z panel for the REBA (aside DCCU) and on sub-platform (BEU above and DAE Power box below).

The BEU and DAE are linked by WIH routing underneath sub-platform to minimise disturbances of thermal V-groove effect.

The recent removal of the stiffeners under sub-platform around DAE power box and across central hole led to modify the routing which is presented here.

The BEU is also connected to the REBA, still for thermal aspect, the harness routes under the sub-platform then jump back atop of it radially to enter in SVM box. From this point, it is going to a disconnection bracket on a shear web, before joining the REBA.



LFI subplatform harness view from below

The LFI WIH is in gold color. The LFI warm units are in green.

The PAU-REU WIH is represented in blue color. The HFI warm units are in purple.

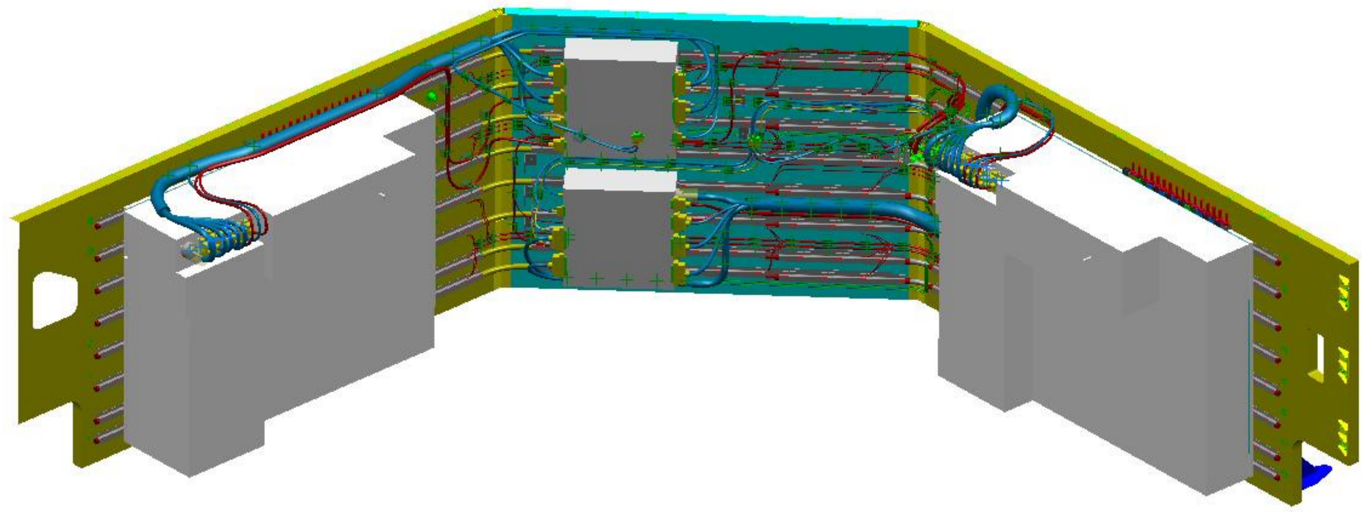
The latest document providing LFI WIH characteristics is H-P-4-NXH-RP-0024 issue A0

6.3.7.6.3 SCS subsystem

Sorption Cooler compressors and electronics are accommodated on –Y-Z, -Z and +Y-Z panels on heat-pipes.

Harnesses routing in-between heat-pipes connect the units altogether, special stand-offs are used to heighten the bundles for mounting accessibility and to allow crossing heat-pipes where necessary.

Additional harnesses run along pipes from SCC to PLM and from SCE to 2 disconnection brackets on sub-platform via shear webs and cone.



The WIH is in blue color, the SVMharness is in red color. The SCS warm units are in grey.

The latest document providing LFI WIH characteristics is H-P-4-NXH-RP-0024 issue A0.

6.3.8 TTC Subsystem

This section describes the proposed architecture and design of the TTC subsystem on both Herschel and Planck satellites.

This subsystem is a full X-X band TM&TC link with the ground stations, Kourou and New Norcia, and possibly Vilspa during LEOP. It ensures reception of ground TC and downlink of all on-board housekeeping telemetries and Instruments data. During Scientific Observation Phase, the Daily TeleCommunication Period (DTCP) with each satellite will last 3 hours per day and the high Telemetry data rate, of 1.5 Mbps at user level, will be used to download the maximum amount of on-board data.

The uplink TC rate can be of 125bps (low bit rate 1) or of 4Kbps (low bit rate 2). The capability of using the –preferred- LBR2 obviously depends on the range Satellite ⇔ Earth and of the selected on-board antenna.

The difference in Gain between Low Gain Antenna (LGA) and Medium Gain antenna (MGA) is significative with –3dBi on coperture edges for the LGA and +12.8dBi for the MGA, but the second open is obviously narrower (more directive) therefore cannot be used if the Satellite antenna is not aligned with the Earth within a maximum aperture angle.

The spacecraft to Earth aspects angles have been optimised to cope with the different ground stations and associated performances. Kourou ground station is far less performant than New Norcia, with an EIRP by 16dB lower. Consequently to keep the possibility of using Medium Gain Antenna (narrow beam) for high TC bit rate transmission, the satellites aperture angle (half cone) is reduced in that case from 15° to 10°.

All New Norcia link budgets are computed with an aperture half-cone angle of 15° whereas only 10° are used for Kourou.

The uplink and downlink data rates are identical between the 2 spacecrafts, the telecommand rate can be either of 125 bps or of 4 Kbps.

The telemetry data rate can be of 500 bps or 150 kbps with Kourou, and of 5K bps, 150 Kbps or 1.5 Mbps with New Norcia.

Originally, the following distribution data rates ⇔ ground stations ⇔ antennas was applied as baseline (as per SGICD):

Uplink

	LGA	MGA
Kourou	125 bps	4 kbps
New Norcia	4 kbps	4 kbps

Downlink

	LGA	MGA
Kourou	500 bps	150 kbps
New Norcia	5 kbps	1.5 Mbps

Then, after the system PDR, ESA required to analyse the possibility to transmit TCs at 4 Kbps, with Kourou, and with the LGA during the transfer phase. This has been analysed, see RF link budgets in H-P-BD-AI-005 § 3.2. The maximum distance Earth ⇔ S/C that fulfil the 3 dB margin minimum on arithmetic link budget is 350 000km.

An other scenario has been studied, that of transmitting LBR2 (5 Kbps) in TM, still with the LGA and with Kourou ground station. The maximum distance Earth ⇔ S/C that fulfil the 3 dB margin minimum on arithmetic link budget is 750 000km.

6.3.8.1 TTC subsystem architecture

Hardware wise, both TTC subsystems are fully identical, only the Planck RFDN (RF distribution network) slightly differs form the Herschel one, due to an increased number of redundant LGA on Planck.

Herschel/Planck satellites use a standard TTC architecture which is also used for telecom data transmission to the ground (no separate channel):

- The TC Receivers are operated in hot redundancy and deliver the telecommand stream together with indications of the lock and signal strength to two hot redundant TC Decoders located inside the CDMU. The addressed decoder is then capable to select the valid signal from a priority based scheme.
- The transmitting chain is operated in cold redundancy. It is composed of 2 TM Transmitters, and 2 TWTA's RF power units plus the switches network and antennae. Each TM transmitter receives an concatenated encoded NRZ-L bit stream from both CDMU TM encoders, and subsequently performs all the modulation steps: this permits to allocate the whole RF performance requirements to the TTC subsystem.

Whereas the receiving chain is permanently ON, even during launch (it cannot actually be switched OFF), the transmitting chain is only turned ON after separation from the launcher The noticeable exception is one EPC, put in a preheating mode during launch to make possible an immediate data transmission after separation, as soon as the rest of the chain is ON. Then the Tx section ON time is limited to the Daily TeleCom Periods mainly to avoid the disturbance of the scientific operations when the TWTA is in use.

The different phases of the mission have lead to different antennas and different bit rates, on both uplinks and downlinks. The required flexibility has been implemented in a very reliable switch network, called RFDN for Radio Frequency Distribution Network which, depending on the Mission phase, connects the right antenna to the TC and TM sections.

The transponders can be commanded and monitored either via analogue lines or via the 1553 Bus, while the TWTA's and RFDN are using exclusively analogue lines.

The design also offers range and Doppler measurements capabilities through the ranging channel and the coherent mode at transponder level (same phase on uplink and downlink carriers).

NOTA: These capabilities are available only when the downlink medium rate is selected.

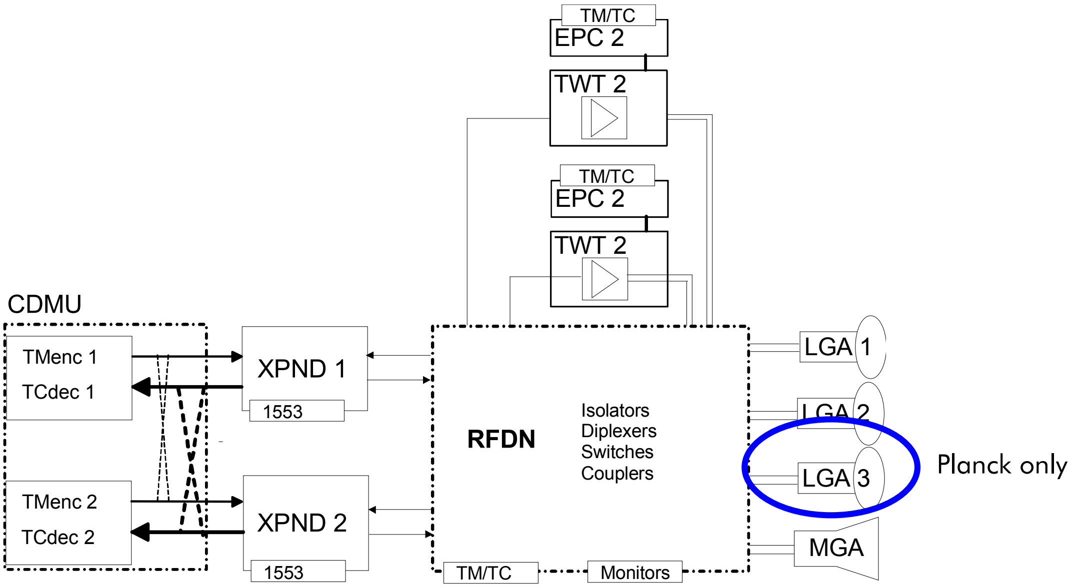


Figure 6.3.8-1 Herschel/Planck TTC Subsystem Redundancy Concept

CDMU dynamic mode ⇔ Tc receiver selection

Taking benefit of the large heritage in ESA project on multiple antennas systems, and also to avoid past problems (XMM) of wrong selection between two receivers, the CDMU supplier (SAAB) has now developed an automatic selection system, called 'dynamic mode'. This automatism will connect the active TC decoder to the strongest signal-to-noise ratio from the two TTC receivers. Each receiver provides a signal called "squelch" proportional to the in-loop Tc carrier Signal-to-noise ratio.

6.3.8.2 TTC Transponder and TWTA

The Transponder is a new design, full X-band Transponder built by AEO, making use of their large experience in S-Band transponders. The Phase demodulator ASIC is totally re-used in this new design with a gain adjustment in the LNA module to comply with the L2 low carrier level (about - 140 dBm).

Up and Down- conversion modules have been also added to move from S-Band to X-Band frequencies.

The GMSK modulation, like the low bit rate and medium bit rate modulations are digitally shaped in base-band (PGA technology) and then modulate the RF carrier with an analogue I/Q phase modulator.

This unit is essentially concentrating on low level signal acquisition and tracking, the TC carrier, and on baseband processing (modulation and filtering) of the downlink telemetry carrier.

Both modulations and TC/TM bit rates are adjustable by Telecommand.

To supply the necessary RF power at L2 (1.8 Million km) the adding of an external amplifier (TWT) has been implemented.

NOTE: the TTC transponder RF output power is settled within [- 6; + 3] dBm, which is a very low power (mw!).

The TWTA is supplied by ETCA, and can be splitted in a 35 W X-Band tube manufactured by THALES and an EPC from ETCA. The tube is very similar to the ROSETTA one and the EPC is derived from previous 1500 V EPCs. Nevertheless to fully qualify this unit and EQM approach has been agreed at the beginning of the project.

TTC Transponder TM/TC interface – evolution since PDR

At the unit PDR the interconnecting diagram between Receiver and Transmitter (one single box) raised a real concern of permanent failure propagation.

Indeed, as it was initially designed by AEO, the core of the transmitter digital processing, a FPGA, was getting its power supply from the Receiver DCDC-converter.

As a reminder, in all ESA projects, the TTC receiver and the TTC transmitter have two separate DCDC-converters. The receiver (essential load), is always connected to the satellite main bus via an FCL and cannot be switched OFF, while the Transmitter is connected via an LCL (Latch current limiter) and is fully switchable.

The H/P TTC transponder is using to the maximum extent digital processing for baseband filtering, phase modulations but also for 1553 bus transceiver handling. Several TM&TCs from the receivers were originally present only on the 1553 bus, hence requiring the FPGA to be always powered ON.

As a consequence, the presented unit DC power budget at PDR was incredibly high on the receiver:

TTC XPDR unit DC power consumption at PDR:

RX ON, Tx OFF	**17W**
Rx ON, Tx ON	25W

This link Rx DCDC-converter ⇔ Tx FPGA was rejected and new design, with no link between Rx and Tx was agreed after the PDR:

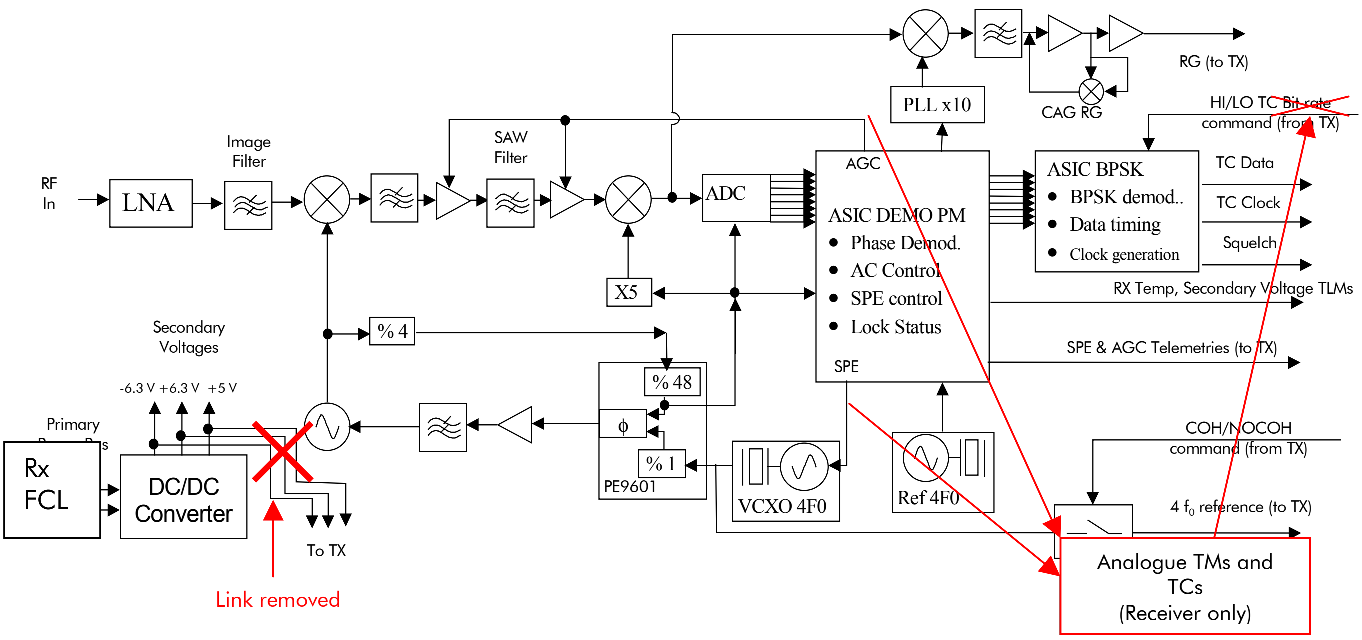


Figure 6.3.8-2 Receiver block diagram (post unit PDR)

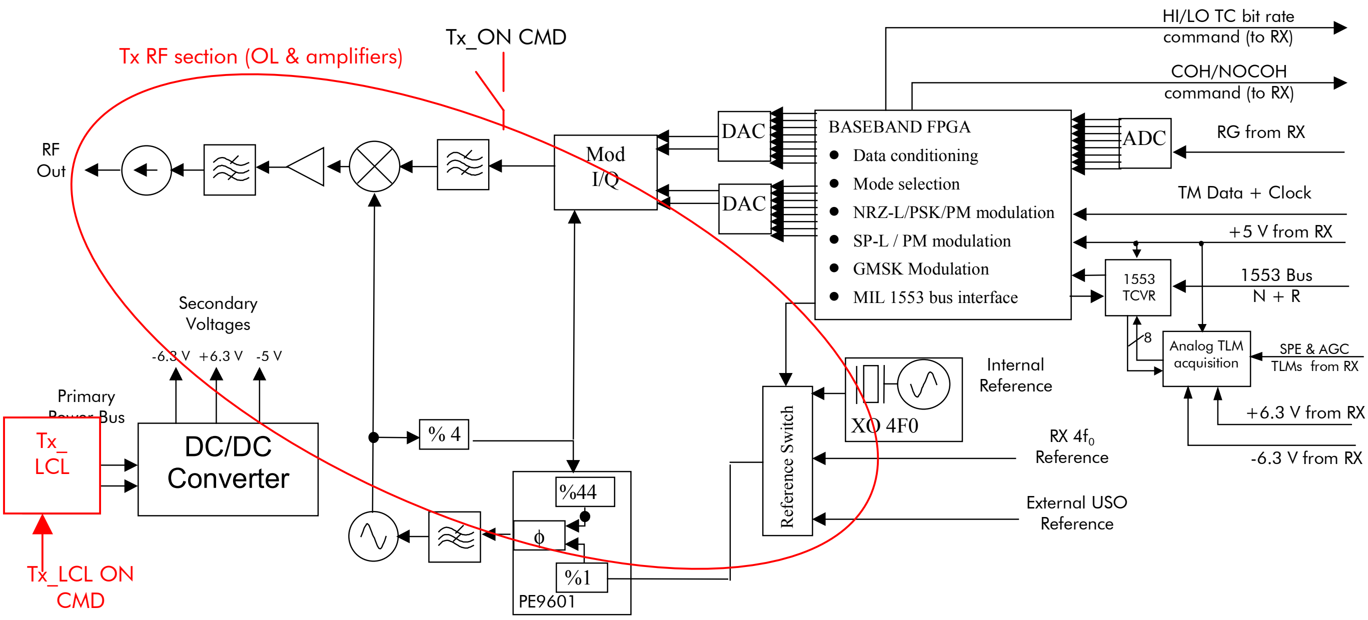


Figure 6.3.8-3 Transmitter Block Diagram (post unit PDR)

The new split Rx ⇔ Tx has improved the unit reliability in case of failure at Tx or at Rx level, no possibility of failure propagation exists anymore, and the DC power budget is now distributed in a more balanced manner:

RX ON, Tx OFF	**10W**
Rx ON, Tx ON	25W

Unit DC power consumption at CDR

Remark: all essential TM and TCs of the Receiver have been now implemented on analogue lines - in addition to the already existing 1553 bus-. The possibility of using also the 1553 bus to access the Receiver is however left to the ground segment, since the Tx FPGA (controlling 1553 access) is powered as soon as the TTC Tx LCL is switched ON. In other words an intermediate operating mode is now available for this unit: Rx ON, Tx OFF, but Tx_LCL ON. This mode requires the following intermediate DC power:

Rx ON, Tx OFF with Tx_LCL ON	23W

Intermediate mode (1553 bus access for Rx)

The Receiver Telemetries, Rx_AGC, Rx_loop_stress, are now also implemented on analogue lines, and the Tc_bit_rate selection (and status) has been removed from the 1553 bus and moved on analogue lines in order to be always available even in the Transmitter FPGA is not active (low power mode, 10W only).

[for more details, refer to TTC XPDR IDS H-P-4-AEO-ID-2002_is2 (CDR issue).

An other major event since system PDR, the ranging tone frequency has been finally selected to be at 698.260 kHz. This frequency as explained in § 6.6.1. more in details, is fully compatible with the MBR TM spectrum and the activation of Ranging channel (RNG ON command) doesn't degrade the TM link Ber by more than 0.1dB (negligible).

6.3.8.3 Antennas

Low Gain Antenna

For both Herschel and Planck satellites, omni-directional coverage is targeted by using a set of low gain antennas offering a –3dBi gain over an hemispherical coverage as shown on the following artistic views:

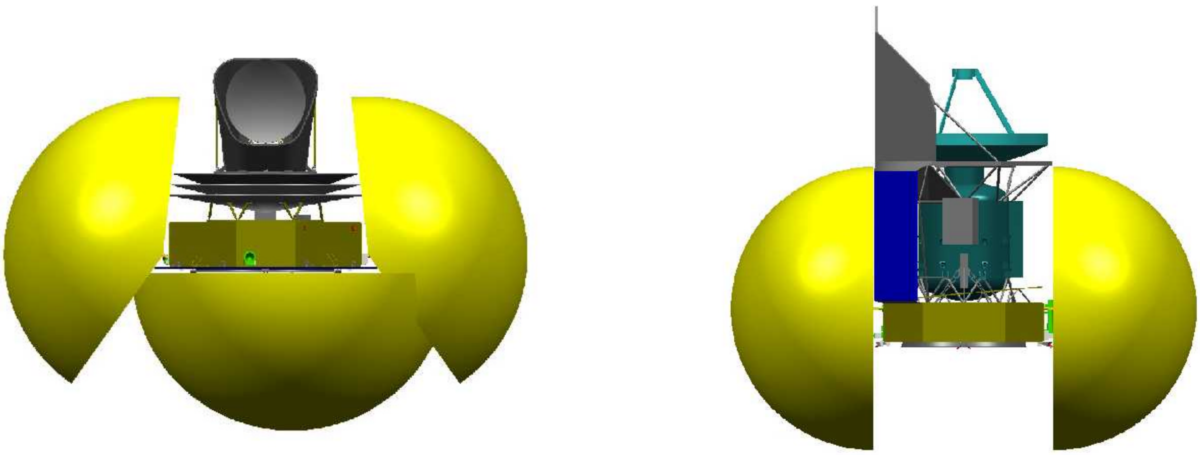


Figure 6.3.8-4 Low gain antennas location – combined coverage

Three antennas have been necessary on Planck in order to cope with the impossibility to install any antenna on +X axis (telescope side).

At system level a GTD analysis has been conducted for Planck to quantify the impact of the structure on the resulting LGA pattern. One outcome of this analysis has been the optimisation of the lateral LGAs tilt angle **(35°)** with respect to the SVM structure.

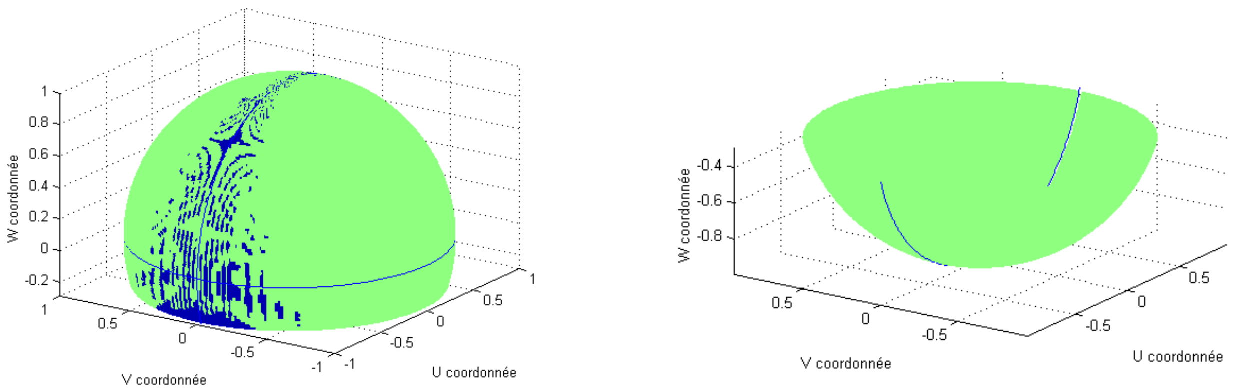


Figure 6.3.8-5 Prediction of Planck combined –3dBi gain coverage

This optimum angle of 35° was later on confirmed by test by the antenna supplier (RYMSA), by test of an Elegant Bread board and then by analysis for the grooves contribution [doc. HP-AN-RY-0091_is1 TN Planck LGA Red MockUp Measurement]. Nevertheless, the percentage of the 4Pi steradian sphere, warrantying the minimum gain of - 3dBi has been evaluated to be about 92 %.

The exact figure will be conforted by the system measurements on both satellites RF mock-ups, in autumn 2004. These RF mock-ups are likeky to reproduce the actual reflections and refractions of the S/C structure and they will be equipped with the actual FM LGAs.

Each mock-up design has been optimised in mass and in height by the supplier (INTA) to cope obviously with the test facilities limitation. All RF patterns (gain, phase, co- and cross-polarisation) will be measured in far field condition in an outdoor test range.

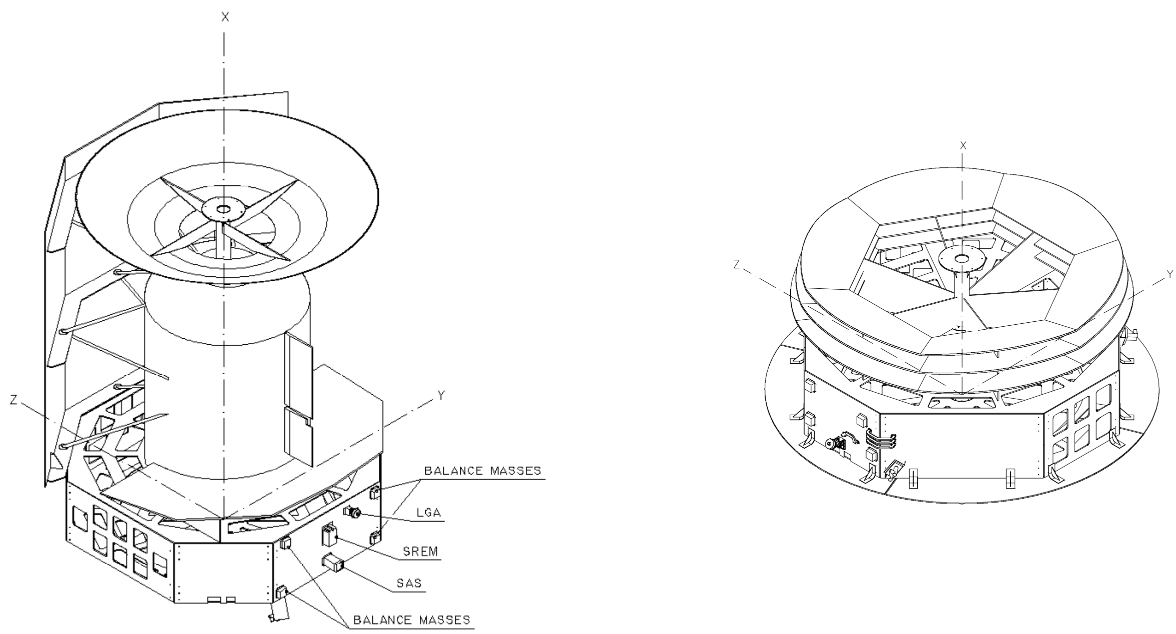


Figure 6.3.8-6 Herschel and Planck RF mock-ups

It must be underlined that the system GTD analysis demonstrated that nothing beyond the grooves is affecting the LGA pattern, on Planck.

On Herschel, the truncation of Sunshield is not having any impact either, please refer to the ASP modelling report RD04.19.

The actual flight support brackets and antennas will be installed on each RF mock-up and on Planck, the phase and amplitude unbalancing between LGA2 and LGA3 (lateral antennas having different waveguides lengths) will also be implemented during the test.

Medium Gain Antenna

A medium gain antenna (peak gain 20 dBi) is also installed on each satellite to give the necessary gain to RF link budgets when transmitting the high data rate (1.5 Mbps).

This antenna, also manufactured by RYMSA, offers about 16 dBi at 10° half cone angle and about 13 dBi at 15° half cone angle.

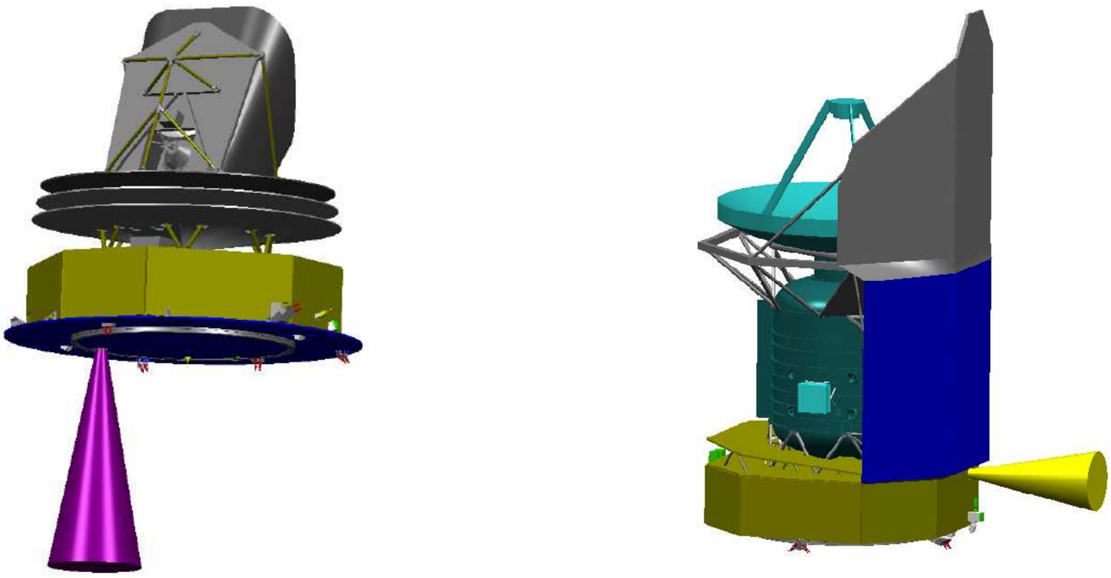


Figure 6.3.8-7 Medium Gain Antennas (MGA) location

The antenna FM units are already manufactured and tested. LGA results are better than the predictions and MGA results are in line with predictions. All FM antennas are therefore already available for integration on RF-mock-up. RF mock-up tests are planned between September 2004 and end of 2004, beginning by tests in Planck configuration followed by Herschel configuration.

6.3.8.4 Antennas Switching Network (RFDN)

This network is simplified to the maximum extent to reduce the complexity (reliability) and also the associated insertion losses that directly impact the RF link budgets margins.

The RFDN is split between and 'internal RFDN' installed on the SVM RF panel together with both TWTAs, Transponders, and an 'external RFDN' composed of a succession of waveguides installed around the SVM central part (cone).

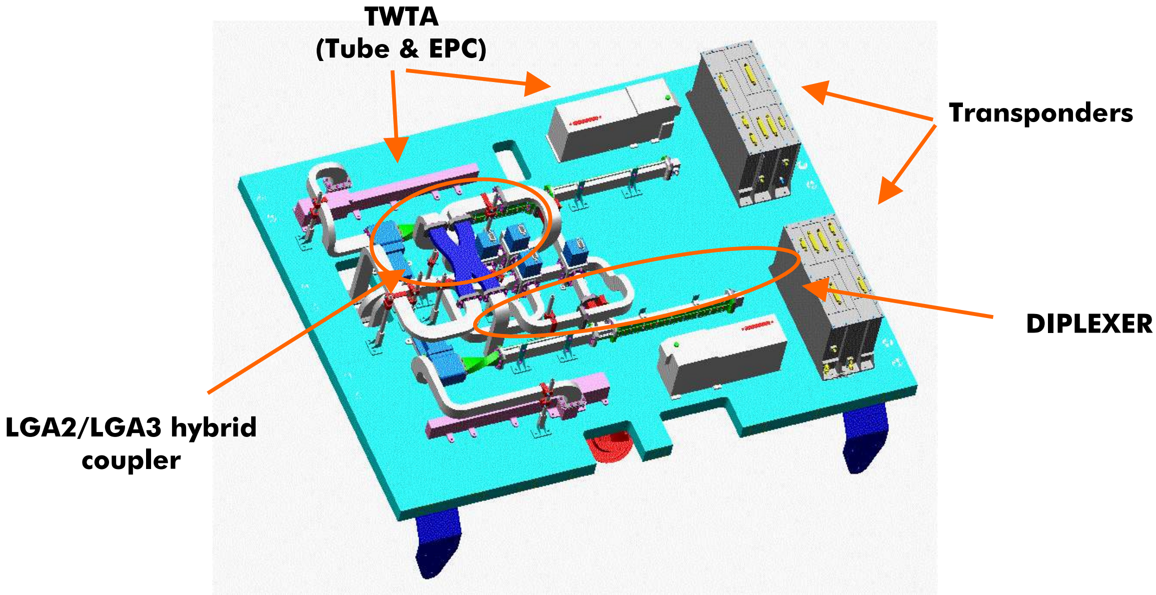


Figure 6.3.8-8 SVM RF panel with internal RFDN

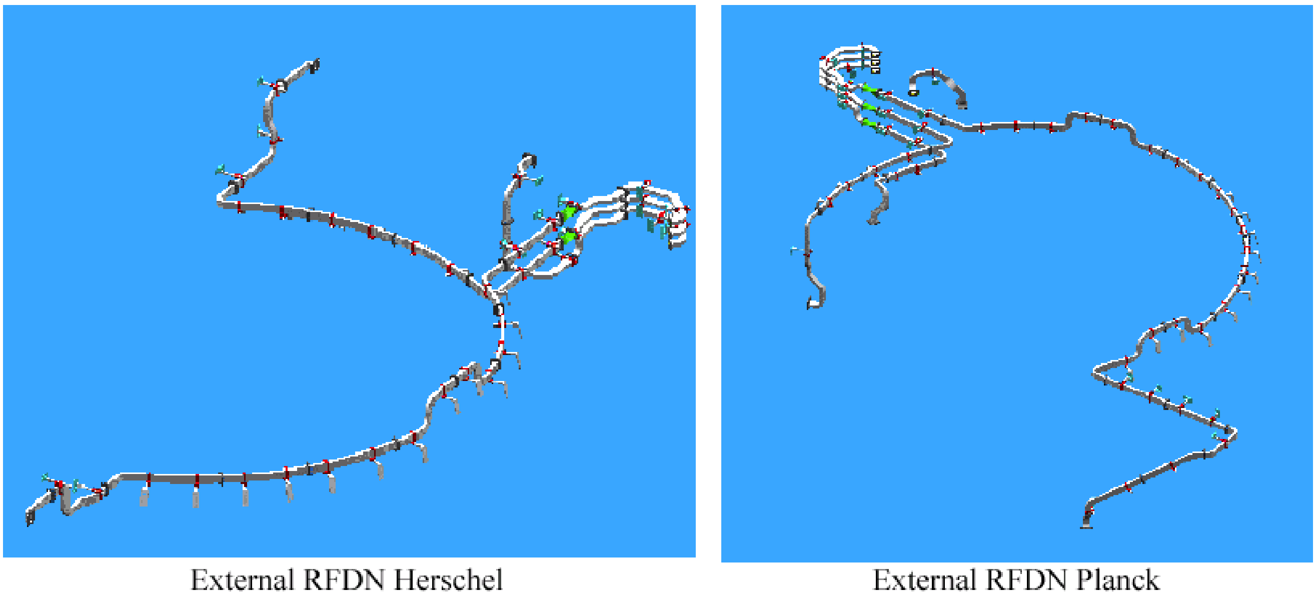


Figure 6.3.8-9 RFDN external parts (waveguides)

The proposed RFDN architecture can be split in a low power section using coaxial cables connected to the TC receivers, and a high power section connected to the high power tube amplifiers (TWTA). To minimise passive losses from the transmit section to the Antennas, waveguide technology has been used.

To give an order of magnitude of the insertion losses:

Rx losses (from antennas to Receivers)

- Nominal LGA
  - Herschel (LGA1 to Rx): 2.2dB
  - Planck (LGA1 to Rx): 1.77dB.
- Redundant LGA (wc)
  - Herschel (LGA2 to Rx): 2.43dB
  - Planck (LGA2 to Rx): 6.27dB (hybrid in between).
- Medium Gain Antenna (MGA)
  - Herschel (MGA to Rx): 2.85 dB
  - Planck (MGA to Rx): 1.8Db.

Tx Losses (from TWTA to Antenna)

- Nominal LGA
  - Herschel (LGA1 to Rx): 1.85dB
  - Planck (LGA1 to Rx): 1.57Db.
- Redundant LGA (wc)
  - Herschel (LGA2 to Rx): 2.08dB
  - Planck (LGA2 to Rx): 5.97dB (hybrid in between).
- Medium Gain Antenna (MGA)
  - Herschel (MGA to Rx): 1.57 dB
  - Planck (MGA to Rx): 1.5dB.

Design evolution since PDR

After discussion at system PDR (ESA RID 7882) it has been commonly agreed that the two coaxial switches on the Rx path were removed.

Originally these switches were thought to allow a different Rx and Tx antenna for a given Transponder, in other words a different a antenna connected to the receiver and to the transmitter. This flexibility was adding insertion losses on a critical path (receiving section) for an operating configuration not seen as really necessary.

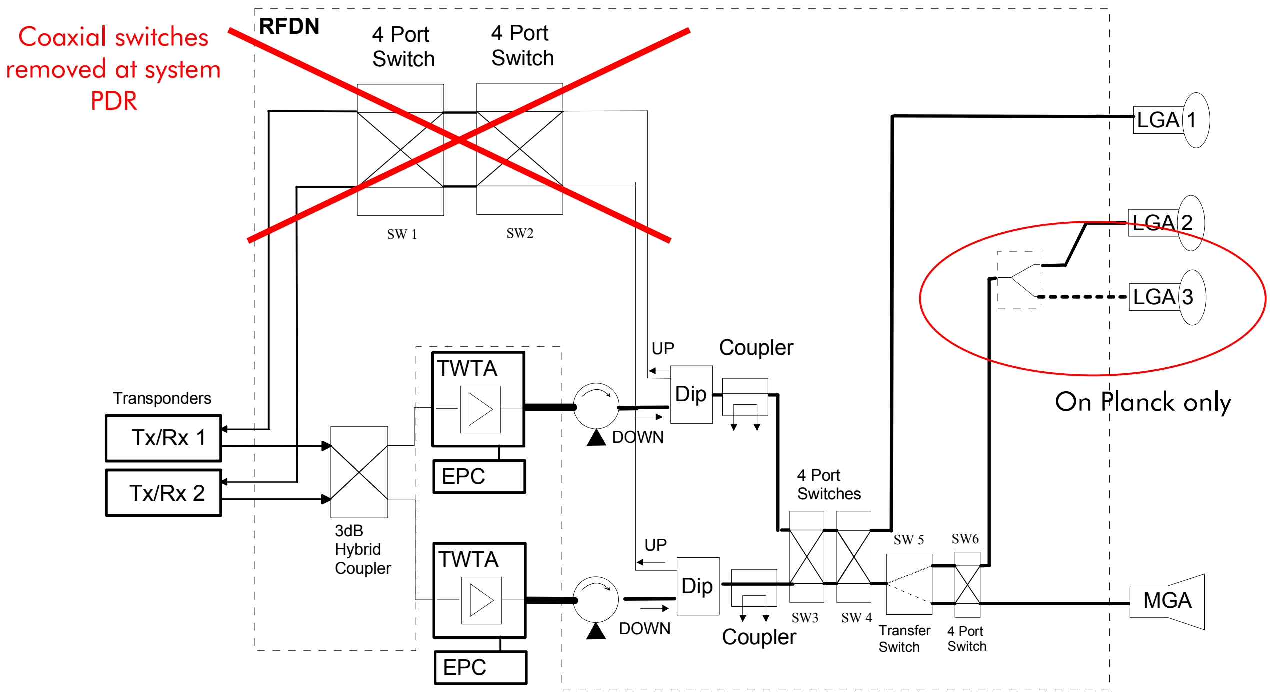


Figure 6.3.8-10 Herschel & Planck RFDN Architecture

So far the RFDN STM and EQM models are already manufactured, and the EQM insertion losses give (at ambient) better results than predicted.

6.3.9 EMC approach

6.3.9.1 General

System level EMC design is based on both:

- a system bonding, grounding and shielding strategy aiming at reducing both the noisy units spurious conducted and radiated emissions, and to control the coupling paths to the Instruments sensitive electronics; this is detailed in the following paragraphs;
- system margins built in the EMC specifications: this is analysed in H/P EMC analyses, RD04.3.

6.3.9.2 System Grounding/Shielding concept

General concept

The general system grounding and shielding concept is described in the GDIR (AD05.1) § 6.2. The main issues are recalled hereafter:

- the distribution of the power lines follows a classic star concept; the primary power return is grounded at one single point in the PCDU; this concept, together with the users primary EMI filters and with the active protections set in the PCDU provides and optimal decoupling between the various power lines, limiting as far as possible the noise propagation from one user to another through the power lines

- DC/DC converters must include galvanic isolation between the 28 V input and the secondary voltages supplying the electronics
- all equipment chassis are connected to the spacecraft structure through the lowest achievable impedance path (not only resistance), the goal being to build an equipotential voltage reference; as far as possible, the units metallic cases shall be in contact with the panels structure (where aluminium face-sheets are used), so that the grounding strap(s) are not the only path for the common mode currents.

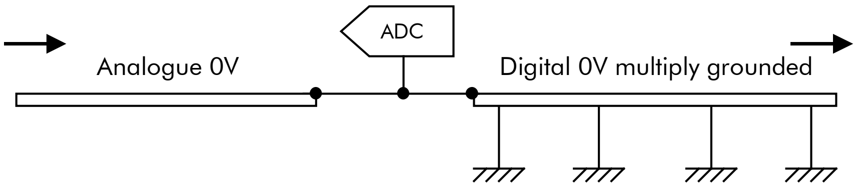
Secondary zero volts grounding

The secondary power return grounding rules specified in the GDIR are the following:

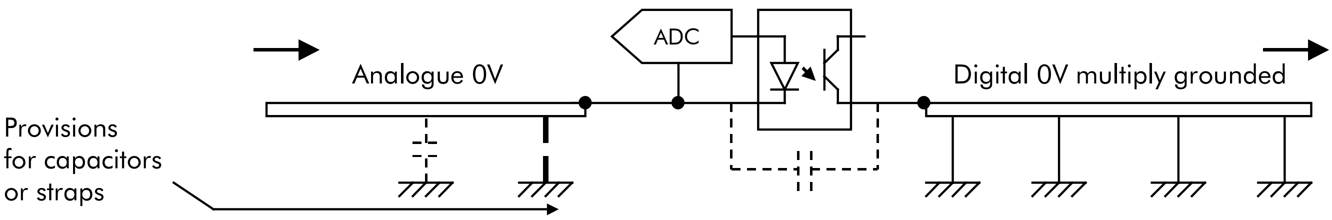
- GDEL-240: Each user secondary power return shall be connected to a single ground (ground point/ground plane). This ground point/ground plane shall be connected to chassis
- GDEL-270: When a single converter via multiple windings supplies one or more equipment, the secondary power return shall be grounded to a single location within the supplied unit(s); one secondary power output shall not be distributed to more than one unit
- however in order to reduce common mode conducted emission and radiated emission, and not to threaten signal integrity, the digital 0Vs should be connected to chassis in a distributed way (i.e. multipoint grounding). The Instruments have been advised so in EMC Working Group meeting.

For mixed analogue/digital boards, they were advised to adopt the following strategy:

- Connection of the analogue 0V to the digital 0V at the ADC, the digital 0V layer being multiply grounded to chassis:



- If the insulation of the analogue 0 V from chassis is absolutely necessary in the unit where A to D conversion is made, to consider insulating the ADC 0V from the next digital stages by opto-couplers, while keeping provisions at PCB level for capacitors or straps to chassis:



Shielding concept

In order to control the radiated emission from harness transmitting digital signals, shielded twisted lines will be used. For that kinds of "high frequency" signals, the shielding if efficient only if grounded at both ends.

This should in particular be applied to all RS-422 lines and to the 1553. For the 1553 this should be applied to the main bus and to the stubs.

6.3.9.3 SVM to PLM bonding implementation

On both satellites, warm SVM and cold PLM are linked by isolating glass fibre struts for thermal decoupling purpose. This implies that the metallic links between SVM structure, PLM structure and optical bench are limited. Anyway on both spacecrafts, some elements ensure structure electrical continuity.

Herschel

Like on ISO, the optical bench is electrically linked to the aluminium CVV through the cryogenic piping.

The CVV is then linked to SVM structure via the cryo-harness overshields. It has been decided not to introduce any additional dedicated direct links (straps…) between the SVM and CVV structures: it is better to concentrate all allowable metal cross section in the overshields, for external cryo-harness protection against ESD (cf. 6.3.7.4.) and against field to cable coupling.

Another metallic link between the Optical Bench and SVM structure is HIFI IF semi-rigid coaxial cables, with shields made of SST.

Concerning the LOU (insulated from the cryostat structure by insulating struts), its structure is electrically bonded to the SVM through the 14 waveguides that link it to the LSU located in the SVM.

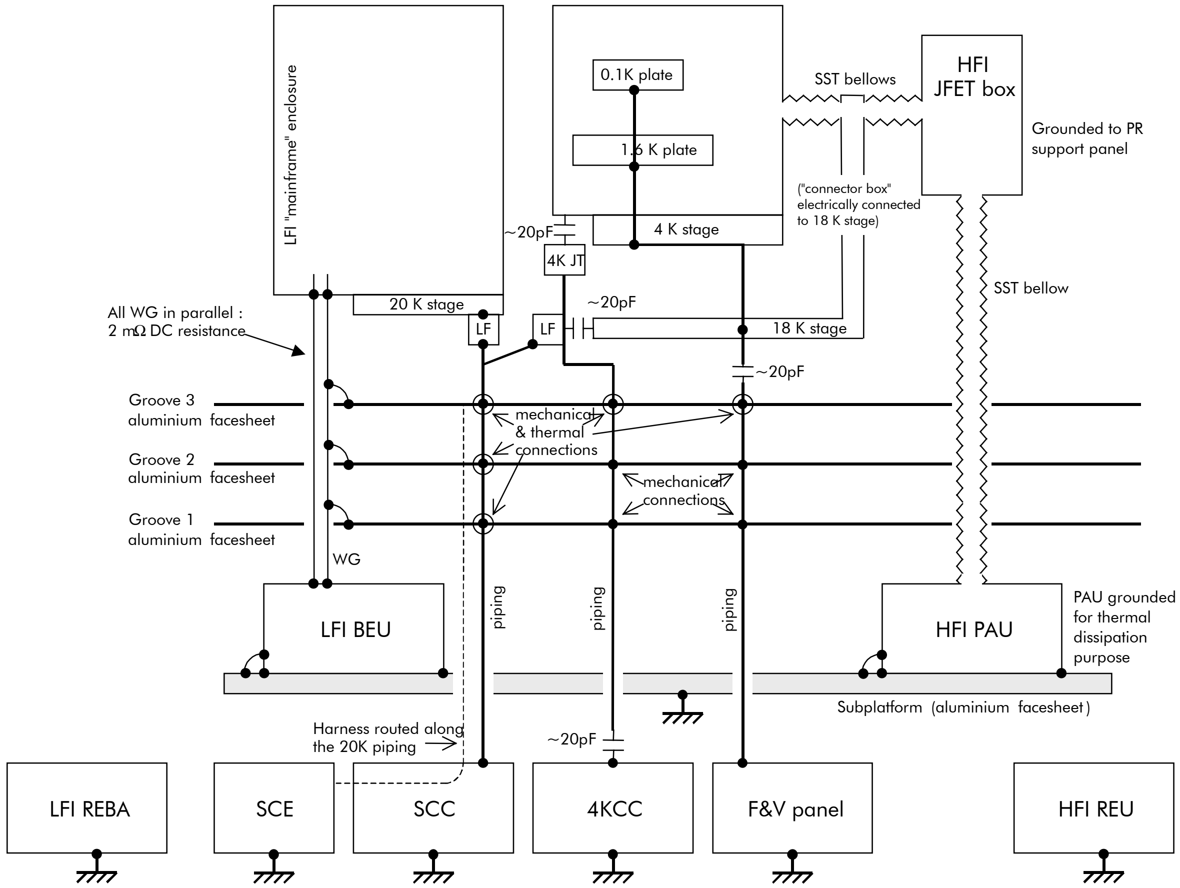
Planck

The electrical connection between FPU and SVM structures is ensured by:

- the three coolers pipings
- LFI waveguides between FEM and BEM
- the SST "bellow" protecting HFI cryo-harness.

Concerning HFI however, the 4K enclosure is planned to be isolated from the 20 K, 4 K, and 0.1 K pipings, so that the 4K enclosure connection to the rest of the spacecraft is through the FPU to JFET bellow only, so avoiding any DC loop involving the 4K enclosure, that is protecting the high impedance part of the detection chains, expected to be particularly susceptible to the so-called "ground loop coupling" (confirmed by both HFI experts experience and H/P EMC analyses, RD04.3, § 5.3.1.2.).

Planck SVM to PLM bonding is summarised in the following figure:



6.4 Propulsion

The Reaction Control System (RCS) provides the necessary forces and torques to achieve spacecraft linear and angular momentum changes necessary for orbit transfer/insertion/maintenance and attitude control, respectively, during all phases of the mission.

This section describes the propulsion subsystem for both Herschel and Planck, and the main features of its use in orbit and on ground.

6.4.1 Changes since the System PDR

Since the PDR, some subcontractors have been selected or confirmed by the ITT or RFQ process:

- EADS: 20-N thrusters and 1-N thrusters
- Man Technologie Satellite Products (MSP): tanks, and PSI as MSP subcontractor for the diaphragm.

The other Suppliers were already selected in the RCS subsystem proposal.

The following technical aspects have changed since the System PDR:

- 10-N thrusters replaced by 20-N thrusters,
- tank shells have been increased of 50μm in order to cope with the required burst safety factor of 2.0, and the scallops of the central ring have been removed,
- slight modification of the diaphragm material in order to avoid out-gassing when the diaphragm and the hydrazine are in contact,
- thrusters relocated after the definition of the thruster brackets, and motion of the spacecraft centre of mass,
- angle between Planck U thrusters increased from 60° to 70° in order to facilitate the reorientation,
- modification of the tank actual filling ratio due to the evolution of the spacecraft mass, and the modification of the required delta-vs for the missions,
- reorganisation of the wiring of the thruster cat bed heaters, either directly from the PCDU or from the ACC. This change does not affect the RCS subsystem itself.

6.4.2 Description

The propulsion architectures of Herschel and Planck are almost identical:

- Each individual diaphragm tank is connected to a dedicated pressurant (nitrogen) fill and vent valve,
- The tanks propellant parts are connected one to another to the upstream pipe,
- Tanks are used in blow down mode, with a MEOP of 24 bars,
- A propellant fill and drain valve is connected to this upstream pipe, as well as a pressure transducer and a 20μm filter,
- Two latching valves separate the upstream pipes from the downstream branches,
- Each branch is equipped with six 20-N thrusters (plus two 1-N thrusters on Planck) and one test port for ground operations.

The propulsion equipment used by Herschel and Planck presents the maximum possible commonality.

The thrusters and the latching valves are commanded by the ACC.

6.4.3 Herschel propulsion

6.4.3.1 Required manoeuvres for Herschel

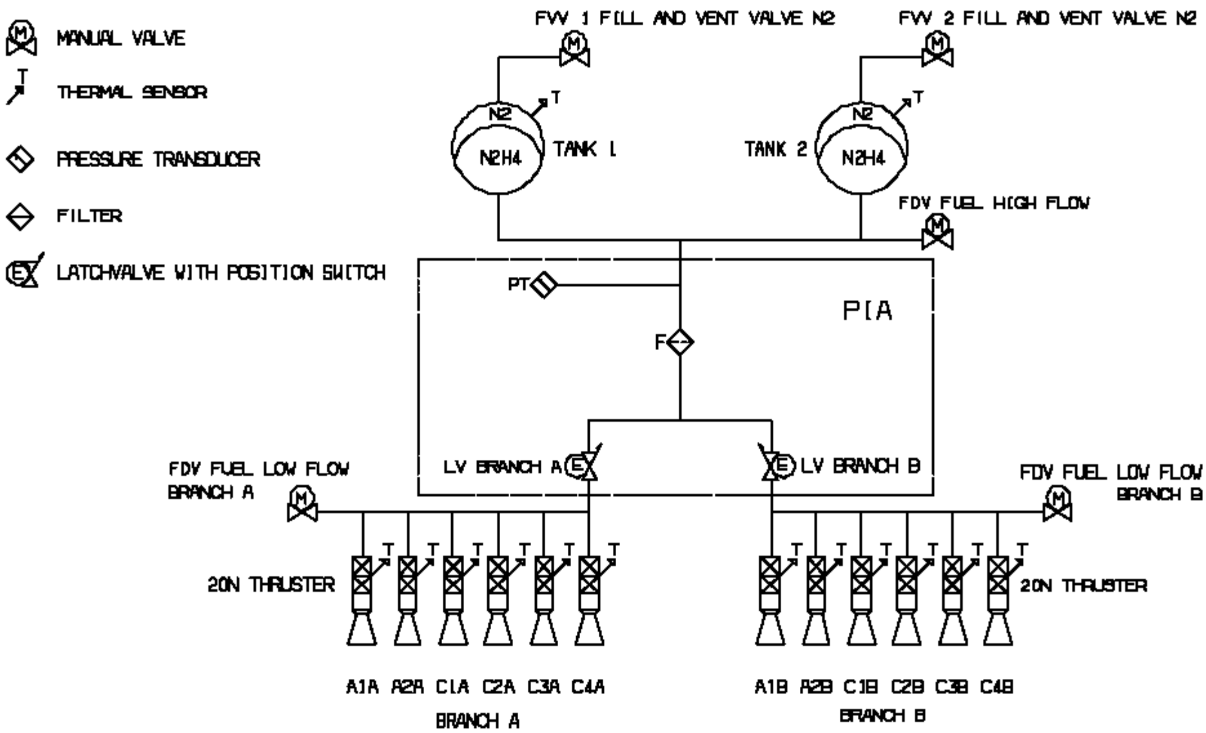
The System Requirements Specification requires the following manoeuvres on Herschel:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Perigee velocity correction	10	any
Removal of launch dispersion	40	any
Manoeuvre on day 12	4	any
Mid-course correction	3	any
Orbit maintenance	4.5	28.4 or 151.6

Most manoeuvres have no deterministic orientations. They will be calculated on-ground from the Doppler measurements, and commanded to the spacecraft. Only the orbit maintenance is systematically performed along the escape-velocity direction.

6.4.3.2 S/S configuration

Herschel RCS configuration is the following:



6.4.3.3 Thruster configuration

The Herschel thruster configuration is optimised with respect to the following criteria:

- capacity to generate forces according to the mission analysis
- capacity to generate torques on all axes to control the spacecraft attitude in orbit control mode and to off-load the accumulated angular momentum
- minimise the number of thrusters
- avoid payload contamination.

Herschel thruster configuration consists of 6 nominal thrusters (and 6 equivalent redundant):

- 4 control ("C") thrusters, located on the –X side of the SVM to avoid contamination of the payload, to generate torques. Choosing 2 thrusters among these 4 leads to 6 possibilities, creating torques in +X, -X, +Y, -Y, +Z and –Z. See torque table below
- 2 acceleration ("A") thrusters used to create the delta-vs. The "A" thrusters are used one at a time. They are pointing to the average centre of mass (with a tilt angle of about 40° from X axis).

The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN S/C FRAME			**DIRECTION IN S/C FRAME**		
			x [mm]	**y [mm]**	**z [mm]**	**x**	**y**	**z**
Branch A	**20N**	**A1A**	-102.6	571.1	1635.0	-0.77333	0.20586	0.59966
		A2A	-145.8	-772.6	-1649.6	-0.77177	-0.27304	-0.57430
		C1A	-113.4	1700.0	-546.1	-0.57358	0.00000	-0.81915
		C2A	-113.4	1700.0	546.1	-0.57358	0.00000	0.81915
		C3A	-113.4	-1700.0	546.1	-0.57358	0.00000	0.81915
		C4A	-113.4	-1700.0	-546.1	-0.57358	0.00000	-0.81915
Branch B	**20N**	**A1B**	-95.1	657.4	1616.3	-0.76996	0.23719	0.59237
		A2B	-118.6	-859.3	-1640.0	-0.76274	-0.30312	-0.57126
		C1B	-113.4	1610.0	-546.1	-0.57358	0.00000	-0.81915
		C2B	-113.4	1610.0	546.1	-0.57358	0.00000	0.81915
		C3B	-113.4	-1610.0	546.1	-0.57358	0.00000	0.81915
		C4B	-113.4	-1610.0	-546.1	-0.57358	0.00000	-0.81915

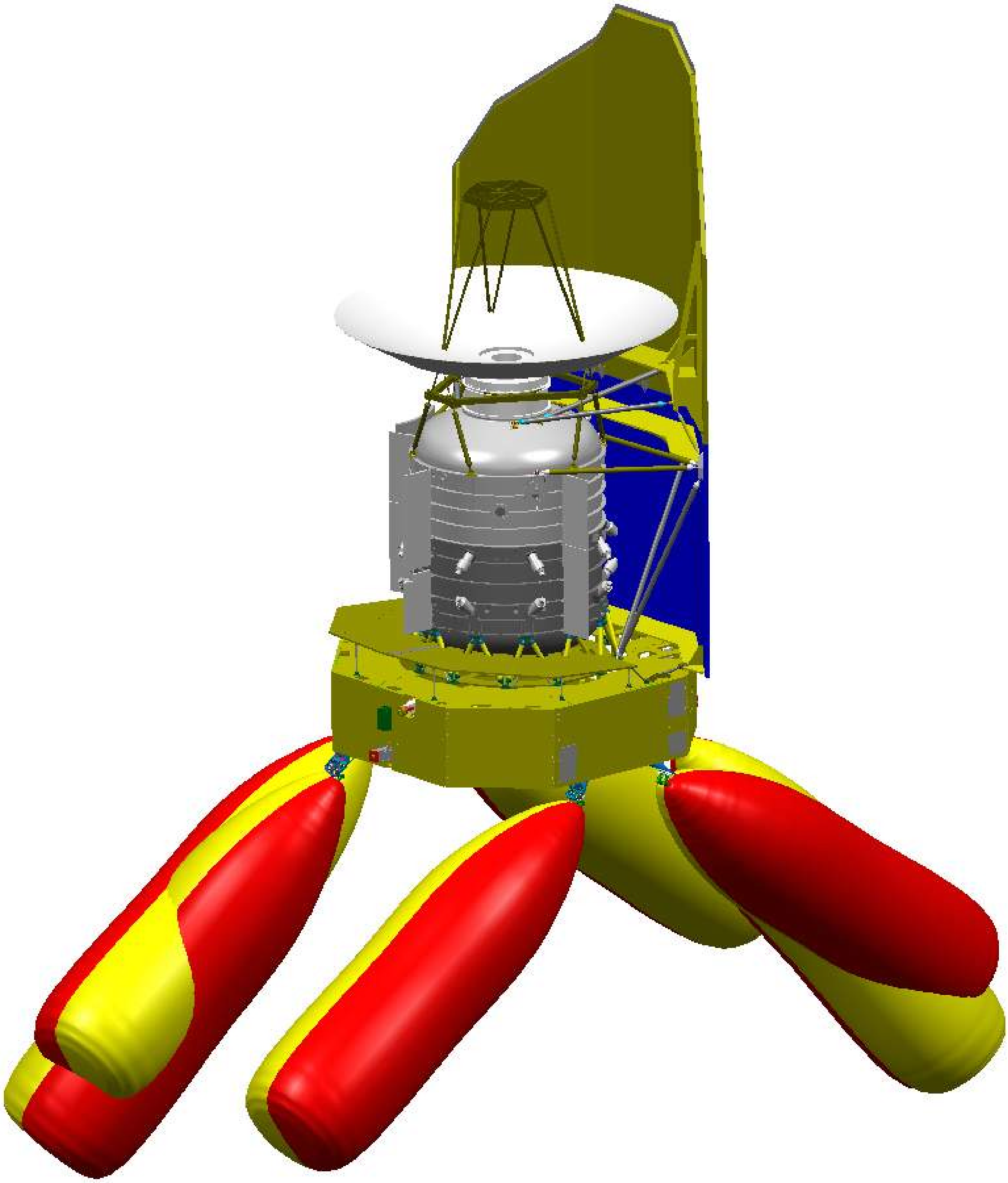
Due to the initial tank filling ratio, Herschel 20-N thruster forces in steady state will be between 23.5N at BOL and maximum and 15.4N at EOL and minimum temperature.

The torques generated by the nominal thrusters (when their force is 20N), around the average centre of mass are:

		TORQUE IN S/C FRAME		
		Tx [N·m]	**Ty [N·m]**	**Tz [N·m]**
Branch A	**A1A**	-0.01	-0.02	-0.01
	A2A	0.00	0.03	-0.01
	C1A	27.85	29.30	-19.50
	C2A	-27.85	-28.73	-19.50
	C3A	27.85	-28.73	19.50
	C4A	-27.85	29.30	19.50
Branch B	**A1B**	0.00	-0.02	0.00
	A2B	-0.03	0.03	0.02
	C1B	26.38	29.30	-18.47
	C2B	-26.38	-28.73	-18.47
	C3B	26.38	-28.73	18.47
	C4B	-26.38	29.30	18.47

The two branches provide similar forces and torques.

The following drawing shows Herschel thruster plumes (6kW) for both nominal are redundant thrusters.



6.4.3.4 Thruster usage

This section of the design report presents the main characteristics of the thruster configuration and their use. More details are presented in the dedicated tech note (Thruster Utilisation, H-P-1-ASP-TN-0689).

The following table describes the different possibilities to use the thrusters.

TYPE OF MANOEUVRE	A THRUSTERS	C THRUSTERS
Orbit correction	One thruster used continuously	Combination in ON-modulation
Torque generation	Not used	Combination in ON-modulation

Herschel can generate a torque in any inertial direction without having to make an attitude manoeuvre.

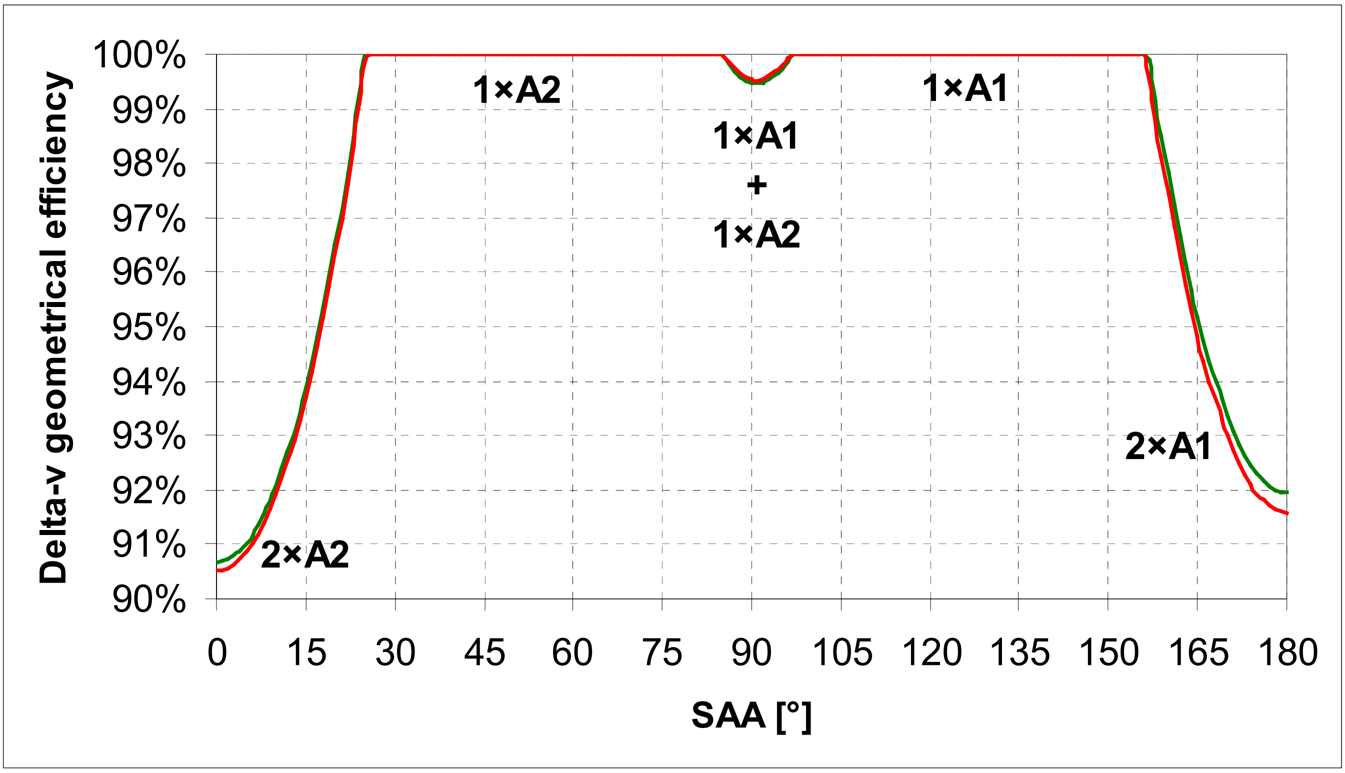
However, it has to slew to generate a delta-v in the required inertial direction. For this, Herschel benefits of a large manoeuvre capacity:

- any rotation about the Sun line, keeping +Z towards the Sun
- rotation of ±1° around X (negligible impact)
- rotation of ±30° around Y.

TYPE OF MANOEUVRE	A1 THRUSTER	A2 THRUSTER	C THRUSTERS
Orbit correction SAA < 25°	Not used.	Used continuously, two times separated by a S/C slew.	On-modulated to generate torque.
Orbit correction 25° < SAA < 84°	Not used.	Used continuously, only once.	On-modulated to generate torque.
Orbit correction 84° < SAA < 97°	Used continuously, only once.	Used continuously, only once. A1 and A2 thrusts are separated by a S/C slew. The two thrusts of A1 and A2 can be performed in either order, never simultaneously.	On-modulated to generate torque.
Orbit correction 97° < SAA < 156°	Used continuously, only once.	Not used.	On-modulated to generate torque.
Orbit correction 156° < SAA < 180°	Used continuously, two times separated by a S/C slew.	Not used.	On-modulated to generate torque.
Torque generation	Not used.	Not used.	On-modulated to generate torque.

6.4.3.5 Thrust geometrical efficiency

The following graph shows the thruster efficiency with respect to the Sun Aspect Angle, with the assumption that –X is pointing towards the Sun. Branch A in green, Branch B in red.



The efficiency curve has been computed assuming no modulation of the thrusters.

The average efficiency over a sphere, assuming a uniform distribution is 99.5 % for both branches.

6.4.3.6 Latching valve usage

In order to cope with on ground and launcher safety regulations, the LV will remain closed during Herschel ground operations.

In orbit, the latching valve commanding the redundant branch will remain closed. Only the nominal LV will be open. Thrusters of two different branches will then never be actuated simultaneously.

6.4.3.7 Pressure transducer usage

The pressure transducer will be used to evaluate the remaining quantity of Fuel. Its loss does not functionally constitute a single point failure, since the ACMS telemetry of the thruster usage will provide the necessary information to evaluate the consumed quantity of Fuel.

6.4.3.8 System Tests specific features

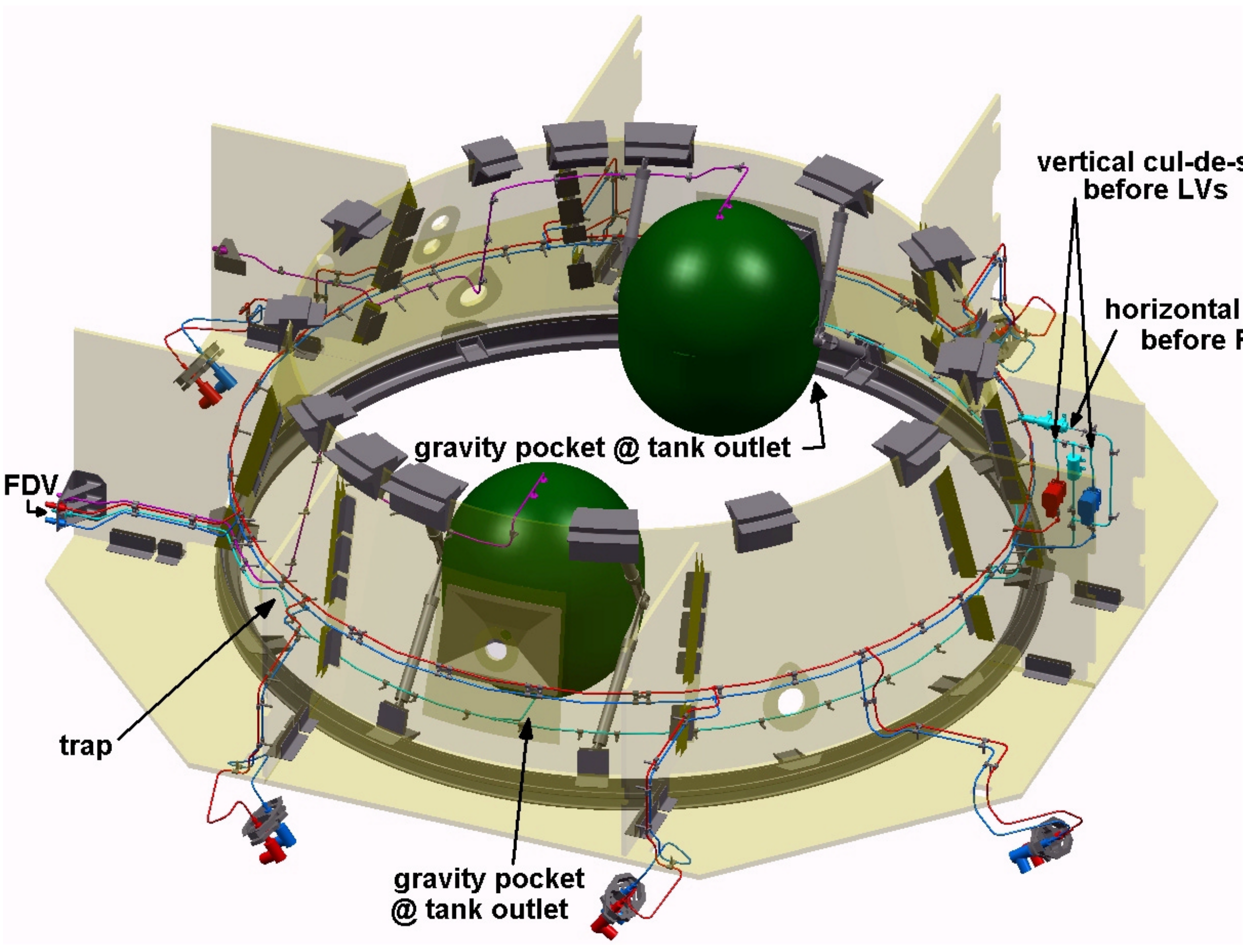
6.4.3.8.1 Environmental Tests

On Herschel STM, the tanks and pipes will be filled with de-ionised water.

On Herschel FM, the tanks and the pipe upstream the latching valves will be filled with isopropyl alcohol (IPA) during the environmental tests. The branches will not be filled with any simulating media, but only with gaseous nitrogen.

IPA is used on the FM, for much quicker to dry, in particular because of the gravity pockets of the upstream pipe. Use of IPA is not a drawback for mass representativity: the current Fuel budget of Herschel is around 76 kg per tank (assuming the last CREMA 2.3 inputs), equivalent to 94 litres of IPA. This quantity fits in the propellant tank.

The following drawing shows the gravity pockets potential issues. During the tests, only the tanks and the upstream pipe (in light blue) are filled with IPA.



There is a non negligible number of issues for draining. The main ones are the gravity pockets at tank outlet, and they cannot be avoided. Use of IPA, as volatile fluid, will facilitate the draining.

6.4.3.8.2 *Thruster Alignment*

When the spacecraft centre of mass is measured, the thrusters can be re-aligned of 2° (half-cone).

The four "A" 20-N thrusters are subject to re-alignment. The eight "C" thrusters will not.

Since the S/C centre of mass is at a minimum distance of 2740mm, the 2° realignment capability corresponds to a lever arm of 95mm.

6.4.4 Planck propulsion

6.4.4.1 Required manoeuvres for Planck

The System Requirements Specification requires the following manoeuvres on Planck:

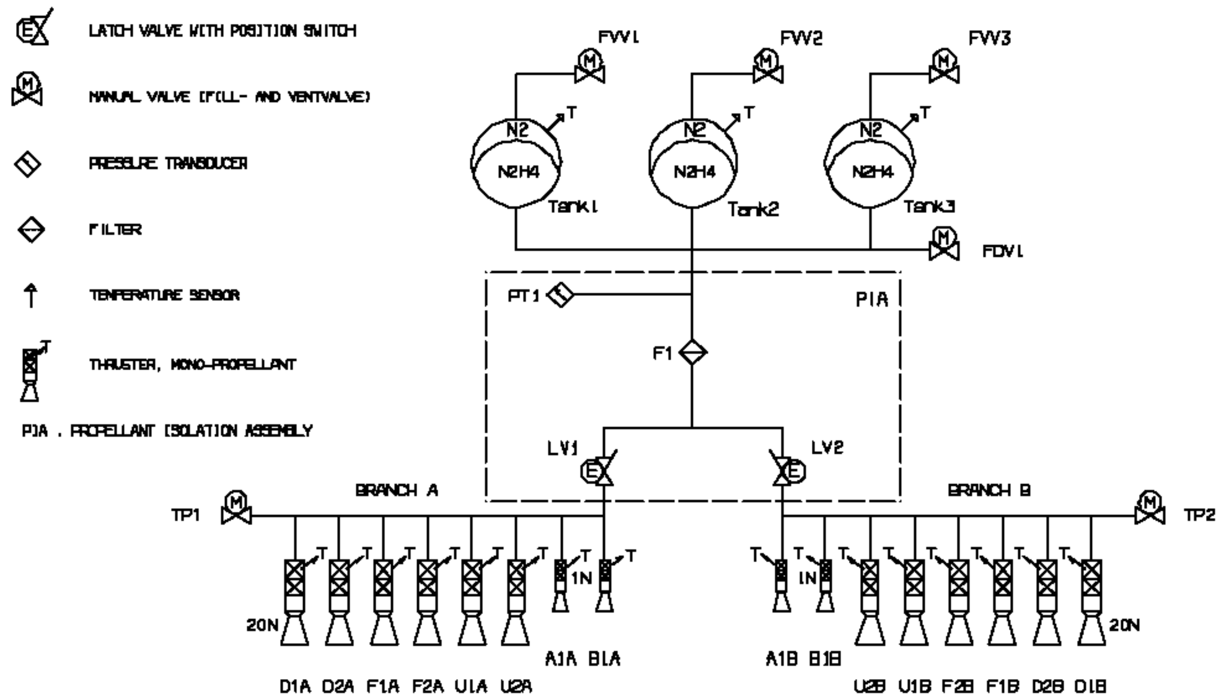
MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Perigee velocity correction	10	Any
Removal of launch dispersion	40	Any
Manoeuvre on day 12	4	Any
Mid-course correction	3	Any
Orbit injection	275/225 (*)	125
Injection correction	5	Any
Orbit maintenance	2.5	28.4 or 151.6

(*) The value of 275m/s for Planck main injection is the one present in the SRS. The value of 225m/s has been agreed in April 04, and is consistent with the duration of the yearly/daily launch window. The value of 225m/s is accounted for in the system budgets.

Most manoeuvres have no deterministic orientations. They will be calculated on-ground from the Doppler measurements, and commanded to the spacecraft. The injection manoeuvre is systematically performed along the non-escape-velocity direction.

6.4.4.2 S/S configuration

Planck RCS configuration is the following:



6.4.4.3 Thruster configuration

The Planck thruster configuration is optimised with respect to the following criteria:

- capacity to generate forces according to the mission analysis
- capacity to generate torques on all axes to control the spacecraft attitude in orbit control mode and to off-load the accumulated angular momentum
- minimise the number of thrusters
- avoid payload contamination.

Each branch of 20-N thrusters consists of 3 pairs of thrusters ("D" for down, "F" for flat, "U" for Up). The thrusters of the same pair are oriented such as their simultaneous use does not create torque.

- The D thrusters provide the capability to perform the manoeuvres with intermediate SAA. The D thrusters are oriented towards +X and are parallel in order to have the maximum efficiency.
- The F thrusters provide the capability to perform the manoeuvres with intermediate SAA. Since it is the main contributor to the overall delta-v, some specific thrusters ("F") have been accommodated to perform this manoeuvre (SAA = 125°) with the maximum efficiency. In particular, they are parallel.
- The U thrusters provide the capability to perform the manoeuvres with low SAA. Due to the presence of the PLM, it was not possible to orient the U thrusters parallel. The two thrusters of a pair form an angle of 70°, which was a compromise between the plume on the sensitive elements, the efficiency, and the sensitivity of the thruster reorientation to the location of Planck centre of mass.

The Delta-V thrusters are too strong to make the re-orientation manoeuvres with the desired accuracy. Specific 1-Newton thrusters are used for that purpose, integrated in the overall hydrazine system.

The 1-Newton thrusters are accommodated so that:

- one thruster (spin-up) has a lever arm of +0.65m around X,
- the other thruster (spin-down) has a lever arm of –0.65m around X,
- both thruster provide a lever arm of 0.4m in YZ plane.

With this configuration, only one thruster can be used for each re-orientation manoeuvre (made in three pulses). The phases of the pulses is chosen to shift the angular momentum and reduce the nutation at the end of the last manoeuvres. Both the spin-up and the spin-down thrusters can perform any reorientation. The thruster choice is made on-board depending on whether the actual spin rate is below or above 1rpm. This allows to maintain the spin rate at 1 rpm ± 1.5 %, in accordance with the SRS requirement MOOF-050.

The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN SVM FRAME			**DIRECTION IN SVM FRAME**		
			x [mm]	**y [mm]**	**z [mm]**	**x**	**y**	**z**
Branch A	**20N**	**Down 1 (D1A)**	-57.86	-575.39	1565.18	-0.99978	0.00790	0.01919
		Down 2 (D2A)	-61.14	575.39	-1565.18	-0.99978	0.00790	0.01919
		Flat 1 (F1A)	-64.60	-1688.27	576.91	-0.61501	-0.26286	0.74342
		Flat 2 (F2A)	-89.46	902.59	1571.80	-0.61501	-0.26286	0.74342
		Up 1 (U1A)	205.46	1837.80	-764.42	0.51558	0.59082	0.62057
		Up 2 (U2A)	208.07	-1840.73	-761.38	0.53113	-0.55607	0.63928
	1N	**Spin Down (A1A)**	826.47	-734.19	1718.09	-0.28343	-0.67811	0.67811
		Spin Up (B1A)	826.47	-1718.09	734.19	-0.28343	-0.67811	0.67811
Branch B	**20N**	**Down 1 (D1B)**	-57.86	-665.39	1565.18	-0.99978	0.00790	0.01919
		Down 2 (D2B)	-61.14	665.39	-1565.18	-0.99978	0.00790	0.01919
		Flat 1 (F1B)	-70.08	-1602.88	604.71	-0.61000	-0.26314	0.74743
		Flat 2 (F2B)	-68.89	816.51	1555.38	-0.61000	-0.26314	0.74743
		Up 1 (U1B)	281.67	1815.89	-808.48	0.45649	0.59118	0.66492
		Up 2 (U2B)	284.05	-1818.91	-805.16	0.47055	-0.55571	0.68540
	1N	**Spin Down (A1B)**	740.16	-716.16	1700.06	-0.28343	-0.67811	0.67811
		Spin Up (B1B)	740.16	-1700.06	716.16	-0.28343	-0.67811	0.67811

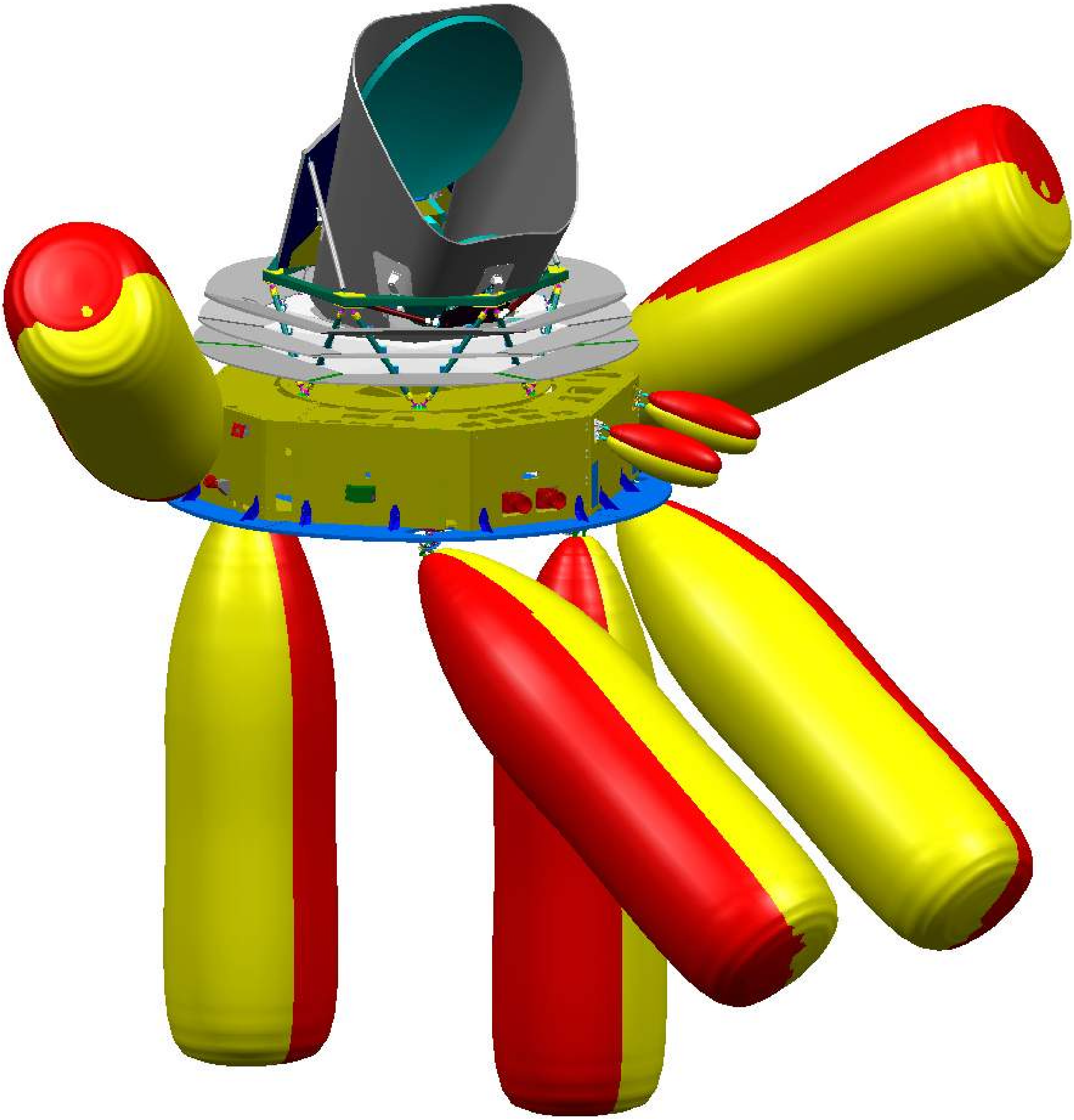
The torques generated by the nominal thrusters (forces of 20N and 1N), around the average centre of mass are:

		Torque in S/C frame		
		Tx [N·m]	**Ty [N·m]**	**Tz [N·m]**
Branch A	**D1A (Down)**	0.47	31.30	11.51
	D2A (Down)	-0.47	-31.30	-11.51
	F1A (Flat)	21.88	-5.94	16.00
	F2A (Flat)	-21.88	5.93	-16.00
	U1A (Up)	-31.73	0.01	26.36
	U2A (Up)	31.72	0.01	-26.35
	A1A (Spin Down)	-0.68	0.46	0.17
	B1A (Spin Up)	0.65	0.18	0.45
Branch B	**D1B (Down)**	0.50	31.30	13.30
	D2B (Down)	-0.50	-31.30	-13.30
	F1B (Flat)	20.58	-5.81	14.75
	F2B (Flat)	-20.59	5.81	-14.76
	U1B (Up)	-33.60	-0.01	23.08
	U2B (Up)	33.60	-0.01	-23.08
	A1B (Spin Down)	-0.68	0.39	0.11
	B1B (Spin Up)	0.65	0.12	0.39

Due to the initial tank filling ratio, Planck 20-N thruster forces in steady state will be between 23.5N at BOL and 11.4N at EOL.

The two branches provide similar forces and torques.

The following drawing shows Planck thruster plumes (6kW) for both nominal are redundant thrusters.



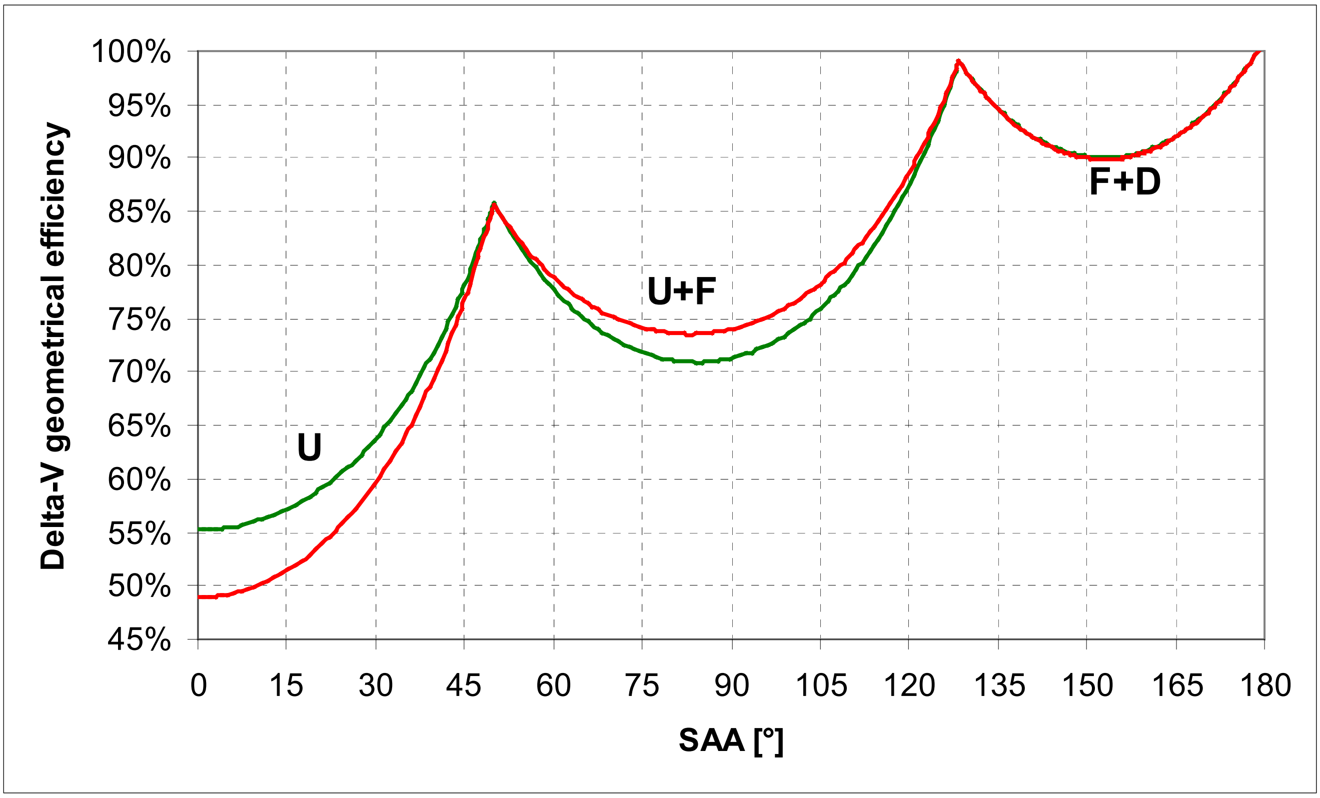
6.4.4.4 Thruster usage

The following table describes the different possibilities to use the thrusters.

TYPE OF MANOEUVRE	D THRUSTERS	F THRUSTERS	U THRUSTERS	1N THRUSTERS
Orbit correction 128°< SAA < 180°	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously.	On-modulated to generate torque.	Not used
Orbit correction 50° < SAA < 128°	On-modulated to generate torque.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously.	Not used
Orbit correction SAA < 50°	On-modulated to generate torque.	On-modulated to generate torque.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously.	Not used
Torque generation (can be superposed to the orbit correction by on-modulation)	Pulses	Pulses	Pulses	Not used
Re-orientation manoeuvre	Not used	Not used	Not used	A single thruster used three times (one pulse each time), every one or two minutes.

6.4.4.5 Thrust geometrical efficiency

The following graph shows the thruster efficiency with respect to the Sun Aspect Angle, with the assumption that –X is pointing towards the Sun. Branch A in green, branch B in red.



The efficiency curve has been computed with the Sun on –X, and assuming no modulation of the thrusters. Planck can be reoriented of 3.5° (maximum at BOL), and remains safe even in case of thruster failure. This small reorientation capability can be used to optimise the thrust efficiency. In particular, this helps reaching the maximum efficiency for the main injection, performed with an SAA of 125°.

The average efficiency over a sphere, assuming a uniform distribution is 78.5 % for both branches.

The maximum arc on which thrusters are continuously used is nominally 36°, changeable by command.

6.4.4.6 Latching valve usage

In order to cope with on ground and launcher safety regulations, the LV will remain closed during Planck ground operations.

In orbit, the latching valve commanding the redundant branch will remain closed. Only the nominal LV will be open. Thrusters of two different branches will then never be actuated simultaneously.

6.4.4.7 Pressure transducer usage

The pressure transducer will be used to evaluate the remaining quantity of Fuel. Its loss does not functionally constitute a single point failure, since the ACMS telemetry of the thruster usage will provide the necessary information to evaluate the consumed quantity of Fuel.

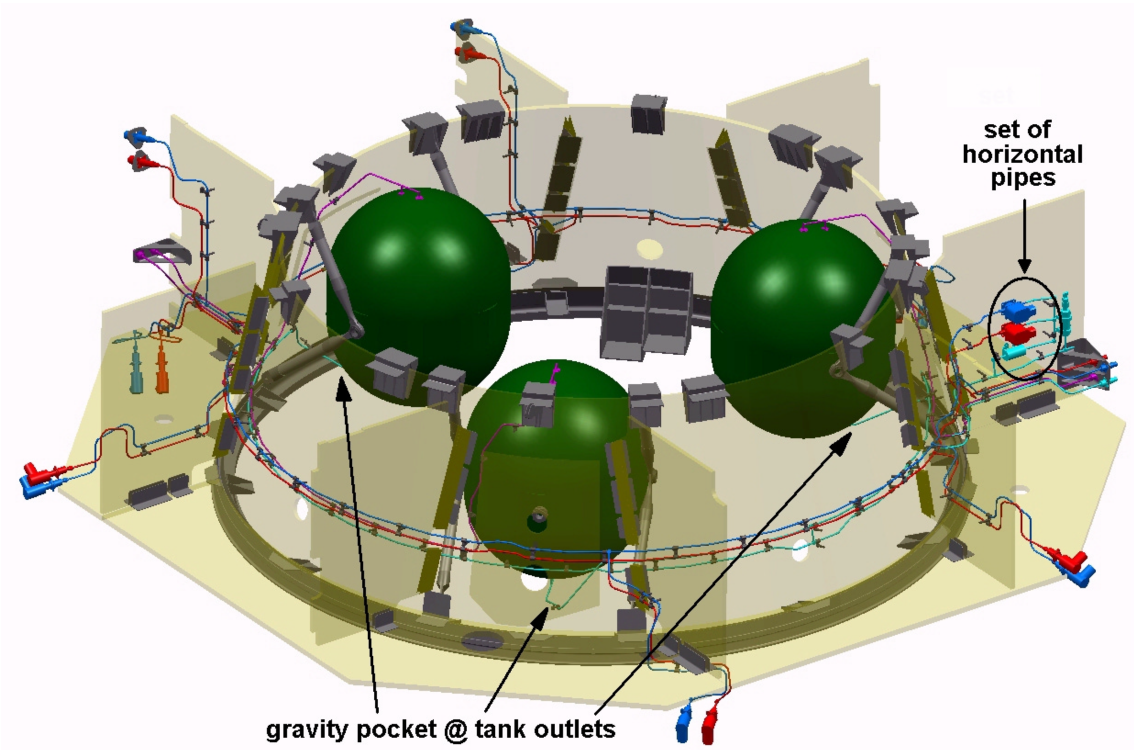
6.4.4.8 System Tests specific features

6.4.4.8.1 Environmental Tests

On Planck PFM, the tanks and the pipe upstream the latching valves will be filled with isopropyl alcohol (IPA) during the environmental tests. The branches will not be filled with any simulating media, but only with gaseous nitrogen.

IPA is used on the FM, for much quicker to dry, in particular because of the gravity pockets of the upstream pipe. Use of IPA is not a drawback for mass representativity: the current Fuel budget of Planck is around 124 kg per tank (assuming the last CREMA 2.3 inputs), equivalent to 154 litres of IPA. This quantity fits in the propellant tank.

The following drawing shows the gravity pockets potential issues. During the tests, only the tanks and the upstream pipe (in light blue) are filled with IPA.



The main issue for draining is the gravity pockets at the 3 tank outlets, and it cannot be avoided. Use of IPA, as volatile fluid, will facilitate the draining.

6.4.4.8.2 Thruster Alignment

When the spacecraft centre of mass is measured, the thrusters can be re-aligned of 2° (half-cone).

The twelve 20-N thrusters are subject to re-alignment. The 1-N thrusters are not.

Since the S/C centre of mass is at a minimum distance of 1870mm, the 2° realignment capability corresponds to a lever arm of 65mm.

6.5 Mission operations

6.5.1 Operations concept

The Herschel and Planck mission presents an intermediate status for operation between missions such as ISO or XMM/Integral which are in constant ground contact, and deep space missions like ROSETTA for which long period of autonomy are foreseen. The basic operation concept in which the 2 spacecraft in orbit around L2 are operated from one single ground station (nominally New Norcia) leads to a ground contact of 3 hours per day in average for each spacecraft (DTCP: Daily Telecommunication Period). When ground contact is not available (OP: Observation Period), the spacecraft are fully autonomous, performing science observation according to a pre-defined schedule uploaded during a preceding ground contact period. The spacecraft have been designed to cope with this autonomy requirement, allowing operation without ground contact for 48 hours, the goal being to maximise the scientific return and to put the spacecraft in safe condition in case of major anomaly only.

Another major driver is to maximise commonality in the way the two spacecraft are operated. Even if they may exhibit differences (Herschel is a 3-axis stabilised spacecraft while Planck is a slow spinner), they share a number of commonalties:

- similar orbits around L2
- use of the same ground stations
- same sharing of daily operations between OP and DTCP
- common electrical and Command/Control architecture for Herschel and Planck
- identical data rates to ground.

Commonality in operation concepts is intended to reduce the operational costs by allowing the use of the same procedure for the two spacecraft.

The Herschel and Planck spacecraft will be operated from the MOC (Mission Operation Centre) at ESOC which interfaces with the Herschel Science Centre (HSC) and Herschel Instrument Control Centres (ICCs) and for Planck with the Data Processing Centres (DCP). Commanding of both spacecraft will be conducted by MOC based on inputs received from these centres. Housekeeping telemetry received from both platform and instruments will be processed by the MOC. Science telemetry as well as relevant housekeeping will be transferred to the scientific centres.

During scientific operation, both spacecraft will be operated from the New Norcia 35 m ground station. However other ground stations are envisaged during the various phases of mission. The planned usage of ground stations during the various phases of mission is shown in Table here after:

MISSION PHASE	GROUND STATION	
Initial orbit phase	ESA Network (Kourou/New Norcia/Villafranca)	
Commissioning phase	New Norcia/Kourou (routine)	Villafranca (emergency)
Performance verification phase	New Norcia/Kourou (routine)	Villafranca (emergency)
Routine operations phase	New Norcia 35 m (Prime station)	Villafranca/Kourou (emergency)

Communication to ground relies on X-Band link for both TM and TC. TM and TC are nominally via the Medium Gain Antenna (MGA). LGA's are back up to the MGA, authorise reduced bandwidth.

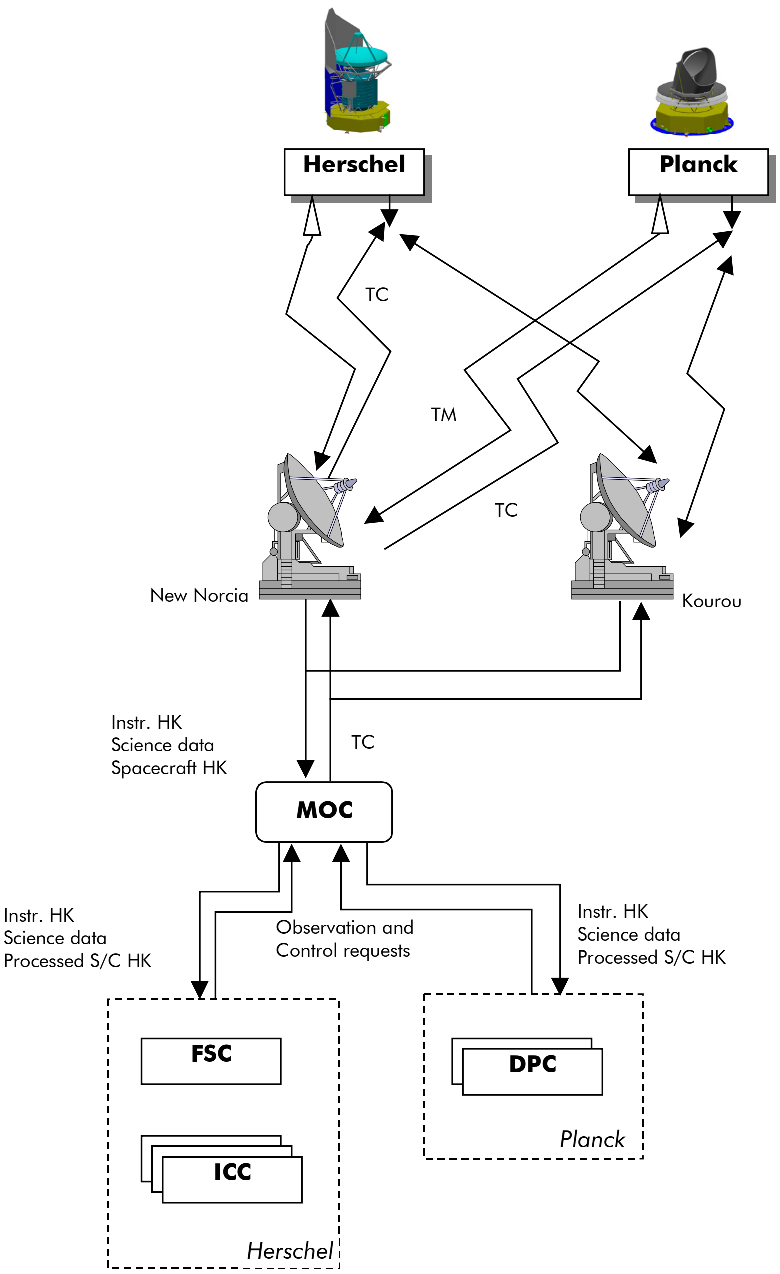
For telemetry, various modes are envisaged as shown in the following table. For commonality reasons, the same data rates have been selected for Herschel and Planck.

	Antenna	Ground Station	Herschel	Planck	Data Transmission
TM Hi-rate	MGA	New Norcia	1.5 Mbps	1.5 Mbps	Real time HK, Stored HK, Real time science, Stored Science
TM medium-rate	MGA	New Norcia/ Kourou	150 kbps	150 kbps	Real time HK + Stored HK + Real time science
TM low-rate	LGA	New Norcia	5 kbps	5 kbps	Real time essential HK
		Kourou	5 kpbs	5 kbps	During LEOP, up to 750 000 km Real time essential HK + stored S/C HK
		Kourou	500 bps	500 bps	Subsampled Real time essential HK.

Nominal TC rate is 4 kbps via MGA when communicating via New Norcia, and 125 bps via LGA when Kourou is used. In addition, TC rate of 4 kbps can be used from Kourou during LEOP, up to a distance of 350 000 km The various TC mode areas summarised in the following table; they are identical for Herschel and Planck.

	S/C ANTENNA	GROUND STATION	DATA RATE	REMARKS
TC low rate	LGA	Kourou	125 bps	
TC nominal	MGA (or LGA)	New Norcia	4 kbps	
	LGA	Kourou		During LEOP, up to 350 000 km
	MGA	Kourou		

The figure hereafter illustrates the Space to Ground link for Herschel and Planck satellites.



The operation of the spacecraft, i.e. the functional interface with Ground, is based on a set of services specified in the Packet Structure ICD. Apart from standard facilities (TM/TC interface, Memory Management, Mass Memory Interface), some features are defined to support the FDIR implementation (On Board Monitoring Function, Event/action) and two facilities are used to support the implementation of the required autonomous spacecraft operation: On Board Scheduling which defines the characteristics and use of the MTL, and On Board Control Procedure (OBCP).

As a matter of fact, the basic concept of operation of the satellites is that all activities will be performed according to the on-board Mission TimeLine (MTL) during nominal operations, even if the spacecraft is in ground visibility, while the context of operation of the satellites is defined by the current Satellite Mode (see § 6.3.3.3. "Satellite Modes"). Autonomy functions allowing spacecraft reconfiguration in order to maintain scientific activities are active on-board and do not require inputs from ground. Actions from ground are limited to receiving telemetry (real time and stored in the mass memory) and sending commands to update the Mission Timeline. The Timeline is sized to support 48 hours of autonomous operations.

Real time commanding of the spacecraft is also possible. In the meantime fault protection functions and possibly MTL are still active on-board, and ground commands are not required to maintain spacecraft safety. This is in accordance with the requirement that ground reaction shall not be required within less than 3 minutes (OIRD, CTRL-1). Protection mechanisms (definition of priorities based on the source of the telecommands) are implemented to manage possible conflicts between commands originated on board and on ground.

The reader may refer to Section 6.3.3.2.1. "Satellite Autonomy Concept" where the On board Scheduling service features are detailed.

The other functionality available to support the nominal operation of the spacecraft will be by execution of pre-defined on-board control procedures (OBCP's).

OBCP's can be activated by:

- MTL (Mission Time Line),
- Ground command
- On-board event, automatically (e.g. FDIR)
- Other OBCP's.

OBCP's are flight procedures, developed and validated on ground, which are uploaded on-board of the Herschel or Planck satellite, stored in Mass Memory until they are started, i.e. interpreted.

Characteristics and intended usage of OBCP's are detailed in Section 6.3.3.2.2.

6.5.2 Mission scenario

Mission scenarios are build from ESA inputs (mainly reference mission scenario technical note).

For CDR, they are limited to the nominal activities relevant for several OD periods. They consist in two part:

- the description of the real time activities during the DTCP,
- the description of the MTL.

6.5.2.1 Commonality on procedures

Both procedures to describe the real time activities and mission time line are described using MOIS (Manufacturing and Operation Information System - refer to Chapter 6.5.3.2.). The way the different MOIS procedures are written follows the rules expressed in the ASP document "MOIS – Rules to support modularity and commonality" and are summarised in Chapter 6.5.3.2.8. Mainly those procedures respect:

a. The commonality between Herschel and Planck.

Thanks to HPSDB (Herschel/Planck System data Base) and to naming convention, all data common between Herschel and Planck share the same definition inside HPSDB and follow the same naming convention, this allows to generate also unique common procedure. Once the procedure has been validated on a real model (AVM, Herschel PFM, Planck PFM, …) it does not need to be re-validated on the other real models.

For instance a star tracker configuration procedure ("A100ECSTR_CONF_001100") to change star tracker mode at model level can be common for AVM, SVM Herschel, SVM Planck. When the procedure has been validated on AVM it can be considered as validated on SVM Herschel and SVM Planck (it is the same procedure referring to the same items inside HPSDB). Note: there is no way from the procedure name to identify a common or specific procedure.

b. The hierarchical structure.

The hierarchical structure allows to satisfy the "smooth transition requirement" and force the user to write modular procedures which can be easily re-used. As HPSDB, The hierarchy includes four levels: generic/ element/subsystem/model. A procedure can be defined at element level, instantiated at subsystem level and re-used at model level. The instantiation principle between the different levels is the same as the instantiation process at HPSDB level (refer to Chapter 6.5.3.1.). A procedure defined at element level will be instantiated at subsystem level by instantiating its name (addition of subsystem identifier as first three characters and addition of position of the element inside the subsystem as three last characters) and by instantiating all reference to HPSDB items following the same rules as in HPSDB. Due to SCOS limitation there is no instantiation between subsystem and model levels.

For instance a star tracker configuration procedure ("ECSTR_CONF001") to change star tracker mode at element level can be instantiated at subsystem level (subsystem A100) in "A100ECSTR_CONF_001100" for nominal star tracker in position 100 and in "A100ECSTR_CONF_001101" for redundant star tracker in position 101. From this example we can see that once a procedure is validated from the nominal element it is also validated for the redundant one.

c. The type of procedure

Four types of procedure have been identified from the ALCATEL experience on other spacecraft integration and test. The procedure themselves which allow to co-ordinate the different calls, the configuration procedures which allow to set and control the configuration, the measurement procedures which allow to run test in a certain configuration and the tool procedures for miscellaneous purpose (report, calculation, …).

For instance procedure "A100ECSTR_CONF_001100" is a configuration procedure identified with the letter "C" as fifth character".

d. The interface via User Defined Constants (UDC's).

Several possibilities are offered by TOPE (Test and Operation Procedure Environment – In fact AIT test language) and SCOS to shared data:

- TOPE procedure parameters,
- TOPE global variables,
- SCOS UDC.

It is required to used the SCOS UDC's. This SCOS facility offered several advantages against the two other TOPE possibilities:

- The UDC are managed as any TM parameter by SCOS: archiving, monitoring, display, replay, …). This will facilitate the validation of the procedure and their,
- In case of TOPE procedure crash, the UDC are still accessible.

However there is a drawback: the UDC shall be declared inside HPSDB as any other parameters, but there is only a unique packet supporting UDC as a consequence allocation shall be done (refer to naming convention) in order to support the merging of test sequences (PLM and SVM to build PFM).

Note: in the current status of the mission scenario, UDC are not allocated.

e. The procedure naming convention

The procedure naming convention is: At element level:

– <Level><Type><mnemonic>

At subsystem, model and generic levels:

– <Subsystem identifier><Level><Type><mnemonic><position>

With

– <Subsystem> = <subsystem type><subsystem number>

With

– <Subsystem type>	is one character ("A" for ACMS, …,"Z")
	Note: "Z" is reserved for pseudo subsystem.
– <Subsystem number>	is three numerical digits
	In order for instance to differentiate Herschel ACMS and Planck ACMS.
– <Level>	is on character
	"M" for model procedure
	"S" for subsystem procedure
	"E" for element procedure
	"G" for generic for procedure
– <Type>	is one character
	"P" for procedure themselves ("X" for cross checks)
	"C" for configuration procedure
	"M" for measurement procedure
	"T" for tool procedure
– <Mnemonic>	is a free 12 characters field
– <Position>	is three numerical digits
	Some position are reserved for subsystem pseudo position and one ("999") is reserved for model pseudo position.

Note: there is no way to differentiate nominal and contingency procedures.

Doc No. : H-P-1-ASP-TN-0777
Fop Issue : 1.0
Issue Date: 23/07/04

HP - Nominal OD
File: Z100MPNOMINAL_OD__999.xls
Author: Felix

Herschel/Planck

Procedure Summary

Objectives

```
Common Herschel / Planck
Model procedure to execute nominal OD scenario
Inputs :
    UDC xx1 : Model
        UDC xx1 = 1 Herschel
        UDC xx1 = 2 Plank
Outputs :
    UDC yy1 : Return code
        UDC yy1 = 1  go
        UDC yy1 <> 1 nogo
    UDC yy2 : TM rate
        UDC yy2 = 3 Medium bit rate
        UDC yy2 = 4 High bit rate
    UDC yy3 : VC
        UDC yy3 = 0 VC0
        UDC yy3 = 4 VC4
    UDC : VC status
        UDC yy4 = 1 ON
        UDC yy4 = 2 OFF
```

Summary of Constraints

n/a

Spacecraft Configuration

Start of Procedure

The procedure starts at RF configuration before AOS
TM is configured 150Kbps
TC is configured 4Kbps
Spacecraft mode : Nominal (science)
ACMS mode : Science (SCM)

End of Procedure

The procedure stops at the end of RF configuration after LOS
The TM is set to 150Kps
The TC is set to 4Kbps
Spacecraft mode : Nominal (science)
ACMS mode : Science (SCM)

Reference File(s)

Input Command Sequences

Output Command Sequences

Referenced Displays

ANDs **GRDs** **SLDs**

Configuration Control Information

Status : Version 8 - Updated
Last Checkin: 7/22/2004

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Fop Issue : 1.0
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HP - Nominal OD
File: Z100MPNOMINAL_OD__999.xls
Author: Felix

Herschel/Planck

DATE	FOP ISSUE	VERSION	MODIFICATION DESCRIPTION	AUTHOR	SPR REF
3/31/2004		1	Created	Administrator	
3/31/2004		2	New	Administrator	
5/5/2004		3	Check in suite a modif	Administrator	
6/18/2004		4	Remise en base pour utilisation par Felix	user1	
6/18/2004		5	test	Chattef	
7/14/2004	cdr	6	None	Chattef	
7/20/2004	1	7	RF conf anf TM rate conf are created in place of the detail calls	Chattef	
7/22/2004	1	8	CDR	Felix	

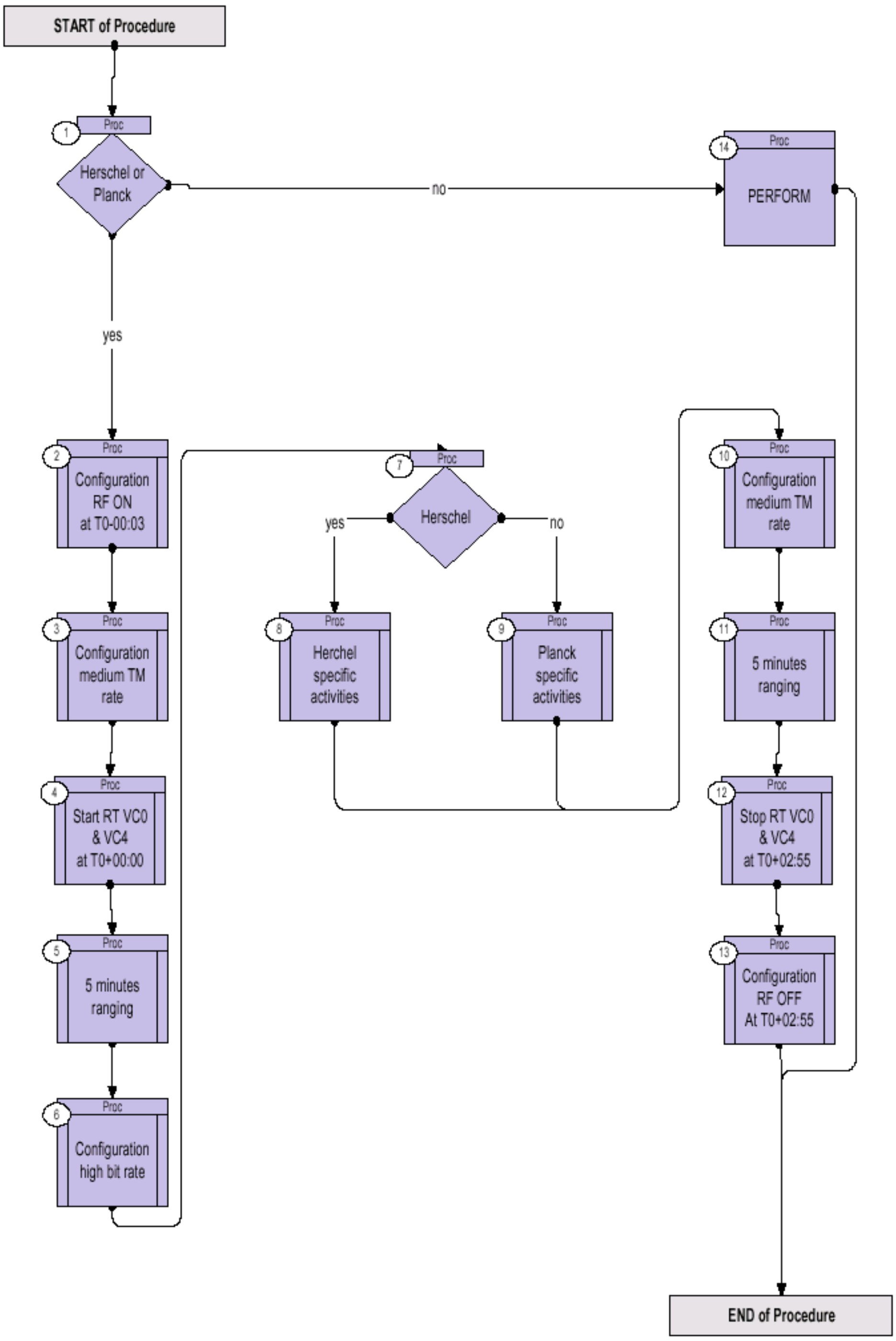
Status : Version 8 - Updated
Last Checkin: 7/22/2004

Doc No. : H-P-1-ASP-TN-0777
Fop Issue : 1.0
Issue Date: 23/07/04

HP - Nominal OD
File: Z100MPNOMINAL_OD__999.xls
Author: Felix

Herschel/Planck

Procedure Flowchart Overview



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Last Check-in : 7/22/2004

Page 1 of 2

Doc No. : H-P-1-ASP-TN-0777
Fop Issue : 1.0
Issue Date: 23/07/04

HP - Nominal OD
File: Z100MPNOMINAL_OD__999.xls
Author: Felix

Herschel/Planck

Step	Label/Time	Activity/Remarks	Telecommand	Telemetry	Display/ Branch	AIT Activity
		Beginning of Procedure				
		Proc Procedure Properties				
1		Herschel or Planck type: [If]			Next Step: yes 2 no 14	
2		Configuration RF ON at T0-00:03 type: [Proc]			Next Step: 3	
		Execute Procedure **Z100MCRF_ON______999** n/a			**FOP**	
3		Configuration medium TM rate type: [Proc]			Next Step: 4	
		Execute Procedure **Z100MCTM_RATE_____999** HP - Configuration of TM rate			**FOP**	
4		Start RT VC0 & VC4 at T0+00:00 type: [Proc]			Next Step: 5	
		Execute Procedure **D100ECVC_ON_OR_OFF150** n/a			**FOP**	
5		5 minutes ranging type: [Proc]			Next Step: 6	
		Execute Procedure **R100STRF_RANGING__430** n/a			**FOP**	
6		Configuration high bit rate type: [Proc]			Next Step: 7	
		Execute Procedure **Z100MCTM_RATE_____999** HP - Configuration of TM rate			**FOP**	
7		Herschel type: [If]			Next Step: yes 8 no 9	
8		Herchel specific activities type: [Proc]			Next Step: 10	
		Execute Procedure **Z100MPHERSCHEL_OD_999** HP - Nominal OD			**FOP**	
9		Planck specific activities type: [Proc]			Next Step: 10	
		Execute Procedure **Z100MPPLANCK_OD___999** HP - Nominal OD			**FOP**	

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Doc No. : H-P-1-ASP-TN-0777
Fop Issue : 1.0
Issue Date: 23/07/04

HP - Nominal OD
File: Z100MPNOMINAL_OD__999.xls
Author: Felix

Herschel/Planck

Step	Label/Time	Activity/Remarks	Telecommand	Telemetry	Display/ Branch	AIT Activity
10		Configuration medium TM rate type: [Proc]			Next Step: 11	
		Execute Procedure **Z100MCTM_RATE_____999** HP - Configuration of TM rate			**FOP**	
11		5 minutes ranging type: [Proc]			Next Step: 12	
		Execute Procedure **R100STRF_RANGING__430** n/a			**FOP**	
12		Stop RT VC0 & VC4 at T0+02:55 type: [Proc]			Next Step: 13	
		Execute Procedure **D100ECVC_ON_OR_OFF150** n/a			**FOP**	
13		Configuration RF OFF At T0+02:55 type: [Proc]			Next Step: END	
		Execute Procedure **Z100MCRF_OFF______999** HP - RF OFF at end of OD			**FOP**	
14		PERFORM			Next Step: END	
		End of Procedure				

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Figure 6.5.2-1 Example of common MOIS procedure

6.5.3 Operation tools

6.5.3.1 Data Base

The Herschel/Planck System Data Base has been developed in order to support the data needed by AIT, operation, software and flight dynamics ensuring the commonality between them.

The data model is composed of two levels:

- One high level data model "object oriented" to support commonality and "smooth transition" requirements,
- One low level relational data model to support the relations between the different items (for instance parameter and curves).

In order to support configuration control of the data, HPSDB provides 3 areas: working area, reference area and archive area.

In order to support flexibility HPSDB support a unique central site and a set of mirror sites. The central site manages the data of all the models of Herschel and Planck. Each mirror site manages a unique model. Currently each EGSE will include a mirror site and ESOC will have two mirror sites (one for Herschel model and one for Planck model).

Finally HPSDB is composed of a set of tool to manipulate the data.

6.5.3.1.1 High level data model

The high level data model is composed of 7 boxes.

- One generic box which contains the definition of all items which can be shared by all the HPSDB user.

  Example: curve "ON/OFF".
- One theoretical box which contains the definition of all the theoretical elements. A theoretical element contains the theoretical definition of the smallest part which can be integrated on a spacecraft. It has a link with the PTI (Product Tree Identifier).

  Example: Star tracker "STR" with a theoretical mass of 10Kg and a parameter M012 with a low limit of 20.
- One real box which contains all the real elements. A real element inherits of the theoretical element from which it is derived and any of the inherited item and attribute can be overwritten. It has a link with the serial number.

  Example: real star tracker "STR1" inherits from theoretical star tracker "STR" but the mass is 11 Kg and real start tracker "STR2" inherits from theoretical star tracker "STR".
- One theoretical box which contains the definition of all the theoretical subsystems. A theoretical subsystem is composed of a set of theoretical elements each one associated to a unique position inside the theoretical subsystem and specific items. All the items identifiers inherited from a theoretical element are automatically instantiated with the subsystem identifier (one character) and the position (3 numerical digits). The inherited items and attributes of the theoretical elements inside the theoretical subsystem can be overwritten. Specific subsystem identifiers are segregated thanks to subsystem pseudo position.

Example: theoretical subsystem "A001" is composed of a nominal theoretical star tracker "STR" in position 100 and a redundant theoretical star tracker "STR" in position 101, as a consequence it will contain the following parameters AM012100 and AM012101. The low limit of parameter AM012100 can be overwritten with 21 while the low limit of parameter AM12101 is still the inherited one: 20. A specific parameter could be AD012109 = AM012100 + AM012101 (note: the position 109 is the pseudo position inside subsystem A)

- One real box which contains all the real subsystems. A real subsystem associates to each theoretical element part of the corresponding theoretical subsystem a real element. A real subsystem inherits of the theoretical subsystem from which it is derived (specific items) and any of the inherited item and attribute can be over written.

  Example: Real subsystem "A001001" derived from theoretical subsystem "A001" is such that the real star tracker "STR1" will be integrated in position 100, and the real star tracker "STR2" will be integrated in position 101. As a consequence the mass for the nominal star tracker is 11 Kg while it is 10 for the redundant one.

- One theoretical box which contains the definition of all the theoretical models. A theoretical model is composed of a set of theoretical subsystems and specific items. The inherited items and attributes of the theoretical subsystems inside the theoretical model can be overwritten. Specific model identifiers are segregated thanks to pseudo subsystem ("Z") and pseudo system position (999). Note: due to SCOS limitation, there is no instantiation of item identifiers when a theoretical subsystem is included inside a theoretical model (A subsystem can be allocated only once to a model)).

  Example: real model "Planck" is composed of theoretical subsystem "A001".

- One real box which contains all real models. A real model associates to each theoretical subsystem part of the corresponding theoretical model a real subsystem. A real model inherits of the specific items of the theoretical model from which it is derived and any of the inherited attribute can be over written. Example: Real model "Planck PFM" derived from theoretical model "Planck" is such that real subsystem "A001001" will be integrated.

From the above description of the seven boxes, the theoretical versus real boxes concept has been implemented in order to satisfy the commonality requirement. Several real object are derived from the same theoretical object. In case real objects differ from theoretical one overwriting of inherited items and attributes is possible. Example: only one definition of a star tracker shall be entered from which could be derived the N real star trackers definition needed for the different models of Herschel and Planck, the mass could be modified.

From the above description of the seven boxes, the different levels (generic, element, subsystem and model) concept has been implemented to satisfy the "smooth transition" requirement. Inherited items and attributes from lower level can be overwritten. Example: the same star tracker definition can be used for element test, subsystem test, system test and operation, the limit could be modified.

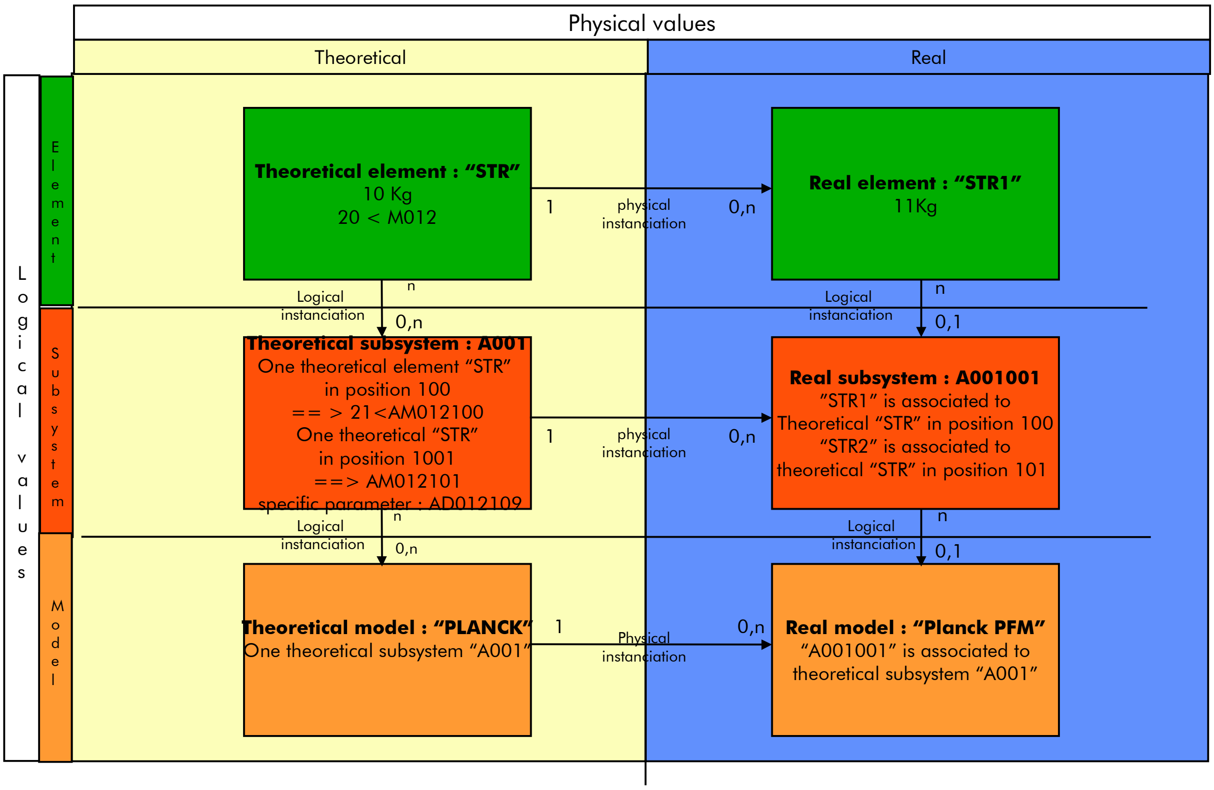


Figure 6.5.3-1 High level data model (generic box not represented)

6.5.3.1.2 *Low level data model*

Each of the box object (for instance "STR", "Planck PFM", …) contains a list of items types. The item types supported by HPSDB are:

- For TM definition:
  - TM packet standard to describe standard TM packet header
  - TM packet PSICD to describe data field header (according to PSICD)
  - TM packet to describe a TM packet except the contents
  - TM packet SCOS archiving to describe the contents of TM packet
  - TM structure to define data structures inside TM packet SCOS archiving
  - TM packet group to define group of TM packet SCOS archiving (used by specific CCS TOPE statements).
- For TC definition:
  - TC packet header to define standard and PSICD TC header
  - TC packet to define TC packet
  - TC structure to define structures inside TC packet
  - Tc packet group to define group of TC.

- For TM/TC links definition:
  - Command verification to support definition of the expected effects (TM packet generation, TM parameter values) of a TC.
- For parameters definition:
  - Parameter to support the definition of different parameter types: acquisition parameter (TM from spacecraft or from SCOE), command parameter (for spacecraft TC or SCOE command), command header (for TC header parameter: APID, type, subtype, constants, …), derived parameter (or synthetic parameters – Note the expression is outside HPSDB), dynamic parameter (modifiable by the user or by TOPE language of CCS), system parameter (set by CCS) and static parameter (constant)
  - Parameter group to define group of parameters which can be referenced by some CCS specific commands
  - Parameter set to define set of command parameters associated to the same TC
  - Parameter value set to associate value to each parameter of a parameter set
  - Parameter range set to control the value of TC parameter.
- For calibration definition:
  - Calibration curve of type digital or analogue (discrete, polynomial or logarithmic).
- For displays definition:
  - Alphanumeric display
  - Graphic display
  - Scrolling display
  - Variable SCOS packet display.
- For constants definition:
  - Constants which are used to allow to set a label for dedicated value and also for flight dynamics data.

Each item type contains a list of items (for instance: parameters M012, M013, …).

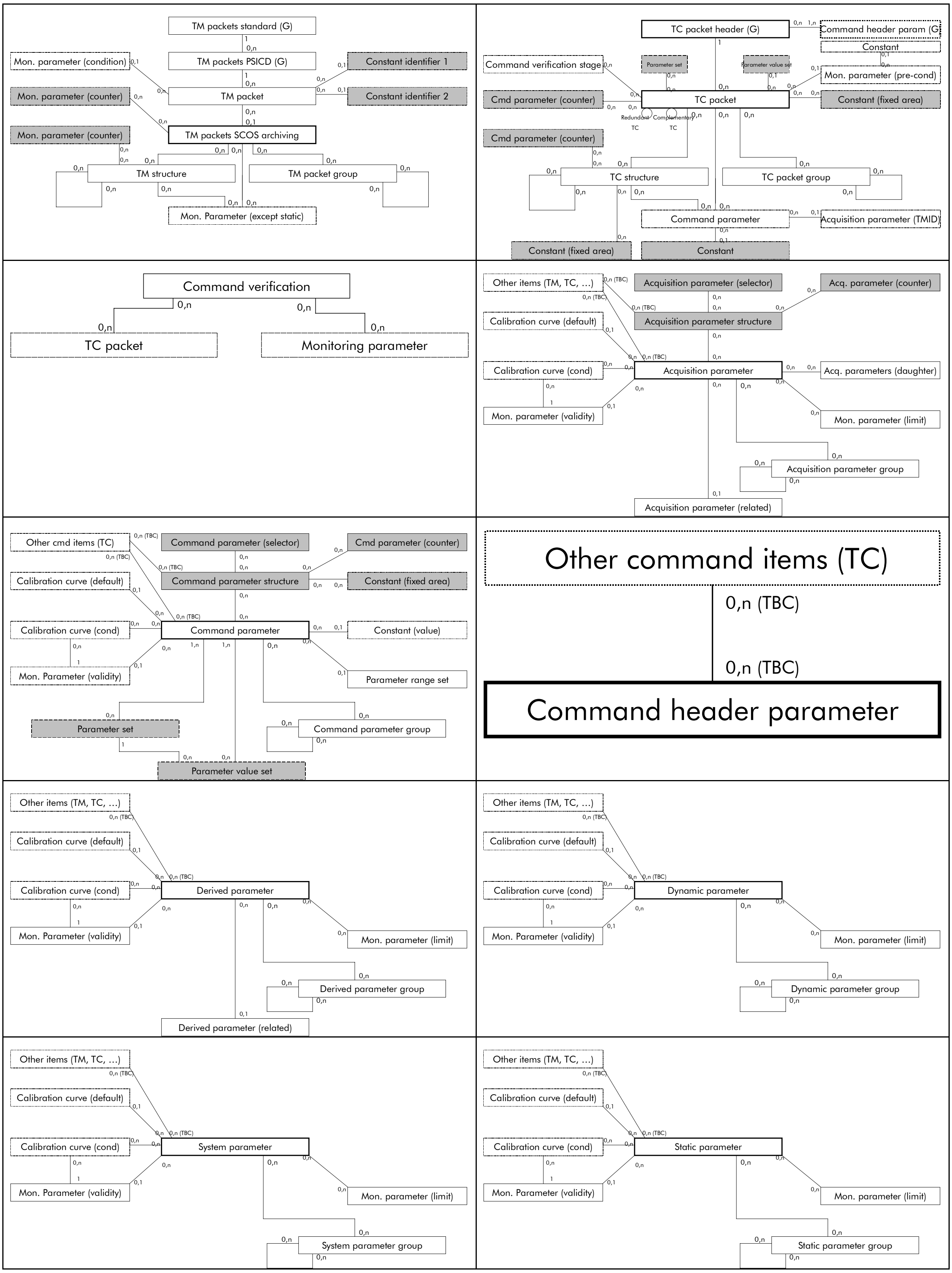
As HPSDB allows users to share common items but also allows users to define specific items, each item has a category flag to indicate to which users this item belongs to. The different users are: AIT, operations, Software and Flight Dynamics data. Each HPSDB user has also an associated category which is used to filter the items to which he can access.

All those items are linked together via a relational data model. For a box object all the link are inside this box object or to the generic box. It is impossible to perform links between items which do not belong to the same box except with generic items (belonging to generic box).

In addition the relational data model inside a "box object" (including the generic data) shall be consistent: this allows to generate bridge files from any box object.

The low level data model is fully compliant with SCOS except command sequences and associated formal parameters which are not supported.

The uniqueness of each item inside a box object is guarantee via a naming convention which is controlled by HPSDB.


TM packets standard (G)
TM packets PSICD (G)
Mon. parameter (condition)
Constant identifier 1
Mon. parameter (counter)
TM packet
Constant identifier 2
Mon. parameter (counter)
TM packets SCOS archiving
TM structure
TM packet group
Mon. Parameter (except static)
TC packet header (G)
Command header param (G)
Constant
Command verification stage
Parameter set
Parameter value set
Mon. parameter (pre-cond)
Cmd parameter (counter)
TC packet
Constant (fixed area)
Redundant TC
Complementary TC
Cmd parameter (counter)
TC structure
TC packet group
Command parameter
Acquisition parameter (TMID)
Constant (fixed area)
Constant
Command verification
0,n
0,n
0,n
TC packet
Monitoring parameter
Other items (TM, TC, …)
Acquisition parameter (selector)
Acq. parameter (counter)
Calibration curve (default)
Acquisition parameter structure
Calibration curve (cond)
Acquisition parameter
Acq. parameters (daughter)
Mon. parameter (validity)
Mon. parameter (limit)
Acquisition parameter group
Acquisition parameter (related)
Other cmd items (TC)
Command parameter (selector)
Cmd parameter (counter)
Calibration curve (default)
Command parameter structure
Constant (fixed area)
Calibration curve (cond)
Command parameter
Constant (value)
Mon. Parameter (validity)
Parameter range set
Parameter set
Command parameter group
Parameter value set
Other command items (TC)
0,n (TBC)
0,n (TBC)
Command header parameter
Other items (TM, TC, …)
Calibration curve (default)
Calibration curve (cond)
Derived parameter
Mon. Parameter (validity)
Mon. parameter (limit)
Derived parameter group
Derived parameter (related)
Other items (TM, TC, …)
Calibration curve (default)
Calibration curve (cond)
Dynamic parameter
Mon. Parameter (validity)
Mon. parameter (limit)
Dynamic parameter group
Other items (TM, TC, …)
Calibration curve (default)
Calibration curve (cond)
System parameter
Mon. Parameter (validity)
Mon. parameter (limit)
System parameter group
Other items (TM, TC, …)
Calibration curve (default)
Calibration curve (cond)
Static parameter
Mon. Parameter (validity)
Mon. parameter (limit)
Static parameter group

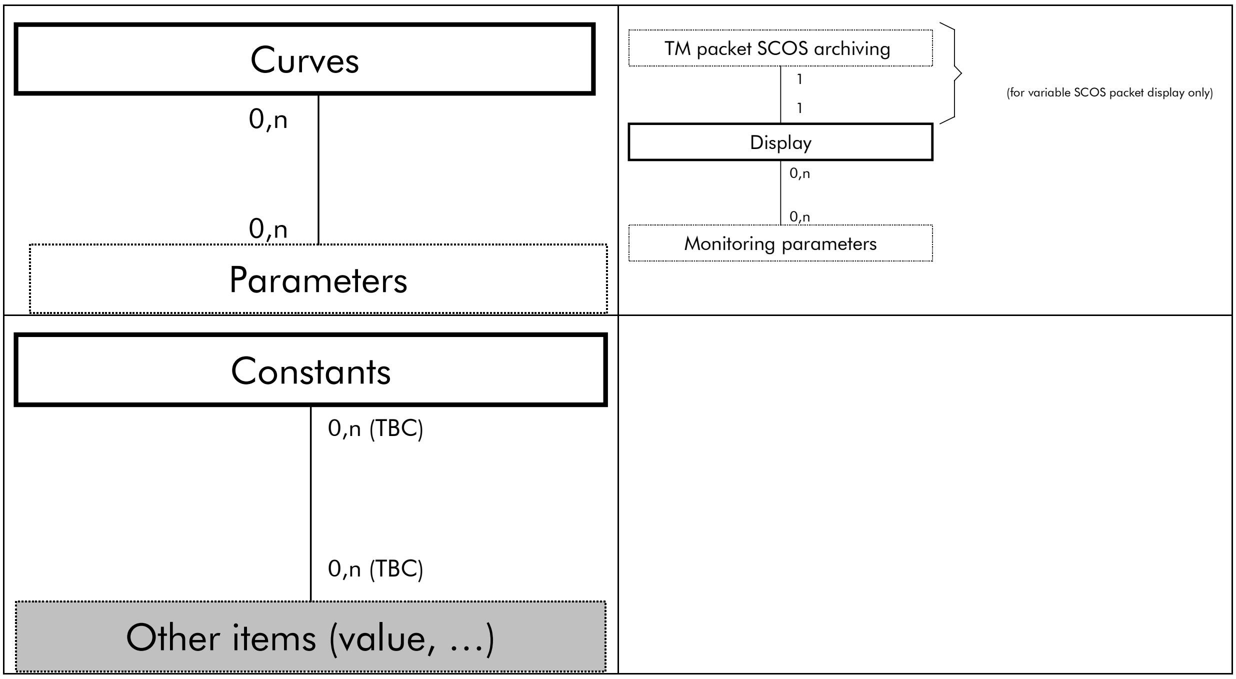


Figure 6.5.3-2 Low level data model

6.5.3.1.3 Areas

In order to support configuration control of data, HPSDB provides three areas.

- Working area: this is the area where the users enter all their data: box object and items. In this area there is no configuration control of the data, a data can be over-written, the previous value is not kept. However each box object or item keeps trace of the last modification: date, user, … In this area the box objects and items are unique per site: for instance central site working area can contain parameter M012 of box object "STR" and can also contain a downloaded modification of the same parameter from a mirror site (in this case this modification was validated on the mirror site – refer to next chapter)
- Reference area: this contains the complete set of the current reference data. By default all the outputs (bridge file generation, display, print, …) are made from this area. In this area the box objects and the items are unique.
- Archive area: this area contains all the previous box objects and items which were in the reference area and which are no more the current reference one's.

The transfer of data from working area to reference area and from reference area to archive area is done by the data base manager when he "validates" a set of working area data (note: The validation granularity is the box object. For instance the data base manager cannot validate parameter M012, but he can validate box object "STR", this will generate the transfer of all the contents of the "STR" box object from the working area to the reference area, the previous box object being transferred from the reference area to the archive area.

The input in the working area can be done either interactively via Internet or via XML input files. XML schema is provided in order to support the generation of the XML files by the different subcontractors.

Under certain conditions it is possible to generate outputs from archive area (mainly for AIT investigation purpose) or for archive area (mainly for analysis of test results).

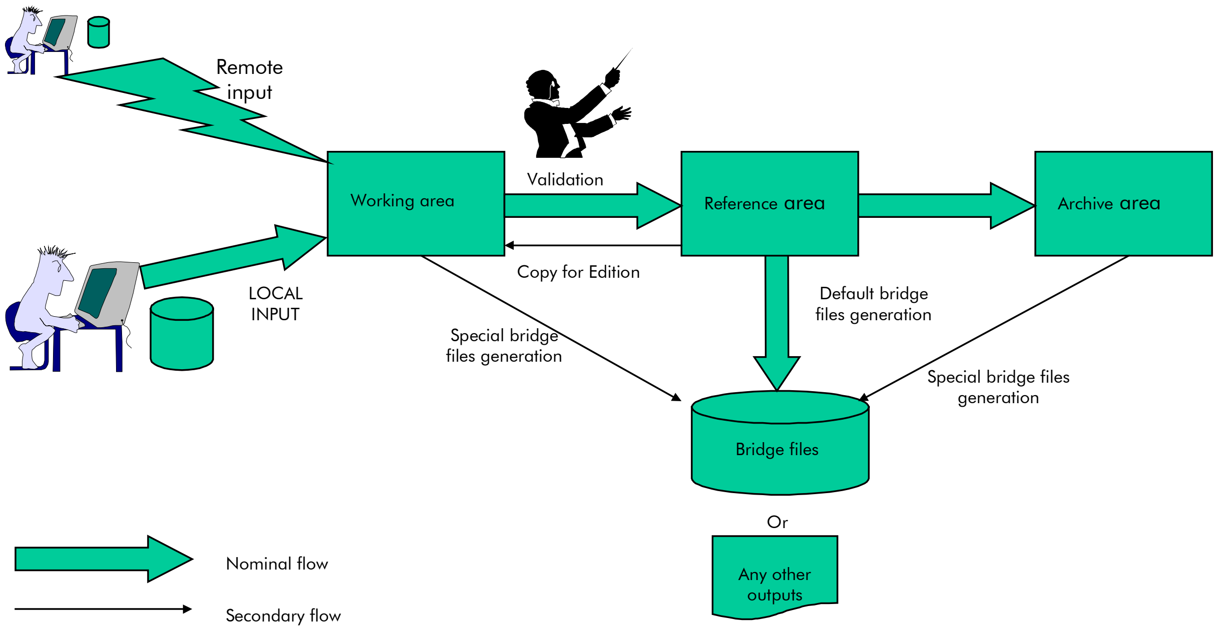


Figure 6.5.3-3 Areas interface

6.5.3.1.4 Mirror sites

In order to support the flexibility requirements, HPSDB offers a central site which contains Herschel and Planck data and a set of mirror sites which contain a unique real box objects (for instance: subsystem A001001, model "Planck PFM").

Time to time the mirror site will be "initialised" with data from the central site: the working and reference areas are deleted and the reference area is filled with the data relevant to one box object from the central site reference area. Locally on mirror site the data can be modified, but only real data can be modified, theoretical data cannot be. When the modified data are validated on mirror site they are, in parallel, recorded inside a log file. This log file is periodically downloaded inside the central site. At central site level the modifications performed at mirror site level will be analysed in order to check if the modifications shall be reported at theoretical level and, as consequence, seen by all the derived box objects or if the modifications shall be kept at real box object level.

For instance: box object "STR2" can be exported to a mirror site. The low limit of parameter M012 can be modified from the inherited one (20) to a new value 25 and validated at mirror site level. This modification will be downloaded inside the central site working area. The data base manager will then decide if this new value shall be "rejected", "accepted" or "promoted". In case the new value is "rejected" the value is directly validated inside the archive area (it cannot be deleted because it has been validated and used on a mirror site). If the value is "accepted" then the value is validated on central site and it becomes the new reference value for the real "box object", the theoretical box object is unchanged. If the value is "promoted" then the corresponding theoretical value is set with this modified value in order that any other real "STR" can inherits of this new value.

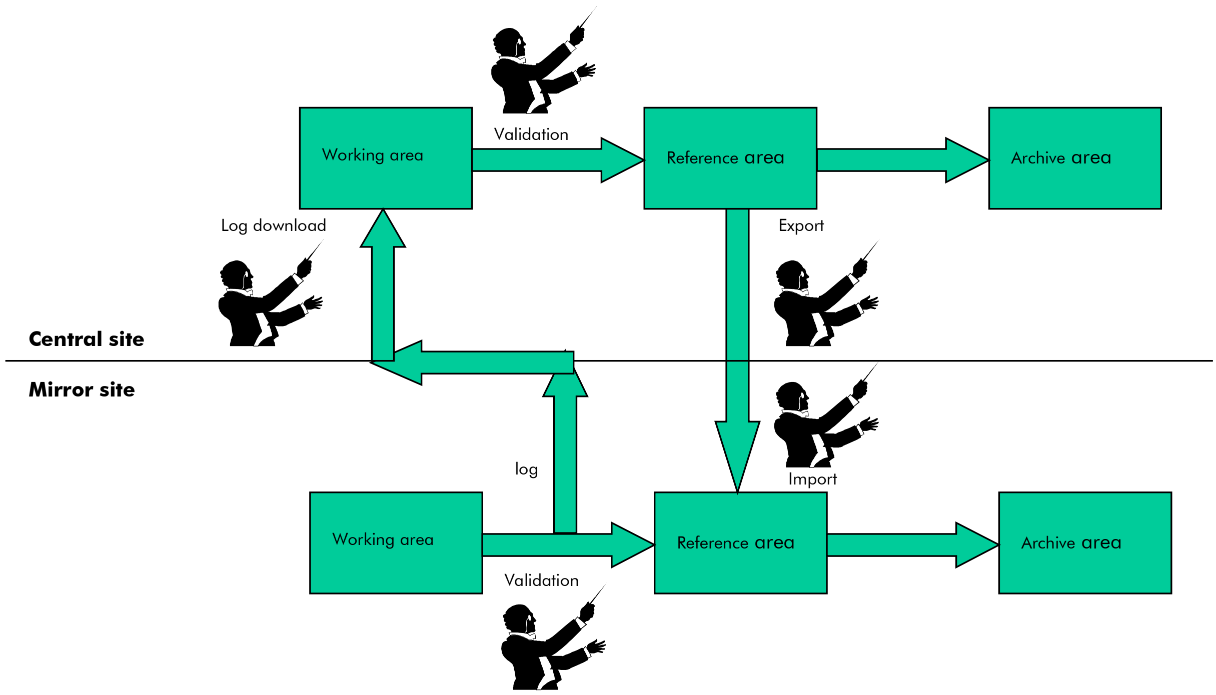


Figure 6.5.3-4 Central and mirror sites interfaces

6.5.3.1.5 HPSDB tools

HPSDB provides a set of tools to manage the data.

- Validation: this tool allows to perform validation of data from working area. The selection for the validation is done at "box object" level inside the working area.
- Export/import: those two tools are used to initialise the reference area of any mirror site. The export tool allow to select from the reference area of the central site all the data associated to a unique box object including the generic data. The import tool will deleted the working and archive areas of the mirror site and load the reference area with the XML files generated by the export tool.
- Log/log-download: Those two tools are used to report to central site the modifications made on any mirror site. The log tool automatically fill a log file (XML format) each time modified data are validated on a mirror site. The down load tool allows to download the log files generated by the log tool inside the working area of the central site.
- History: this tool allow to get the history of a box object or item.
- Bridge file generator: this tool allows to generate bridge files according to different ICD's. Currently there are three ICD's, one for S2K interface, one for CCS interface and one (XML format) for software interface. The generated bridge files will contain the data relevant to one box object. By default, the generation will be done from the reference area.
- Bridge file loading: this tool allows to reload inside HPSDB bridge files under S2K format or CCS format or XML format. In case of S2K or CCS formats the loading is "simplified", theoretical box object are created but they are empty, all the data are at real box object level.
- Consistency check: this tool allow to check the consistency for a box object or for an item.

- TM and TC verification: this tool combined with CCS TOPE facility allows to report inside HPSDB the AIT validation of any TC packet and TM parameter.
- Real element status: this tool combined with CCS procedures allows to record the number of times a real equipment has been switched ON and how long it has been ON.
- Print/display: those tools allow to display via the MMI or print under XML format the HPSDB data for a box object or an item selection.
- Item cross reference: this tool allows to know where an item is referenced. For instance if a TM parameter is modified it is possible to know where this parameter id referenced in order to facilitate the analysis of the impact of the modification.
- Configuration: this tool allows to manage the reason of change. Each HPSDB modification is recorded with the date, the user, the site, and a reference to a reason of change. The same reason of change can be shared by several items or box objects (for example: an NCR).
- User management: this tool allow to define the different user rights. There are different type of users: administrator, data base manager, element engineering, element fabrication, subsystem engineering, subsystem fabrication, model engineering and AIT (or model fabrication).
    - "Administrator" is in charge to manage (create/modify/delete) schemas and associated data base managers (one per schema)
    - "Data base manager" in addition to specific activities (validation, export, import, …), he is in charge to manage (create /modify/delete) the different users types. He has write and read access to all data. Only the data base manager has write access to generic data, while all other users have read access to them
    - "Element engineering" user has write access to a theoretical element and read access to all derived real elements
    - "Element fabrication" user has write access to a real element and have read access to the associated theoretical element
    - "Subsystem engineering" user has write access to a theoretical subsystem, read access to the associated real subsystems and read access to all theoretical and real elements
    - "Subsystem fabrication" user has write access to a real subsystem, read access to the associated theoretical subsystem and read access to all theoretical and real elements
    - "Model engineering" user has write access to a theoretical model, read access to the associated real models and read access to all theoretical and real subsystems and elements
    - "AIT" (or "Model fabrication") user has write access to a real model, read access to the associated theoretical model and read access to all theoretical and real subsystems and elements.
- Reset tool: reset tool allow the following three kinds of reset of any item:
    - The real item is reset with the theoretical one
    - The theoretical item is reset with the real one
    - The theoretical item is created from a direct definition item (item which has been created directly at rel level and has no corresponding theoretical item).

6.5.3.2 MOIS

MOIS (Manufacturing and Operations Information System) has been proposed in order to allow:

- The validation of Operation procedures part of satellite user manual in AIT
- Common test sequences development environment for all the companies participating to the model and system AIT activities in order to support smooth transition of procedures.

6.5.3.2.1 Presentation

MOIS has already been used for operations and, in a limited number of cases, for AIT (ROSETTA avionics AIT tests where it generated ELSA language), but it is intended to be used on other projects for AIT.

This tool is based on a set of Microsoft office tools: excel, visio, word, access, source safe, Project.

Its mainly composed of a library which contain the procedures, the data bases and the documents. It contain also the schedules which are not planed to be used in Herschel/Planck AIT activities.

In order to manage the procedures, databases, documents and schedules at set of tool is provided:

- Flowcharter: to edit procedure flow chart
- Writer: to insert the TOPE statement in the different steps generated by Flowcharter
- Function editor: to create function which can be used by writer
- Publisher: to produce the documentation associated to each procedure
- DB: to support the data bases which are imported under the CCS bridge file format as generated by HPSDB
- Reporter: to manage the problems, this tool is not planed to be used on Herschel/Planck
- Validator: to emulate the execution of a procedure against SCOS (this will not be used on Herschel/Planck) and against the test harness
- Supervisor: to control the procedure execution via Validator
- Test harness: to simulate telemetry and record telecommand when validating a procedure via Validator
- Timeliner: to support schedule generation.

For the specific needs of Herschel/Planck the following functions have been added which are presented in more detail in following chapters:

- CCS TOPE generation
- HPSDB interface
- Procedure merging
- Reverse generation
- Cross references
- Instantiation.

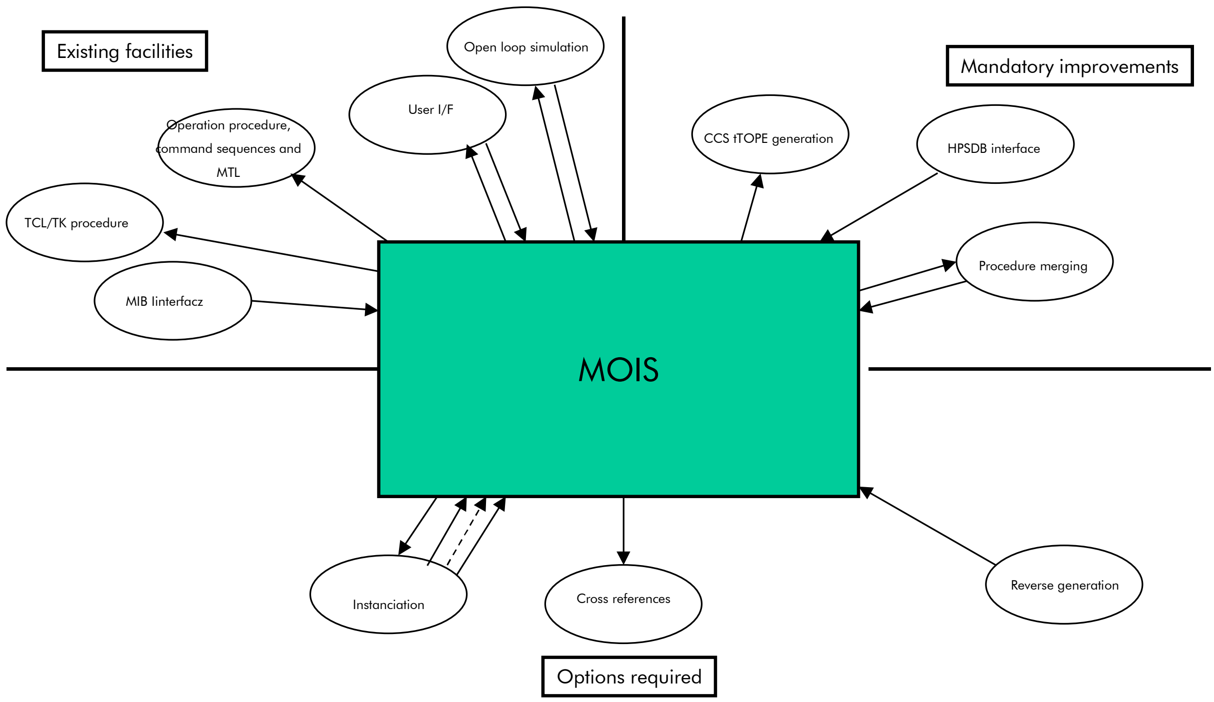
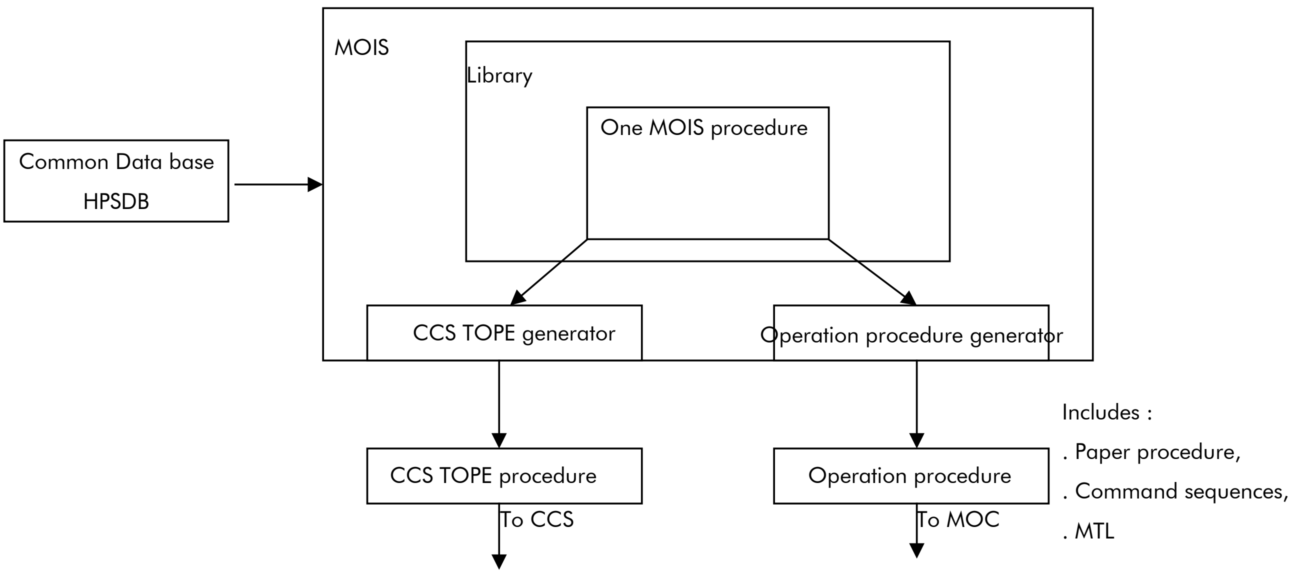


Figure 6.5.3-5 Overview of MOIS

6.5.3.2.2 *CCS TOPE interface*

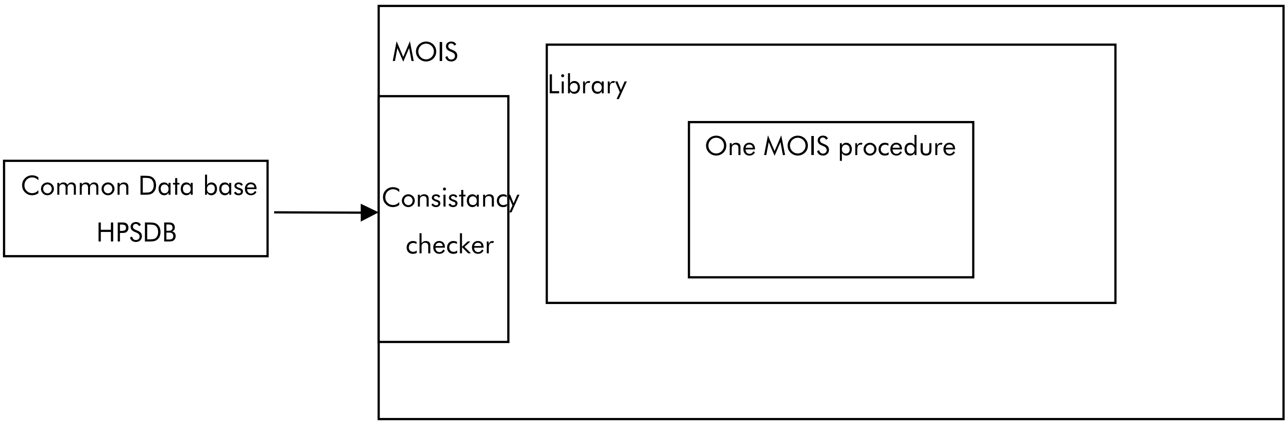


As soon the CCS TOPE procedure has been validated in AIT, the operation procedure is declared validated.

Figure 6.5.3-6 Commonality AIT/operations

From a common "MOIS procedure", MOIS can generate different instances, each one in a different language. One of this instance is under TOPE language used to support AIT test sequences to be executed on CCS. This facility is the main one to support AIT and operations commonality.

6.5.3.2.3 HPSDB interface



The MOIS interface with HPSDB shall be compatible with the three HPSDB interface levels:

- Element (for element test or/and instantiation)
- Subsystem (for subsystem level test)
- Model (for module and system test and operations)

and shall follow the naming convention.

Figure 6.5.3-7 HPSDB interface

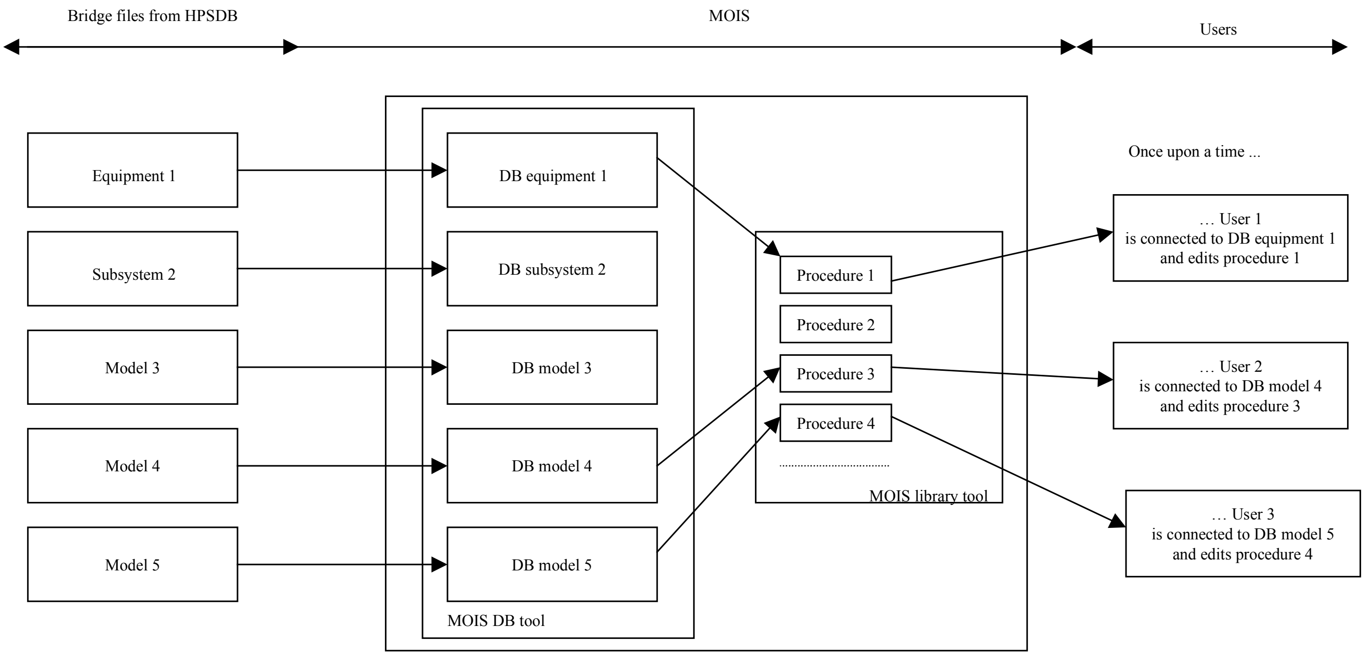


Figure 6.5.3-8 HPSDB interface - scenario 1 at T0

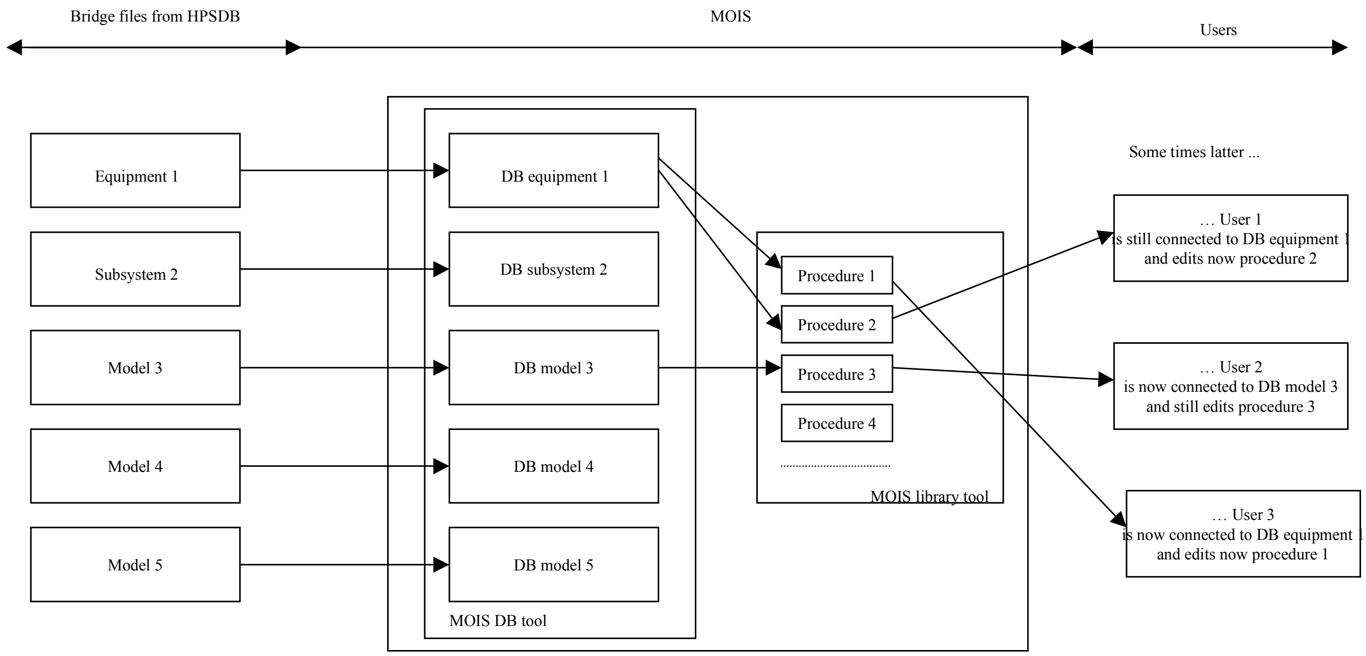


Figure 6.5.3-9 HPSDB interface - Scenario 2 at T1

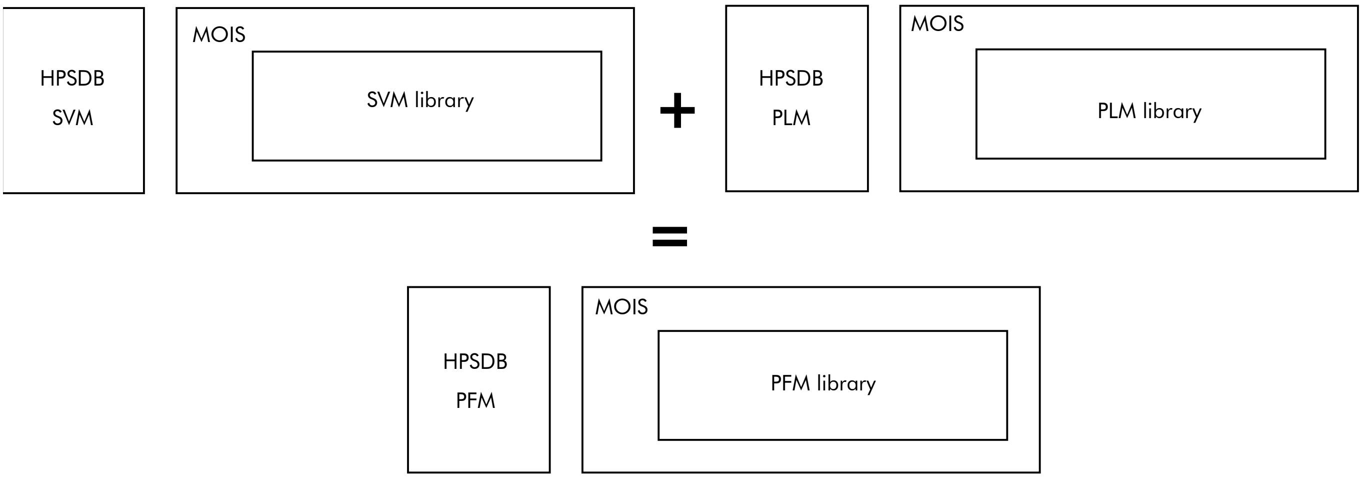
For Herschel/Planck a dedicated tool as been specified to support all the engineering, AIT, operations and software data for both Herschel and Planck. This tool is named: HPSDB (Herschel/Planck System Data base). It is proposed that the consistency checks performed by MOIS (HPSDB interface) used the same bridge files than the ones between HPSDB and the CCS (compatible with SCOS-2000).

In order to satisfy the commonality requirement over several models, MOIS is able to support several instances of HPSDB (one per model). At connection time, the user is required against which model he would like to work, then it will edit any MOIS procedure from the (unique) library against the selected model (Data base). MOIS supports also that several users work in parallel on the same server but use different models (Data bases). This MOIS evolution allows to satisfy the MOIS procedure commonality requirement over several models: on Herschel/Planck the AVM, the Herschel SVM PFM and the Planck SVM PFM are integrated using a unique MOIS server in order to guarantee to the maximum extent the commonality between those three models.

From HPSDB interface - scenario 1 at T0 and HPSDB interface – scenario 2 at T1:

- a procedure can be common to several element/subsystem/model: procedure P3 is common to model 3 and model 4
- At a time a user is only connected to a unique procedure and a unique element/subsystem/model data base: at T0 user 1 is connected to procedure 1 and to equipment 1 and at T1 he is connected to procedure 2 and to equipment 1.
- A procedure can be manipulated by different users at different times (at T0 procedure 1 is edited by user 1, at T1 it is edited by user 3.

6.5.3.2.4 Procedure merging

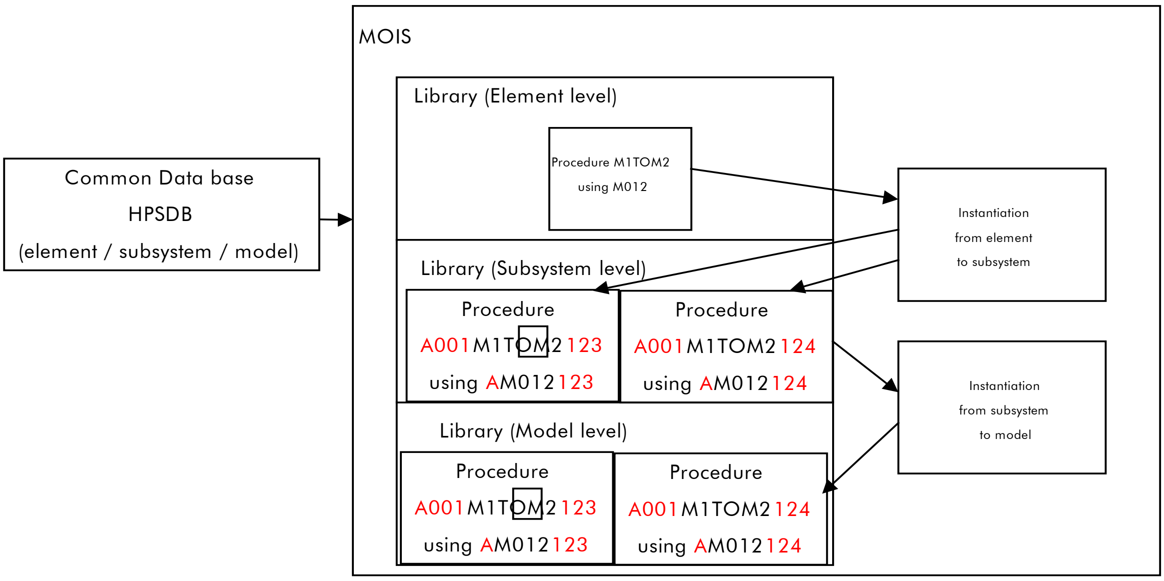


The SVM library and PLM library are merged to build the PFM library for both Herschel and Planck

Figure 6.5.3-10 Merging

This facility is required in order to be able to merge the SVM and PLM AIT test sequences which are developed under two separate servers in order to generate PFM test procedures on one unique server. This applies for both Herschel and Planck.

6.5.3.2.5 Instantiation



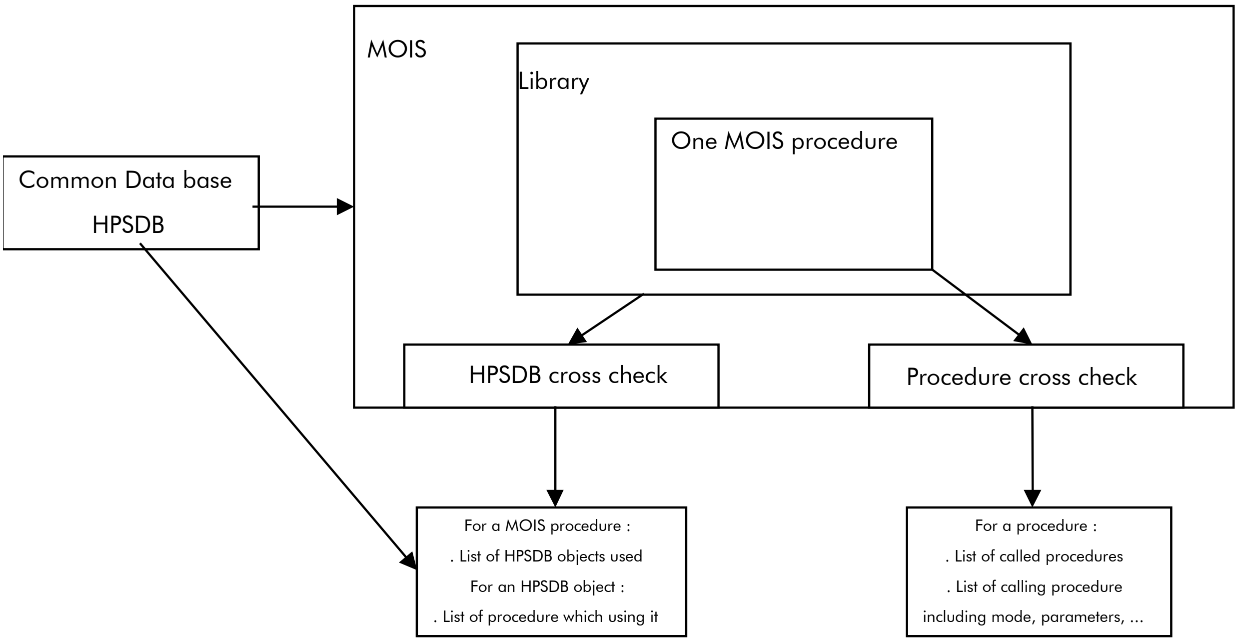
A procedure defined once at element level can be used to generate the different procedure need at subsystem or model levels for nominal and redundant elements and for the different subsystems and models (Herschel / Planck, ...).
This forces to generate modular procedure (element / subsystem / model)

Figure 6.5.3-11 Instantiation

The data base HPSDB is built such that the data are entered at element level, then instantiated at subsystem level with the subsystem identifier and the position inside the subsystem. For instance a parameter which is named M001 at element level will be named AM001123 if the corresponding element is mounted in subsystem A and in position 123, an other instance could be CM001555 if the element is mounted in subsystem C and in position 555.

The requirements of this chapter are aimed to implement a similar facility inside MOIS. A test procedure can be defined at element level (refer only to attributes of this element: TM packet, TC packets, Parameters, …). This procedure can be instantiated according to an instance of the element and validated. Then the other instances can be generated and due to automatic generation there is no more need to validate them. For instance Herschel and Planck have identical star trackers. A total of 5 star trackers could be used at a time (2 on Hershel, 2 on Planck and 1 on AVM). Integration time can be saved if the specific star tracker (only depending of star tracker objects) test procedures can be generated automatically after one of them has been validated.

6.5.3.2.6 Cross references



This facility helps the user to analyse the impact of one change in the data base or in a procedure by providing all the cross references

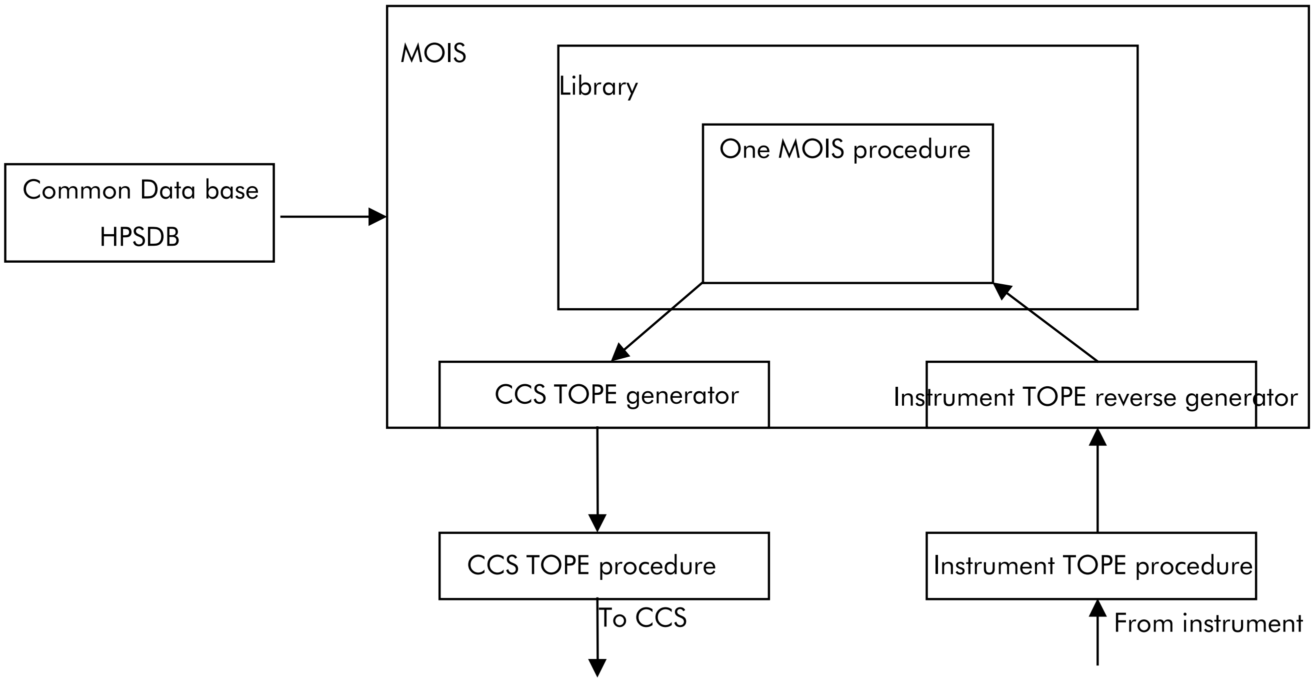
Figure 6.5.3-12 Cross references

During AIT and operations it is very important to have some tools allowing to facilitate the analysis of the impacts of a modification. There are two levels of cross reference required: one against HPSDB and one, internal, against the MOIS procedures themselves.

If an HPSDB object is modified, the HPSDB cross reference allows to quickly know which MOIS procedures can be impacted. If a MOIS procedure is modified, the HPSDB cross reference allows to quickly know which HPSDB objects can be impacted.

If a MOIS procedure is modified, the MOIS procedure cross check allows to quickly know which MOIS procedures call it and which MOIS procedures are called by it.

6.5.3.2.7 Reverse generation



The instrument TOPE procedures from subsystem level test are loaded inside MOIS, It is then possible to generate CCS TOPE procedures for module and system level test,
It is also possible to generate operation procedures.

Figure 6.5.3-13 Reverse generation

On the Herschel/Planck project, instrument level tests are done using a specific EGSE SCOS version. This version use a language named TOPE (and we will name it "instrument TOPE" to differentiate it from "CCS TOPE"). This TOPE language is base also on TCL/TK and is a subset of the "CCS TOPE".

The hereafter reverse generation requirement are aimed to allow from a source "instrument TOPE" procedure to generate the corresponding MOIS procedure. Then from the MOIS procedure it will be possible to generate the "CCS TOPE" one.

The instruments TOPE procedures do not use HPSDB, but they are compliant with the naming convention, so the HPSDB object identifier manipulated by instrument TOPE procedures are the same as the one manipulated by the CCS TOPE procedures.

6.5.3.2.8 MOIS rules to support modularity and commonality

Rules to code the AIT test sequences using MOIS have been defined in order to ensure the modularity of the test sequences and the commonality between the different level of tests including the operation.

It is not realistic to think that a high level test sequence can be converted in an high level operation procedure mainly because:

- the simulation environment could be not representative,
- a high level test sequence includes a lot of call to other test sequences which generates in fact a quite big expended test sequence which reduce the possibility of commonality with operation.

It is more realistic to make small modular procedures which can be combined in different way to produce either high level AIT test sequences or high level operation procedures.

The following paragraphs present mainly how to generate modular procedures in a way compatible with the HPSDB high level data model (element/subsystem/model) and compatible with the specific MOIS implementation (multiple data bases, instantiation, …).

There are four levels of tests sequences:

- "generic" test sequence is a test sequence which refers only to:
    - generic items,
- "Element" test sequence is a test sequence which refers only to:
    - generic items,
    - one element box object specific items,
- "Subsystem" test sequence is a test sequence which refers only to:
    - generic items,
    - all the inherited items from the elements included inside the subsystem,
    - one subsystem box object specific items,
- "model" test sequence is a test sequence which refers only to:
    - generic items,
    - all the inherited items from the elements included inside the subsystems themselves included inside the model,
    - all the inherited items from the subsystems included inside the model,
    - one model box object specific items.

Inside a level there are 4 types of test sequences:

- Procedure test sequences which are aimed to execute a test. They have visibility to any lower level test sequences and they can call any test sequence at the same level (see Figure 6.5.3-14).
- Configuration test sequences which are aimed to configure a box object, they include also the verification of the target configuration. They have visibility to any other lower level configuration test sequences and to tool test sequences inside the same level (see Figure 6.5.3-14).
- Measurement test sequences which are aimed to perform acquisition and checks in a certain configuration. They have visibility to any lower level measurement test sequences and to tool test sequences inside the same level (see Figure 6.5.3-14).
- Tool test sequences which are aimed to perform some common activity for all other test sequences. They have visibility to any lower level tool test sequences (see Figure 6.5.3-14).

> ^	Level	Element				Subsystem				Model				Generic			
Level	**TS Type**	**P**	**C**	**M**	**T**	**P**	**C**	**M**	**T**	**P**	**C**	**M**	**T**	**P**	**C**	**M**	**T**
EL.	**P**	X	X	X	X									X	X	X	X
	C				X										X		
	M				X											X	
	T				X												X
S/S	**P**	X	X	X	X	X	X	X	X					X	X	X	X
	C		X						X						X		
	M			X					X							X	
	T				X				X								X
Mod.	**P**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	C		X				X						X		X		
	M			X				X					X			X	
	T				X				X				X				X
Gen.	**P**													X	X	X	X
	C																X
	M																X
	T																X

Figure 6.5.3-14 Possible calls between test sequences

6.5.3.3 Description of the real time activities during the DTCP.

The highest level procedure allows to start a common model procedure (Z100MPNOMINAL_OD__999). As input parameter this procedure accepts the model Herschel or Planck. This common procedure executes the following steps by calling low level procedures (refer to attached example):

- Switching ON the RF,
- Configuration in medium TM rate,
- 5 minutes of ranging execution,
- Configuration in High TM rate,
- Execution of specific activities according to model,
- Configuration in medium TM rate,
- 5 minutes of ranging execution,
- Switching OFF the RF.

All those procedures are written in such a way they can be re-used. For instance only one procedure exists to configure TM rate allowing to configure any TM rate for both RF and CDMS, the target TM rate being provided as an input parameter.

6.5.3.4 Description of mission time line

Any procedure to describe mission time line contain only:

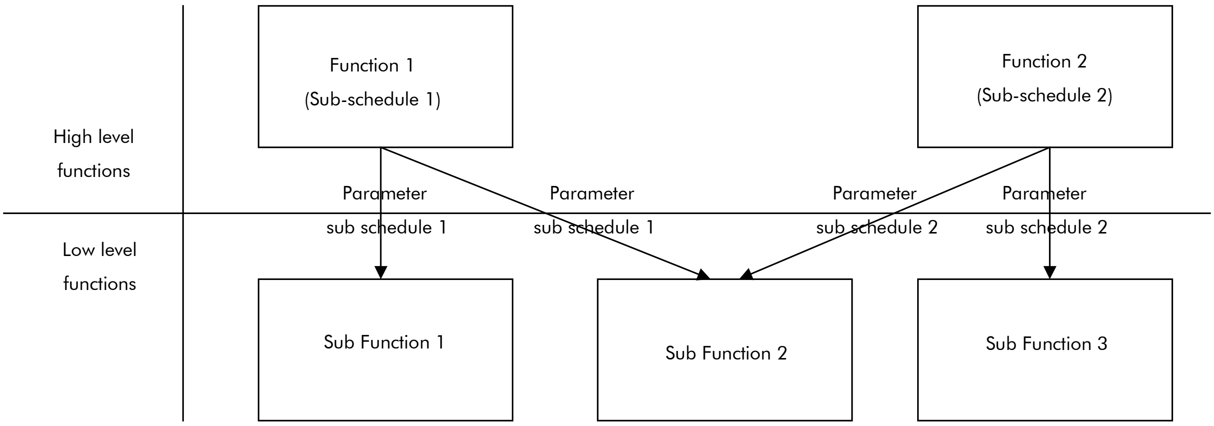
- a set of commands to be loaded,
- a set of call to lower level mission time line description procedures.

There is no TM check associated inside the mission timeline procedure. SCOS real time monitoring will allow to check the correct acceptance and loading (TBC) according to the acknowledge flag set in the LOADTT (Load Time Tag) SCOS command.

As afar as:

- each function should be associated to a sub-schedule,
- a procedure can be shared by several higher level procedures.

The sub-schedule will be transmitted via UDC.



6.6 External interface

6.6.1 Ground segment interfaces

This chapter describes all the means, hardware and software, by which the satellites interface with the ground segment.

6.6.1.1 General

The interfaces with the ground segment are specified via in two documents:

- Space to Ground ICD (AD03.2) which defines the telecommunication interface between spacecraft and ground
- Operational Interface Requirement Document (AD03.1) which defines the functional requirements for spacecraft operations.

Uplink

The up link communication between Earth and the spacecraft is performed in X-Band, and makes use of the Kourou and/or New Norcia ground stations.

It is based on-board on:

- 2 LGAs for Herschel and 3 LGAs for Planck. One single LGA is used in nominal for each spacecraft, the other one(s) implementing the required quasi omni directional coverage in TC.
- The MGA as a back up to the LGAs.

One single set of uplink data rate is specified. Two nominal rates are then considered:

- 125 bps on from Kourou, on LGA
- 4 kbps on LGA and MGA with New Norcia. With Kourou the 4kbps will be available via MGA, except at the beginning of mission (up to 350 000 km) where it can be used via LGA.

The TTC design is compliant with the ranging signal used by the ESA Ground station and the TC frame structure is compliant with the ESA packet TC standard.

The uplink modulation scheme is a NRZ-L/PSK/PM onto a sine subcarrier, and no special encoding is applied.

Downlink

The downlink communication between the spacecraft and Earth is performed in X-Band.

It is based on-board on:

- 2 LGAs for Herschel and 3 LGAs for Planck for near Earth operations and in case of emergency thanks to their quasi omnidirectional transmit capability
- 1 MGA for both spacecraft in nominal operational mode.

It makes use of the following ground station:

- the Kourou 15 m station during post Launch activities and in emergency cases
- the New Norcia 32 m station during normal operation.

As far as the downlink telemetry is concerned, one single set of data rates is used common to both satellites:

- low rate: 500 bps on LGAs with Kourou and 5 kbps with New Norcia and with Kourou at the beginning of mission, up to 750 000 km
- medium rate: 150 kbps on MGA with Kourou
- high rate: 1.5 Mbps on MGA with New Norcia.

The downlink modulation scheme is:

- NRZ-L/BPSK/PM for low rates
- SP-L/PM for medium rate and
- NRZ-L/GMSK/PM for high rates.

The telemetry data stream is Reed Solomon and Convolutional encoded (concatenated code) which permits to achieve a minimum E_b/N_0 of 2.7 dB for a frame loss probability of 10^{-5}. The frame structure complies with the Packet Telemetry Standard. An additional data scrambler has been selected for the GMSK modulated high rate to guarantee the proper transition density at the ground station level.

Link configurations

Regarding the switching function, the proposed RFDN design allows connecting the receivers and transmitters to the nominal LGA, or the redundant one in case of attitude loss, or/and to the MGA for high bit rate transmissions.

For the MGA, this is also valid for the uplink.

6.6.1.2 Specific features

The SGICD defines the main features of the ground stations foreseen on H/P, and the present section gives all elements to demonstrate that the implemented design complies with these requirements.

From the intended Kourou, New Norcia and possibly Vilspa in LEOP, the on board carrier modulation scheme, frequency stability, data encoding scheme have been defined and implemented in the SVM corresponding units. In addition to this need for a compatibility with the ground formats, the on-board transmitted signals shall respect a certain bandwidth allocation, and also the susceptibility of the protected RF bands in the vicinity of Herschel and Planck frequencies. Last, all ESA TTC systems are now requested to provide a ranging channel to allow transmission and reception from Ground of a ranging tone. Selection of this tone is also detailed in this section.

<u>Verification of on board modulations</u>

The on-board modulations for Low bit rate and Medium bit rate have nothing new compared to the existing ESA TTC standard modulations, and then no dedicated test was deemed necessary. On the opposite, the High bit rate modulation GMSK has never been used on ESA previous projects. For this reason a compatibility test between EBB of H/P transponder and the ESOC ground demodulator (IFMS) was run on H/P project.

This test took place in February 2004 and is duly documented in test report TOS-ONV/HP/AG/12-2003 is.1.4).

It must be noted that on that time the GMSK demodulator of the IFMS was not yet present and that the compatibility test was run with only the standard O-QPSK demodulator. The demodulation of the GMSK signal worked properly and the resulting demodulation/mismatch loss of 1.6dB is in line with theoretical mismatch GMSK⇔O-QPSK, and therefore validated the on-board GMSK modulator design.

It must be noted that during this test campaign at ESOC, the Medium bit rate was also demodulated and the measured BER loss was of 0.3dB worst case which is a good indicator of the adequacy of the on-board modulator design.

<u>Choice of Ranging tone frequency</u>

The selection of ranging tone frequency within the specified range of [100KHz to 1.5MHz offset from carrier] is always a compromise between on-board compatibility Ranging⇔Telemetry spectrum and ground segment instrumentation and uses for a dedicated ground station. This mode is obviously not supported in high data rate mode due to the telemetry spectral occupancy, and in Low bit rates (500bps or 5Kbps), the minimum ranging tone frequency is so far from the telemetry spectrum that no question of compatibility remains. In Medium bit rate mode, the 99 % of transmitted Rf power is spread over several MHz around the residual carrier. In such a case the ranging tone frequency must be done with minimum impact on Telemetry link quality.

Herschel/Planck tone has been selected to be 10KHz offseted from the first null on TM spectrum as shown on following figure:

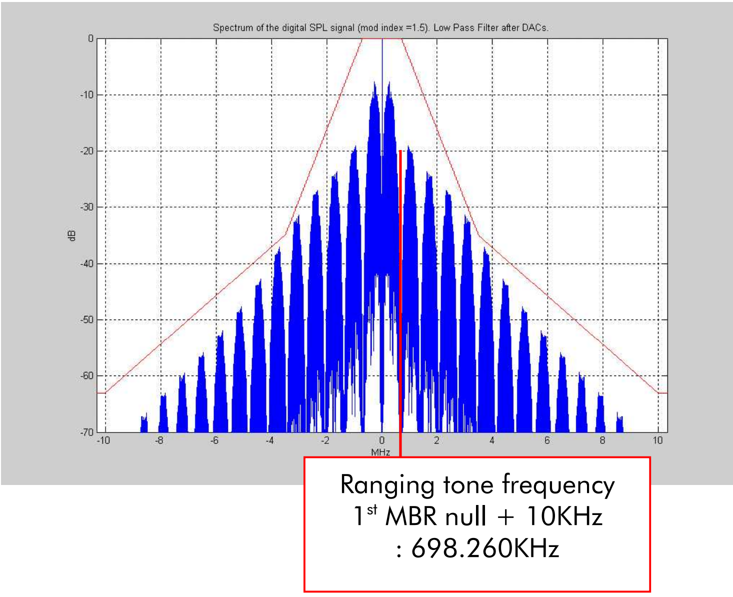


Figure 6.6.1.1a MBR spectrum with Ranging tone

During the GMSK compatibility test at ESOC, a quantification of the Ranging signal impact on Telemetry link quality was also done and successfully completed with a worst case BER loss on TM of less than 0.1dB.

<u>On-board Telemetry data rate stability</u>

The present on-board architecture is driving all TM data rates and sub-carrier stability on one crystal oscillator located in the CDMU, and then triggered at TTC Transponder level. This performance is of high interest to design the ground receiver acquisition phase loop, in particular the track-in PLL BW.

The SGICD is weak in that respect and only refers to the ESA PSS 04 105 (§ 5.1.4.2.) where only the sub-carrier stability is specified. However the sub-carrier exists only in the Low bit rate mode, not in MBR and not in HBR! Moreover nothing is specified about data rate and/or data clock stability! Both performances are also of interest for the ground demodulator to specify the bit-sync recovery algorithm.

On H/P the CDMU architecture uses the same crystal to derive sub-carrier stability and all data rates and data-clocks.

Since at the unit PDR and CDR the predicted short term stability by the supplier was not compliant, a test in temperature was run on the EQM.

To remind the ESA PSS 04 105 requirement:

- Telemetry sub-carrier shall at any time have its frequency within +/-100ppm of its nominal value
- medium term variation due to power supply voltage changes, temperature and other S/C influences shall be within +/-10ppm
- short term stability shall be better than +/-1ppm over a measurement time less or equal to the sub-carrier waveform.

The measured CDMU EQM TM data rate stability over qualification temperature is of 0.9ppm stability, which shows very little margin but can be considered as the order of magnitude for the on-board TM data, clock and sub-carrier short term stability.

<u>Doppler Measurement</u>

As identified in SGICD the ranging mode is not compatible with high data rate mode, and only Doppler measurement will be made during these phases (SGICD § 2.1.4.).

The Doppler mode requires no particular design change in the architecture, already offering the required phase coherent mode between up-link and down-link carrier. The constraint is however put on the selection of on-board crystal stability and in particular phase noise.

The ESA PSS 04 104 defines in § 2.3.3.1. the Allan Variance of on-board carrier. This performance can be verified either by test or by analysis, but the test is really time consuming and requires a non usual test set-up. The carrier Allan Variance has so far never been measured on the H/P TTC XPDR (new design) and will be addressed during the EQM test campaign.

It must be noted that a fulfilment of the ESA PSS 04 104 Figure 2.7 is equivalent to introduce an uncertainty in the Doppler measurement of 0.5mm/s.

<u>Spectral occupancy</u>

As for all satellites an assignation was done for Herschel and Planck TM/TC frequencies but also in terms of occupied bandwidth.

The attributed bandwidth for TC spectrum is of 3MHz, and was initially of 10MHz for TM spectrum. The successive releases of SGICD decreased the TM allocated BW to 7MHz and then to 4.2MHz. This latter figure was based only on consideration made with the high data rate mode, and couldn't be met in medium bit rate mode.

Indeed the high data rate mode occupies less bandwidth (and meets the 4.2MHz BW). This achievement is a direct consequence of using the GMSK which offers a higher spectral efficiency than standard PSK modulations.

To reduce the MBR spectrum occupancy a sharp on-board digital I and Q filtering was added at transponder level, in addition to the existing analogue filters for far out-of-and spurious rejection. The challenge here is to avoid any degradation on the TM link quality (truncating the TM spectrum). This optimisation work ended with a figure of **6.2MHz**.

In spite of this optimised spectral occupancy, one can see that the secondary lobes of the MBR spectrum are slightly transgressing the SGICD specified RF mask, as shown below:

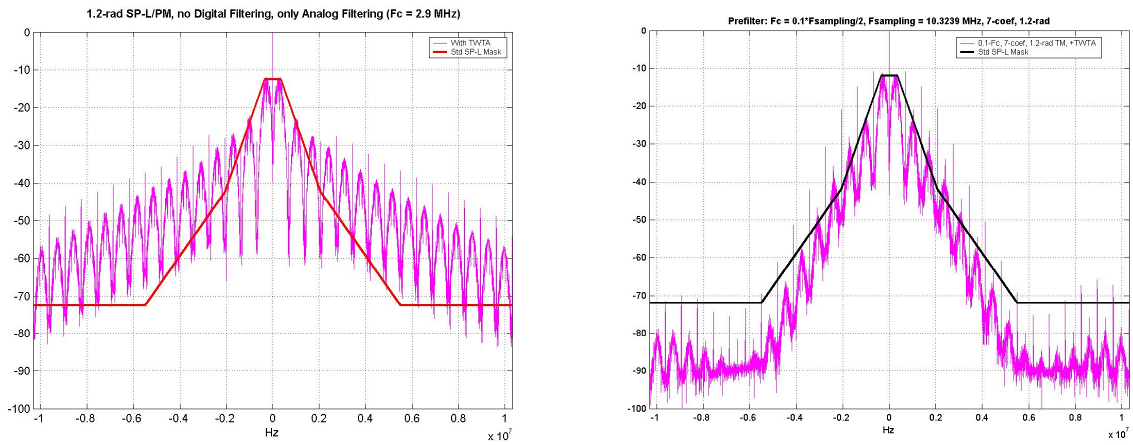


Figure 6.6.1.1b Medium bit rate spectrum unfiltered/after additional filtering (SGICD specified RF mask in red)

The comparison here above illustrates how sharp and close to the spectrum is the selected filtering (7th order). Sharper filters have been modelled but the corresponding BER losses were not compatible with H/P TM link budget margins and the filter implementation would have required a much higher number of poles and a significant need for additional space in the on-board transponder memory, that was not available.

<u>Out-of-band spurious & protected bands</u>

The far out-of-band rejection of –60dBc is clearly addressed in the SGICD with the specified RF mask discussed previously. The transmitting RF chain is as for other projects generating spurious, carrier harmonics and intermodulation products. To reject below the –60dBc line all these components, different means have been implemented on-board. The undesirable close spectral components are filtered at transponder level with digital baseband filters, then followed by a serie of analogue low-pass and band-pass filters. Then, after the non linear amplifier (TWTA) a sharp filtering to reject far out-of band spurious is obtained with a Diplexer.

From the predicted filters responses and from test results at TWTA and Diplexer level, a good feeling has been obtained up to now and the final end-to-end verification will take place during the TTC SIT on the AVM.

<u>Maximum levels acceptable on Earth</u>

The ESA PSS addresses two requirements that have to be met on H/P, one is in § 4.5.3. about Power Flux Density (PFD) in 4KHz BW for any transmitting frequency within [8025; 8500]MHz, and another one in § 4.5.1.3. about Power Spectral Density (PSD) at Deep Space ground station level within [8400; 8450]MHz.

The technical note H-P-TN-AI-0091 gives all computations.

The PFD on Earth at carrier frequency (worst case) is not met at separation but about 1 hour from separation in case of Medium bit rate and 6 hours after separation with low bit rate and LGA. The explanation being that the energy is more concentrated around the carrier in the low bit rate case.

<u>Deep Space Band</u>

The Low bit rate spectrum (even at 5Kbs) is concentrated in a very narrow BW of about 300KHz, so that the harmonics level in Deep Space band (-5MHz offset from Planck carrier) are already negligible at separation and meet the requirement.

In Medium bit rate, the Satellite EIRP is obviously higher due to the antennas gain difference, and the spectrum is significantly spread by secondary lobes over harmonics of the medium bit clock (about 344kHz). **The protection of Deep Space network is granted at separation with the low bit rate transmission but only after 4 hours from separation with MBR mode.**

Conclusion Ground segment IF

Several tests and modelling have been already carried out on H/P to check modulation compatibility, including the GMSK, and also to quantify the ground demodulation loss and impact on TM link quality. So far the results show good correlation with the figures assumed in the system link budgets and also confirm the compliance to the specified modulation standards.

The selection of the ranging tone frequency is now frozen and a compatibility test has also demonstrated the negligible impact on the TM spectrum and link quality.

Remaining performances to be verified are the Allan variance in view of Doppler measurement and the end to end TTC chain out-of-band spurious.

6.6.2 Launcher interfaces

Details concerning Launcher interfaces are provided by documents:

Herschel DCI 10/501 31 Issue 0 Revision 0 date February 2004

Planck DCI 10/501 32 Issue 0 Revision 0 date March 2004

NOTE: Revision 1 of both documents will be available in the frame of the CDR review.

6.6.2.1 Launch configuration

Both Satellites will be launched on the same ARIANE 5 ECA in dual launch configuration as illustrated by Figure 6.6.2-1:

- Planck Satellite in lower position:
  - on top of ACU 2624 (mass = 120 kg, height = 325 mm).
- Herschel satellite in upper position:
  - on top of the SYLDA-5F (mass = 440 kg)
  - on top of ACU 2624 (mass = 120 kg, height = 325 mm)

under a long fairing.

Figure 6.6.2-1 Herschel & Planck launch configuration

6.6.2.2 Spacecraft Geometry in flight configuration

There are no unfolded items on Herschel and Planck Satellites. The geometry in flight configuration is defined by:

- drawing PLS S000 A 002S for Planck
- drawing HES S000 A 002S for Herschel.

6.6.2.3 Launch Vehicle Adapter (LVA)

Arianespace supplies the LVA. Both Herschel and Planck Satellites have a reference diameter of 2624 mm at the interface Satellite/launch vehicle interface plane. To take into account the volume of the ECA stage, Arianespace has increased the height of the standard 2624 LVA, as defined in the Ariane 5 User's Manual, by 150 mm.

Herschel and Planck will rest on the forward frame of the Arianespace 2624 standard adapters and separation systems.

At separation, the clamp-band is opened in two places by a bolt cutter mounted on the adapter, the pieces remaining captive to the adapter. Operation of the LVA standard separation system shall not generate debris nor contamination particles detrimental to the Herschel and Planck Satellites.

The complete LVA is pre-assembled with all harness brackets, lower harness, separation systems (e.g. spring assemblies) prior to mating with the Herschel and Planck Satellites.

Separation Push System is part of the LVA and interfaced with the internal flange of the spacecraft rear frame as defined by:

- drawing HPS A1AA S 001S.

The umbilical connectors are mounted on specific brackets with their locations defined by:

- drawing PLS A1AH S 001S for Planck
- drawing HES A1AH S 001S for Herschel.

6.6.2.4 Fairing

Herschel Satellite is designed to fit with the allowable volume beneath the long fairing when Planck is designed to fit with the allowable volume beneath the SYLDA-5F.

The accommodation of both satellites in dual launch configuration is defined by:

- drawing PLS S0A0 A 001S for Planck
- drawing HES S0A0 A 001S for Herschel.

The free allowable volume is understood as a « static volume» that limits the static dimensions of the complete Satellite. The following waivers are needed.

Planck

- Outer diameter of the solar array (at the base of the satellite) up to 4200 mm
- Thrusters and ACMS sensors below separation plane
- Additional volume above top of SYLDA 5.

Herschel

- Top of the sunshade.
- Thrusters below separation plane.

6.6.2.5 RF transparent window

During POC activities RF link (TM only) in X-Band between the satellites and the DIANE Station will be performed.

These tests will be done before encapsulation so no RF transparent window is needed. But a Passive Repeater (SRP) linked to an antenna located on the roof of the BAF is requested. Link budgets are under analysis by Arianespace.

The antenna locations are defined by:

- drawing PLS A15N S 010S A for Planck (Antenna to be used is LGA-1),
- drawing HES A15N S 010S A for Herschel (Antenna to be used is LGA-2; LGA-3 shall be covered with a test cap).

6.6.2.6 Umbilical connectors definition

The umbilical link will provide the following connections between each satellite and its corresponding spacecraft checkout equipment:

- 28 V Power Bus
- TC signal link to the decoder
- TM signal link from the decoder
- heater supply and temperature monitoring for Herschel PLM
- TMs from the Herschel and Planck Payload Modules.

Since both satellites will use their on-board batteries during the launch phase, no additional electrical power supply from the launcher is required for Herschel and Planck (power is provided to Planck coolers to their launch lock mode).

During Launch, TC (dry loop commands) shall be sent by the launcher to Herschel to open valves in the cryostat.

Herschel

The electrical interfaces will be achieved via two 61-pin connectors.

While the connectors on the satellite will be 61 pins, only 37 pins of each connector will be routed between Satellite and Check-Out Terminal Equipment (COTE), with two (one per connector) left free for shielding.

- Plug DBAS 70.61.OSY.090, named "HU1"
- Plug DBAS 70.61.OSN.090, named "HU2".

Herschel will require 4 nominal + 4 redundant Dry Loop commands to manage the cryostat, to open valves of the superfluid Helium system during the ascent phase of the launch.

	HU1	HU2
Shielding COTE harness:	1	1
Monitoring & Control via Umbilical Link:	36	36
Total to COTE:	**37**	**37**
Shielding	1	1
Dry Loop Commands:	4 x 2	4 x 2
Separation Status TM	4 x 2	4 x 2
Spares	7	7
Total Pins on Satellite Connector:	**61**	**61**

The grounding scheme is to be defined by Arianespace.

The interface, which receives the Dry Loop commands, will be specified to be compatible with the command characteristics, as defined in ARIANE 5 user's manual. The main electrical characteristics (figures from ISO Satellite) are (TBC):

- R off ≥ 10 MΩ
- R for ground utilisation ≤ 10 Ω
- R on board ≤ 1 Ω
- On board circuit insulation >10 MΩ under 50 V dc
- Umax = 45 V with T = 1.5 ± 0.5 s (relay closure duration)
- Imax = 0.5 A.

The timing of initiation in flight is:

- Command #1 (external valves for vent-line evacuation) = after FJ (fairing jettisoning) + TBD s
- Command #2 (external valves for vent-line evacuation) = Command #1 + 10 s
- Command #3 (internal valves for Phase Separator start) = Command #2 + TBD min (or TBD s before ESC-A shutdown)
- Command #4 (internal valves for Phase Separator start) = Command #3 + 10 s.

The final timing will be provided after RAMP completion and as inputs for RAMF.

Planck

The electrical interfaces will be achieved via two 61-pin connectors.

While the connectors on the satellite will be 61 pins, only 37 pins of each connector will be routed between Satellite and Check-Out Terminal Equipment (COTE), with two (one per connector) left free for shielding.

- Plug DBAS 70.61.OSY.090, named "PU1"
- Plug DBAS 70.61.OSN.090, named "PU2".

	PU1	PU2
Shielding COTE harness:	1	1
Monitoring & Control via Umbilical Link:	36	36
Total to COTE:	**37**	**37**
Shielding	1	1
Separation Status TM:	4 x 2	4 x 2
Spares	15	15
Total Pins on Satellite Connector:	**61**	**61**

The grounding scheme is to be defined by Arianespace.

6.6.2.7 Herschel Launch Autonomy and He S/S design impact

According to preliminary POC provided by Arianespace, the last access to Herschel (in upper position) without fairing is at J-4. This imposes (and it is agreed with Arianespace) to start the HTT (He II Tank) Top-up at J-5 after ESCA final preparation and to continue it during two additional days up to fairing closure remaining J-4.

In order to provide the necessary autonomy during S5 to BAF transportation (at J-7) and during the combined operations in BAF up to launch (requirement of 6 days including 25 hours for launch delay) an additional auxiliary tank filled with He I is necessary (HOT) with a last refilling at J-2 through the fairing.

NOTE: the HOT will be emptied just prior to lift-off.

These specific Herschel activities are summarised hereafter:

- S5 to BAF transportation at J-7 (in He II conditions)
- refilling of HOT at J-8
- ESCA final preparation at J-5
- HTT reconditioning below 1.7K (by pumping operations) starting at J-5 up to J-4 (noon) including two "extended J-5"
- Fairing integration at J-4
- Additional HOT refilling at J-4 through fairing
- Dress rehearsal at J-3
- HOT refilling at J-2 through fairing
- ….

So four access doors to Herschel through fairing is requested for HOT refilling at J-4 and J-2:

- Door #1 = access for LHe I transfer-line to airlock SV121
- Door #2 = access for operator using a diving board (like ISO) to airlock SV121
- Door #3 = access for ventline to V502
- Door #4 = access for operator using a diving board (like ISO) to V502.

The locations of these doors have to be defined according Herschel clocking defined by SAA constraints and following location of items:

	Co-ordinate (S/C axis)			Vector		
Item	**X**	**Y**	**Z**	**X**	**Y**	**Z**
SV121	2965.1	899.4	-441.8	0	-0.920505	0.390731
V502	2329.5	-668.57	-728.57	0	-0.707107	0.707107

NOTE: the vector for SV121 gives the direction the plug of SV121 is moving and not the direction of the transfer line while inserting it into the filling port.

6.6.3 GSE interfaces

The description of the MGSE general interfaces with spacecraft can be found in document AD07.8. Detailed interfaces related to each MGSE can be found in the Requirements Specification of each item.

For EGSE, general interfaces are described in document AD07.9.

6.7 Cleanliness

6.7.1 Summary of requirements

They are derived either from system needs, or in the case of some Planck elements (such as the V-Grooves), from internal thermal needs. End of life cleanliness needs have also been derived by instruments teams. These needs are presented in the conclusion. For each spacecraft, the first section presents the upper level needs, the next section presents the identified critical items (parts on the spacecraft which are sensitive to contamination), and finally, the end of life needs, on each critical item, are presented. The hypotheses (e.g. particle distribution, emissivity increase computation, thermo-optical index…) and the computations are detailed and justified in a dedicated technical note (cf. [RD03.16]).

6.7.1.1 Upper level performances requiring cleanliness

This section lists the upper level requirements on which the cleanliness is a contributor, and the allocation made for contamination impact. These requirements are all derived from the following considerations:

Contamination shall be sufficiently low not to degrade thermal/cryogenic performances of PLM's

Contamination shall be sufficiently low to keep optical performances in the specified requirements: optical quality, transmission, straylight, self emission.

EOL contamination of instruments shall not exceed the instruments requirements.

The following tables lists the upper level performance requirements.

6.7.1.1.1 Planck upper level requirements

REFERENCE	REQUIREMENT	CONTAMINATION ALLOCATION
SRS SPER-060	Scattering effect due to contamination shall not affect the rejection requirements for Sun, Earth and Moon.	TIS due to contamination < 25 % of the TIS induced by 2 μm roughness.
SRS SPER-065	Internal straylight requirements.	RF budget allocates 10 % as the maximum emissivity increase due to the contamination on the internal side of the baffle.
Planck Telescope Optical & RF specification PTPE-025	Telescope self emission increase	1%
Telescope Design specification PTPE-035	Contamination shall be sufficiently low to keep antenna gain in the specified requirements	Allocation in gain budget 10-2 dB at 857 GHz (worst case frequency).
P-PLM internal needs	Emissivity increase on low emissivity V-Groove surfaces	0.025 emissivity increase is allocated in thermal budgets.
	Emissivity increase on high emissivity V-Groove and baffle surfaces	0.02 emissivity decrease is allocated in thermal budgets.

6.7.1.1.2 *Herschel upper level requirements*

REFERENCE	REQUIREMENT	CONTAMINATION ALLOCATION
SRS SGEN-200	Herschel Telescope Transmission losses	<1%
SRS SPER-050 SPER-055	The straylight induced by contamination shall be taken in the straylight analyses	Cf. ASED Straylight analysis
HIFI-IID-B §5.8.2.3	Optical window transmission	<10 %

6.7.1.2 Critical elements

This section lists, for both spacecrafts, the critical elements.

6.7.1.2.1 *Planck critical elements:*

- Focal Plane Unit
- Reflectors
- V-grooves low emissivity surfaces
- V-groove honeycomb blackbody
- Baffle external side - high emissivity surface
- Baffle inner side - low emissivity surface.

6.7.1.2.2 *Herschel critical elements*

- FPU's Inside cryostat
- LOU windows on CVV
- Telescope Mirrors (optical surfaces)
- LOU mirrors (inside the LOU).

6.7.1.3 End of life needs

This section presents, on each critical element, the maximum end of life contamination allowed. The driving need, between system and instruments ones have been taken into account.

6.7.1.3.1 *Planck end of life cleanliness needs*

EOL cleanliness level needs	**Molecular (g/cm^2)**			**Particulate (ppm)**
	H_2O	**NH_3**	**On ground contaminants**	
Focal Plane Unit	$6\ 10^{-6}$			5000
Telescope (each reflector)	$4\ 10^{-6}$			5000
Groove 1 (low emissivity surfaces)	$10\ 10^{-5}$	$1.4\ 10^{-5}$	$13\ 10^{-5}$	10 000
Groove 2	$15\ 10^{-5}$	$1.4\ 10^{-5}$	$13\ 10^{-5}$	10 000
Groove 3	$10\ 10^{-5}$	$10\ 10^{-5}$	$13\ 10^{-5}$	10 000
Groove 3 and baffle external side (high emissivity surfaces)	$3\ 10^{-5}$	$1.5\ 10^{-5}$	$3\ 10^{-5}$	15 000
Baffle (internal side)	$20\ 10^{-5}$	$5.6\ 10^{-5}$	$1\ 10^{-5}$	10 000

6.7.1.3.2 *Herschel end of life cleanliness needs*

EOL cleanliness level needs	**Molecular (g/cm^2)**			**PARTICULATE (ppm)**
	H_2O	**NH_3**	**On ground contaminants**	
Telescope M1	$4\ 10^{-6}$			4500(*)
Telescope M2	$4\ 10^{-6}$			4500(*)
instruments FPU (outside)	$6\ 10^{-6}$			1200
HIFI LOU CVV windows	$6\ 10^{-6}$			1200
LOU first mirror	$6\ 10^{-6}$(TBC)			1200(TBC)

(*) Average level for M1 and M2

6.7.2 Planck contamination analysis

6.7.2.1 Planck molecular contamination

6.7.2.1.1 *On ground*

Taking into account the level at delivery and the contamination due to the AIT sequence, the level expected at the end of the AIT sequence (before encapsulation) is:

M1/M2	**FPU**	**Optical cavity**	**External PPLM**	**Grooves**	**SVM**
$6.4\ 10^{-7}\ g/cm^2$	$3.14\ 10^{-6}\ g/cm^2$	$7.7\ 10^{-7}\ g/cm^2$	$1.36\ 10^{-6}\ g/cm^2$	$1.52\ 10^{-6}\ g/cm^2$	$2\ 10^{-6}\ g/cm^2$

NOTE: the groups are defined as follow:

- grooves: it concerns the areas between the grooves.
- optical cavity: it includes the telescope (structural parts) and the inner side of the baffle.

- M1/M2/FPU: they have the same policy of covers, so they are submitted to the same contamination
- external PPLM: it concerns the external side of the baffle and the upper part of the groove 3 extension
- SVM: it is not supposed to be protected.

6.7.2.1.2 *Launch pad activity and fairing contribution*

We expected a maximum duration of 12 days in class 10 000, leading to 3.6 10-8 g/cm² molecular contamination on the sensitive surfaces.

6.7.2.1.3 *In orbit*

This phase covers the outgassing (main phenomena) and the thruster plume impact analysis.. All the details (hypotheses, simulations tools, …) of these analyses are available in RD04.6.

6.7.2.1.3.1 *Outgassing analyses*

The outgassing simulations are performed, based on the residence time approach. Ones of the input of this approach are the outgassing kinetic parameters for each implemented material. These parameters are determined by the help of the VBQC (Vacuum Balance Quartz Crystal) test, performed at ESTEC. The results of the tests already performed are available in an ESTEC report which reference is TOS-QMC 99/011.

Various phases are distinguished and analysed separately on Planck satellite. These phases are the following:

- Launch phase (all equipment at 20°C during 133 minutes)
- Transient phase (satellite cool down)
- Heating phase (M1, M2 and FPU at 40°C during 2 weeks)
- Operational phase (temperatures equal to the nominal ones, output at 2 weeks, 21 months and 2.5 years).

All the simulations performed for the Planck satellite outgassing estimation are summarised on the following sketch (Figure 6.7-1).

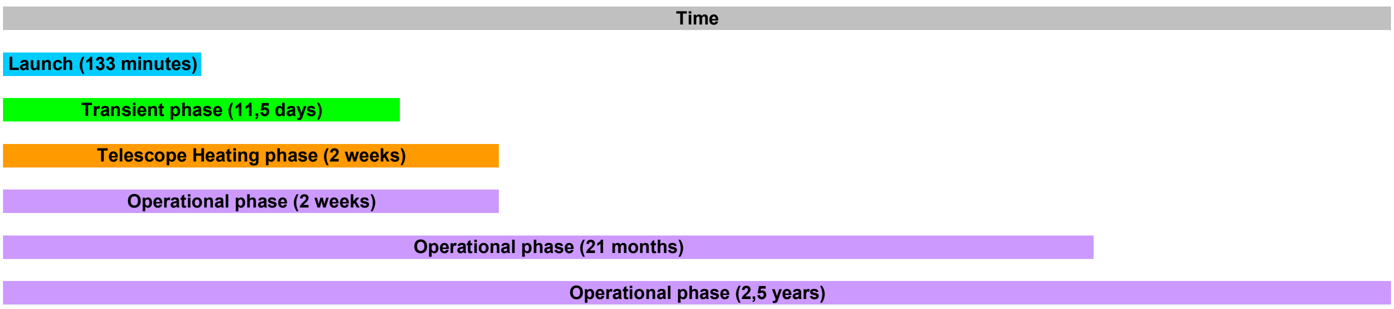


Figure 6.7-1 Planck Outgassing simulations strategy

The simulations are performed with ESABASE/OUTGASSING software, except for the transient phase where an Excel file permits the calculation of the TML as a function of time.

Due to the lack of information concerning the re-evaporation phenomenon, it is not considered in the simulations. In order to be as near as possible of the reality, a post treatment of the results is done with the hypothesis of a contamination by water. The re-evaporation is finally estimated with the equation determining the vaporisation rate of a water splash under vacuum conditions.

$$\frac{dW}{dt} = 4{,}36.10^{-3} * P_s * A * S_1 * \sqrt{\frac{M}{T_s}} \text{ (in kg/s)}$$

With

Ps: vapour pressure of water (Pa)

S1: condensation coefficient (comprised between 0 and 1)

A: surface area

M: molecular mass (atomic mass unity)

Ts: surface temperature (K)

The ESABASE model used for the outgassing simulations is available in Figure 6.7-2. This model is derived from the thermal model.

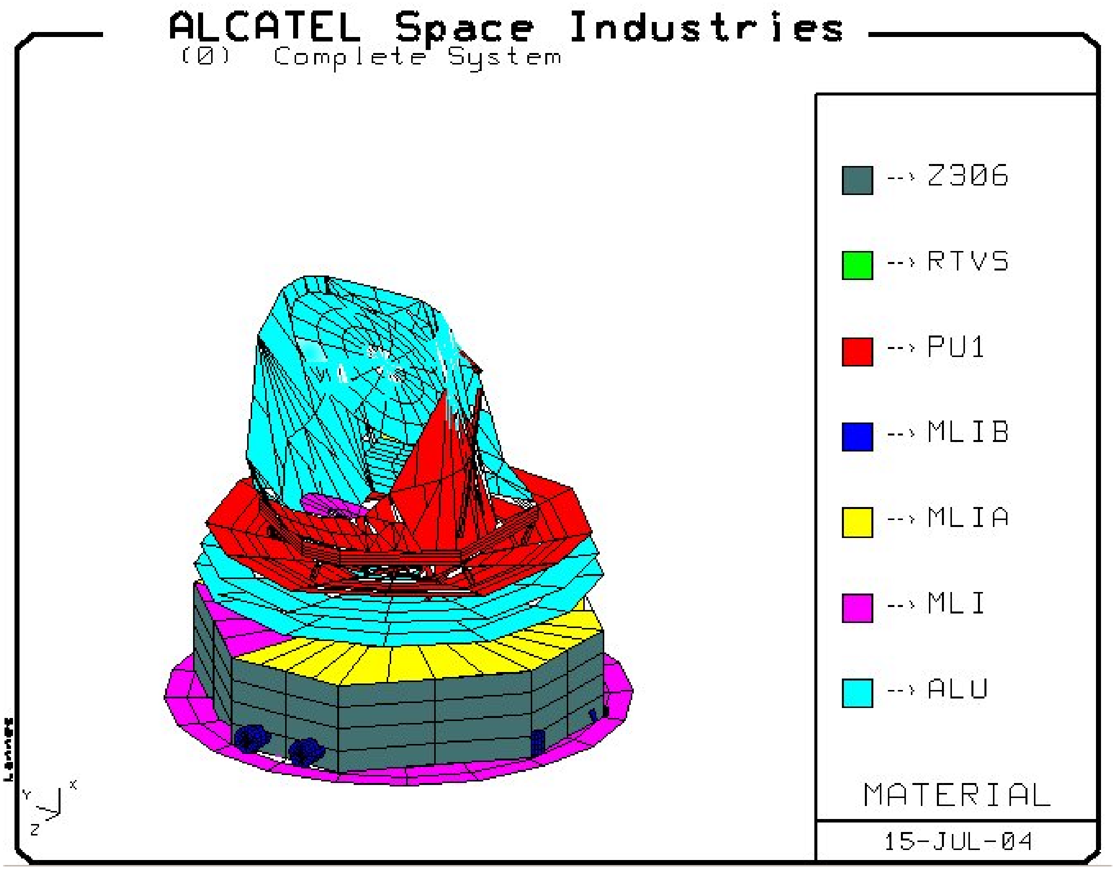


Figure 6.7-2 Planck Outgassing Model

The way the TML (Total Mass Lost) and the CVCM (collected volatile and condensable materials) are calculated in the outgassing numerical scheme is explicated in the ESTEC VBQC report.

6.7.2.1.3.1.1 Outgassing analysis during launch phase

During this phase, all the equipment are set to 20° C.

The results of the ESABASE simulations are presented in document RD04.6.

The amount of cumulative contamination during the launch is quite high, but it does not take into consideration the competitive phenomenon of evaporation. (the time for a complete re-evaporation at the maximum location of 20 ms)

In conclusion, it can be said that there is no more contamination at the end of the launch phase on the Planck satellite because the deposited water is almost instantaneously reavaporated.

6.7.2.1.3.1.2 Outgassing analysis during transient phase

Due to the fact that the temperature variations can not be taken into account by ESABASE/OUTGASSING, a specific Excel file was developed in order to cope with the need of estimating the contamination during the transient phase. This part of the analysis was performed in various steps. First, the temperature was discretised in very small intervals. Second, only very few elements of the satellite were selected for this study (V-grooves, baffle, M1, M2). Third, the TML of each material presents on each surface was determined taking into consideration the historic of the outgassing phenomenon (i.e.: the amount of material already outgassed, and the amount still to outgas). Fourth, the viewing factors of all the selected elements were determined by the help of ESARAD software. Fifth, the contamination of the each element by all the others was determined. The surfaces and mass values for each material are output of the ESABASE software.

The temperature profile of each studied equipment during transient phase is available in Figure 6.7-3.

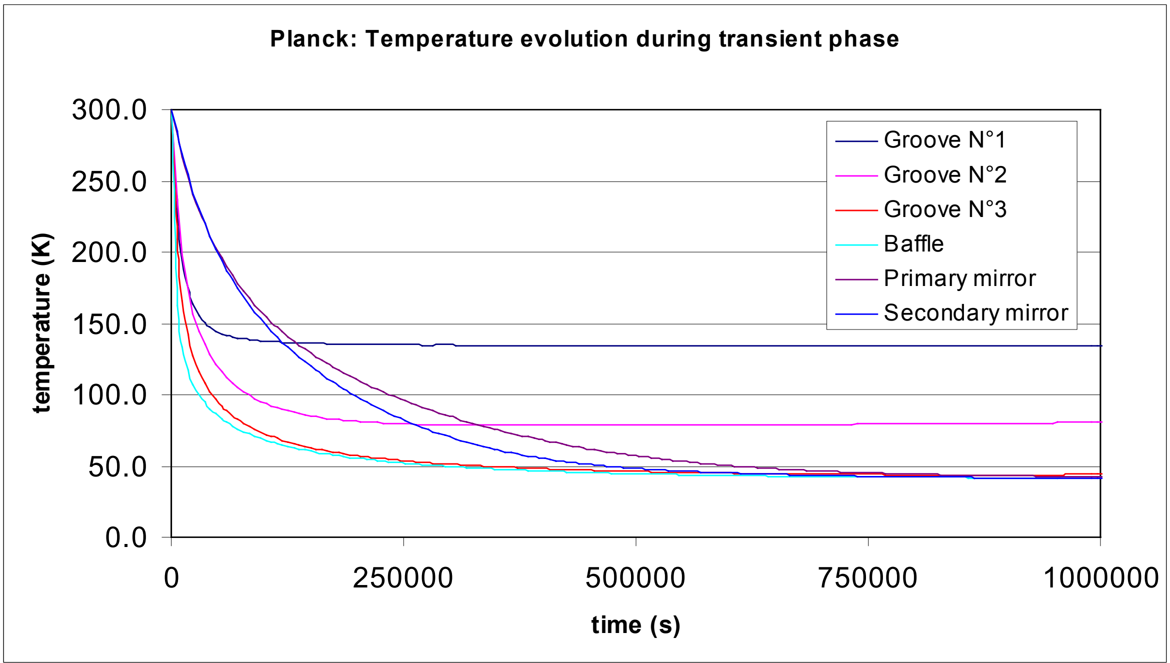


Figure 6.7-3 Planck temperature evolution during transient phase

The total contamination during the transient phase is presented in Table 6.7–1.

Sum-up	**Contamination (kg/m²)**	**Contamination (g/cm²)**
Groove #1+x	6.00E-07	6.00E-08
Groove #1 -x	0.00E+00	0.00E+00
Groove #2+x	5.10E-09	5.10E-10
Groove #2-x	1.91E-04	1.91E-05
Groove #3 +x (PUK)	6.31E-05	6.31E-06
Groove #3 +x (Alu)	2.27E-04	2.27E-05
Groove #3-x	2.29E-04	2.29E-05
Baffle : internal	1.88E-05	1.88E-06
Baffle : external	6.07E-05	6.07E-06
M1 PM front	2.66E-06	2.66E-07
M1 PM rear	4.77E-08	4.77E-09
M2 SM front	7.23E-06	7.23E-07
M2 SM rear	3.59E-05	3.59E-06
FPU (active side)	1.46E-05	1.46E-06

Table 6.7–1 Planck contamination during transient phase

6.7.2.1.3.1.3 Contamination during operational phase

The simulations were performed for the operational phase, i.e. for a hot SVM and a cold PPLM, the temperatures are coming from the "PPLM radiative environment description" (HP-3-ASPI-TN-0190).

The simulations were performed for the nominal lifetime (21 months) and for the extended lifetime (2.5 years). An additional point was extracted after 2 weeks. The re-evaporation phenomenon was estimated for this phase except for surfaces which temperature was lower than 159K (sticking temperature for water under vacuum conditions).

The results are available in Table 6.7–2 to Table 6.7–4.

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Maximum contamination (g/cm²)	Minimum contamination (g/cm²)
GS front side	RTVS	3.187	13.850	399.0	1.21E-04	1.21E-04	1.21E-04
GS rear side	MLI	5.334	13.850	312.0	2.92E-05	2.92E-05	2.92E-05
SVM lateral	CFRP	75.124	9.763	281.0	4.39E-04	6.57E-04	3.09E-04
SVM upper	MLIA	3.745	10.116	303.0	8.04E-05	1.69E-04	3.01E-05
Groove #1 +X	NO OUTGASSING	0.000	10.590	129.0	0.00E+00	0.00E+00	0.00E+00
Groove #1 -X	NO OUTGASSING	0.000	10.590	129.0	6.64E-07	1.07E-06	2.71E-07
Groove #2 +X	NO OUTGASSING	0.000	10.098	80.0	1.10E-06	6.60E-06	0.00E+00
Groove #2 -X	NO OUTGASSING	0.000	10.098	80.0	3.10E-06	1.86E-05	0.00E+00
Groove #3 +X (PUK)	PU1	5.889	8.412	45.0	1.61E-15	1.85E-15	1.38E-15
Groove #3 +X (Alu)	NO OUTGASSING	0.000	1.261	45.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 -X	NO OUTGASSING	0.000	8.060	45.0	1.28E-11	1.30E-11	1.26E-11
Cryo Struts	PU1	0.731	1.589	300.0	6.14E-05	3.60E-04	0.00E+00
Cadre	PU1	0.233	1.094	42.0	3.41E-08	2.36E-07	2.83E-16
FPU (active side)	NO OUTGASSING	0.000	0.260	20.0	3.18E-09	3.18E-09	3.18E-09
PAU	MLIA	0.325	0.844	312.0	1.96E-04	4.25E-04	6.70E-06
Wave guide	NO OUTGASSING	0.000	4.937	300.0	1.33E-05	2.30E-04	0.00E+00
M1 support rear side	PU1	0.545	3.112	42.0	4.51E-06	1.91E-04	1.11E-14
M1 support towards M1	NO OUTGASSING	0.000	3.112	42.0	6.58E-07	1.26E-05	8.86E-13
M1 support struts	PU1	0.348	1.990	42.0	4.50E-06	1.35E-04	0.00E+00
Baffle internal side	NO OUTGASSING	0.000	8.022	44.0	2.65E-07	3.50E-06	1.69E-12
Baffle external side	PU1	5.615	8.022	44.0	1.19E-06	8.00E-06	0.00E+00
M2 support	PU1	0.076	0.194	42.0	1.63E-05	6.43E-05	6.63E-16
M2 support struts	PU1	0.072	0.184	42.0	3.68E-07	2.16E-06	0.00E+00
M2 front side	NO OUTGASSING	0.000	0.957	42.0	2.89E-06	2.89E-06	2.89E-06
M2 rear side	MLI	0.326	0.957	42.0	3.84E-06	3.84E-06	3.84E-06
STM 1	MLIB	0.070	0.334	281.0	3.11E-04	5.82E-04	1.41E-05
STM 2	MLIB	0.070	0.334	281.0	5.69E-04	7.10E-04	4.33E-04
Sensor #1	MLIB	0.007	0.033	281.0	4.73E-04	1.68E-03	0.00E+00
Sensor #2	MLIB	0.006	0.030	281.0	7.80E-04	2.14E-03	0.00E+00
Sensor #3	MLIB	0.007	0.033	281.0	6.83E-04	1.67E-03	1.62E-08
Sensor #4	MLIB	0.020	0.097	281.0	1.79E-03	8.68E-03	0.00E+00
BEU	MLIA	0.179	0.465	309.0	1.00E-04	1.74E-04	1.02E-05
BEU Z306	Z306	0.005	0.058	301.0	7.94E-05	7.94E-05	7.94E-05
M1 front face	NO OUTGASSING	0.000	2.764	42.0	3.15E-06	1.70E-04	4.78E-17
M1 rear face	MLI	0.940	2.764	42.0	0.00E+00	0.00E+00	0.00E+00

Table 6.7–2 Planck contamination during operational phase (21 months)

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Maximum contamination (g/cm²)	Minimum contamination (g/cm²)
GS front side	RTVS	3.187	13.850	399.0	1.21E-04	1.21E-04	1.21E-04
GS rear side	MLI	5.334	13.850	312.0	2.94E-05	2.94E-05	2.94E-05
SVM lateral	CFRP	75.124	9.763	281.0	4.42E-04	6.62E-04	3.11E-04
SVM upper	MLIA	3.745	10.116	303.0	8.11E-05	1.69E-04	3.05E-05
Groove #1 +X	NO OUTGASSING	0.000	10.590	129.0	0.00E+00	0.00E+00	0.00E+00
Groove #1 -X	NO OUTGASSING	0.000	10.590	129.0	6.66E-07	1.07E-06	2.72E-07
Groove #2 +X	NO OUTGASSING	0.000	10.098	80.0	1.15E-06	6.90E-06	0.00E+00
Groove #2 -X	NO OUTGASSING	0.000	10.098	80.0	3.15E-06	1.89E-05	0.00E+00
Groove #3 +X (PUK)	PU1	5.889	8.412	45.0	2.58E-15	2.96E-15	2.21E-15
Groove #3 +X (Alu)	NO OUTGASSING	0.000	1.261	45.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 -X	NO OUTGASSING	0.000	8.060	45.0	2.05E-11	2.08E-11	2.01E-11
Cryo Struts	PU1	0.731	1.589	300.0	6.22E-05	3.60E-04	0.00E+00
Cadre	PU1	0.233	1.094	42.0	3.42E-08	2.37E-07	5.66E-16
FPU (active side)	NO OUTGASSING	0.000	0.260	20.0	3.34E-09	3.34E-09	3.34E-09
PAU	MLIA	0.325	0.844	312.0	1.96E-04	4.25E-04	6.90E-06
Wave guide	NO OUTGASSING	0.000	4.937	300.0	1.34E-05	2.32E-04	0.00E+00
M1 support rear side	PU1	0.545	3.112	42.0	4.56E-06	1.91E-04	2.22E-14
M1 support towards M1	NO OUTGASSING	0.000	3.112	42.0	6.90E-07	1.32E-05	1.77E-12
M1 support struts	PU1	0.348	1.990	42.0	4.67E-06	1.42E-04	0.00E+00
Baffle internal side	NO OUTGASSING	0.000	8.022	44.0	2.83E-07	3.68E-06	2.96E-12
Baffle external side	PU1	5.615	8.022	44.0	1.23E-06	8.37E-06	0.00E+00
M2 support	PU1	0.076	0.194	42.0	1.71E-05	6.74E-05	1.33E-15
M2 support struts	PU1	0.072	0.184	42.0	3.92E-07	2.28E-06	0.00E+00
M2 front side	NO OUTGASSING	0.000	0.957	42.0	3.10E-06	3.10E-06	3.10E-06
M2 rear side	MLI	0.326	0.957	42.0	4.04E-06	4.04E-06	4.04E-06
STM 1	MLIB	0.070	0.334	281.0	3.12E-04	5.87E-04	1.41E-05
STM 2	MLIB	0.070	0.334	281.0	5.73E-04	7.15E-04	4.37E-04
Sensor #1	MLIB	0.007	0.033	281.0	4.77E-04	1.69E-03	0.00E+00
Sensor #2	MLIB	0.006	0.030	281.0	7.87E-04	2.16E-03	0.00E+00
Sensor #3	MLIB	0.007	0.033	281.0	6.88E-04	1.68E-03	1.62E-08
Sensor #4	MLIB	0.020	0.097	281.0	1.80E-03	8.75E-03	0.00E+00
BEU	MLIA	0.179	0.465	309.0	1.01E-04	1.76E-04	1.03E-05
BEU Z306	Z306	0.005	0.058	301.0	7.98E-05	7.98E-05	7.98E-05
M1 front face	NO OUTGASSING	0.000	2.764	42.0	3.27E-06	1.71E-04	9.57E-17
M1 rear face	MLI	0.940	2.764	42.0	0.00E+00	0.00E+00	0.00E+00

Table 6.7–3 Planck contamination during operational phase (2.5 years)

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Maximum contamination (g/cm²)	Minimum contamination (g/cm²)
GS front side	RTVS	3.187	13.850	399.0	1.20E-04	1.20E-04	1.20E-04
GS rear side	MLI	5.334	13.850	312.0	2.27E-05	2.27E-05	2.27E-05
SVM lateral	CFRP	75.124	9.763	281.0	3.50E-04	5.28E-04	2.49E-04
SVM upper	MLIA	3.745	10.116	303.0	6.91E-05	1.51E-04	2.57E-05
Groove #1 +X	NO OUTGASSING	0.000	10.590	129.0	0.00E+00	0.00E+00	0.00E+00
Groove #1 -X	NO OUTGASSING	0.000	10.590	129.0	6.39E-07	1.03E-06	2.58E-07
Groove #2 +X	NO OUTGASSING	0.000	10.098	80.0	4.66E-07	2.80E-06	0.00E+00
Groove #2 -X	NO OUTGASSING	0.000	10.098	80.0	2.23E-06	1.34E-05	0.00E+00
Groove #3 +X (PUK)	PU1	5.889	8.412	45.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 +X (Alu)	NO OUTGASSING	0.000	1.261	45.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 -X	NO OUTGASSING	0.000	8.060	45.0	0.00E+00	0.00E+00	0.00E+00
Cryo Struts	PU1	0.731	1.589	300.0	5.24E-05	3.51E-04	0.00E+00
Cadre	PU1	0.233	1.094	42.0	3.29E-08	2.30E-07	0.00E+00
FPU (active side)	NO OUTGASSING	0.000	0.260	20.0	1.25E-09	1.25E-09	1.25E-09
PAU	MLIA	0.325	0.844	312.0	1.83E-04	4.14E-04	4.21E-06
Wave guide	NO OUTGASSING	0.000	4.937	300.0	1.14E-05	2.09E-04	0.00E+00
M1 support rear side	PU1	0.545	3.112	42.0	3.92E-06	1.89E-04	0.00E+00
M1 support towards M1	NO OUTGASSING	0.000	3.112	42.0	2.67E-07	4.96E-06	0.00E+00
M1 support struts	PU1	0.348	1.990	42.0	2.17E-06	5.32E-05	0.00E+00
Baffle internal side	NO OUTGASSING	0.000	8.022	44.0	9.87E-08	1.38E-06	0.00E+00
Baffle external side	PU1	5.615	8.022	44.0	6.48E-07	3.65E-06	0.00E+00
M2 support	PU1	0.076	0.194	42.0	6.78E-06	2.53E-05	0.00E+00
M2 support struts	PU1	0.072	0.184	42.0	1.39E-07	8.33E-07	0.00E+00
M2 front side	NO OUTGASSING	0.000	0.957	42.0	1.06E-06	1.06E-06	1.06E-06
M2 rear side	MLI	0.326	0.957	42.0	1.50E-06	1.50E-06	1.50E-06
STM 1	MLIB	0.070	0.334	281.0	2.69E-04	4.62E-04	1.40E-05
STM 2	MLIB	0.070	0.334	281.0	4.87E-04	5.67E-04	3.36E-04
Sensor #1	MLIB	0.007	0.033	281.0	3.73E-04	1.30E-03	0.00E+00
Sensor #2	MLIB	0.006	0.030	281.0	6.11E-04	1.66E-03	0.00E+00
Sensor #3	MLIB	0.007	0.033	281.0	5.35E-04	1.29E-03	1.56E-08
Sensor #4	MLIB	0.020	0.097	281.0	1.39E-03	6.73E-03	0.00E+00
BEU	MLIA	0.179	0.465	309.0	8.68E-05	1.45E-04	9.65E-06
BEU Z306	Z306	0.005	0.058	301.0	7.57E-05	7.57E-05	7.57E-05
M1 front face	NO OUTGASSING	0.000	2.764	42.0	2.29E-06	1.32E-04	0.00E+00
M1 rear face	MLI	0.940	2.764	42.0	0.00E+00	0.00E+00	0.00E+00

Table 6.7–4 Planck contamination during operational phase (2 weeks)

6.7.2.1.3.1.4 Contamination during heating phase

An outgassing simulation was performed with ESABASE software, taking into consideration the telescope (M1, M2, FPU) heating during 2 weeks at 40° C, while the other parts of the Planck satellite stay at the operational temperatures.

The results of the simulation are available in Table 6.7–5, with the contaminant evaporation estimation as presented in the introduction. A complete evaporation of the contamination deposit is estimated on the sensitive elements during the heating phase.

The difference between the results obtained with the telescope heating phase and the results obtained for the operational conditions after 2 weeks are available in Table 6.7–6.

This heating phase induces a contamination amount increase (maximum increase of 1.4×10^{-4} g/cm²) on the baffle internal part, due to the outgassing of the material implemented on the M1 and M2 rear sides.

Element	Material	Mass (kg)	Surface (m²)	Delta Temperature (K)	Delta Average contamination (g/cm²)	Delta Maximum contamination (g/cm²)	Delta Minimum contamination (g/cm²)
GS front side	RTVS	3.187	13.850	0.0	1.00E-07	1.00E-07	1.00E-07
GS rear side	MLI	5.334	13.850	0.0	0.00E+00	0.00E+00	0.00E+00
SVM lateral	Z306	0.762	9.763	0.0	2.00E-08	0.00E+00	1.00E-08
SVM upper	MLIA	3.745	10.116	0.0	4.38E-08	1.00E-07	1.00E-08
Groove #1 +X	NO OUTGASSING	0.000	10.590	-14.0	0.00E+00	0.00E+00	0.00E+00
Groove #1 -X	NO OUTGASSING	0.000	10.590	-14.0	-2.83E-10	0.00E+00	-1.00E-10
Groove #2 +X	NO OUTGASSING	0.000	10.098	-3.0	0.00E+00	0.00E+00	0.00E+00
Groove #2 -X	NO OUTGASSING	0.000	10.098	-3.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 +X (PUK)	PU1	5.889	8.412	23.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 +X (Alu)	NO OUTGASSING	0.000	1.261	23.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 -X	NO OUTGASSING	0.000	8.060	23.0	0.00E+00	0.00E+00	0.00E+00
Cryo Struts	PU1	0.731	1.589	0.0	6.65E-07	-1.00E-07	0.00E+00
Cadre	PU1	0.233	1.094	27.0	-4.29E-11	-3.00E-10	0.00E+00
FPU (active side)	NO OUTGASSING	0.000	0.260	66.0	-1.25E-09	-1.25E-09	-1.25E-09
PAU	MLIA	0.325	0.844	0.0	-1.63E-08	-1.00E-07	2.00E-09
Wave guide	NO OUTGASSING	0.000	4.937	0.0	4.77E-06	1.00E-07	0.00E+00
M1 support rear side	PU1	0.545	3.112	255.0	1.45E-05	-2.00E-07	0.00E+00
M1 support towards M1	NO OUTGASSING	0.000	3.112	255.0	5.43E-05	8.96E-05	2.10E-05
M1 support struts	PU1	0.348	1.990	0.0	1.45E-05	5.54E-05	0.00E+00
Baffle internal side	NO OUTGASSING	0.000	8.022	25.0	1.50E-05	1.37E-04	0.00E+00
Baffle external side	PU1	5.615	8.022	25.0	2.82E-07	8.68E-07	0.00E+00
M2 support	PU1	0.076	0.194	267.0	7.99E-06	1.13E-05	1.14E-08
M2 support struts	PU1	0.072	0.184	267.0	3.40E-05	9.24E-05	0.00E+00
M2 front side	NO OUTGASSING	0.000	0.957	271.0	-1.06E-06	-1.06E-06	-1.06E-06
M2 rear side	MLI	0.326	0.957	271.0	-1.50E-06	-1.50E-06	-1.50E-06
STM 1	MLIB	0.070	0.334	0.0	3.67E-08	1.00E-07	-1.00E-08
STM 2	MLIB	0.070	0.334	0.0	6.67E-08	2.00E-07	0.00E+00
Sensor #1	MLIB	0.007	0.033	0.0	-1.63E-08	-1.00E-07	0.00E+00
Sensor #2	MLIB	0.006	0.030	0.0	1.67E-09	0.00E+00	0.00E+00
Sensor #3	MLIB	0.007	0.033	0.0	-1.92E-08	-1.00E-07	0.00E+00
Sensor #4	MLIB	0.020	0.097	0.0	5.17E-08	3.00E-07	0.00E+00
BEU	MLIA	0.179	0.465	0.0	7.20E-09	0.00E+00	6.00E-09
BEU Z306	Z306	0.005	0.058	0.0	1.00E-08	1.00E-08	1.00E-08
M1 front face	NO OUTGASSING	0.000	2.764	271.0	-1.95E-07	-6.98E-06	0.00E+00
M1 rear face	MLI	0.940	2.764	271.0	0.00E+00	0.00E+00	0.00E+00

Table 6.7–5 Planck contamination during heating phase

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Maximum contamination (g/cm²)	Minimum contamination (g/cm²)
GS front side	RTVS	3.187	13.850	399.0	1.20E-04	1.20E-04	1.20E-04
GS rear side	MLI	5.334	13.850	312.0	2.27E-05	2.27E-05	2.27E-05
SVM lateral	CFRP	75.124	9.763	281.0	3.50E-04	5.28E-04	2.50E-04
SVM upper	MLIA	3.745	10.116	303.0	6.91E-05	1.51E-04	2.57E-05
Groove #1 +X	NO OUTGASSING	0.000	10.590	115.0	0.00E+00	0.00E+00	0.00E+00
Groove #1 -X	NO OUTGASSING	0.000	10.590	115.0	6.39E-07	1.03E-06	2.58E-07
Groove #2 +X	NO OUTGASSING	0.000	10.098	77.0	4.66E-07	2.80E-06	0.00E+00
Groove #2 -X	NO OUTGASSING	0.000	10.098	77.0	2.23E-06	1.34E-05	0.00E+00
Groove #3 +X (PUK)	PU1	5.889	8.412	68.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 +X (Alu)	NO OUTGASSING	0.000	1.261	68.0	0.00E+00	0.00E+00	0.00E+00
Groove #3 -X	NO OUTGASSING	0.000	8.060	68.0	0.00E+00	0.00E+00	0.00E+00
Cryo Struts	PU1	0.731	1.589	300.0	5.30E-05	3.51E-04	0.00E+00
Cadre	PU1	0.233	1.094	69.0	3.29E-08	2.29E-07	0.00E+00
FPU (active side)	NO OUTGASSING	0.000	0.260	86.0	5.08E-09	5.08E-09	5.08E-09
PAU	MLIA	0.325	0.844	312.0	1.82E-04	4.14E-04	4.22E-06
Wave guide	NO OUTGASSING	0.000	4.937	300.0	1.62E-05	2.09E-04	0.00E+00
M1 support rear side	PU1	0.545	3.112	297.0	1.84E-05	1.89E-04	0.00E+00
M1 support towards M1	NO OUTGASSING	0.000	3.112	297.0	5.45E-05	9.46E-05	2.10E-05
M1 support struts	PU1	0.348	1.990	42.0	1.67E-05	1.09E-04	0.00E+00
Baffle internal side	NO OUTGASSING	0.000	8.022	69.0	1.52E-05	1.39E-04	0.00E+00
Baffle external side	PU1	5.615	8.022	69.0	9.30E-07	5.81E-06	0.00E+00
M2 support	PU1	0.076	0.194	309.0	1.48E-05	3.66E-05	1.14E-08
M2 support struts	PU1	0.072	0.184	309.0	3.41E-05	9.33E-05	0.00E+00
M2 front side	NO OUTGASSING	0.000	0.957	313.0	2.14E-04	2.14E-04	2.14E-04
M2 rear side	MLI	0.326	0.957	313.0	4.97E-05	4.97E-05	4.97E-05
STM 1	MLIB	0.070	0.334	281.0	2.69E-04	4.62E-04	1.40E-05
STM 2	MLIB	0.070	0.334	281.0	4.88E-04	5.67E-04	3.36E-04
Sensor #1	MLIB	0.007	0.033	281.0	3.73E-04	1.30E-03	0.00E+00
Sensor #2	MLIB	0.006	0.030	281.0	6.11E-04	1.66E-03	0.00E+00
Sensor #3	MLIB	0.007	0.033	281.0	5.35E-04	1.29E-03	1.56E-08
Sensor #4	MLIB	0.020	0.097	281.0	1.39E-03	6.74E-03	0.00E+00
BEU	MLIA	0.179	0.465	309.0	8.68E-05	1.45E-04	9.66E-06
BEU Z306	Z306	0.005	0.058	301.0	7.57E-05	7.57E-05	7.57E-05
M1 front face	NO OUTGASSING	0.000	2.764	313.0	2.34E-04	4.52E-04	0.00E+00
M1 rear face	MLI	0.940	2.764	313.0	0.00E+00	0.00E+00	0.00E+00

Table 6.7–6 Planck contamination difference between heating phase and nominal conditions (2 weeks)

6.7.2.1.3.2 Planck plume analysis

At PDR, the plume impact analysis was performed with a simple first order approach, used on ISO. For CDR, a complete dedicated model has been built.

The simulations of the contamination due to UPS activation are performed with the CONTAMINE software. This software was developed under CNES contract. It permits to simulate first, the contaminants propagation from the reaction chamber to the satellite surfaces, and second the interactions between the contaminants and the satellite surfaces (deposits and surfaces properties modifications).

The model takes into account:

- Planck satellite 20N and 1 N thrusters design, location and orientations
- Hydrazine composition and sticking temperature.

COMPONENT	FORMULA	PROPORTION	STICKING TEMPERATURE (K)
Ammonia	NH3	34.31%	102
Nitrogen	N2	57.86%	26
Hydrogen	H2	6.22%	4
Water	H2O	0.65%	159
Hydrazine	N2H4	0.46%	165
Aniline	C6H5NH2	0.50%	190

Table 6.7–7 Planck - composition of an hydrazine catalytic thruster plume

- The thrusters utilisation strategy

MANŒUVRE	FUEL MASS	THRUSTER
Compensation for perigee velocity variation	9.6	(D1 + D2) or (F1 + F2) or (U1 + U2)
Removal of launcher dispersion	68	(D1 + D2) or (F1 + F2) or (U1 + U2)
Manoeuvre on day 12 from perigee	6.7	(D1 + D2) or (F1 + F2) or (U1 + U2)
Mid course correction	5	(D1 + D2) or (F1 + F2) or (U1 + U2)
Orbit injection	275	F1 + F2
Orbit maintenance for mission lifetime	8.9	(D1 + D2) or (F1 + F2) or (U1 + U2)
Orbit maintenance due to attitude control	8.7	(D1 + D2) or (F1 + F2) or (U1 + U2)
Attitude control	16.7	A1 or B1

Table 6.7–8 Planck – thrusters utilisation strategy

To compute the worst case for the chemical thrusters contamination, the following scenario has to be used:

- 275 kg with 50% on F1 and 50% on F2
- 16.7 kg on the worst contaminating thruster A1 or B1
- 107 kg on the worst contaminating thrusters couple (D1,D2) or (F1,F2) or (U1,U2) with 50 % consumption on each thruster.

All the thrusters strategies have been done. The worst case in term of contamination is found with the F1A, F2A and A1A thrusters combination.

All these hypotheses lead to the contamination presented in Table 6.7–9.

Element	Contamination by H2 (g/cm²)	Contamination by H2O (g/cm²)	Contamination by N2 (g/cm²)	Contamination by N2H4 (g/cm²)	Contamination by NH3 (g/cm²)
Groove1_X	0	0	0	NC	1.05E-18
Groove1_-X	0	1.92E-11	0	NC	2.94E-18
Groove2_X	0	0	0	NC	4.29E-08
Groove2_-X	0	0	0	NC	3.36E-17
Groove3_+X#1	0	0	0	NC	0
Groove3_+X#2	0	0	0	NC	0
Groove3_-X	0	0	7.37E-25	NC	0
Cryo_strut#1	0	0	0	NC	3.43E-21
Cryo_strut#2	0	0	0	NC	1.77E-21
Cryo_strut#3	0	0	0	NC	5.19E-21
Cryo_strut#4	0	0	0	NC	1.77E-20
Cryo_strut#5	0	0	0	NC	8.26E-21
Cryo_strut#6	0	0	0	NC	6.78E-21
Cryo_strut#7	0	0	0	NC	1.10E-20
Cryo_strut#8	0	0	0	NC	2.14E-21
Cryo_strut#9	0	0	0	NC	2.83E-21
Cryo_strut#10	0	0	0	NC	6.12E-22
Cryo_strut#11	0	0	0	NC	1.41E-21
Cryo_strut#12	0	0	0	NC	2.14E-21
FPU_active	**0**	**0**	**0**	**NC**	**0**
Baffle_ext	0	0	2.70E-23	NC	5.30E-16
M2_front	**0**	**0**	**0**	**NC**	**0**
M1_front	**0**	**0**	**0**	**NC**	**0**

Table 6.7–9 Planck telescope contamination due to plume activation

The contamination by N2 and H2 are presented for information only, due to the fact that surfaces at 50 K do not trap these components.

There is no noticeable contamination of the Planck sensitive elements by the plumes

6.7.2.1.3.3 Planck in orbit molecular contamination budget

Considering that

- there is a complete evaporation of the contaminants produced by materials outgassing during the launch phase
- considering the results of the outgassing phenomenon during the transient phase for the telescope and the V-grooves
- the results of the contamination during operational phase (with or without heating phase)
- the results of the plume contamination.

The following **in orbit** contamination budgets (see Table 6.7–10 and Table 6.7–11) have to be considered on Planck satellite.

(g/cm²)	Launch	Transient	Operationnal (21 months)	Total contamination
V-groove#1 +X	0	6.00E-08	0.00E+00	6.00E-08
V-groove #1-X	0	0.00E+00	6.64E-07	6.64E-07
V-groove #2 +X	0	5.10E-10	1.10E-06	1.10E-06
V-groove #2 -X	0	1.91E-05	3.10E-06	2.22E-05
V-groove #3 +X (Nextel part)	0	6.31E-06	1.61E-15	6.31E-06
V-groove #3 +X (Alu part)	0	2.27E-05	0.00E+00	2.27E-05
V-groove #3 -X	0	2.29E-05	1.28E-11	2.29E-05
Baffle internal part	0	1.88E-06	2.65E-07	2.14E-06
Baffle external part	0	6.07E-06	1.19E-06	7.26E-06
Primary mirror front	0	2.66E-07	3.15E-06	3.41E-06
Secondary mirror front	0	7.23E-07	2.89E-06	3.61E-06
FPU (active side)	0	1.46E-06	3.18E-09	1.46E-06

Table 6.7–10 Planck in orbit contamination budget without telescope heating phase

(g/cm²)	Launch	Transient	Operationnal (21 months) + heating (2 weeks)	Total contamination
V-groove#1 +X	0	0.00E+00	0.00E+00	0.00E+00
V-groove #1-X	0	0.00E+00	6.63E-07	6.63E-07
V-groove #2 +X	0	0.00E+00	1.10E-06	1.10E-06
V-groove #2 -X	0	0.00E+00	3.10E-06	3.10E-06
V-groove #3 +X (Nextel part)	0	0.00E+00	1.61E-15	1.61E-15
V-groove #3 +X (Alu part)	0	0.00E+00	0.00E+00	0.00E+00
V-groove #3 -X	0	0.00E+00	1.28E-11	1.28E-11
Baffle internal part	0	0.00E+00	1.54E-05	1.54E-05
Baffle external part	0	0.00E+00	1.47E-06	1.47E-06
Primary mirror front	0	0.00E+00	8.64E-07	8.64E-07
Secondary mirror front	0	0.00E+00	1.83E-06	1.83E-06
FPU (active side)	0	0.00E+00	1.93E-09	1.93E-09

Table 6.7–11 Planck in orbit contamination budget with telescope heating phase

6.7.2.2 Planck particulate contamination

6.7.2.2.1 On ground

Taking into account:

- the Planck AIT sequence and the associated particulate cleanings (one PPLM cleaning before the baffle mounting, one S/C cleaning at the end of the assembly / integration phase, one S/C cleaning before the first vacuum thermal test, one S/C cleaning in Kourou before encapsulation)
- the level at delivery (for the non cleaned parts during AIT)
- the redistribution into the optical cavity (surface ratio).

The Planck particulate contamination at the end of the AIT sequence (before encapsulation) is:

M1/M2/FPU	Optical cavity	External PPLM	grooves	SVM
1945 ppm	1945 ppm	1000 ppm	1000 ppm	2495 ppm

6.7.2.2.2 Launch pad activity and fairing contribution

We expect a maximum duration of 12 days in class 10 000, leading to 720 ppm contamination on the sensitive surfaces.

The launcher contribution (from encapsulation to separation) is specified to be 2300 ppm.

6.7.2.2.3 In orbit

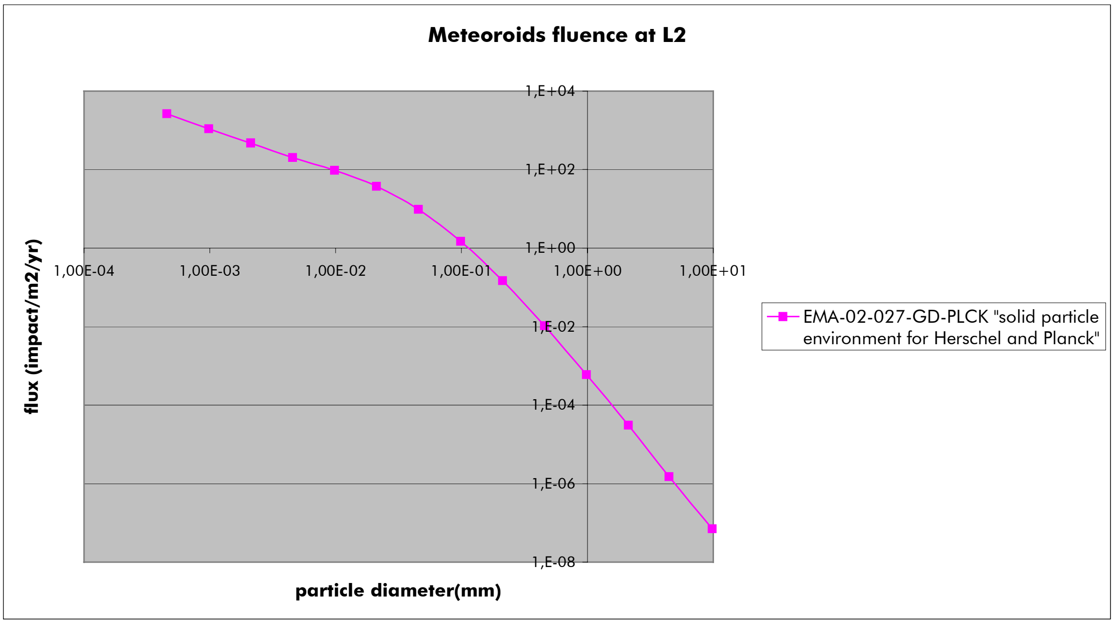
The in-orbit particulate contamination on Planck, orbiting around L2, come from two different sources: in-orbit redistribution and micrometeoroids. These two sources are analysed in the following sections, and their impact are quantified.

6.7.2.2.3.1 In-orbit redistribution

At the beginning of in-orbit life, the particulate contamination level on each element of a group is the same. This is due to the fact that the redistribution has already been taken into account during launch. No further redistribution can happen.

6.7.2.2.3.2 Micrometeoroids

The distribution of micrometeoroids around L2 is the following:



Taking into account Planck antenna diameter and Planck in-orbit life time, and the assumption (due to J. Mac Donnel in 1979 and used in the frame of ISO programme) that the pit diameter is 4 times the micrometeoroid diameter, this leads to a total of 1.5 ppm. This is completely negligible with regards to the on-ground contamination level, and with regards to the performance degradation.

6.7.2.3 Planck End of life contamination budgets and compliance

By summing all the contributors described before, one can build the End of life contamination budgets, and compare them to the needs. This is presented in the system budget report (cf. [RD02.3]).

The main conclusion is that all requirements are met without the need of heating, except for the reflectors mirror molecular contamination, which reaches 4.3 10-6 g/cm² for the 4 10-6 g/cm² specified by the instruments.

In terms of contamination, it is thus useful to heat the optical cavity which leads to 1.6 10-6 g/cm² for PR and 2.5 10-6 g/cm2 for SR both within specification. However it leads to the following constraints:

- need to heat both mirrors **and** the FPU
- connection of mirrors and FPU heaters to the SVM (copper harness), as well as thermal sensors, generating a heat leak which will induce a heat load mainly on the FPU's
- delay of 2 weeks on operations due to the duration of mirrors heating

The capability of heating is available in the CDR design (heating lines output in the PCDU, thermal sensors acquisition in the CDMU) and heaters are mounted on both reflectors, and planned to be implemented on the FPU. It is also recommended to use the heaters to limit contamination during on-ground activities (e.g. heat-up at the end of cryogenic testing).

6.7.3 Herschel contamination analysis

6.7.3.1 Herschel molecular contamination

6.7.3.1.1 On ground

According to the AIT sequence and the level at delivery, the molecular contamination expected at the end of Herschel AIT (before launch pad activities) is:

LOU WINDOWS (Internal and External)	FPU	TELESCOPE	S/C OUTSIDE
6 10^{-7} g/cm^2	78 10^{-7} g/cm^2 (*)	2.9 10^{-7} g/cm^2	27 10^{-7} g/cm^2

This high level is due to

- 40 10-7 gm/cm² for instruments at delivery
- 12 10-7 gm/cm² for the air permeation
- 25 10-6 gm/cm² for the internal outgassing of the CVV.

6.7.3.1.2 Launch pad activity and fairing contribution

We expect a maximum duration of 8 days in class 10 000, leading to 2.4 10-8 g/cm² molecular contamination.

The specified hypothesis for the launcher contribution (from the encapsulation to the separation) are (cf. SRS) **2300 ppm,** and no special molecular contamination.

6.7.3.1.3 In orbit

As for the Planck in orbit analyses, all the details (hypotheses, simulations tools, …) of the Herschel in orbit analyses are available in RD04.6.

6.7.3.1.3.1 Herschel outgassing analyses

The outgassing simulations are performed based on the residence time approach (see Planck paragraphs).

It is supposed in the outgassing simulations that the materials have not been baked out.

Various phases are distinguished and analysed separately on Herschel satellite. These phases are the following:

- Transient phase (satellite cool down)
- Heating phase (M1, M2 at a temperature of 40°C during 3 weeks)
- Operational phase (temperatures equal to the nominal ones, output at 3 weeks, 3.5 years and 6 years).

The ESABASE model used for the Herschel outgassing simulations is available in Figure 6.7-4. This model is derived from the mechanical model.

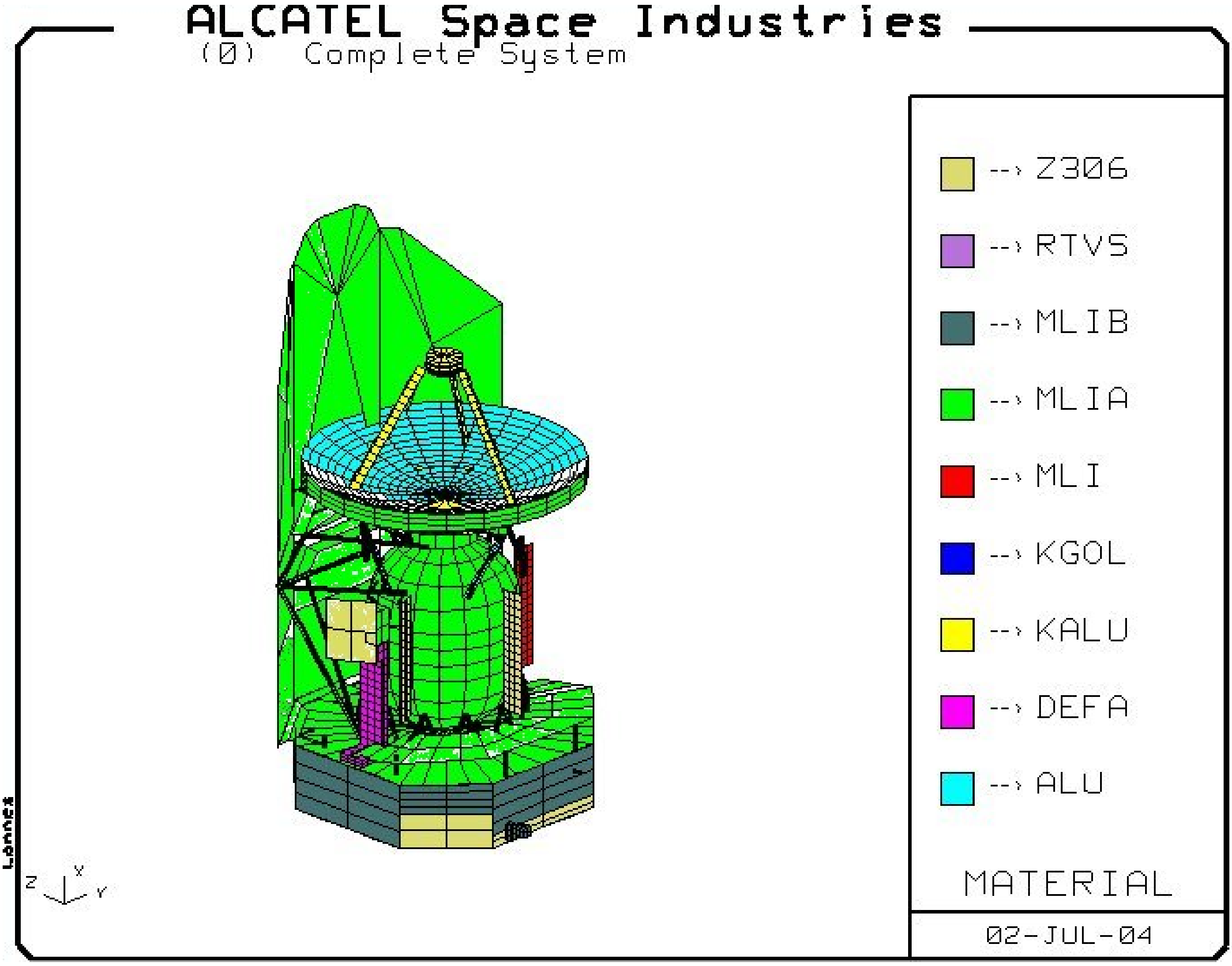


Figure 6.7-4 Herschel outgassing model

6.7.3.1.3.1.1 Outgassing analysis during transient phase

Due to the heating phase (3 weeks at 40°C) on the Herschel telescope, there is no contamination possible during the transient phase on M1 and M2. The contamination will not remain on M1 and M2 due to the consideration of the re-evaporation phenomenon.

For the LOU (mirrors and CVV window) which is a not covered and not heated element, a specific approach is performed. Due to the fact that the temperature variations can not be taken into account by ESABASE/OUTGASSING, a specific Excel file was developed in order to cope with the need of estimating the contamination during the transient phase. This part of the analysis was performed in various steps.

First, the temperature was discretised in very small intervals. Second, only the most outgassing elements of the satellite were selected for this study (Sunshield, sunshade, SVM top, M1, M2, CVV radiators, LOU wave guide, SVM shield and CVV). The MLI on the MLI baseplate as well as the LOU support struts have been considered. Third, the TML of each material presents on each surface was determined taking into consideration the historic of the outgassing phenomenon (i.e.: the amount of material already outgassed, and the amount still to outgas). Fourth, the LOU was suppressed and a factitious surface which represents the LOU aperture and the LOU window was designed, the viewing factors between this test surface and all the selected elements were determined by the help of ESARAD software. Fifth, the contamination due to the selected elements on the LOU surface was determined. The surfaces and mass values for each material are output of the ESABASE software.

The sum, on both surfaces (+/-Y), of contamination is computed. The sensitive surface, representing both the LOU baseplate and the LOU windows is a cold trap, on which the molecules stick for ever.

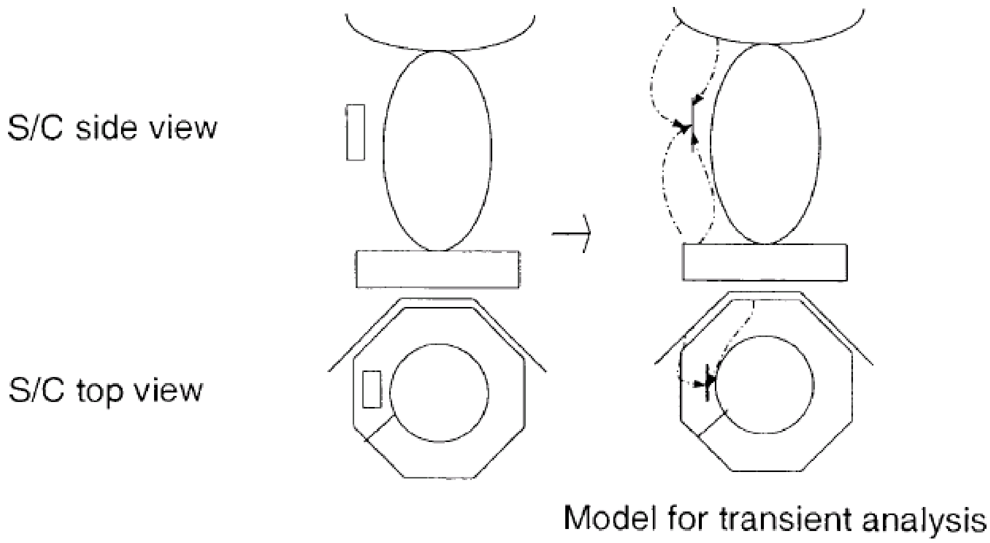


Figure 6.7-5 Herschel outgassing – LOU transient model

Indirect paths of molecules reflected on the hot sunshade are also considered.

The result of this analysis gives a molecular contamination of the LOU test surface during the transient phase of **4.61 E-5 g/cm²** in average on the LOU windows surface.

6.7.3.1.3.1.2 Outgassing analysis during operational phase

The simulations were performed for the operational phase, i.e. for an hot SVM and a "hot" HPLM, the temperatures are output of the thermal model (the 'Hot' HPLM model is 2 K hotter than the 'Cold' HPLM model).

The simulations were performed for the nominal lifetime (3.5 years) and for the extended lifetime (6 years). An additional point was extracted after 3 weeks. The re-evaporation phenomenon was estimated for this phase except for surfaces which temperature was lower than 159K (sticking temperature for water under vacuum conditions).

The results are available in Table 6.7–12 to Table 6.7–13.

It is also important to notice that the outgassing behaviour of Herschel has a slow dynamic, due to the low temperature of the sunshade, which makes the contamination of M1 growing continuously from beginning to end of life.

	g/cm²
M1 active side	1.11^E-05
M2 active side	9.5^E-08
LOU windows	1,9E-05
LOU mirrors	2,5E-06

Table 6.7–12 Herschel outgassing contamination after 3.5 years

	g/cm²
M1 active side	1,0E-07
M2 active side	2,3E-08
LOU windows	1,8E-05
LOU mirrors	2,4E-06

Table 6.7–13 Herschel outgassing contamination after 3 weeks

6.7.3.1.3.1.3 EOL Outgassing results

Knowing that a null contamination is expected on the primary and secondary mirrors at the end of the heating phase, these results are available in Table 6.7–14. The results of dedicated analysis performed for the LOU windows and mirrors (transient case) are included.

These results show that heating improves the contamination level on Herschel Telescope, although the main contamination occurs during the operational phase, because of the slow behaviour of the sunshade.

	g/cm²
M1 active side	1.11E-05
M2 active side	9.52E-08
LOU windows	5.19E-05
LOU mirrors	6.75E-06

Table 6.7–14 Herschel outgassing contamination with heating phase consideration (3.5 years)

The M1 contamination is mainly due to the sunshade long term outgassing.

LOU windows contamination is mainly dominated by the indirect molecules migrations, coming from the hidden part of the sunshield and CVV, reflected on the visible part of the hot sunshield, and coming on the LOU windows.

6.7.3.1.3.2 Herschel plume contamination analysis

At PDR, the plume impact analysis was performed with a simple first order approach, used on ISO. For CDR, a complete dedicated model has been built.

The simulations of the contamination due to UPS activation are performed with the CONTAMINE software. This software was developed under CNES contract. It permits to simulate first, the contaminants propagation from the reaction chamber to the satellite surfaces, and second the interactions between the contaminants and the satellite surfaces (deposits and surfaces properties modifications).

The model takes into account:

- Herschel satellite 20N thrusters design, location and orientations
- Hydrazine composition and sticking temperature.

COMPONENT	FORMULA	PROPORTION	STICKING TEMPERATURE (K)
Ammonia	NH3	34.31 %	102
Nitrogen	N2	57.86 %	26
Hydrogen	H2	6.22 %	4
Water	H2O	0.65 %	159
Hydrazine	N2H4	0.46 %	165
Aniline	C6H5NH2	0.50 %	190

Table 6.7–15 Herschel - composition of an hydrazine catalytic thruster plume

- The thrusters utilisation strategy.

The Table 6.7–16 shows the thruster utilisation strategy for Herschel satellite.

MANOEUVRE	FUEL MASS (kg)	THRUSTER
Compensation for perigee velocity variation	16.5	A1 or A2
Removal of launcher dispersion	68.4	A1 or A2
Manoeuvre on day 12 from perigee	6.8	A1 or A2
Mid course correction	4.7	A1 or A2
Orbit maintenance for mission lifetime	8.9	A1 or A2
Orbit maintenance due to attitude control	8.7	A1 or A2
Attitude control	16.7	C1 or C2 or C3 or C4

Table 6.7–16 Herschel - thrusters utilisation strategy

To compute the worst case for the chemical thrusters contamination, the following scenario has to be used:

- 114 kg on the worst contaminating thruster A1 or A2
- 17 kg on the worst contamination thruster C1, C2, C3 or C4 and 15 kg for attitude control during delta-V manoeuvres representing 32 kg to be computed for the worst contaminating thruster C1, C2, C3 or C4.

All these hypotheses lead to the contamination presented in Table 6.7–16.

Contaminant	M1 contamination (g/cm²)	M2 contamination (g/cm²)	LOU windows contamination (g/cm²)	LOU mirrors contamination (g/cm²)
NH3	0	6.6 10-10	0	0
H2O	0	1.03 10-11	1.53 10-12	2.0 10-13
N2H4	0	6.0 10-13	7.13 10-14	1.0 10-14

Table 6.7–17 Herschel contamination due to plume activation

As anticipated at PDR, the contamination of Herschel sensitive elements by plume components is not a critical point.

6.7.3.1.3.3 Herschel in-orbit molecular contamination budget

Considering that:

- there is a complete evaporation of the contaminants produced by materials outgassing during the launch phase and the heating phase
- the results of the contamination during operational phase
- the results of the plume contamination.

The following **in orbit** contamination budgets (see Table 6.7–18) have to be considered on Herschel satellite.

g/cm²		**BEFORE LAUNCH**	**OUTGASSING**	**THRUSTER**	**TOTAL**
M1 active side		6,2E-07	1,1E-05	Negl	1,2E-05
M2 active side		6,2E-07	9,6E-08	Negl	7,20E-07
LOU windows	Internal	6,0E-07	5,4E-07	Negl	11,4E-07
	External	6,2E-07	5.2E-05	Negl	5,3E-05
LOU mirrors		4,1E-06	6.8E-06	Negl	1,1E-05
FPU's		4.1E-06	4,2E-06(*)	Negl	8,3E-06

Table 6.7–18 Herschel in orbit contamination budget with telescope heating phase

(*) includes water permeation and on-ground internal outgassing of the CVV

6.7.3.2 Herschel Particulate contamination

6.7.3.2.1 On ground

According to the AIT sequence and the level at delivery, the particulate contamination expected at the end of Herschel AIT (before launch pad activity) is:

LOU windows	FPU and optical bench	telescope		S/C outside
		M1	M2	
300 ppm	500 ppm	2100 ppm	400 ppm	2060 ppm

6.7.3.2.2 Launcher Launch pad activity and fairing contribution

We expect a maximum duration of 8 days in class 10 000, leading to

- 480 ppm contamination on M1
- 24 ppm on M2
- 48 ppm on the LOU external side.

The launcher contribution (from encapsulation to separation) is specified to be 2300 ppm.

6.7.3.2.3 In-orbit

The in-orbit particulate contamination on Herschel, orbiting around L2, come from two different sources: in-orbit redistribution and micrometeoroids. These two sources are analysed in the following sections, and their impact are quantified.

6.7.3.2.3.1 In-orbit redistribution

At the beginning of in-orbit life, the particulate contamination level on each element of a group is the same. This is due to the fact that the redistribution has already been taken into account during launch. The only remaining redistribution which can occur is the one coming from the telescope + baffles cavities (having around 5000 ppm worst case) into the open and clean cryostat. This redistribution can be assessed in the way the in-orbit redistribution was quantified in the frame of ISO (cf. ISO cleanliness Policy). The computation [cf. RD04.6] leads to 5 ppm increase in the cryostat.

6.7.3.2.3.2 Micrometeoroids

The distribution of micrometeoroids around L2 is the same than the one for Planck.

Taking into account the same policy than for Planck, but the Herschel configuration and life time, the computation (cf. [RD04.6] leads to a total of 3.43 ppm. This is completely negligible with regards to the on-ground contamination level, and with regards to the performance degradation.

6.7.3.3 Herschel End of life contamination budgets

By summing all the contributors described before, one can build the End of life contamination budgets, and compare them to the needs. This is all presented in the budget report (cf. [RD02-3]). It identifies the following non-compliances:

- On M1, the particulate contamination is around 5000 ppm instead of the 4500 ppm specified. This is counterbalanced by the lower contamination on M2 (2700 ppm), which makes the average value (3600 ppm) acceptable
- On M1, the molecular contamination is around 1.2 10-5 g/cm2. As on the M2, the molecular contamination is low 7 10-7 g/cm², the overall effect is reduced with an average of 6 10-6 g/cm² still above the requirement of 4 10-6 g/cm². It is shown in RD03.21 that the impact on transmission is compatible the specification. A RFD will be submitted.
- On the LOU window external surface, particulate contamination is around 2700 ppm instead of the 1200 ppm specified. A dedicated transmission analysis shows that this is acceptable with regards to HIFI transmission need as specified in the IID-B
- On the LOU mirror, the need is slightly exceeded (same phenomenon as for the windows). Due to the lower level and the lower sensitivity of icing on the mirror, this should also be acceptable for ESA/HIFI
- On the FPU's, the molecular contamination (8.3 10-6g/cm²) exceeds the needs (<6.0 10-6g/cm²) because of CVV internal outgassing and air permeation. However, the order of magnitude is maintained. A RFD, generated by ASED, will be submitted.

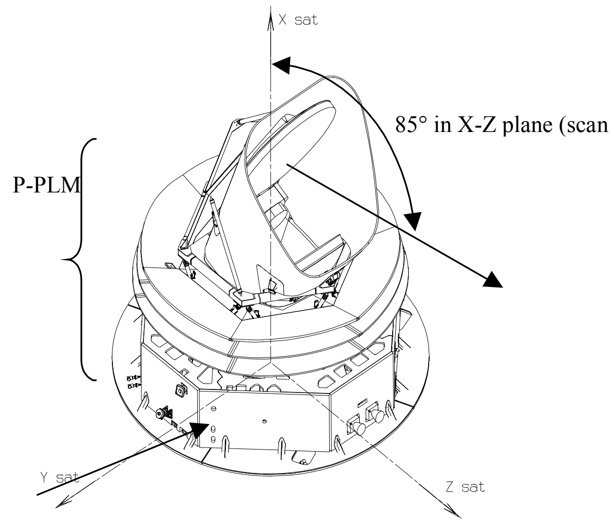
6.8 Alignment

This section describes the main figures related to Herschel and Planck satellite alignment. This points are extensively described in " Herschel System Alignment Plan " [RD03.4] and in "Planck System Alignment Plan" [RD03.5].

For each spacecraft, we will firstly describe the spacecraft relevant I/F, then alignment needs. We will then describe the contributors and justify the allocations. Then the alignment sequence is described, and the alignment budgets are shown. As a conclusion, for each spacecraft, the compliance status is shown, and the open points are highlighted.

6.8.1 RD03.4 Planck alignment

The alignment at system level covers the needs of relative position, knowledge, and stability of P-PLM (including telescope, cryostructure, and instruments), and SVM. It does not cover the internal alignment of these subsystems.



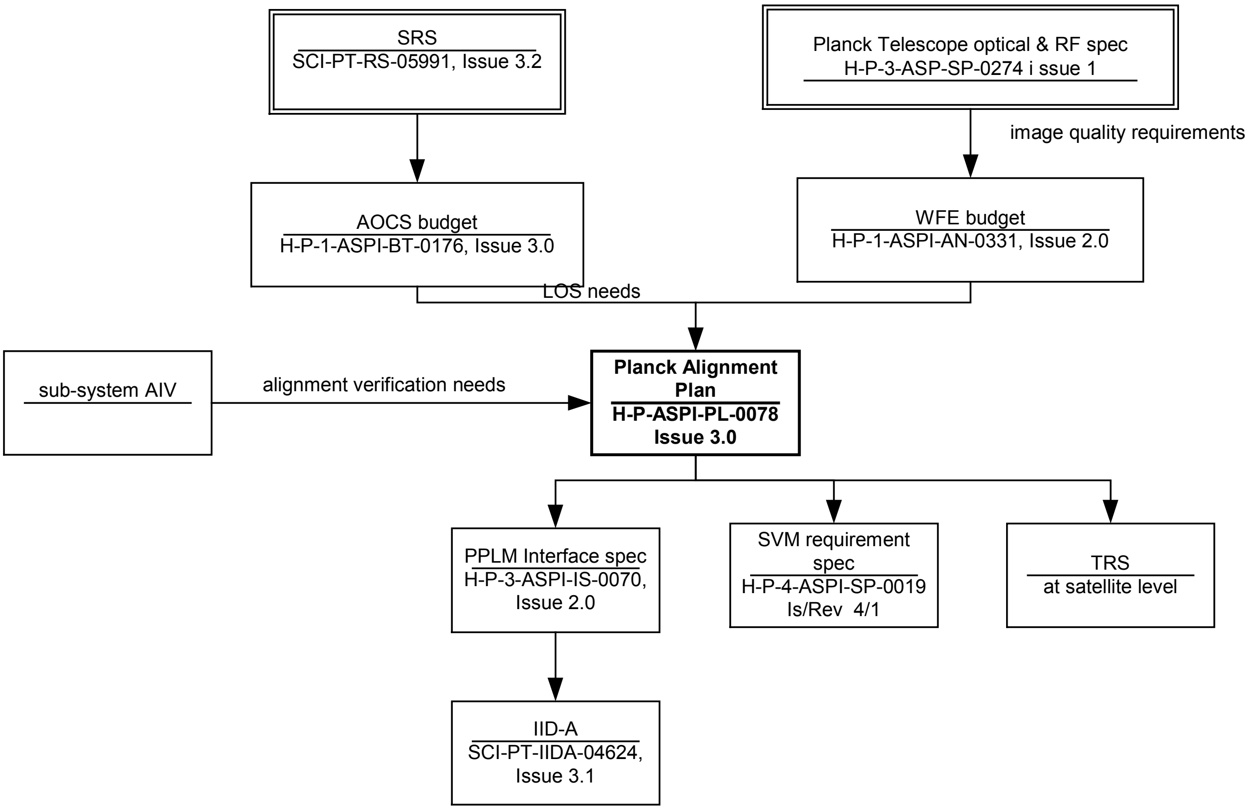
System alignment needs come from two origins:

- the pointing accuracy and orbit correction and maintenance needs, derived from SRS by the "Herschel/Planck Pointing Budget Module Allocation" [RD03.7]
- image quality needs, derived from "Planck Telescope design specification" via the "Planck PLM optical analysis"
- on top of that, alignment check verification might be requested by subsystems (SVM and P-PLM), as far as optical references are visible at satellite level.

The alignment plan outputs are inputs to:

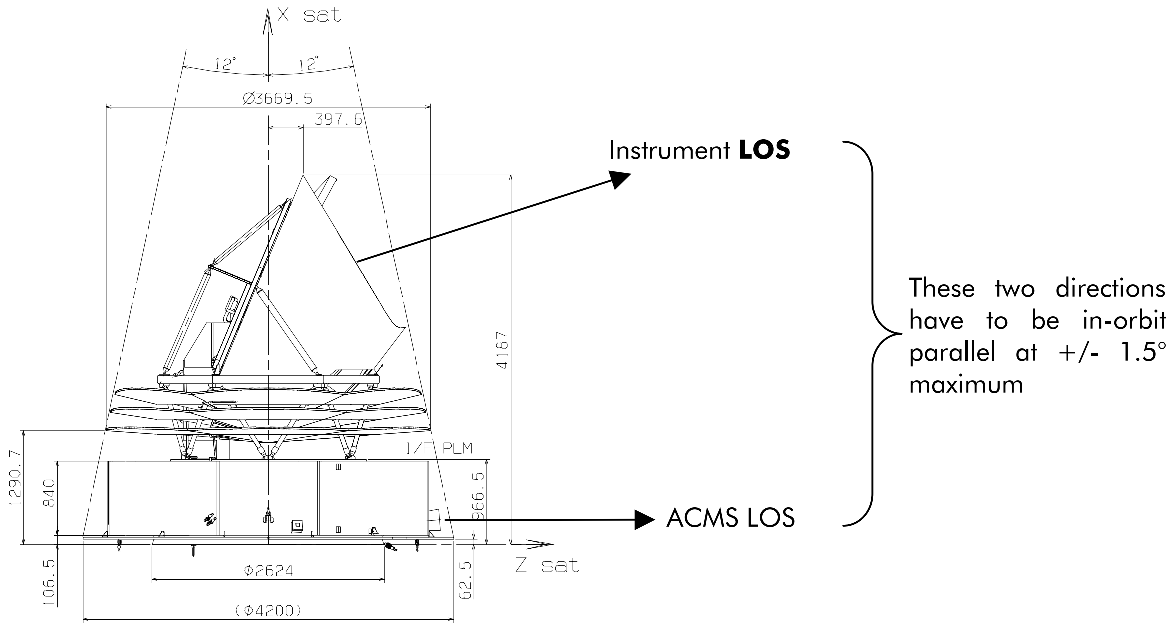
- alignment requirement to instruments (internal alignment), expressed in the IID-A
- alignment and stability requirements to PPLM, expressed in the "P-PLM Interface and Applicability Specification" [AD07.3]
- alignment and stability requirements to SVM, expressed in " SVM Requirement Specification "
- test requirement sheets at satellite level.

This is illustrated by the following flowchart:



6.8.1.1 System alignment needs

As presented before, the alignment requirements come from both pointing and orbit correction and maintenance, and from image quality needs. These needs are precisely expressed in the "Planck alignment Plan" [RD03.5], and briefly presented in the three following subsections:



6.8.1.1.1 System needs coming from pointing

They are declined in 4 requirements ([RD03.7]):

- Req 1

  The Planck instrument LOS shall be aligned with ACMS LOS with an accuracy of 1.50 degree maximum.

- Req 2

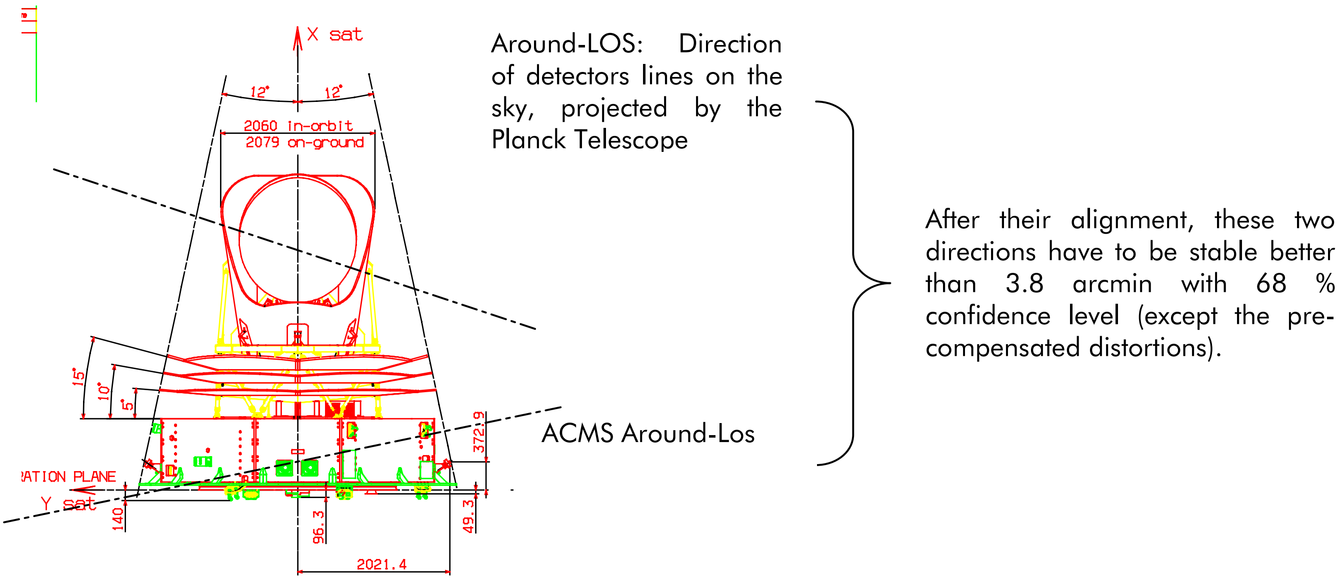
  The stability around LOS_{PLM} axes with regards to AOCS axes (due to launch and in orbits effects) shall not exceed 3.8 arcmin at 68 % confidence level.

- Req 3

  The wobble adjustment wrt satellite frame accuracy shall be better than 2 arcmin at 68 % confidence level. This is a direct requirement to AIT.

- Req 4

  The around LOS misalignment knowledge wrt satellite frame accuracy shall be better than 3 arcmin at 68 % confidence level.



Two hypotheses are underlying behind these needs:

- LOS calibration is performed in-orbit (this is the baseline)
- at satellite level, the spin axis is re-aligned with regards to instrument around LOS direction. This is done by adjusting, on a rotating machine at 30rpm, the inertia axes with regards to the known around LOS direction.

6.8.1.1.2 System needs coming from orbit correction and maintenance

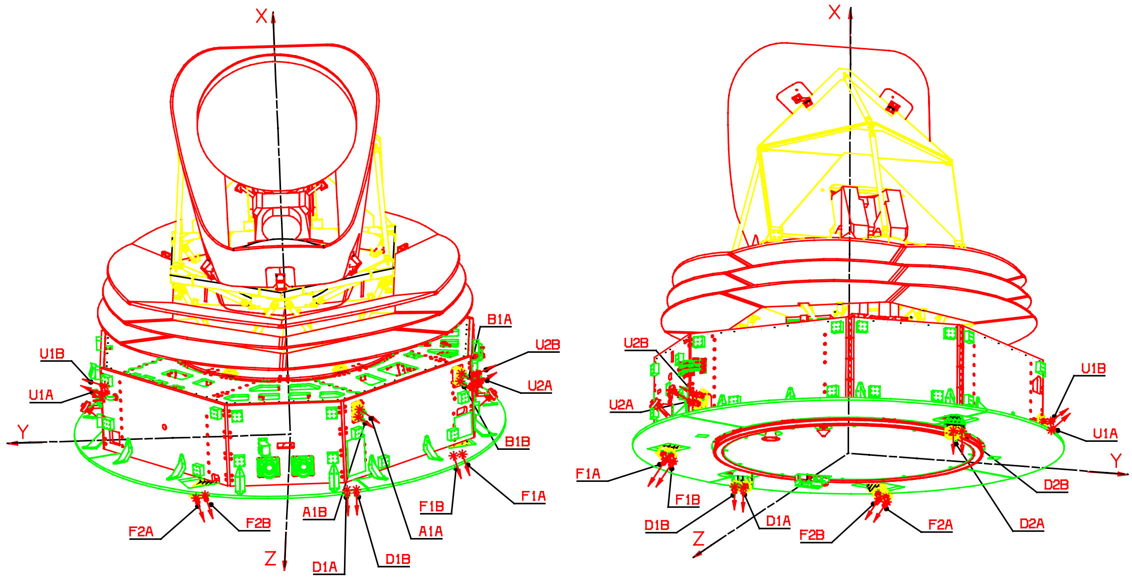
They are derived in "ACMS inputs to Planck System Alignment Plan" H-P-3-ASPI-TN-0245 Issue 1/0.

- Req 5

  Taking in account thruster accommodation (typically in the order of 2 meter from center of mass), the alignment accuracy between the thruster push axis and the BOL S/C CoG shall be better than 0.5°.

- Req 6

  The thruster adjustment range shall be large enough to cover the difference between the theoretical CoG and the actual one at BOL. A 2 deg half cone adjustment range is specified which covers this requirement.

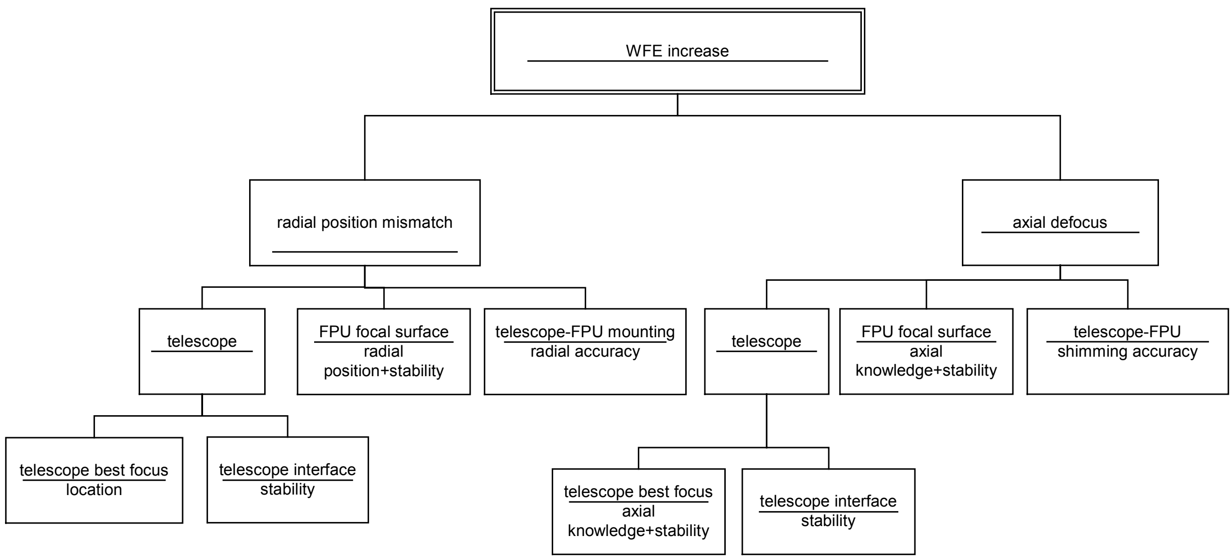


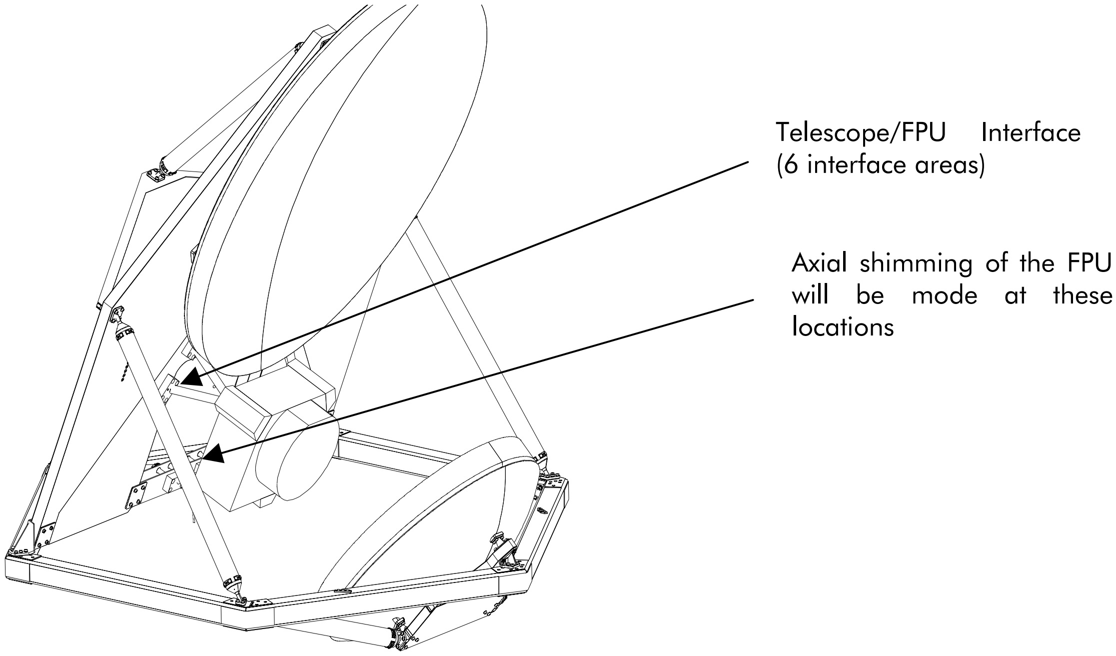
Each one of these thrusters shall be aligned with regards to the satellite CoG.

6.8.1.1.3 System needs coming from image quality

A defocus between the telescope best focus and the FPU focal surface induces an increase of the Wave Front error. Moreover, the fact that the image surface is not a plane - this is due to the Planck Telescope optical design, a shift in X/Y plane of the telescope image with regards to the FPU focal surface will also induce a Wave Front Error increase.

Taking into account what is presented in the next section, and particularly the fact that the best focus location of the telescope will be known at cryo-temperature, and that a shimming is performed in axial direction, the following contributors tree represents the contribution of misalignments to Wave-Front Error.



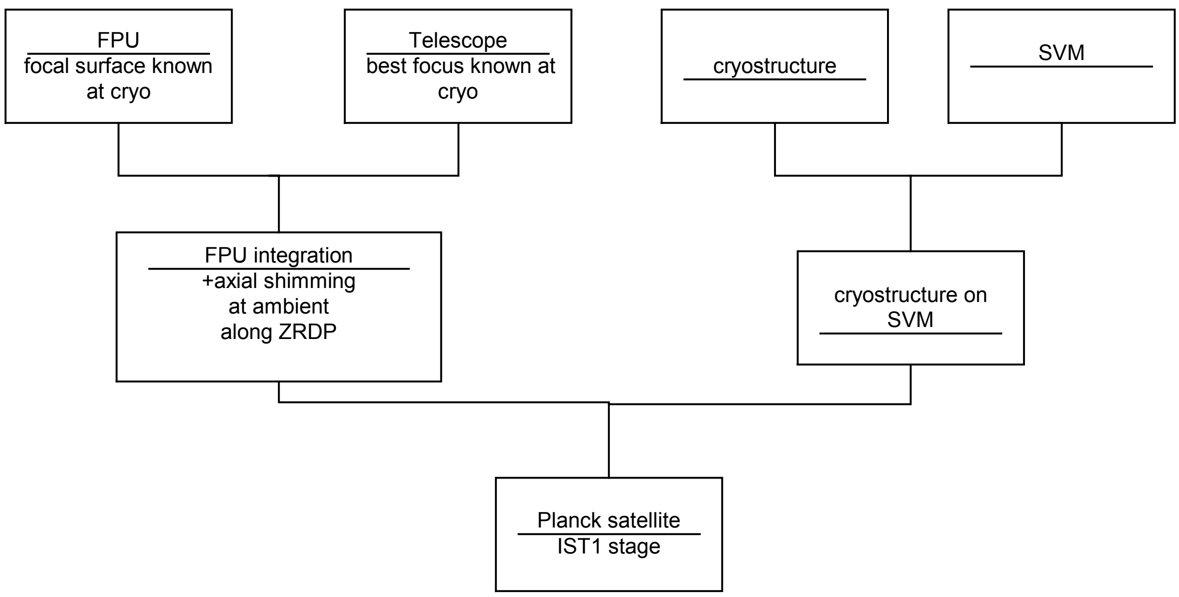


The compliance to these needs is justified in the Planck Alignment Plan, and in the Planck PLM optical performance analyses. The alignment is described in the P-PLM CDR design report.

6.8.1.2 System alignment sequence

To perform the preceding alignment, the following sequence is foreseen:

6.8.1.2.1 At P-PLM level



The cryostructure is mechanically mounted on the SVM: no alignment.

The FPU is mounted at telescope focus: an axial shimming is performed, based on data coming:

- on one hand from telescope manufacturer - telescope focus knowledge at cryo-temperature
- on the other hand from instruments.-average focal surface at cryo-temperature.

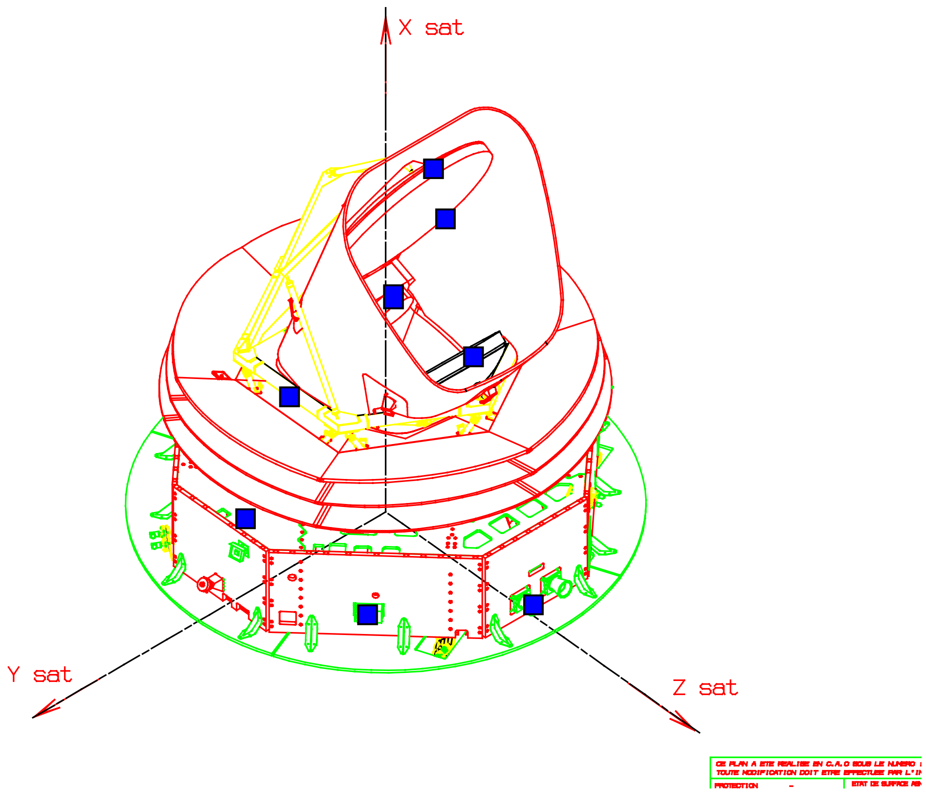
Then the telescope is mounted on the cryostructure: no alignment.

At this stage, the Spacecraft is mounted, and Planck reaches IST1 stage.

6.8.1.2.2 *At Planck Spacecraft level*

A first alignment measurement, based on theodolites, is made once the Spacecraft is complete (this corresponds to the IST1.5 stage). This gives a reference to which all the next alignment checks will be compared. This alignment reference measurement will concern:

- FPU
- Reflectors
- Telescope frame
- SVM optical reference
- Star trackers and other SVM Equipments
- Spacecraft optical references.



At IST1.6, a MCI measurement is made. Based on this, the thrusters are aligned. Their position is referenced.

At SFT3 stage - after the mechanical tests, an alignment check is performed.

Planck is then transported to CSL to perform thermal tests, and when it comes back to Cannes - IST2.2 stage- the alignment is checked, for the last time.

6.8.1.3 System alignment budgets

The Planck Alignment Plan [RD03-5] builds and justifies, for each upper level requirement, the needs at subsystem level. The budgets are as following:

6.8.1.3.1 Los maximum deviation (Req. 1)

The budget is the following:

The following table gives the relevant specified contributions and the relevant references

CONTRIBUTOR		LOS POSITION WORST CASE	REFERENCE
PPLM	Telescope+ cryostructure	+/- 50 arcmin	PPLM interface specification (AD07.3)
	PFU internal	+/- 0.9arcmin	IID-A (AD04.1)
SVM		+/- 30 arcmin	SVM Structure specification (AD06.9)
Mating		5 arcmin	
budget		86 arcmin	

6.8.1.3.2 Around LoS instability (Req. 2)

The requirements derivation is the following:

CONTRIBUTOR		AROUND-LOS STABILITY 68 % CONFIDENCE LEVEL	REFERENCE
PPLM	Telescope+ cryostructure	+/- 3.4 arcmin	PPLM interface spec PPLM optical performances analysis [RD01]
	FPU internal	+/- 0.33 armin	IID-A
Budget		+/- 3.77 arcmin	+/- 3.8 arcmin are required

6.8.1.3.3 Around LoS misalignment knowledge with regards to the satellite frame (Req. 3)

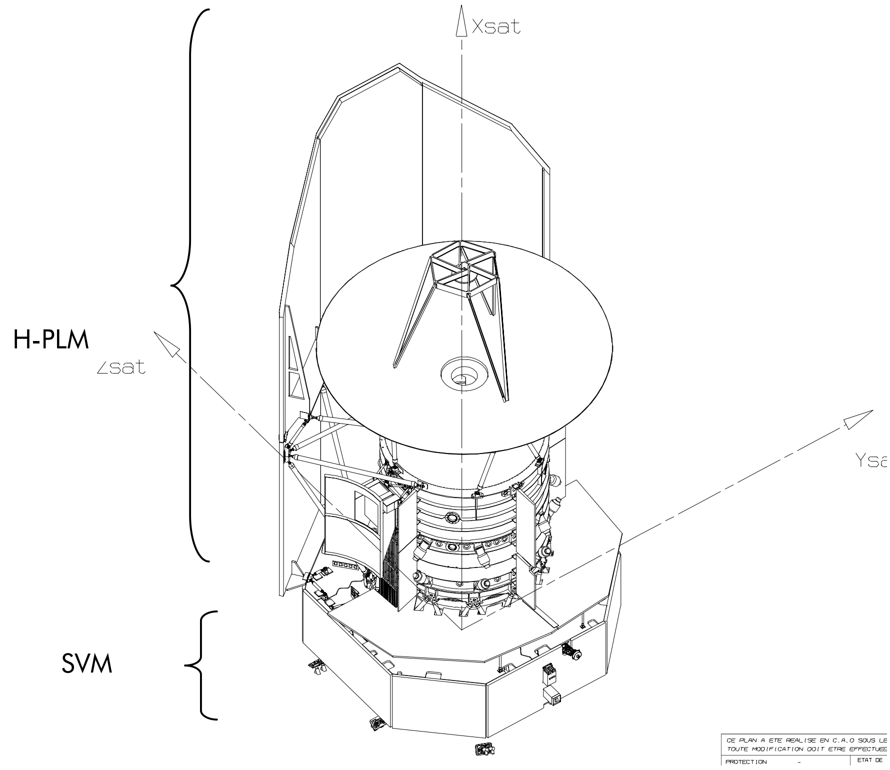
CONTRIBUTOR		AROUND-LOS KNOWLEDGE 68 % CONFIDENCE LEVEL	STATUS	REFERENCE
PPLM	Telescope	+/- 1 arcmin	specified	PPLM interface spec PPLM optical performances analysis [RD01]
	FPU internal	+/- 0.33 armin	Specified	IID-A
Telescope frame orientation measurement with regards to launcher I/F		+/- 1 arcmin	State of the art	
Contingency		0.67arcmin		
total		+/- 3 arcmin	Compliant	Spec = +/- 3 arcmin

6.8.1.3.4 Thruster plume alignment accuracy(Req. 4)

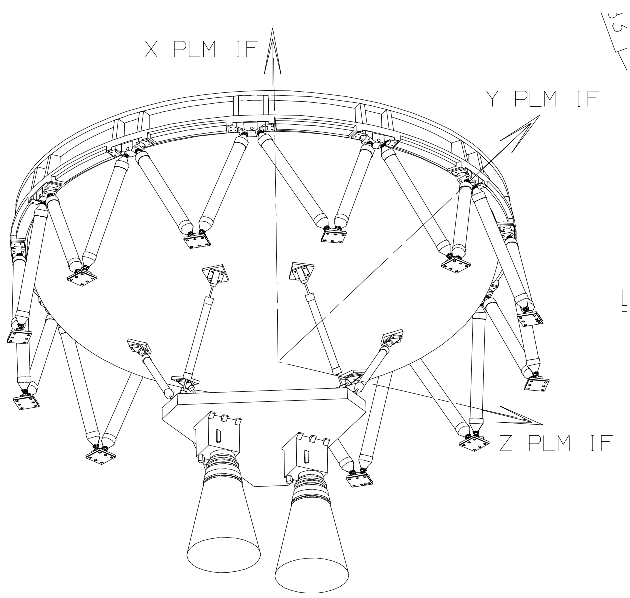
	Contribution (arcmin)	Status	Reference
Thruster-plume knowledge & stability	+/-15	specified by Alenia	
System level thruster-plume alignment accuracy	+/-3	State of the art with margin	included in system level TRS
S/C CoG on-ground knowledge accuracy	+/-12	Specification to AIT	
Total	30	Compliant	

6.8.2 Herschel alignment

The alignment at system level covers the needs of relative position, knowledge, and stability of P-PLM (including telescope, cryostat, and instruments), and SVM. It does not cover the internal alignment of these subsystems.



A main evolution since PDR is the new Star-Tracker accommodation, directly fixed onto the CVV:



this new accommodation is more favorable for the thermoelastic stability of the star-tracker, and thus ACMS performance.

System alignment needs come from the pointing accuracy and orbit correction and maintenance needs, derived from SRS by the "Herschel/Planck Pointing Budget Module Allocation" [RD03.7].

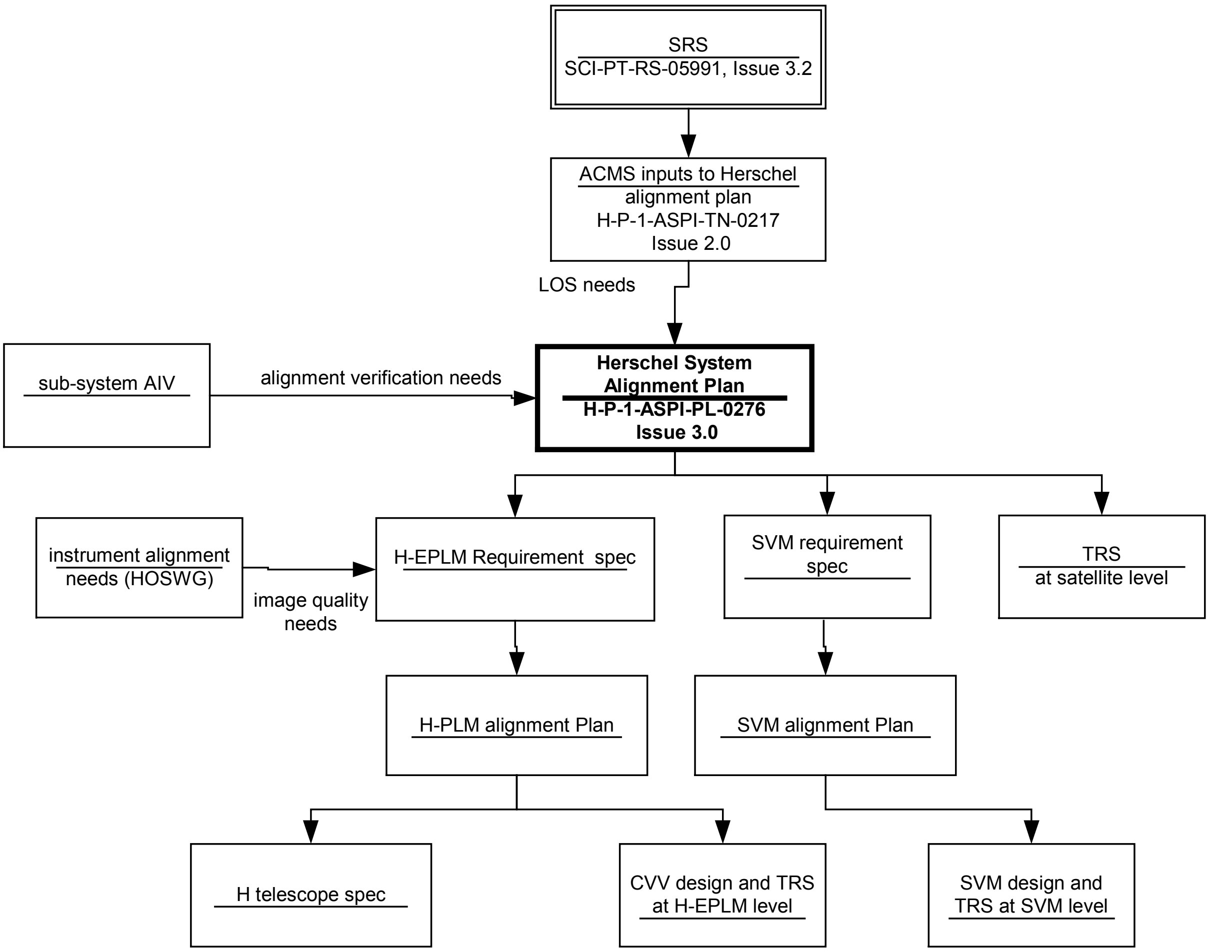
On top of that, alignment check verification might be requested by SVM as far as optical references are visible at satellite level.

Alignment needs coming from optical imaging quality are entirely under H-PLM designer responsibility, and are covered in the H-PLM alignment Plan (cf. [RD06.8]).

The alignment plan outputs are inputs to:

- alignment and stability requirements to H-PLM, expressed in the "H-EPLM Interface Specification" [AD07.2]
- alignment and stability requirements to SVM, expressed in the "SVM Requirement Specification"
- Test requirement sheets at satellite level.

This is illustrated by the following flowchart:



6.8.2.1 System alignment needs

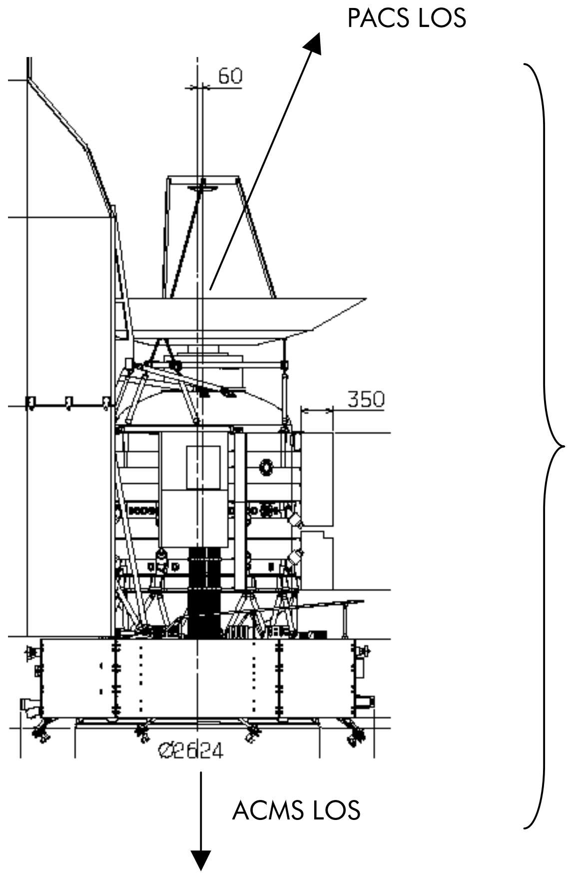
As presented before, the alignment requirements come from both pointing and orbit correction and maintenance. These needs are precisely expressed in the "Herschel system alignment Plan" [RD03.4], and briefly presented in the two following subsections.

6.8.2.1.1 System needs coming from pointing:

They are declined in 4 requirements:

- Req 1

  To allow a proper calibration in-orbit, the maximum misalignment between PACS LOS and ACMS LOS shall be less 0.47 degree maximum(requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).



The angle between these two directions have to be in-orbit at 0.47° maximum.

By design, PACS LOS is orientated at 0.17° from $+X_{IF}$. Misalignments (ground and in-orbit effects) shall thus remain below 0.3°, i.e. 18 arcmin.

– Req 2

The SPIRE LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec 1-sigma each axis (Y, Z) (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]), required in AD05.7.

– Req 3

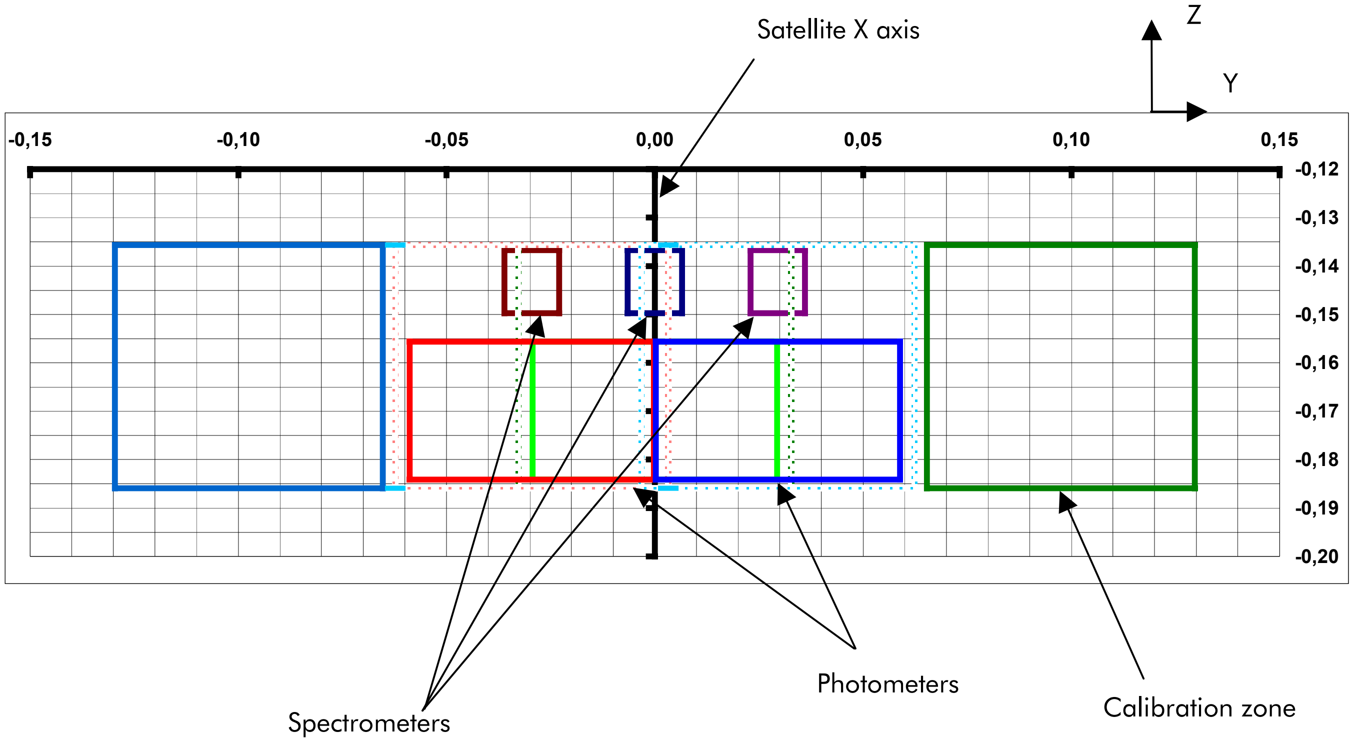
The HIFI LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec 1-sigma each axis (Y, Z) (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]), required in AD05.7.

The two preceding requirements are directly applicable to the H-EPLM level.

– Req 4

For each instrument, the Around LOS misalignment knowledge with regards to the H-PLM/SVM interface coordinate system shall be less than 0.5 arcmin at 68 % confidence level.

To illustrate this requirement, the PACS instrument is taken as an example. It's nominal field of view depending on the use (photometer mode or spectrometric mode), as projected in the sky is the following:



The angle between this FOV orientation and Y satellite (nominally 0dg), quantifies the PACS around LOS.

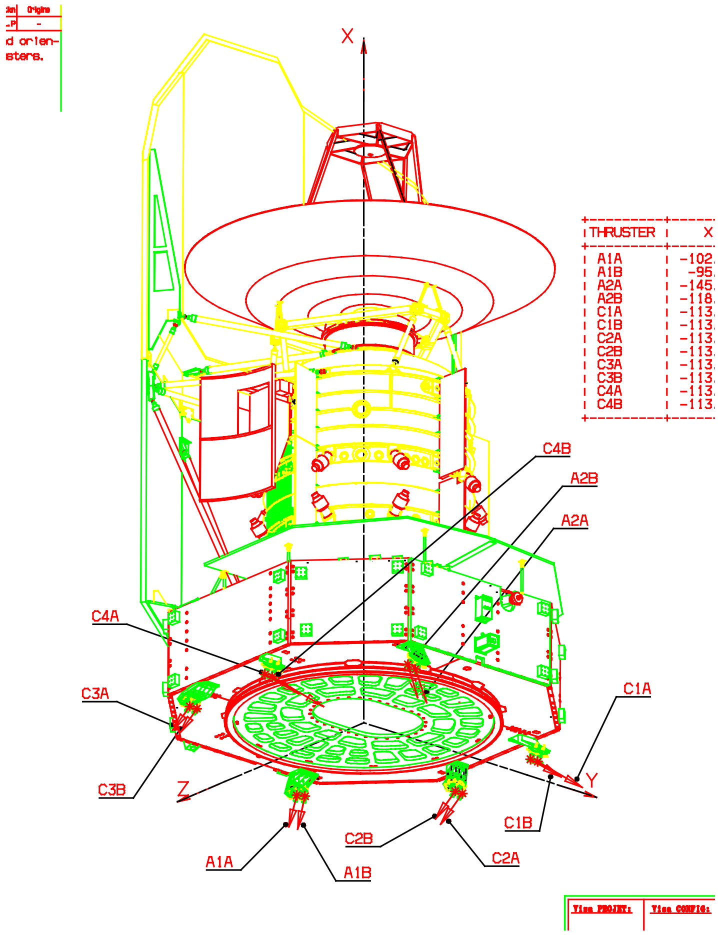
6.8.2.1.2 *System needs coming from orbit correction and maintenance*

– Req 5

Taking in account thruster accommodation (typically in the order of 2 meter from centre of mass), the alignment accuracy between the thruster push axis and the BOL S/C CoG shall be better than 0.5°.

– Req 6

The thruster adjustment range shall be large enough to cover the difference between the theoretical CoG and the actual one at BOL. A 2 deg half cone adjustment range is specified which covers this requirement.



Each one of these thrusters shall be aligned with regards to the satellite CoG.

6.8.2.2 System alignment sequence

To perform the preceding alignment, and alignment checks, the following sequence is foreseen:

- The alignment sequence is the following:
  1. Delivery to ALCATEL of the SVM and aligned H-PLM, each one with one reference cube at least.
  2. Integration of the Star Trackers bellow the CVV by ALENIA (see Section 4.3.2 for more details).
  3. Possible adjustment of the star-tracker platform orientation to align it with regards to H-PLM/SVM Interface plane – made by ALENIA.
  4. Mating & mating verification (by verification of the alignment of the two cubes: PLM cube and SVM cube).
  5. As the AAD will not be aligned at SVM level, it will be aligned (if needed) by ALS during spacecraft AIT.
  6. The optical reference for the satellite is the satellite optical cube (AC1 and AC2 on "Herschel alignment cube access ME.HES.A010.A.01SA, given in annex), whose position will be referenced with regards to the launcher interface plane.
  7. A reference alignment measurement is performed with theodolites: the mating is verified, and all the accessible cubes are referenced with regards to the satellite cube.
  8. Once the helium tanks are filled, an alignment stability check is performed.
  9. The spacecraft CoG is measured, and the thrusters are aligned with regards to this known CoG.[7] This operation is made under ASP responsibility in the frame of the spacecraft AIT activities.
  10. After EMC and acoustic tests, the alignment stability is checked for the last time.

The only alignment activities performed during Herschel spacecraft AIT are:

- STR alignment with regards to H-PLM LOS (under ALENIA responsability) (see Herschel alignment plan for more details)
- Thruster alignment with regards to spacecraft COG (under ASP responsibility).

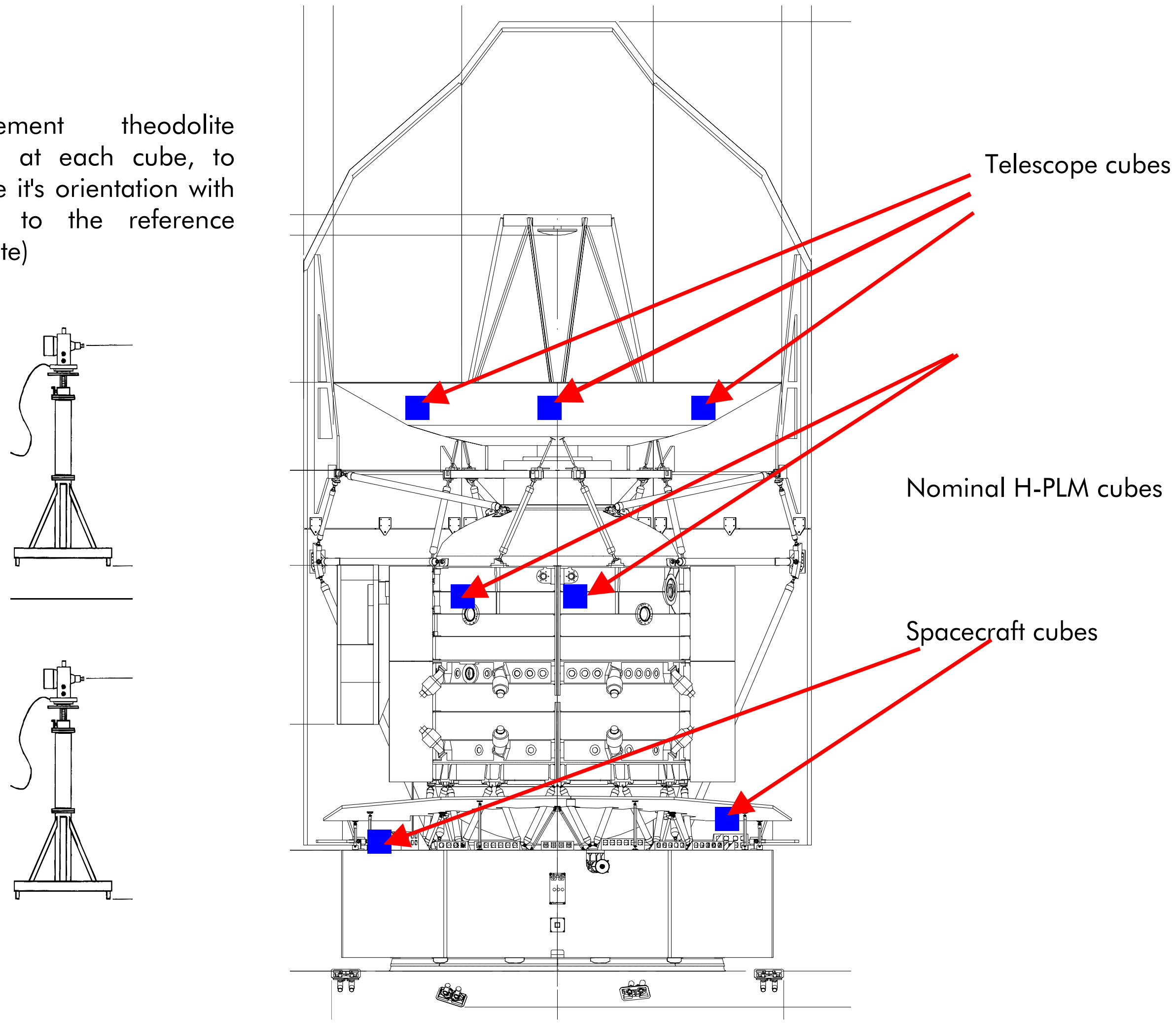
The alignment check is based on a "reference" measurement made after mating, and regular alignment checks which are compared to the reference to verify that there is no evolution of the alignment of the module and subsystems during the satellite AIV sequence.

The alignment of:

- TELESCOPE
- CVV
- SVM
- Thrusters
- Star/Tracker

are checked via theodolites.

[7]the referred CoG is the one at a given time of the mission, i.e. with given fuel and helium filling ratios, not the spacecraft CoG at the time of the measurement test



6.8.2.3 System alignment budgets

The Herschel system Alignment Plan [RD03-4] builds and justify, for each upper level requirement, the needs at subsystem level. The budgets are as following.

6.8.2.3.1 PACS LoS and ACMS LOS co-alignment

– Req 1

Contributor		Contribution (worst case)
SVM	Bias	15arcmin
	stability	+/-1.15 *2<3.15each axis
HPLM	HPLM Bias	5arcmin
	Telescope	10 arcmin
	stability	<+/-0.2 arcsec each axis
Total	RSS	<19arcmin

[8]

6.8.2.3.2 Around-LOS mis-alignment knowledge

– Req 4

	CONTRIBUTION @ 68 % CONFIDENCE	STATUS	REFERENCE
HPLM bias	0.5	Required to H-EPLM	In line with "pointing budget module allocations" [RD03-7]
Mating	0.03 arcmin	State of the art	
Total(*)	0.5 arcmin	Compliant	0.5 arcmin are required

6.8.2.3.3 Thruster plume alignment accuracy

– Req 5

	Contribution (arcmin)	Status
Thruster-plume knowledge & stability	+/-15	Specified by Alenia
System level thruster-plume alignment accuracy	+/-3	Direct specification to AIT
S/C CoG on-ground knowledge accuracy	+/-12	Direct specification to AIT
Total	30 arcmin	compliant

[8] Requirements 2 and 3 related to LOS co-alignment knowledge between instruments, are directly derived to the H-EPLM, without further re-allocation.

6.9 Safety

The Herschel and Planck safety analysis are described in the documents:

- Herschel Safety analysis – Doc. RD03.22.
- Planck Safety analysis - Doc. RD03-23.

This document are based on the subsystem safety analysis (H-EPLM, PPLM and SVM) and design summary and are wrote for the submission Phase 1.

6.9.1 Purpose

The primary objectives of the performed safety analyses are to identify the hazards confronting the Satellite and to ensure that the hazard controls are in compliance with the requirements of the Launch Authorities.

These documents constitute the "back bone" of the safety analysis and is used as input for Safety Submissions.

1. For Safety Phase 0, it has been written a preliminary safety analysis for both Herschel and Planck satellites,
2. For Safety Phase 1, actually in progress, two separated documents, one by satellite, has been edited,
3. For Safety Phase 2, both documents will be updated.

Compliance with ARIANE Launchers being the first goal, we have used the requirements coming from the Guyana Space Center Range Safety.

This Safety Analysis covers also all the Ground Phases on the Launch Range, the Lift-off until Satellites separation from the Launcher but these parts shall be described during safety submission Phases 1 and 2.

6.9.2 Safety analysis result

At the present time, the design analysed shows non compliance versus the Safety Launch Agency. This concerns:

- For Herschel and Planck SVM:
    - Latch Valve Back Pressure Relief is not redunded. This has been accepted by range safety with the respect of mention in filling procedure to exit the filling room when Latch Valve is activated (open or close position).
- Moreover, complete information is not available concerning:
    - Ground support equipment (electrical, mechanical, tanking, cryogenic, optical and for experiment). This point shall be treated in safety submission Phase 2.
    - Launch site ground operations: this point shall be treated in safety submission Phase 2.

6.10 Reliability and fault tolerance

6.10.1 General

This section describes the means which will be implemented in order to ensure the reliability of the satellites during their missions. These means will be applied to the extent necessary to satisfy the requirements of the project.

They are grouped in the following categories:

- Quality
  - EEE parts procured with Hi-Rel quality levels (SCC-B for active parts, SCC-C for passive parts or Mil equivalent).
  - Use of qualified processes for assembly of parts, boards... (e.g.: soldering, crimping performed according to specifications); use of qualified materials; respect of cleanliness conditions.
- Margins
  - Application of derating specification for EEE parts in order to assure stress margins (electrical, thermal).
  - Application of specified margins for strength of structural elements.
  - Application of specified margins on performance of mechanisms (e.g.: motorization margin of mechanisms).
  - Existence of margins on performance of critical electronic circuits (Worst Case Analyses).
- Fault tolerant architecture
  - Fault tolerance by implementation of redundancies, protections, and allowance of degraded performances (no Single Point Failure of EEE parts will be allowed for the vital functions).
  - Implementation of cross couplings between redundant items.
  - If single operator commands resulting in mission termination are identified, measures to reduce the risk will be implemented (arming, means for command verification before execution for errors having fast effect, telemetry for errors resulting in slow effect...).
- Tests
  - Capability to test redundancies and protections as close as possible to launch (in particular when the satellite is integrated) gives the possibility to assure a reliability close to 1 at launch time.
- Reliability design rules, interface requirements in case of failure
  - Reliability oriented design rules introduced in design and performance specifications as well as interface requirements in case of failure contribute to the construction of the satellites reliability from the early phases of the project. In particular, it contributes to avoid failure propagation to redundancies/protections and to other equipment.

6.10.2 Reliability features of the architecture

6.10.2.1 Structure (SVM or PLM)

Reliability of structural elements is assured by application of specified safety margins and by verifying their application through the environmental qualification and acceptance tests.

6.10.2.2 Thermal Control

a. Passive thermal control (SVM or PLM)

Items like MLI, paints, coatings, surface treatments, OSR are subject to known slow deterministic degradations for which design margins are provided. Besides, local defects have minor consequences.

b. Active thermal control (SVM)

The thermal regulation uses the following items:

– heaters

– thermal sensors

– PCDU to control the electrical power applied to the heaters

– CDMU which acquires the temperature for regulation via the thermal sensors, and performs the processing of the thermal regulation and its FDIR.

The PCDU includes two cold redundant sets of 54 lines each controlling the heaters. One set is divided into 9 branches of 6 lines, each branch being provided with one current limiter (overcurrent protection of the power bus) and one safety switch (protection against permanent heating). Both sets are under control of the nominal and redundant bus couplers.

3 failure independent sets of 64 thermal sensors ITB are implemented, 3 per heater set including margin, in order to perform majority voting. Retained solution for their conditioning and acquisition is:

– the 3 sets of 64 thermal sensors are conditioned in the CDMU shared I/O I/F in order that the DH CDMU can make majority voting. The conditioning circuits are in this case supplied by hot redundant supplies and arranged so that no single failure results in loss of more than one of the three groups of sensors. The health of the common link acquiring the temperature information (acquisition circuit) is verified by measurement of reference resistors put in the conditioning circuits in place of sensors (in case a voted temperature or the link between sensors and CDMU is declared as abnormal, the DH CDMU controls a switchover to the redundant set of 54 heaters).

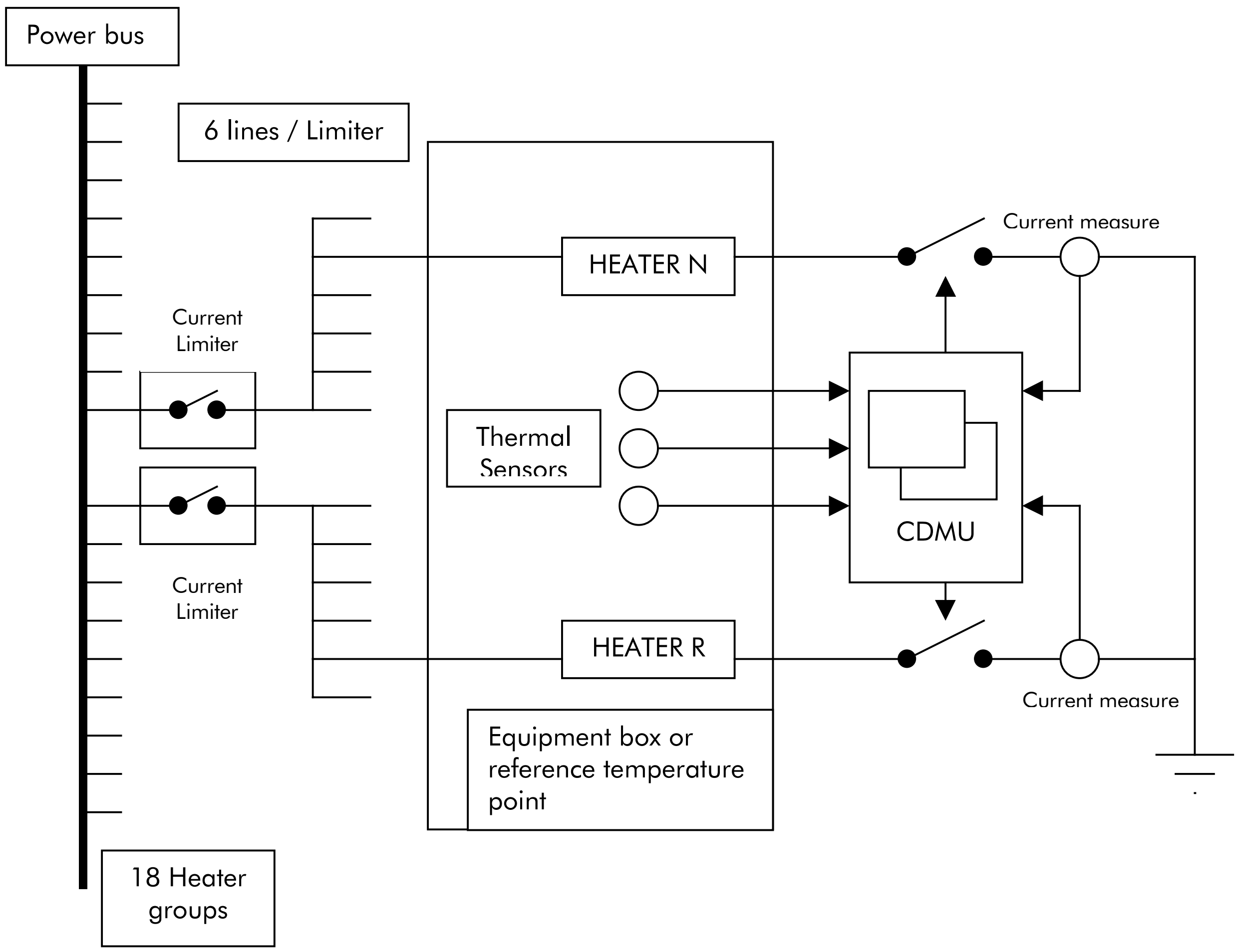


Figure 6.10-1 Heater lines

In addition, survival heaters (non redundant) controlling temperature by means of thermostats will be connected to the power bus through a Fold back Current Limiter (FCL). This permits to maintain an acceptable temperature at the level of the critical items without any unit turned on (apart from the PCDU itself). Following so-called SOHO failure case analysis, the survival heaters have been maintained only the battery which has a survival heater connected to a thermostat internal to it.

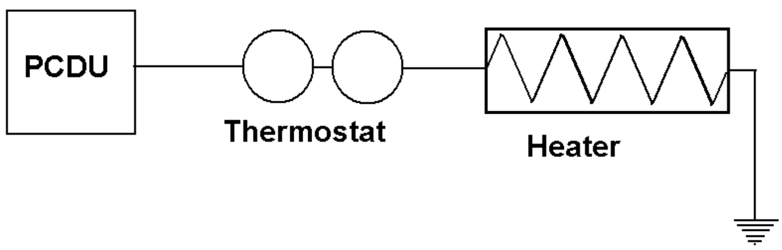


Figure 6.10-2 Survival heater line

6.10.2.3 Solar Array

The Solar Array includes for both spacecraft an electrical network mounted on structural panels.

The reliability of the electrical network is obtained by the following means:

- a tolerated power loss corresponding to one section out of 30 + 1 string out of 142 for Herschel (135 for Planck) to cover the power section failures within PCDU, (deterministic solar cells degradations being covered by other margins). The Solar Array, for both spacecraft, is therefore oversized by ≈4 %
- redundant wires and connectors will transmit the power from the electrical network to the PCDU (Redundant wires and connectors are requested as SA may be dismounted after environmental tests).

6.10.2.4 Power S/S

The Power S/S is composed of one PCDU and one SPF free battery.

The Power S/S:

- provides a regulated 28 V on a main bus from the unregulated power delivered by the Solar Array or the battery
- assures the battery charge
- distributes the main bus power to the users
- controls the thermal control heaters.
- supply power to the non contaminating cover actuator for Herschel.

The most general necessary fault tolerance characteristic for the main bus is that no single failure causes a permanent overvoltage or undervoltage (including due to users failures).

The Power S/S functional description is presented in Figure 6.10-3 it exhibits the following reliability features:

- **Battery**

  One battery is provided and is SPF free. It is composed of 144 cells (6 series of 24 parallels), this allows similarly to the Solar Array case, to lose one battery string with still enough power margin. Apart form the Launch phase, no eclipse is foreseen during nominal mission, so that battery is only necessary in case a failure results in an attitude loss and SA power decreases or in case of power demand during a short time (e.g. power peaks due to reaction wheels or cat beds preheating).

- **PCDU**

  Power bus 28 V regulation from Solar Array (SA) sections is performed by 30 shunt sections (one per SA section) controlled by one Main Error Amplifier (MEA).

  The sections are non redundant, therefore one shunt section is allowed to fail in open or short circuit. Short circuit is covered by a Solar Array power margin upper to 3.3 %, open circuit is covered by presence of a permanent load on the power bus. This load is guaranteed by the permanently supplied users and is consistent with the max current delivered by one section. The MEA (2/3 MEA hot redundant channels + reliable voter) is designed so that a single failure cannot cause an over or undervoltage on the power bus. MEA is hot redundant. It assures an autonomous fault tolerant power bus regulation (no possible control by TC).

Battery charging is autonomously performed from 3 SA sections in hot redundancy by specific charge circuits under MEA control. The current of the SA, when not necessary for the power bus, is re-routed to charge the battery when necessary. Nominal charge control algorithm (voltage tapering) is implemented for the battery, via H/W in the PCDU. On top of that the CDMU monitors the battery voltage and temperature.

Main bus filter is composed of numerous in parallel capacitors, so that the open circuit of anyone has a negligible effect on the filtering performance. To prevent short circuit on the bus, both sets of two in series capacitors and self healing types are used.

Two parallel Battery Discharge Regulators (BDR) in series with the battery assure the 28 V on the power bus when the SA cannot deliver the necessary power. Risk to produce overvoltage on the power bus is covered by an overvoltage protection in the BDR. Besides, BDR modules are protected so that no single failure can short the battery or the power bus, nor directly connect the battery to the power bus. Also, each BDR is sized to handle the maximum discharge current, such that the design is tolerant to the loss of one BDR.

Auxiliary Supply (AS) for low power circuits is designed so that no single failure can result in over/undervoltage of supplied circuits, or in main bus short circuit (as well as no single failure in the low power circuit can short the auxiliary supply output). Circuits being permanently connected to both AS (hot redundant MEA, voters...) include protection so that a failure cannot result in overload of both AS. Circuits supplied by AS but cold redundant (TM/TC I/F, 1553 bus coupler) are for their normal part connected to AS normal side and their redundant part connected to AS redundant side.

Each bus coupler (A or B) has access to A and B 1553 buses.

LCL Distribution Module

Main Bus power lines to users are provided with 72 LCL (Latching Current Limiters)/FCL (Foldback Current Limiter) which prevent excessive load on the main bus in case of users abnormal current consumption.

- LCL are used for ON/OFF control of users.

  For those users for which turn off is critical:

  - from a power budget point of view or
  - for operational constraints reasons.

  2 levels of independent switch-off are provided. All Class III LCLs and selected LCL's for instruments are provided with 2 level of independent switch-off.

  LCL status is latched such that in case the nominal AS is lost, the status of the LCL is kept, therefore the failure is not propagated to higher level. This doesn't apply to heater lines switches

- FCL are used for permanently supplied users (RF Rx, CDMU TC decoder mass memory bank, Reconf Modules, ...).

Heater Distribution Module (HDM)

HDM contains the redundant heating lines control and isolation items as described in section on active thermal control. Commands for isolating heaters groups LCL's and thermal regulation switches are free of common cause failures resulting in permanent heating. Nominal and redundant heating lines are segregated on different PCDU connectors

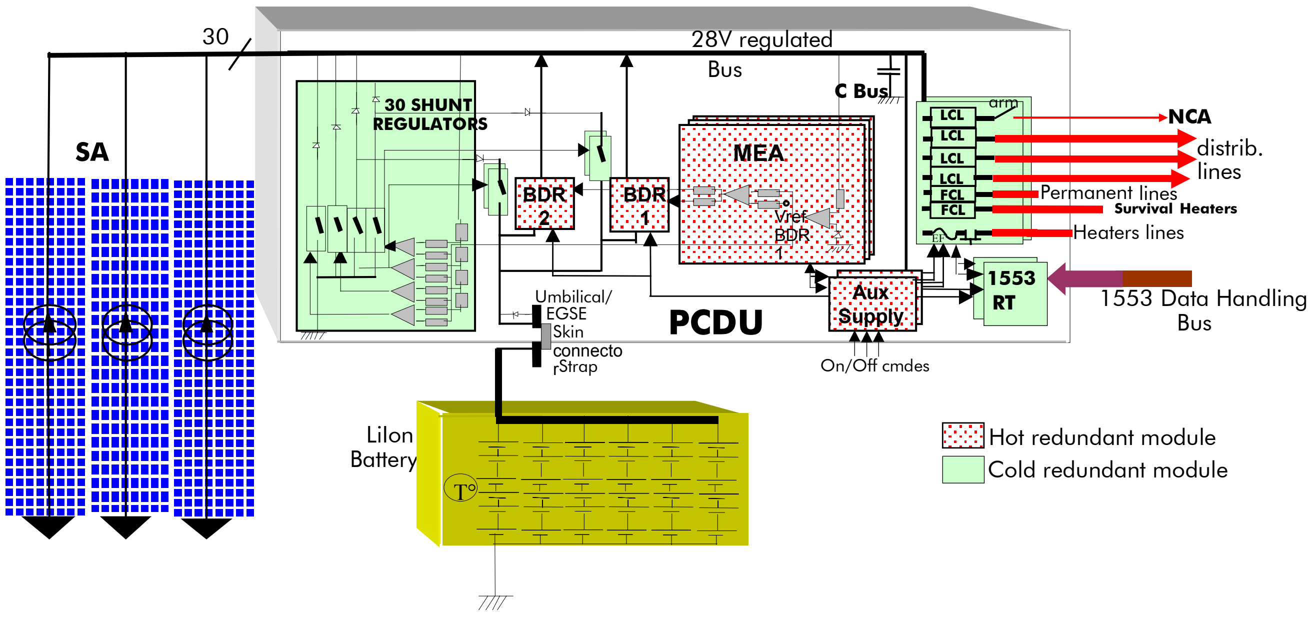


Figure 6.10-3 Power subsystem functional description

6.10.2.5 Data Handling (CDMS)

The CDMS is essentially composed of one internally redundant CDMU, identical for Herschel and Planck. It is functionally described in Figure 6.10.2-4, and comprises the following modules:

- 2 hot redundant RF Receiver interface modules
- 2 hot redundant TM/TC modules cross strapped with RF receiver I/F modules, each module including a Reconfiguration Module (RM) and a high accuracy timing module in hot redundancy
- 2 cold redundant Processor Modules (PM) cross strapped with TM/TC modules and Mass Memory Controllers, each PM having a 1553 I/F to A and B data handling buses
- 1 set of failure tolerant Mass Memory Banks
- 2 hot redundant Mass Memory Controllers both having access to Mass Memory Banks
- I/O I/F circuits providing cross strapped links between redundant PM and users redundant channels
- 2 hot redundant converters to supply the hot redundant circuits
- 2 cold redundant converters to supply the cold redundant circuits
- thermal regulation processing module.

It is to be noted that links between processors and users are done via I/O I/F circuits or 1553 bus. Any nominal or redundant chain of an user of the 1553 bus is provided with a bus coupler having access to normal and redundant 1553 physical buses.

Cross couplings are designed to be SPF free.

Concerning items of the spacecraft controlled through double in series switches or valves (protection against untimely operation) like heaters, thrusters, cryo valves, the control switch and the safety switch will be controlled by failure independent command channels (so that no single failure can untimely activate or leave active both switches or both valves).

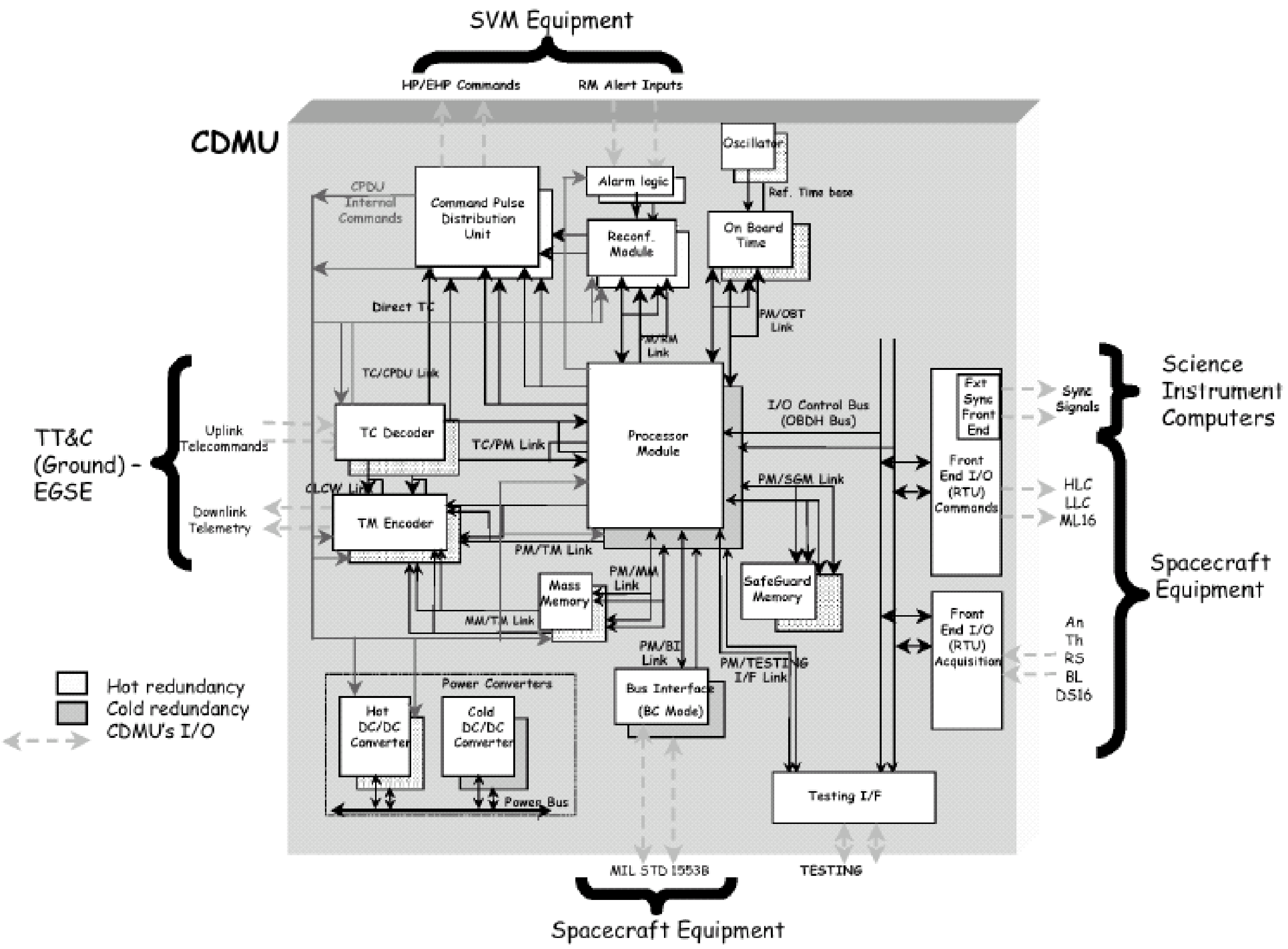


Figure 6.10-4 CDMU functional Block Diagram

6.10.2.6 ACMS

The ACMS is composed of:

- 1 Attitude Control Computer (ACC) (same ACC is used for Herschel and Planck) internally redundant. It is functionally described in Figure 6.10-5, and includes the following modules:
    - 2 cold redundant Processor Modules (PM). Each with RAM and PROM/EEPROM and 1553 I/F to A and B ACMS buses as bus controller and 1553 I/F to A and B data handling buses as remote terminal
    - 2 hot redundant Reconfiguration Modules (RM) having access to both PM

- I/O I/F circuits assuring exchange of data between any processor and any user (in the particular case of the link with the 4 wheels, 4 failure independent physical links are provided)
- 2 hot redundant converters to supply the hot redundant circuits
- 2 cold redundant converters to supply the cold redundant circuits.

– Sensors for Herschel
  - 2 Sun Acquisition Sensors (SAS): 2 SAS are necessary, each one is internally 2 for 1 hot redundant.
  - 2 Coarse Rate Sensors (CRS) used in 2 for 1 hot redundancy.
  - 1 GYRo blocks (GYR) of 4 rate sensors and 2 processor modules used in hot redundancy.
  - 2 Star TRackers (STR) used in 2 for 1 cold redundancy.
  - 1 Attitude Anomaly Detector (AAD) internally redunded.

– Actuators for Herschel
  - 4 Reaction Wheel Systems (RWS) in 4 for 3 cold redundancy.
  - Reaction Control System: 2 cold redundant branches of 6 x 20N thrusters each.

– Sensors for Planck
  - 1 Attitude Anomaly Detector (AAD) internally redunded: Sun presence alarm sensor.
  - 2 Sun Acquisition Sensors (SAS): 2 SAS are necessary, each one being 2 for 1 internally redunded.
  - 2 Coarse Rate Sensor (CRS) in 2 for 1 hot redundancy (nominal mode).
  - 1 Coarse Rate Sensor (CRS) (survival mode).
  - 2 Star TRackers (STR) in 2 for 1 cold redundancy.

– Actuators for Planck
  - Reaction Control System: 2 cold redundant branches of 6 x20N thrusters plus 2x1N thrusters each.

The functional connections of Planck (resp. Herschel) sensors and actuators to the ACC are shown in Figure 6.10-6 (Planck) and Figure 6.10-7 (Herschel).

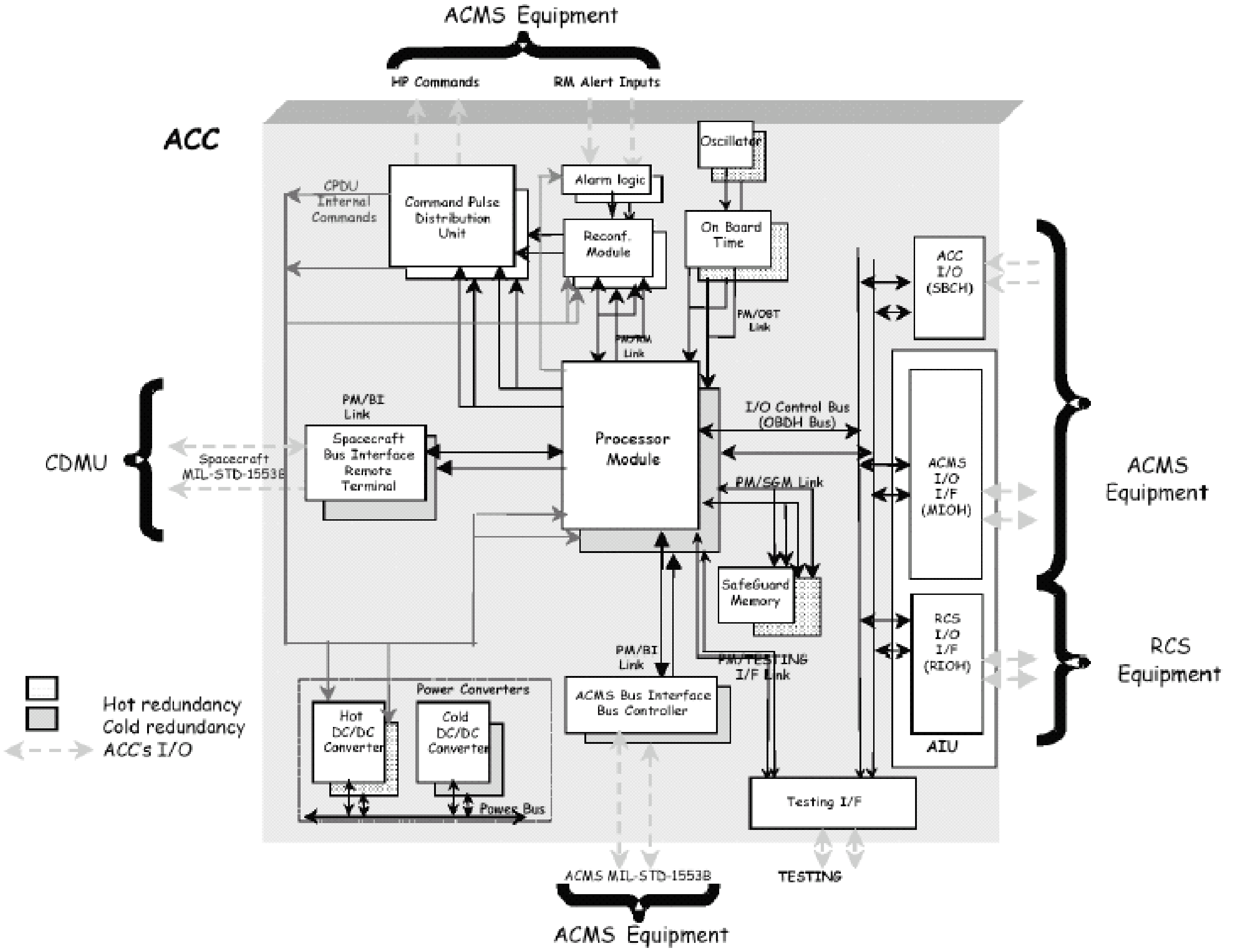


Figure 6.10-5 ACC functional Block Diagram

Any nominal or redundant chain of a user of the 1553 bus is provided with a bus coupler having access to normal and redundant 1553 physical buses.

Cross couplings internal to ACMS are designed to be SPF free.

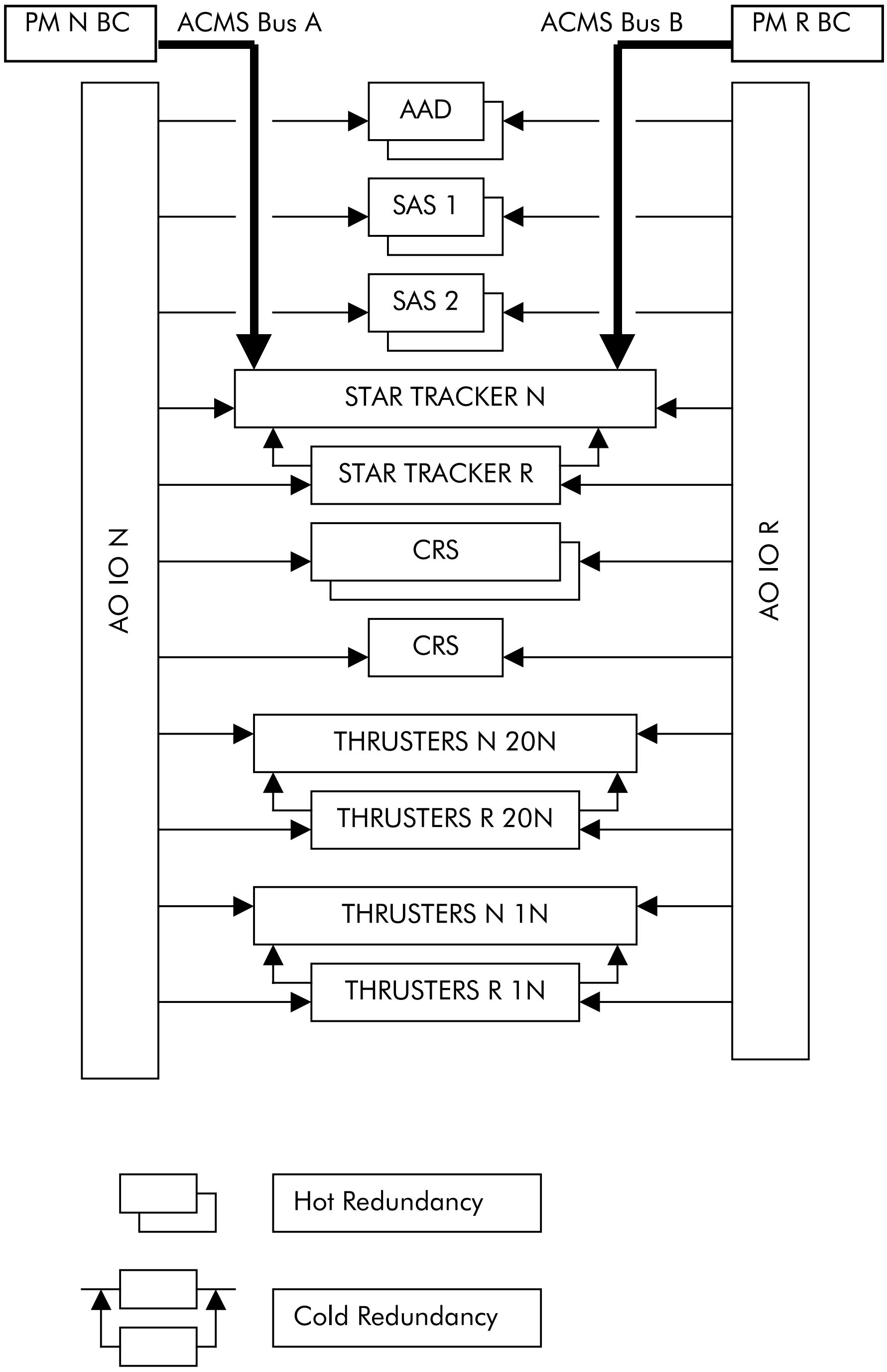


Figure 6.10-6 Planck sensors and actuators interfaces

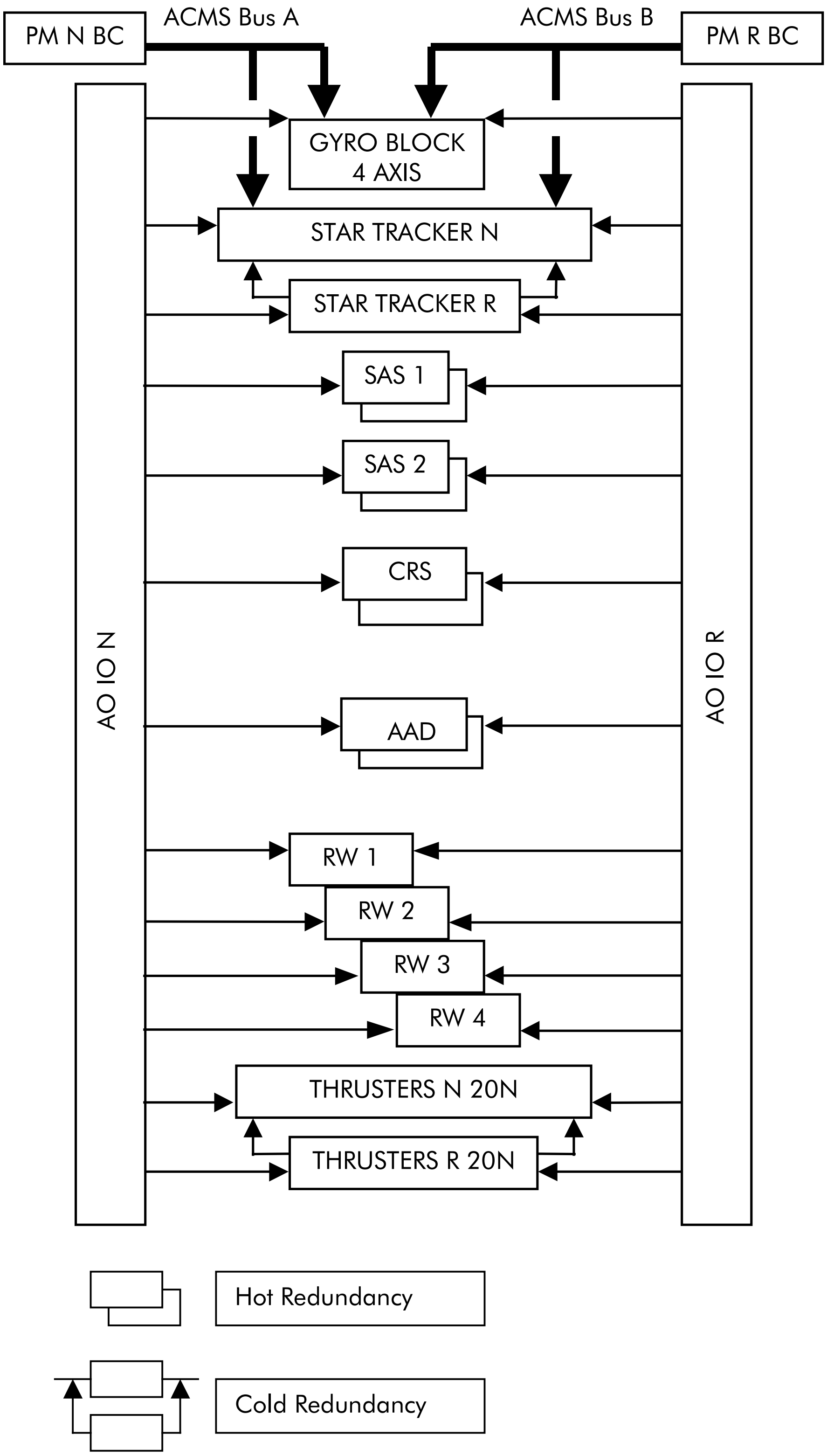


Figure 6.10-7 Herschel sensors and actuators interfaces

6.10.2.7 CDMS/ACMS FDIR management

FDIR principles for Herschel and Planck are detailed in § 6.5. The main features of FDIR management are recalled below:

- FDIR management performed by CDMS and ACMS is based first on a reliable manager which is the processing part of the CDMU and ACC
- this reliable manager is obtained through the use of a specific Reconfiguration Module (RM) which in case of processor alarm or high level alarm, controls at least a switchover to the redundant processor. The RM independence from the other functions is such that no single failure mode (in particular common cause) can result in simultaneous processor failure and no detection/action by the reconfiguration module. Although a single failure can trigger an unnecessary reconfiguration, this reconfiguration will remain correct. 2 hot redundant RM are provided; the active one is selected by default, before launch, and can be changed by ground command
- this reliable processing made by CDMU or ACC assures a FDIR reliable action on the functions/equipment under their control (1553 I/F, Power, Thermal Control... for CDMU; 1553 I/F, Attitude Control sensors and actuators for ACC).
- Another point is that, in order to minimise frequency and cumulated duration of mission outages, several levels of fault processing are considered:
  - Level 0, which corresponds to equipment failures internally recovered (no effect or action to/from another equipment)
  - Level 1, in which a processor (of CDMU or ACC) reconfigures a user on basis of its alarms or incorrect response on 1553 bus
  - Level 2, in which a processor reconfigures a user or a functional chain on basis of detected abnormal performance (cross check/consistency check, continuity check, threshold) at function level.
  - Level 3a, in which a RM reconfigures a processor in case it issues internal alarms
  - Level 3b, in which a RM performs a switchover to the redundant computer
  - Level 4, in which a RM reconfigures a processor and some related equipment to the redundant branch in case it receives high level (system) alarms.
- A Safeguard Memory (SGM) in the RM contains:
  - the list of equipment on which to reconfigure
  - the reconfiguration sequence
  - the context necessary for the restart - after reconfiguration - of interrupted tasks: spacecraft status, current mission timeline, …
- Activation of autonomous FDIR according to mode of control: Autonomous Fail Operational (AFO), Autonomous Fail Safe (AFS). In AFS, FDIR favors spacecraft safety and leads to safe mode in case of failures 1 to 4. In AFO, mission continuation is favored, and only failures 3 (TBC) and 4 will result in safe mode initiation.

6.10.2.8 Propulsion

Redundant/isolating components are provided so that no single failure of hardware is identified which could result in critical/catastrophic situation except those leading to external leakage of propellant or burst (tanks, lines), and mixing of propellant/ pressurant in tanks.

Downstream tanks and filter, the thrusters are arranged in two redundant branches, each one being isolated by a latch valve. Besides, in order to satisfy the 3 inhibits safety requirement, each thruster valve has two in series independent seats.

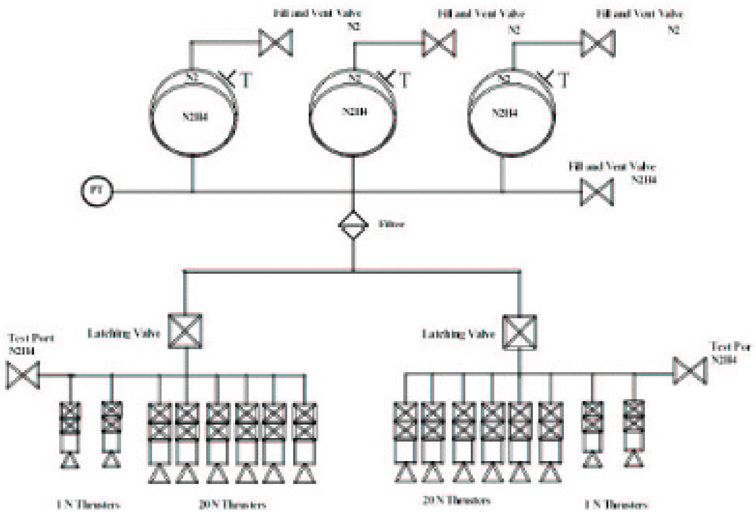


Figure 6.10-8 Planck propulsion example

6.10.2.9 Telecommunication Subsystem

The subsystem can be represented as follows:

- two X-Band transponders in hot redundancy for the receiving part and cold redundancy for the transmitting one
- two cold redundant 30 W TWTA cross strapped (via a non redundant hybrid) with the transponders transmitters
- one non redundant MGA
- two non redundant LGA for Herschel and three for Planck (assuring quasi omnidirectional coverage)
- items connecting the antennas to transponders receivers and TWTA. These items are wave guides, RF switches, hybrid, diplexers, MGA filter, test couplers. They are non redundant and SPF, except the RF switches which are all redunded. The failure mode "stuck in intermediate position" will be covered by an operational procedure, sending double commands to ensure positive switching as on ISO/INTEGRAL.

LGA can be a back-up for MGA in case a low transmission rate is acceptable, and LGA is a back up to MGA for TC uploading.

An automatism (part of the spacecraft level FDIR) periodically changes the crossing configuration between LGA in case both Rx do not detect any RF signal after a certain delay (timeout on TC reception from ground).

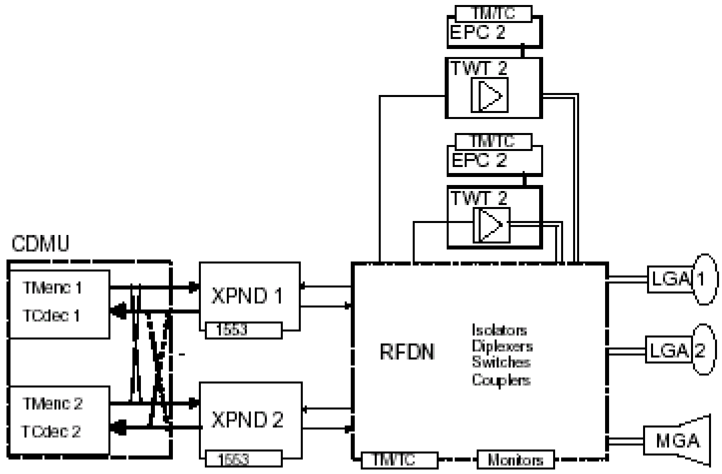


Figure 6.10-9 Herschel Radio Frequency Subsystem

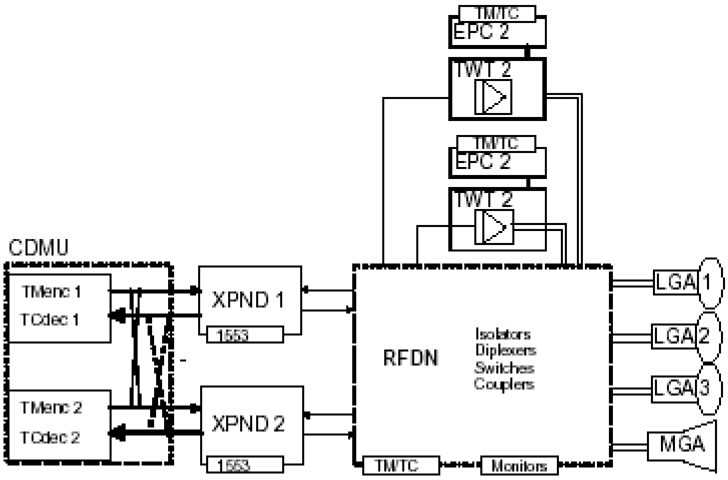


Figure 6.10-10 Planck Radio Frequency Subsystem

6.10.2.10 Harness

The harness elements have the same level of redundancy than the units they connect. Besides, the application of technological design rules (e.g.: use of backshell to protect from EMC, use of mechanical keying to avoid permutation of connectors...) contributing to reduce the risks of failure propagation/common cause failures. Separate connectors will be used to segregate the links between redundant items.

6.10.2.11 Herschel PLM

Reliability of optical elements is assured by application of specified safety margins, by qualification and acceptance tests, use of materials whose optical degradation in space environment is predictable and covered by margins.

Cryostat Control Unit (CCU) and valves arrangement are designed to assure the failure tolerance of the cryo valves control at Helium subsystem level. Cryo valves which are normally actuated after launch are redundant with regard to their critical failure modes. The cryo valves control in the CCU is such that redundant valves are controlled by separate redundant circuits, and that each valve is protected from premature control by an arming. For other functions (DLCM, temperature measurements...), no critical SPF is identified.

Helium tank SPF correspond to mechanical failures.

The cryostat cover has no redundancy except for some HRM and DEM (NCA) parts (see RD6):

- a hold down and release mechanism (HRM): The release actuator uses a redundant non explosive spool device which operates with a pyro pulse command. A retraction spring removes the release bolt of the separation nut from the interface. The toggle arms are actuated via redundant spring actuators. Redundant kick springs fixed on the cover are used to overcome adhesion forces
- a deployment hinge and end stop mechanism (DEM): The hinge provides radial and axial redundant journal bearings and a redundant spring actuator. Two redundant mechanical micro switches provide the status monitoring for open and closed position. The end stop uses redundant flat springs to limit the deployment range. The cover is latched by fully redundant actuator and stop springs.

6.10.2.12 Planck PLM

Reliability of optical elements is assured by application of specified safety margins, qualification and acceptance tests, use of materials whose optical degradation in space environment is predictable and covered by margins, qualification and acceptance tests.

6.10.3 List of critical Single Point Failures

From the Failure Modes Effects and Criticality Analysis, the following list of hardware critical Single Point failure (1S, 2S) can be established. These SPF are proposed to be accepted due to the very low risk resulting from the risk reduction arguments. It can be noted that most SPF concern mechanical items, and that the failure modes of the electronic parts being SPF have an extremely low probability of occurrence.

Category 1S

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
Structural and mechanical parts (SVM + PLM)	Rupture/distortion of structural item	Safety margins Qualification/acceptance tests
Optics (PLM)	Rupture/distortion of structural item	Safety margins Qualification/acceptance tests
	Degradation of optical characteristics (radiation)	Tests, learned lessons (space proven materials)
Thermal Control (Planck SVM)	Burst/ Leakage of Heat pipe	Hot redundancy of heat pipe
TTC Subsystem (SVM)	Wave guides Coax cables and connectors 3 dB hybrid couplers test couplers filter diplexers ports RF SW	Simplicity of the items Functional tests after acceptance environmental tests Components with low failure rates Qualified technologies Redundant LGA for TC/low rate TM
	LGA/MGA, RF SW blockage in intermediate position	**RF switches having high margin with regard to number of switching** Qualified item Item acceptance tests demonstrating correct switching at extremes of the temperature range Operational procedure
Propulsion (SVM)	Rupture/external leakage of item containing pressurant or propellant (tanks, F/D valves, pipes, filter, latch valves, pressure transducer, welds, screws)	Safety margins Qualification/acceptance tests Inspection Qualified weld process + X-ray inspection Screwing procedure Leak tests Proof/burst pressure tests
	Propellant filter obstruction	Pre filtering of fuel before filling Inspection of filter before assembly
	Thruster internal/external leakage	Safety margins Qualification/acceptance tests Inspection Leak tests Proof/burst pressure tests

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
Power S/S (SVM)	Short circuit of self healing capacitors	Non credible failure mode because self healing energy is available
	Burst of battery	Pressure release lid or fissurable envelope prevent burst
	Leakage of battery	Battery overcharge/short circuit protections prevent overpressure/leakage
Helium S/S (Herschel PLM)	External leakage of items containing Helium (tank, valves, pipes, seals...) Internal leakage of Helium valves or safety valves or HTT/HOT rupture disks.	Safety margins Qualification environmental tests demonstrating no leakage Tightness monitoring capability on launch site via temperature information For valves: design preventing particle generation + filter upstream the valves + acceptance test report at valve level demonstrating correct tightness
	Unwanted opening or closure of valves due to launch environmental conditions (shock, acceleration, vibrations).	Safety margin Environmental tests passed without change of valve position
	Partial blockage of phase separator	Use of clean Helium Procedure to prevent presence of air PLM functional tests satisfactory
HIFI Optical Windows S/S (Herschel PLM)	Fracture of O-ring, sealing of CVV or leakage (contamination of instruments)	Safety margin Tests
Cover S/S (Herschel PLM)	Premature release of opening mechanism	Safety margin 2 independent levels of commanding
	No release of opening mechanism when necessary, cover stuck closed	Functional safety margin Use of anti cold welding material Cover opening tests Redundant DEM spring actuators Redundant kick springs Redundant HRM

Category 2S

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
Thermal Control (SVM+SVM)	MLI, paints, coatings, surface treatments, OSR	Tests, learned lessons (space proven materials) Possible compensation by active thermal control
	Unstick of heaters on same support	Tests and inspections showing the absence of air-lock
	Short circuit between redundant heaters on same support	Tests showing isolation between tracks, electrical margin, robustness of Kapton layer, Thermal Control performance tests
TTC Subsystem (SVM)	MGA	Functional tests after acceptance environmental tests Qualified technologies Redundant LGA for TC/low rate TM
Power S/S (SVM)	Loss of 1 SA section among the 3 SA sections dedicated to battery charge	The complete charge will be complete with additional 120 min in worst case, not critical
Cover S/S (Herschel PLM)	Cryo cover damaging other items when released	Safety margin Cover opening test Low probability for a free part to enter the cryostat Redundant end stop springs
	Fracture of O-ring, sealing of CVV or leakage (contamination of instruments)	Tests and inspections of seals before launch
	Insufficient tightness of cover/tank interface	Tests before launch demonstrating correct tightness
Propulsion (SVM)	Mixing of propellant/pressurant in a tank (tanks diaphragm)	Qualified diaphragm with N2H4, leak tested diaphragm Thrust possible tolerance to N2/N2H4 mixing

7. Herschel SYSTEM ANALYSES

7.1 Mechanical analyses

7.1.1 Introduction

For the dynamic and sine analyses, the calculation details are in the document "CDR Herschel DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT" reference [RD04.1]

Several mathematical models (FEM) and mechanical analyses have been prepared and carried out in order:

- to assess the ability of the structural concept of Herschel satellite (Launcher requirements)
- to verify and update subsystem (H-PLM and SVM) structural requirements
- to perform a sine prediction with ARIANE V level. From the computed accelerations, equipment and subsystem qualifications levels are evaluated as well as primary and possible secondary notching levels are investigated.

Herschel mathematical model has been prepared from SVM FE model delivery coming from ALENIA and H-PLM FE model delivery coming from ASTRIUM D and H telescope delivery coming from ASTRIUM F.

For the random/vibro-acoustic analyses, the calculation details are in the document "Herschel Random environment Analyses" ref. [RD04.16]

For the shock analyses, the calculation details are in the document in the document " Shock Evaluation Results, Launcher Shock" reference [RD04.9]

For the micro-vibration analyses, the calculation details are in the document "CDR Herschel MICRO-VIBRATION ANALYSIS REPPORT" reference [RD04.12]

7.1.2 Analysis of Herschel satellite dynamic behaviour

7.1.2.1 Herschel Satellite mathematical model

The mathematical model of the whole Herschel satellite is assembled using the models of the various subsystems: service module, and Herschel payload module (see FEM description in the document RD04.1 "CDR Herschel DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT").

Main characteristic of the model

The SVM and H-PLM models are connected to each other with CELAS elements (spring elastic elements). The main characteristics of the Herschel satellite mathematical model are:

Number of physical nodes:	68490
Number of elements:	71418
Total number of degrees of freedom:	410940.

Global Mass budget :

The following table presents the mass budget of Herschel satellite

Subsystem	Mass in the model [Kg]
Telescope	310
HPLM (without telescope)	1970
SVM	1102
Total mass	3382

The inertia and CoG properties of the FEM model are listed hereafter from a NASTRAN computation.

```
O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                REFERENCE POINT =        0
                                        M O
*  3.382553E+03 -3.583920E-10 -1.802754E-09  1.635449E-09 -1.946209E+00 -4.064157E+00 *
* -3.583920E-10  3.382553E+03  3.694076E-10  1.949139E+00 -1.276931E-09  6.733414E+03 *
* -1.802754E-09  3.694076E-10  3.382553E+03  4.006843E+00 -6.733414E+03 -4.621299E-10 *
*  1.635449E-09  1.949139E+00  4.006843E+00  4.468877E+03  1.861800E+02 -5.847768E+02 *
* -1.946209E+00 -1.276931E-09 -6.733414E+03  1.861800E+02  2.160342E+04  1.404142E+00 *
                      * -4.064157E+00  6.733414E+03 -4.621299E-10 -5.847768E+02  1.404142E+00
2.207971E+04 *
                                            S
                     *  1.000000E+00  0.000000E+00  0.000000E+00 *
                     *  0.000000E+00  1.000000E+00  0.000000E+00 *
                     *  0.000000E+00  0.000000E+00  1.000000E+00 *
          DIRECTION
     MASS AXIS SYSTEM (S)      MASS              X-C.G.        Y-C.G.        Z-C.G.
             X            3.382553E+03      4.834954E-13  1.201506E-03 -5.753667E-04
             Y            3.382553E+03      1.990630E+00 -3.775049E-13 -5.762331E-04
             Z            3.382553E+03      1.990630E+00  1.184562E-03 -1.366216E-13
                                          I(S)
                     *  4.468872E+03 -1.941561E+02  5.886569E+02 *
                     * -1.941561E+02  8.199684E+03 -1.401804E+00 *
                     *  5.886569E+02 -1.401804E+00  8.675973E+03 *
                                           I(Q)
                     *  8.208247E+03                              *
                     *                4.378357E+03                *
                     *                              8.757924E+03 *
                                            Q
                     * -4.361448E-02 -9.894923E-01  1.378507E-01 *
                     * -9.976985E-01  5.030945E-02  4.546009E-02 *
                     * -5.191760E-02 -1.355507E-01 -9.894092E-01 *
```

The total mass of the spacecraft fem is 3382Kg including 71 kg of ergol per tank. This is well in line with the document "system budget report" ref [RD02.3] which is between 3262 kg (nominal mass) and 3444 kg (mass max) with 71 kg of ergol per tank.

The cog of the FEM is at 1.991 m in X direction, which is well in line with the document "system budget report" ref [RD02.3], where it is at 1.995 m.

The Meshing of Herschel mathematical model is presented hereafter.

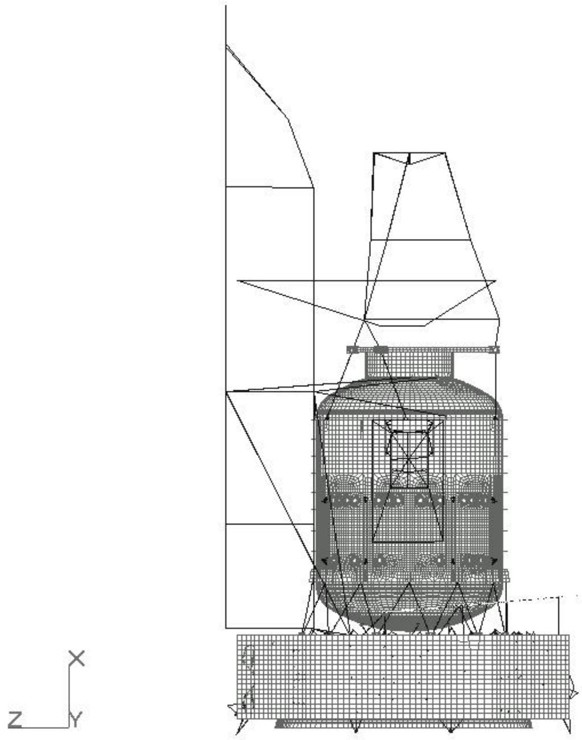


Figure 7.1-1 Y view of Herschel mathematical model

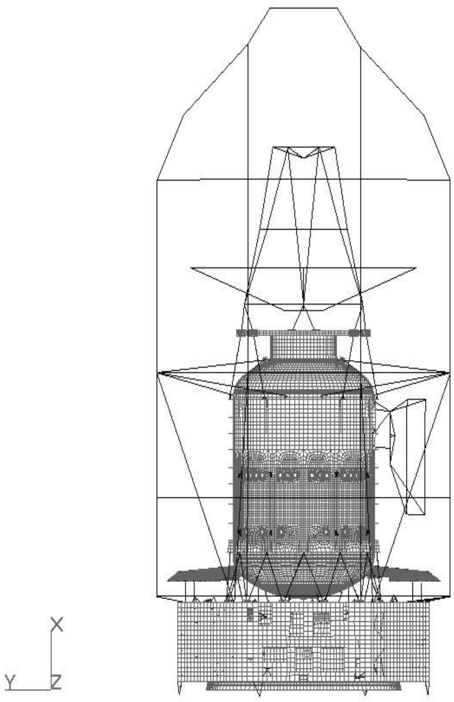


Figure 7.1-2 Z view of Herschel mathematical model

7.1.2.2 Overall system mechanical analyses

7.1.2.2.1 General

The dynamic system analysis is carried out in two different steps:

- An overall dynamic modal analysis is performed with NASTRAN software in order to identify the primary and secondary main modes of Herschel satellite and their effective mass and to check if there is no coupling between subsystems.
- A dynamic response analysis is performed to predict the accelerations responses of equipment during AR V launch. From the computed accelerations, quasi static loads are evaluated and design loads are defined for subsystems sizing and the equipment qualifications levels.

7.1.2.2.2 Herschel Satellite overall dynamic analyses

Herschel dynamic analysis (modal and sine response of the satellite) is performed up to 140 Hz.

The boundary conditions applied at the interface of the spacecraft are simply boundary conditions (123 degrees of freedom and clamped).

Modal analysis

The main modes are described in the following table (only modes with effective mass greater than 50 kg are taken into account).

EFFECTIVE MASS								
Mode N	**Freq Hz**	**Mxx Kg**	**Myy Kg**	**Mzz Kg**	**Ixx Kg,m²**	**Iyy Kg,m²**	**Izz Kg,m²**	**Mode Description**
5	14,4	0	1	**1872**	5	**20175**	13	S/C Global Z mode
6	15,07	0	**1977**	2	26	13	**20334**	S/C Global Y mode
8	19,26	**63**	0	0	0	1	0	HTT (X mode)
10	25,66	0	**47**	2	**1436**	4	0	S/C Global torsion X
11	26,22	10	0	313	3	5	0	Secondary S/C lateral Z mode
12	26,53	1	**201**	0	**95**	0	3	Secondary S/C lateral Y mode
21	37,16	**96**	28	52	4	40	33	SVM panel Y+Z- (out of plane)
22	37,33	**1518**	0	2	0	5	3	Global X mode
31	42,44	**57**	14	40	3	147	66	SVM upper closure panel (side Y-Z-), panel Y-Z- (out of plane)
36	44,56	**96**	5	1	0	113	**148**	SVM X box mode (Y+Z- side), HTT (Y sloshing)
40	46,27	**66**	7	16	5	12	63	SVM panel Y- (out of plane), THERMAL SHIELD (out of plane bending), HSS (Z mode)
42	47,19	**105**	3	23	0	1	23	SVM upper closure panel (side Y-), panel Y-Z+, panel Y-Z- (out of plane)
82	60,46	1	3	**82**	**124**	21	52	SVM upper closure panel (side Y-), Y+(out of plane), tank 2 (Z mode), THERMAL SHIELD (out of plane bending)
87	62,87	16	5	**61**	2	5	1	SVM tank 1 (Z mode), HSS mode
107	71,43	**193**	0	3	4	0	2	PLM (mode X)
120	76,43	1	0	31	**325**	6	1	SVM (torsion X)
Total		3078	3220	3185	4114	21405	21821	
Rigid Mass		3383	3383	3383	4469	21603	22080	
Residual Mass		**304**	**163**	**197**	**355**	**198**	**258**	
Residual Mass (%)		**9**	**5**	**6**	**8**	**1**	**1**	

Table 7.1–1 Herschel satellite modal analysis results

Comments:

Herschel satellite main modes

The Herschel satellite main modes are located at the following frequencies :

- Herschel longitudinal mode = 37.3 Hz (Margin >20 %)
- Herschel lateral mode = 14.4 Hz (Margin >60 %).

Herschel longitudinal mode is driven by the longitudinal mode of CRYOSTAT suspended masses. The CRYOSTAT suspended mass (Helium tanks, optical bench) have a significant contribution in this mode. The frequency of the longitudinal mode fulfils the Launcher frequency requirement (> 31 Hz) in longitudinal direction.

Herschel lateral main modes are determined by the stiffness of the primary structure (CRYOSTAT). The frequencies of these lateral modes are more than 20 % higher than the minimal required frequency and are compliant with the lateral launcher frequency requirement (> 9 Hz).

The second lateral main modes of Herschel satellite are located around 26 Hz and are driven by the stiffness of GFRP struts and Herschel lateral mode of CRYOSTAT suspended masses.

Herschel satellite secondary modes

The following table describes SVM main modes, which correspond to the maximum accelerations of sine analysis.

EFFECTIVE MASS					
Mode N	Freq Hz	Mxx Kg	Myy Kg	Mzz Kg	Mode Description
7	16,53	5	0	0	SVM thermal closure panel (out of plane)
14	29,15	5	0	0	SVM sub platform (out of plane)
21	37,16	96	28	52	SVM panel Y+Z- (out of plane)
31	42,44	57	14	40	SVM upper closure panel (side Y-Z-), panel Y-Z- (out of plane)
33	43,75	0	14	9	SVM panel Y- (out of plane)
34	43,86	29	40	1	SVM upper closure panel (side Y-), panel Y- (out of plane)
35	44,43	1	9	0	THERMAL SHIELD (out of plane bending)
36	44,56	96	5	1	SVM (X box mode, Y+Z- side), HTT (Y sloshing)
39	45,51	11	2	1	THERMAL SHIELD (out of plane bending)
40	46,27	66	7	16	THERMAL SHIELD (out of plane bending), SVM panel Y-
42	47,19	105	3	23	SVM upper closure panel (sideY-), panel Y-Z+, panel Y-Z- (out of plane)
43	47,25	2	15	31	SVM upper closure panel (sideY-), panel Y-Z+ (out of plane), THERMAL SHIELD (out of plane bending)
46	49,39	15	28	6	SVM panel Y+ (out of plane)
47	49,64	1	43	0	SVM upper closure panel (out of plane, side Y-, Y-Z-), panel Y+ (out of plane)
65	55,22	8	5	25	SVM torsion Y
76	58,48	2	29	1	SVM upper closure panel (side Y-,Y+), panel Y-,Y-Z- (out of plane)

EFFECTIVE MASS					
Mode	**Freq**	**Mxx**	**Myy**	**Mzz**	**Mode**
N	**Hz**	**Kg**	**Kg**	**Kg**	**Description**
82	60,46	1	3	82	SVM upper closure panel (side Y-),Y+(out of plane), tank 2 (Z mode), THERMAL SHIELD (out of plane bending)
84	61,23	0	24	27	thrusters (152827), reaction wheels (152827 152831)
87	62,87	16	5	61	SVM tank 1 (Z mode)
116	74,05	0	1	1	SVM panel Y+Z+ (out of plane)
122	77,15	3	47	12	SVM upper closure panel (side Y+Z-), panel Y+Z- (out of plane bending, FPBOLC), panel Z- (out of plane, HSDPU, HSFCU)
143	85,35	0	19	1	SVM panel Z-, Y-Z- (bending out of plane), panel Z- (out of plane CCU)
156	88,94	11	2	1	SVM upper closure panel (side Z+Y-)
160	90,52	13	0	2	SVM upper closure panel (side Z+Y-), tank 2 (sloshing, X mode)
171	94,91	4	1	0	THERMAL SHIELD (out of plane bending)
180	97,61	2	2	0	SVM lower closure panel (side Y+)
187	100,1	3	1	0	SVM sub platform (bending)
188	100,5	0	7	1	SVM sub platform (bending)
248	118,7	4	3	2	SVM lower panels Y- (out of plane)

Table 7.1–2 SVM main modes

The following table describes HPLM main modes, which correspond to the maximum accelerations of sine analysis.

EFFECTIVE MASS					
Mode	**Freq**	**Mxx**	**Myy**	**Mzz**	**Mode**
N	**Hz**	**Kg**	**Kg**	**Kg**	**Description**
8	19,26	**63**	0	0	HTT (X mode)
9	24,01	0	5	0	HSS (torsion X)
10	25,66	0	**47**	2	CVV frame IF (Y, Z mode)
11	26,22	10	0	**313**	HOT (Z mode), HTT (Z mode), OBA (Z mode)
12	26,53	1	**201**	0	HOT (Y mode), HTT (Y mode), OBA (Y mode), TELESCOPE (Y mode)
13	28,46	0	0	5	HSS (Z mode)
20	36,41	11	0	0	TELESCOPE (torsion X)
22	37,33	**1518**	0	2	HOT (X mode), HTT (X mode), OBA (X mode), CVV frame IF (X mode)
25	38,87	43	0	1	LOU (torsion X)
28	41,46	24	7	21	TELESCOPE (M1 mode out of plane)
36	44,56	**96**	5	1	SVM (X box mode, Y+Z- side), HTT (Y sloshing)
69	57,27	26	0	28	HSS mode (lower Y-, out of plane)

EFFECTIVE MASS					
Mode N	Freq Hz	Mxx Kg	Myy Kg	Mzz Kg	Mode Description
78	58,87	1	0	23	HSS mode (lower out of plane)
80	59,5	31	3	1	HSS mode (lower Y+, out of plane)
92	65,12	24	28	12	LOU (torsion X)
106	71,18	15	6	13	HOT (Z sloshing)
107	71,43	**193**	0	3	STA (antenna and support Y,Z modes), LOU interface (X,Y), TELESCOPE (longi X, hexapod legs, support)
119	75,76	2	0	0	HSS mode (middle upper, out of plane)
144	85,81	10	4	5	TELESCOPE (hexapod legs)
146	86,14	10	2	1	HSS mode (upper angles, out of plane)
156	88,94	11	2	1	HSS mode (lower IF Y-, X mode)
206	106,8	24	2	0	TELESCOPE (M1 mode X), STA antennas (X mode)

Table 7.1–3 HPLM main modes

Herschel SSH modes are found at 24/28 Hz and 57/59 Hz and are mainly global modes. The two Lateral SSH Y and Z modes located around 24 and 28 Hz are not coupled with the main S/C mode. Morever, these modes have a very weak effective masse.

The frequencies of the first telescope main modes are above 41 Hz and are slightly coupled with the longitudinal main mode of the satellite located at 37 Hz. The control the of longitudinal mode of the telescope has to be checked to avoid overpassing the telescope loads.

The main SVM thermal shield mode is above 44/47 Hz and 60 Hz. These modes are not coupled with the S/C ones.

The Herschel box service module modes are found above 44.5 Hz which ensure the modal de-coupling with Herschel satellite main modes (lateral and longitudinal ones).

7.1.3 Dynamic Sine Response analyses

- Methodology

The dynamic response analysis is performed using the qualification levels specified by ARIANE5 user's manual referenced in the document GDIR [AD05.1]:

- **Longitudinal axis :** ± 1.25g from 5 Hz to 100 Hz
- **Lateral axis :** ± 1g from 5 Hz to 25 Hz
  ± 0.8g from 25 Hz to 100 Hz.

These qualification levels are applied at the base of the spacecraft . The reduced damping factor considered in this analysis is 2 % for each mode which is usually consistent with most of the experimental tests.

Primary Notchings

The following table presents the qualification maximal loads at the launcher interface due to the dynamic response (with qualification factor of 1.25), the maximum quasi static loads at the interface and the foreseen notching values.

The analyses and notching level evaluation have been performed from the main ARIANE V quasi static loads (7.5g longitudinal and 2.5g lateral) . The main ARIANE V quasi static load cases are summarised in the following table.

Flight Event	Longitudinal flight Level [g]	Lateral flight Level [g]	Longitudinal Qualif Level [g]	Lateral Qualif Level [g]
Max dyn pressure	- 3.2	± 2	- 4	± 2.5
SRB en of flight	- 6	± 1	- 7.5	± 1.25
Max tension case	2.5	± 0.9	3.125	± 1.125

The estimated notching levels are presented hereafter.

	Notched Level [g]	Freq. [Hz]	Notched I/F Loads [daN/daNm]		
			Fx	My	Mz
X drive	0.60	37.1	**25369**		
Y drive	0.11	15			**16833**
Z drive	0.11	14.2		**16833**	

Table 7.1–4 Herschel primary notching

These values are consistent with usual values found on other satellites with a similar weight.

Maximum I/F flux at launcher I/F

For each excitation axis, the flux at launcher interface has been computed at frequency, which leads to minimum notching level for every excitation drive.

Excitation Drive	Max flux (N/mm)	Static SVM Qualif. Allowable flux (N/mm)	Ratio
X	44,06	102.5	2.33
Y	40,29	102.5	2.54
Z	39,37	102.5	2.60

Table 7.1–5 Flux at launcher interface compliance

The maximum sine flux is covered by the current static one with a ratio of 2.3.

7.1.3.1 Secondary notching due to SVM specification:

Possible secondary notching requirements are investigated in this paragraph. Sine specifications and quasi-static loads of SVM subsystems, equipments or instruments may cause to notch the excitation profile injected at the base of the spacecraft. The following SVM subsystems have been considered:

- SVM Short & Long Panels
- SVM Shear Panels
- SVM Equipments
- SVM Upper & Lower Closure Panels
- SVM Thermal Shield

They shall withstand the quasi-static load and sine environment requirements as defined in the following paragraphs.

	PANEL	EQUIPMENT	MASS (kg)	SPEC EQUIPMENT QSL		
				X	Y	Z
SVM LATERAL PANELS	Y-Z+	RWL1	9,5	25	25 (⊥)	25
		RWL2	9,5	25	25 (⊥)	25
		RWL3	9,5	25	25 (⊥)	25
		RWL4	9.5	25	25 (⊥)	25
	Z+	AAD	9,5	25	36 (⊥)	25
	Y+Z+	RFNRD	6,0	44	25 (⊥)	44
		XPND1	4,3	44	25 (⊥)	44
		XPND2	4,3	44	25 (⊥)	44
		TWTA1	1,0	44	25 (⊥)	44
		TWTA2	1,0	44	25 (⊥)	44
		EPC1	1,6	44	25 (⊥)	44
		EPC2	1,6	44	25 (⊥)	44
	Y+	Battery	7,7	25	25 (⊥)	25
	Z-	SAS	0,2	25	29 (⊥)	25
SVM WEB	Z+Y-	LGA1	0,6	25	38 (⊥)	25
	Z+Y+	SAS	0,3	25	38 (⊥)	25
		MGA	0,7	25	38 (⊥)	25
	Z-Y+	LGA2	0,6	25	36 (⊥)	25
	Y+Z+	CRS1	2,2	25	25	38 (⊥)
		CRS2	2,2	25	25	38 (⊥)
LOWER CLOSURE PANEL		Thruster	1.5	33 (⊥)	25	25
		Thruster	1.5	33 (⊥)	25	25
		Thruster	1.5	33 (⊥)	25	25
		Thruster	1.5	33 (⊥)	25	25
		Thruster	1.5	33 (⊥)	25	25
		Thruster	1.5	33 (⊥)	25	25

Table 7.1–6 SVM platform equipments minimal quasi-static loads

	PANEL	EQUIPMENT	MASS (kg)	SPEC EQUIPMENT QSL X_{SAT}	SPEC EQUIPMENT QSL Y (⊥)	SPEC EQUIPMENT QSL Z
SVM LATERAL PANELS	Z+	VMC	1,1	20	25	20
	Y+	ACC	14,2	20	25	20
		CDMU-A	16,0	20	25	20
		PDCU	29,5	20	25	20
	Y+Z-	FPMEC-DEC	28,1	20	25	20
		FPBOLC	17,1	20	25	20
		FPDPU	7,4	20	25	20
		FPSPU	7,6	20	25	20
	Z-	HSDPU	7,4	20	25	20
		CCU	10,9	20	25	20
		HSDCU	17,3	20	25	20
		HSFCU	17,0	20	25	20
		SREM	2,7	20	25	20
	Y-Z-	FHFCU	8,2	20	25	20
		FHHRV	13,7	20	25	20
		FHICU	8,5	20	25	20
		FHWEV	9,1	20	25	20
		FHWOV	7,1	20	25	20
		FH3DV	0,6	20	25	20
	Y-	FHHRH	13,7	20	25	20
		FHWEH	9,1	20	25	20
		FHWOH	7,1	20	25	20
		FHLCU	18,2	20	25	20
		FHLSU	19,0	20	25	20
		FH3DH	0,6	20	25	20
SVM WEB	Z+Y+	GYR	6,4	20	25	20

Table 7.1–7 SVM instruments and CFE equipments quasi-static loads

				SPEC EQUIPMENT SINE			
	PANEL	**EQUIPMENT**	**MASS (kg)**	**New spec //**	**Old spec(1) //**	**New spec (2)** (⊥)	**Old spec (1)** (⊥)
SVM LATERAL PANELS	**Y-Z+**	**RWL1**	9,5	5-60 Hz 20g 60-80 Hz 6g 80-100 Hz 12g	5-90 Hz 33g 90-100 Hz 20g	20g	27g
		RWL2	9,5				
		RWL3	9,5				
		RWL4	9.5				
	Z+	**AAD**	9,5	5-80 Hz 17g 80-100 Hz 8g	5-80 Hz 17g 80-100 Hz 8g	6g	6g
	Y+Z+	**RFNRD**	6,0	20g	5-80 Hz 36g 80-100 Hz 27g	22g	15g
		XPND1	4,3	20g		35g	
		XPND2	4,3	20g		35g	
		TWTA1	1,0	20g		20g	
		TWTA2	1,0	20g		20g	
		EPC1	1,6	20g		35g	
		EPC2	1,6	20g		35g	
	Y+	**Battery**	7,7	22g	22g	19g	13g
	Z-	**SAS**	0,2	20g	19g	25g	33g
SVM WEB	**Z+Y-**	**LGA1**	0,6	15g	11g	16g	6g
	Z+Y+	**SAS**	0,3				
		MGA	0,7				
	Z-Y+	**LGA2**	0,6				
	Y+Z+	**CRS1**	2,2				
		CRS2	2,2				
LOWER CLOSURE PANEL		**Thruster**	1.5	7g	12g	21g	16g
		Thruster	1.5				
		Thruster	1.5				
		Thruster	1.5				
		Thruster	1.5				
		Thruster	1.5				

Table 7.1–8 SVM platform equipments sine environment requirements

(1) **Old spec:** SVM Mechanical Environment and Test Specification H-P-SP-AI-0033, Issue 2.0

(2) **New spec:** SVM CDR data Package Review – Mechanical Splinter H-P-ASP-MN-5074, dated 17&18/06/04.

	PANEL	EQUIPMENT	GRID	Coord Syst	MASS (kg)	SPEC EQUIPMENT QSL X_{SAT}	SPEC EQUIPMENT QSL Y (⊥)	SPEC EQUIPMENT QSL Z
	Z+	VMC	17192	1001	1,1	20	25	20
	Y+	ACC	17200	1003	14,2	20	25	20
		CDMU-A	17202	1003	16,0	20	25	20
		PDCU	17203	1003	29,5	20	25	20
	Y+Z-	FPMEC-DEC	17204	1004	28,1	20	25	20
		FPBOLC	17205	1004	17,1	20	25	20
		FPDPU	17206	1004	7,4	20	25	20
		FPSPU	17207	1004	7,6	20	25	20
	Z-	HSDPU	17210	1005	7,4	20	25	20
		CCU	17208	1005	10,9	20	25	20
		HSDCU	17209	1005	17,3	20	25	20
		HSFCU	17211	1005	17,0	20	25	20
		SREM	17213	1005	2,7	20	25	20
	Y-Z-	FHFCU	17214	1006	8,2	20	25	20
		FHHRV	17215	1006	13,7	20	25	20
		FHICU	17216	1006	8,5	20	25	20
		FHWEV	17217	1006	9,1	20	25	20
		FHWOV	17218	1006	7,1	20	25	20
		FH3DV	152813	1006	0,6	20	25	20
	Y-	FHHRH	17219	1007	13,7	20	25	20
		FHWEH	17222	1007	9,1	20	25	20
		FHWOH	17223	1007	7,1	20	25	20
		FHLCU	17220	1007	18,2	20	25	20
		FHLSU	17221	1007	19,0	20	25	20
		FH3DH	152812	1007	0,6	20	25	20
SVM WEB	Z+Y+	GYR	17180	3	6,4	20	25	20

Table 7.1–9 SVM instruments and CFE equipments sine environment requirements

	PANEL	Coord Syst	DESIGN LOADS X_{SAT}	DESIGN LOADS Y	DESIGN LOADS Z
SVM LATERAL PANELS	**Y-Z+**	1008	26	21 (⊥)	16
	Z+	1001	16	24 (⊥)	10
	Y+Z+	1002	26	21 (⊥)	16
	Y+	1003	16	19 (⊥)	10
	Y+Z-	1004	26	21 (⊥)	16
	Z-	1005	16	19 (⊥)	10
	Y-Z-	1006	26	21 (⊥)	16
	Y-	1007	16	19 (⊥)	10
SVM LOWER CLOSURE PANEL		3	22 (⊥)	10	10
SVM UPPER CLOSURE PANEL		3	30 (⊥)	10	10
SVM WEB	**Z+Y-**	3	10	43 (⊥)	10
	Z+Y+	3	10	43 (⊥)	10
	Z-Y-	3	10	43 (⊥)	10
	Z-Y+	3	10	43 (⊥)	10
	Y+Z-	3	10	10	43 (⊥)
	Y+Z+	3	10	10	43 (⊥)
	Y-Z-	3	10	10	43 (⊥)
	Y-Z+	3	10	10	43 (⊥)
Thermal closing panel		3	-	-	-
Sub platform		3	43 (⊥)	25	25

Table 7.1–10 SVM panels Design Loads

The design quasi static loads for the SVM propellant tank are summarised in the following table.

Load case Nr.	X[g]	Y[g]	Z[g]
1	+ 14	+ 10	-
2	+ 14	- 10	-
3	+ 14	-	+ 10
4	+ 14	-	- 10

The design quasi static loads for the Thermal Shield are:

#1: 70g axial

#2: 25g lateral

load cases #1 & #2 taken separately.

Notching levels due to SVM requirements (panels, equipments) are presented in the following tables and figures:

Location, Equipment	Axis	Requirement	Spec (g)	Max sine (g)	Notched Input (g)	Freq (Hz)
FPBOLC (SVM Y+Z- Panel)	X_{SAT}	Equipment QS Loads	20	29.22	0.86	44.13
FPDPU (SVM Y+Z- Panel)	X_{SAT}	Equipment QS Loads	20	30.3	**0.83**	**44.13**
FPSPU (SVM Y+Z- Panel)	X_{SAT}	Equipment QS Loads	20	29.08	0.86	44.13
SVM Y+Z- Panel	X_{SAT}	Equipment Sine Requirements	20	25.81	0.97	44.13
FPMEC-DEC (SVM Y+Z- Panel)	X_{SAT}	Equipment QS Loads	20	25.4	0.98	44.42
SVM Y-Z- Panel	⊥	Equipment Sine Requirements	25	34.24	0.91	46.98
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	15.65	**0.47**	**63.13**
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	11.27	0.66	63.48
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	12.95	0.57	63.84
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	10.44	**0.71**	**71.43**
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (Z local)	Equipment Sine Requirements	12	13.69	**1.09**	**90**

Table 7.1–11 Secondary notching due to SVM requirements – X Drive

Location, Equipment	Axis	Requirement	Spec (g)	Max sine (g)	Notched Input (g)	Freq (Hz)
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	10.39	0.46	61.2
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	11.16	**0.43**	**61.2**
FPBOLC (SVM Y+Z- Panel)	// (Z local)	Equipment QS Loads	20	27.05	**0.59**	**77.25**
CRS1, CRS2 (SVM Shear Panel Y+Z+)	⊥	Equipment Sine Requirements	16	23.92	**0.53**	**100**

Table 7.1–12 Secondary notching due to SVM requirements – Y Drive

Location, Equipment	Axis	Requirement	Spec (g)	Max sine (g)	Notched Input (g)	Freq (Hz)
SVM Y+Z- Lateral Panel	⊥	Equipment Sine Requirements	25	28.18	**0.71**	**37.16**
Reaction Wheels (SVM Y-Z+ Lateral Panel)	⊥	Equipment Sine Requirements	20	24.95	0.64	60.67
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	18.62	**0.25**	**61.76**
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (Z local)	Equipment Sine Requirements	6	9.04	0.53	62.32
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	9.22	0.52	62.48
Reaction Wheels (SVM Y-Z+ Lateral Panel)	// (X local)	Equipment Sine Requirements	6	7.94	**0.60**	**66.78**
TWTA (SVM Y+Z+ Lateral Panel)	⊥	Equipment Sine Requirements	20	23.66	**0.67**	**74.04**

Table 7.1–13 Secondary notching due to SVM requirements – Z Drive

7.1.3.2 Global SVM/PLM interface loads

Global SVM interface loads have been calculated by CASA with the loads given in the document "Performance analysis Report "ref. H-P-4-CASA-RP-0012 is 4 dated 10/12/03 to design the interfaces. A comparison between loads found during system analyses and the design loads has been performed. For the details, see "CDR Herschel DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT" ref [RD04.10].

Envelopes of loads at the SVM/PLM Interfaces (with only the primary notchings) are presented here below

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	7911	6791
T	3793	11254
X (Long.)	26581	30605
Mr	17	96
MT	63	99
MX	10	19

Table 7.1–14 Interface load for X drive

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	5111	6791
T	10604	11254
X (Long.)	20937	30605
Mr	39	96
MT	50	99
MX	18	19

Table 7.1–15 Interface load for Y drive

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	6698	6791
T	12410	11254
X (Long.)	23929	30605
Mr	50	96
MT	65	99
MX	17	19

Table 7.1–16 Interface load for Z drive

Levels found during system analyses are lower than design loads except for FR (X drive), which is of 7911 N (at 37 Hz) and for FT (Z drive), which is of 12410 N (at 26 Hz) A notching of 0.52 g (for X drive) at 37 Hz and of 0.73 g (for Z drive) at 26 Hz are then necessary in order to stay within the design load.

7.1.3.3 Secondary notching due to HPLM requirements

Possible secondary notching requirements are investigated in this paragraph. Quasi-static loads of HPLM subsystems, equipments or instruments may cause to notch the excitation profile injected at the base of the spacecraft.

The following HPLM subsystems have been considered:

- Complete HPLM
- Star Tracker
- LOU
- HSS
- HOT
- HTT
- Optical Bench (OBA)
- Telescope.

They shall withstand the quasi-static load requirements as defined in the following paragraph.

SUBSYSTEM	MASS (kg)	CASE	SPEC EQUIPMENT QSL	
			Axial (g) (X_{SAT})	Lateral (g) (Y_{SAT} Z_{SAT})
Complete HPLM	2280	1	12.5	+/- 1.56
		2	2	+/- 4
HTT	551	1	15	+/- 2.5
		2	2	+/- 7.5
OBA	248	1	16.25	+/- 4
		2	2	+/- 7.5
HIFI/PACS/ SPIRE instruments		1	18	+/- 5
		2	7	+/- 8
HOT	24	1	30	+/- 2.5
		2	2	+/- 7.5
Telescope	310	1	12	+/- 4.6
		2	3.2	+/- 10
Star Tracker	13	1	30 (separately)	
LOU	59	1	14	+/- 2.5
		2	7	+/- 8
HSS	227	1	15	+/- 21.25 (+/-4.25g/m rotation)

Table 7.1–17 HPLM subsystems Quasi –Static Loads

Telescope Secondary Notching

ASEF requires the following secondary notching for telescope sine qualification (see document "Herschel TELESCOPE, vibration notching Needs ref HER.NT.0253.T.ASTR dated 28/08/03):

- 40 g hoop acceleration at the middle of the hexapods
- 40 g axial acceleration at the outside border of the M1.

SVM Thermal Shield I/F Loads:

The thermal shield is mounted on SVM upper closure panels through 14 interface structures as shown in Figure 7.1-3.

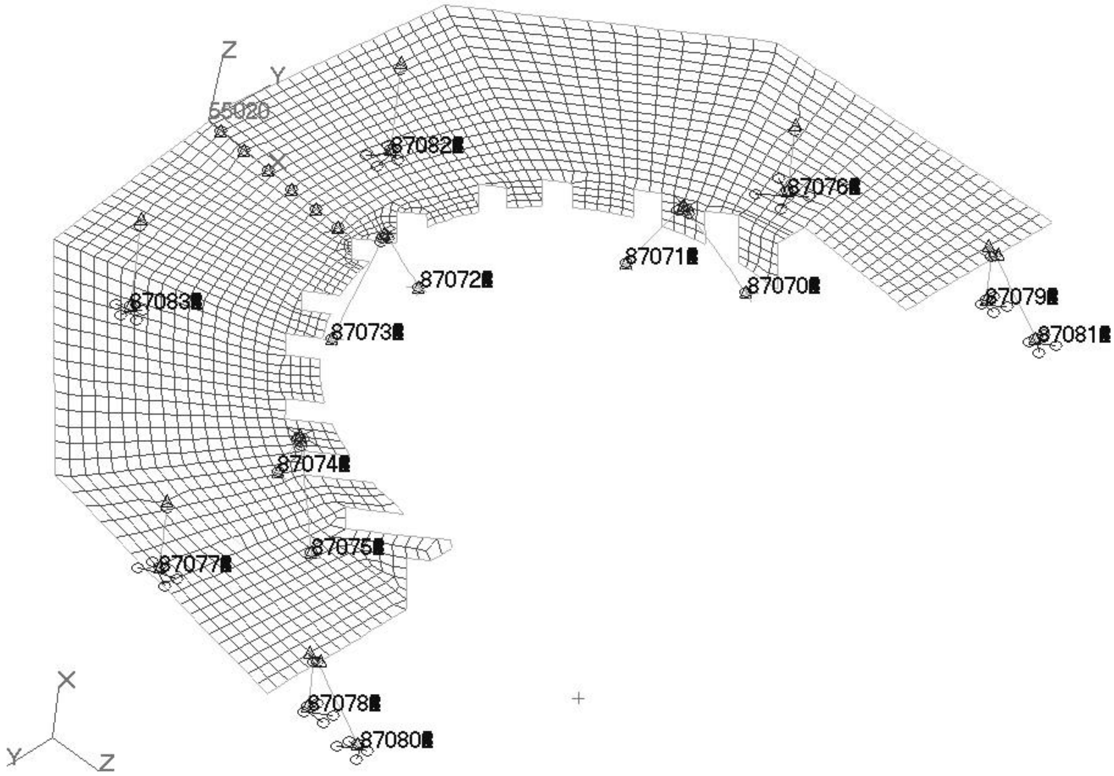


Figure 7.1-3 SVM Thermal shield interface view

No need for notching is identified for the SVM thermal shield.

Notching levels due to HPLM requirements (panels, equipments) are presented in the following tables:

Location, Equipment	Axis	Spec (g,N)	Max sine (g,N)	Notched Input (g)	Freq (Hz)
OBA	Axial	13862	17476	**0.69**	**37.82**
HTT	Axial	18939	21400	0.77	37.82
LOU	Axial	6374	7731	1.03	38.45
Telescope M1	X_{SAT}	40	41	1.22	71.59
Telescope Hexapods		40	44	1.14	71.29
Telescope	X_{SAT}	12	16.21	**0.92**	**71.29**
Telescope	Global Moment	14.5 kN.m	16.11 kN.m	1.125	41.7

Table 7.1–18 Secondary notching due to HPLM requirements – X Drive

Axial: Axial force for interface structure

Location, Equipment	Axis	Spec (g,N)	Max sine (g,N)	Notched Input (g)	Freq (Hz)
Telescope	Y_{SAT}	10	11.39	**0.70**	**26.52**

Table 7.1–19 Secondary notching due to HPLM requirements – Y Drive

Location, Equipment	Axis	Spec (g,N)	Max sine (g,N)	Notched Input (g)	Freq (Hz)
HOT	Z_{SAT}	7.5	9.83	**0.61**	**26.21**
HTT	Axial	13000	16055	0.64	26.21
Telescope	Z_{SAT}	10	10.52	**0.76**	**26.30**
Telescope	Global Moment	14.5 kN.m	15.26 kN.m	**0.76**	**41.45**

Table 7.1–20 Secondary notching due to HPLM requirements – Z Drive

Axial: Axial force for interface structure

HSS I/F Loads:

The details are in the document "CDR Herschel DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT" reference [RD04.1]

No notching is needed.

Telescope I/F Loads:

The details are in the document "Herschel Telescope Mass Sensitivity Analysis " reference H-P-1-ASP-TN-0766 is 1 dated 13/04/04. The notchings are in the Table 7.1-18, 7.1-19 and 7.1-20.

7.1.3.4 Conclusion

The main results of the dynamic analysis are:

- The Herschel first modes are compliant with Arianespace requirement.
- The spacecraft interface dynamic flux is covered by the required flux for the SVM static test.
- The Herschel notching profiles (including primary and secondary notching) for the 3 directions are shown the following (see Figure 7.1-4 to Figure 7.1-6.
- The sine responses on substructures and equipments/instruments are compliant with their quasi static and sine requirement. For instruments the specified levels are those of the document referenced IID Part A [AD04.2]. Some discrepancies were found which are covered by the following secondary notching: see Figure 7.1-4 to Figure 7.1-6.

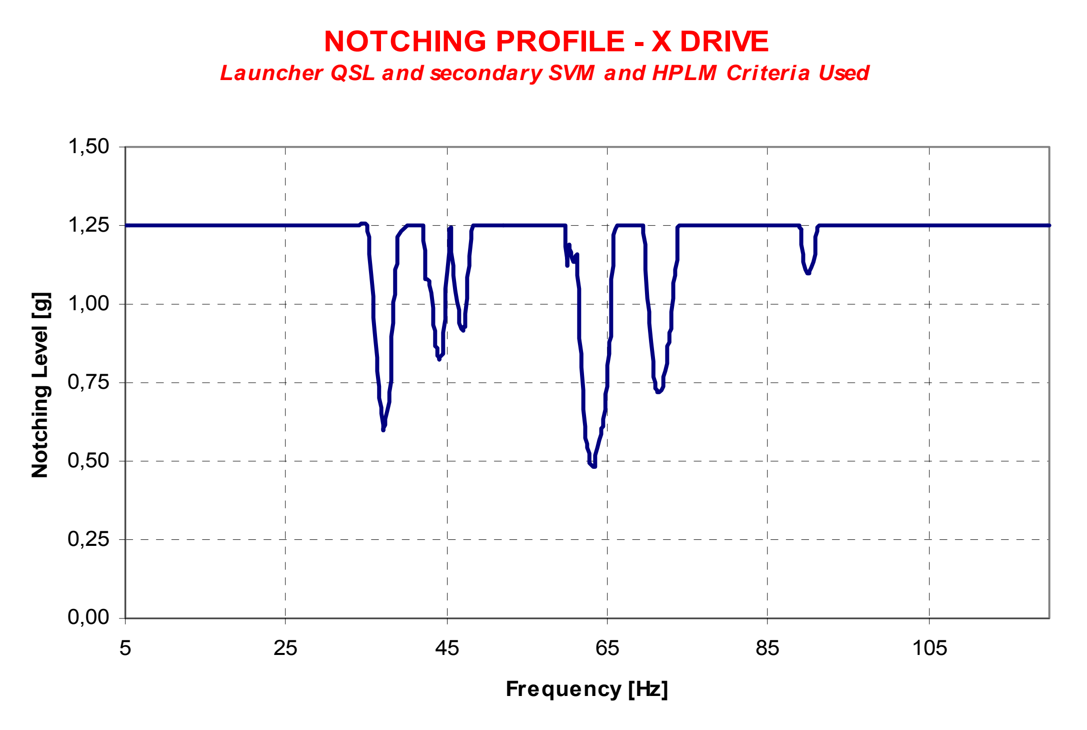


Figure 7.1-4 Primary and Secondary SVM and HPLM notching profile (X-drive)

Remark: a notching of 0.52 g at 37 Hz shall be added to this picture in order to be within the design loads for the SVM interface loads.

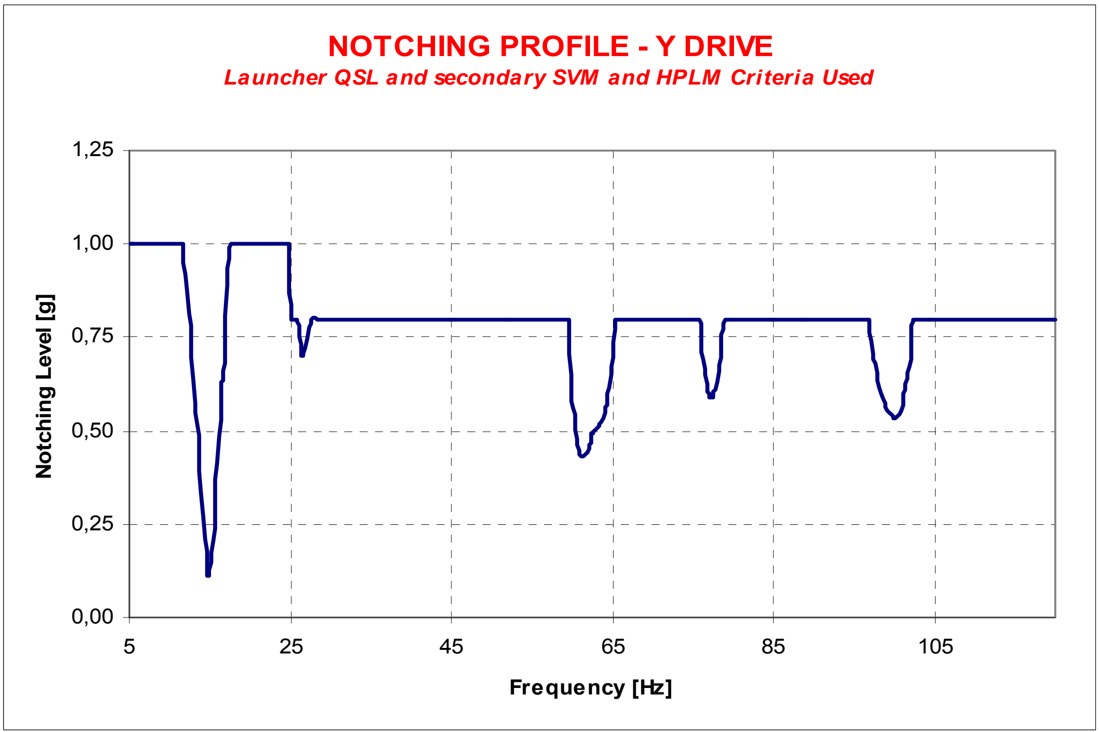


Figure 7.1-5 Primary and Secondary SVM and HPLM notching profile (Y-drive)

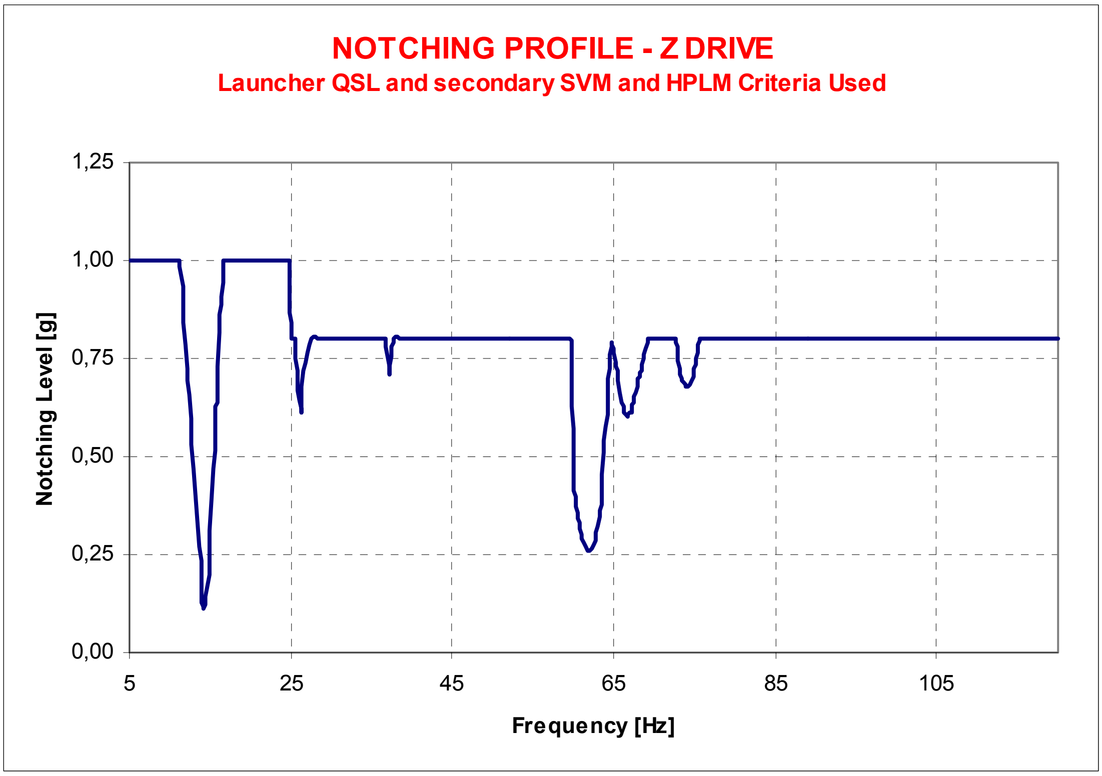


Figure 7.1-6 Primary and Secondary SVM and HPLM notching profile (Z-drive)

Remark: a notching of 0.73 g at 26 Hz shall be added to this picture in order to be within the design loads for the SVM interface loads. A notching of 0.76 g at 41 Hz shall be added to this picture in order to be within the design loads for the telescope interface loads.

The sine S/C input levels are considered compatible with Ariane V. The levels are generally higher than the minimum ones asked by ESA (Appendix 14 document [RD04.10]) excepted at 62 Hz in Z direction (0.25 g). But these levels are higher than the CLA preliminary ones (see document " Ariane V ECA/Herschel preliminary coupled load analysis evaluation" ref [RD04.21])

SVM lateral panels load reduction

Following the mass problem of the SVMs (about 50 kg too much for each SVM), it has been asked by ESA to lower the Quasi-Static Loads specifications for lateral panels of both SVM taking into account a possible reduction of the launcher spectrum. (see RD04.10 for details)

This exercise lead to the following QS loads for the lateral panels of the equipements. (See M.O.M."Revision of DLL for SVM structure – convergence meeting" ref H-P-ASP-MN-4812, dated 23/04/04)

Loads taken separately

	R	L	T
Long Panels +Y; -Y; -Z	16g	10g	10g
Long Panel +Z	23g	10g	10g
Short Panels	15g	14g	14g

The new QS loads on the SVM lateral panels found after the mass reduction exercise have not been taken into account in these analyses. I/F sine S/C levels found with these new QS lateral panel loads are presented in Appendix 14 in the document [RD04.10]. The levels are generally higher than the minimum ones asked by ESA.

7.1.4 Herschel Random vibration analyses

Methodology

Levels presented here-after have been derived from the theoretical ESA PSS formulae, from experimental results coming from XMM tests and from acoustic analyses performed with the ASTRYD software. Description of the different methods is included in the document " Herschel Random environment Analyses" ref. [RD04.16].

HPLM equipement levels (PACS,SPIRE,HIFI) have been derived using acoustic analyses and SVM equipement have been derived using results coming from XMM with a comparison with the ESA PSS curves.

HPLM random vibration specification

The following levels presented in the next table are the random vibration levels specified for H-PLM equipment. These levels define a random spectrum with an horizontal maximal level:

- 20-100Hz : +3dB/Oct
- 100Hz-300Hz : PSDmax [g^2/Hz]
- 300Hz-2000Hz : -5dB/Oct.

Herschel SVM equipment random vibration specification

The random qualification levels for Herschel equipment located inside SVM are presented in the next table. These levels are the specified random vibration levels for SVM equipment.

Item	Mass Nom [Kg]	Mounted Panel	Panel mass/surf [Kg/m²]	Out of Plane Level [g²/Hz]	In plane Level [g²/Hz]
FPDMDEC	23	-Z+Y	68	0.2	0.1
FPBOLC	15.3			0.2	0.1
FPDPU	6.6			0.2	0.1
FPSPU	6.8			0.2	0.1
Battery	7	+Y	119	0.2	0.1
PCDU	27.7			0.2	0.1
ACC	13.3			0.2	0.1
CDMU	15			0.2	0.1
CRS	2*2	Web (+Z)+Y	16	0.6	0.3
TWTA	2*0.79	+Z+Y	31	0.6	0.3
XPND	3.98			0.6	0.3
RFDN	5.48			0.6	0.3
EPC	2*1.4			0.6	0.3
FHFCU	7.3	-Y-Z	58	0.2	0.1
FHICU	7.6			0.2	0.1
FHHRV	12.3			0.2	0.1
FHWOV	6.4			0.2	0.1
FH3DV	0.4			0.2	0.1
FHWEV	8.1			0.2	0.1
Support RWL	4*8.6	+Z-Y	46	0.2	0.1
FH3DH	0.4	-Y	72	0.2	0.1
FHLCU	15			0.2	0.1
FHLSU	14			0.2	0.1
FHWEH	8			0.2	0.1
FHHRH	12.3			0.2	0.1
FHWOH	6.4			0.2	0.1
HSDPU	6.6	-Z (+Y side)	45	0.2	0.1
HSFCU	15.28			0.2	0.1
HSDCU	15.5	-Z (-Y side)	52	0.2	0.1
Cryoelec CCU	9.9			0.2	0.1
SREM	2.6	-Z (centre)	15	0.69	0.22
SAS	0.175			0.6	0.3

Table 7.1–21 Qualification random levels for Herschel SVM equipment

Item	Mass Nom [Kg]	Mounted Panel	Panel mass/surf [Kg/m²]	Out of Plane Level [g²/Hz]	In plane Level [g²/Hz]
I/F bracket VMC	1	Web (+Z) -Y	11	0.68	0.4
LGA	0.45			0.7	0.35
LGA	0.45	Web (-Z) +Y	10	0.7	0.35
MGA	0.6	Web (+Z) +Y	25	0.6	0.3
SAS	0.175			0.6	0.3
AAD	0.21			0.6	0.3
Gyroscope	6			0.6	0.3

Table 7.1–22 Qualification random levels for SVM equipment (CDR configuration)

Levels presented hereafter are derived from ASTRYD acoustic analyses. See ref [RD04.14] for more details and explanation of the method.

Proposed levels for all OB instruments are the following:

For HIFI, PACS and SPIRE

- 20 – 100 Hz : +3 dB /octave
- 300 – 2000 : -7 dB / octave.

0.05 g²/Hz on the range [100,150] Hz **0.02 g²/Hz** on the range [150,300] Hz	Longitudinal Axis
0.02 g²/Hz on the range [100,150] Hz **0.0125 g²/Hz** on the range [150,300] Hz	Lateral Axis

These levels have been included in IIDA (ref AD04.1).

7.1.5 Herschel Shock analyses

General

A shock analysis is performed in order to evaluate the shock environment of the Herschel equipment inside H-PLM and SVM. Herschel spacecraft position is the upper position with SYLDA 5 interface.

Shock excitation assumptions

At the spacecraft interface, the shock response spectrum of shock excitation considered in our shock estimations is the shock response spectrum presented in Figure 7.1-7 call "HP specification". This shock specification has been given by Arianespace as the S/C interface shock input. The main results are presented in the document RD04.9 " Shock Evaluation Results, Launcher Shock".

The comparison of the present Herschel/Planck specification with those agreed for SPACEBUS Family and for MSG-2 shows that for Herschel/Planck the level remains especially high and might be still very conservative.

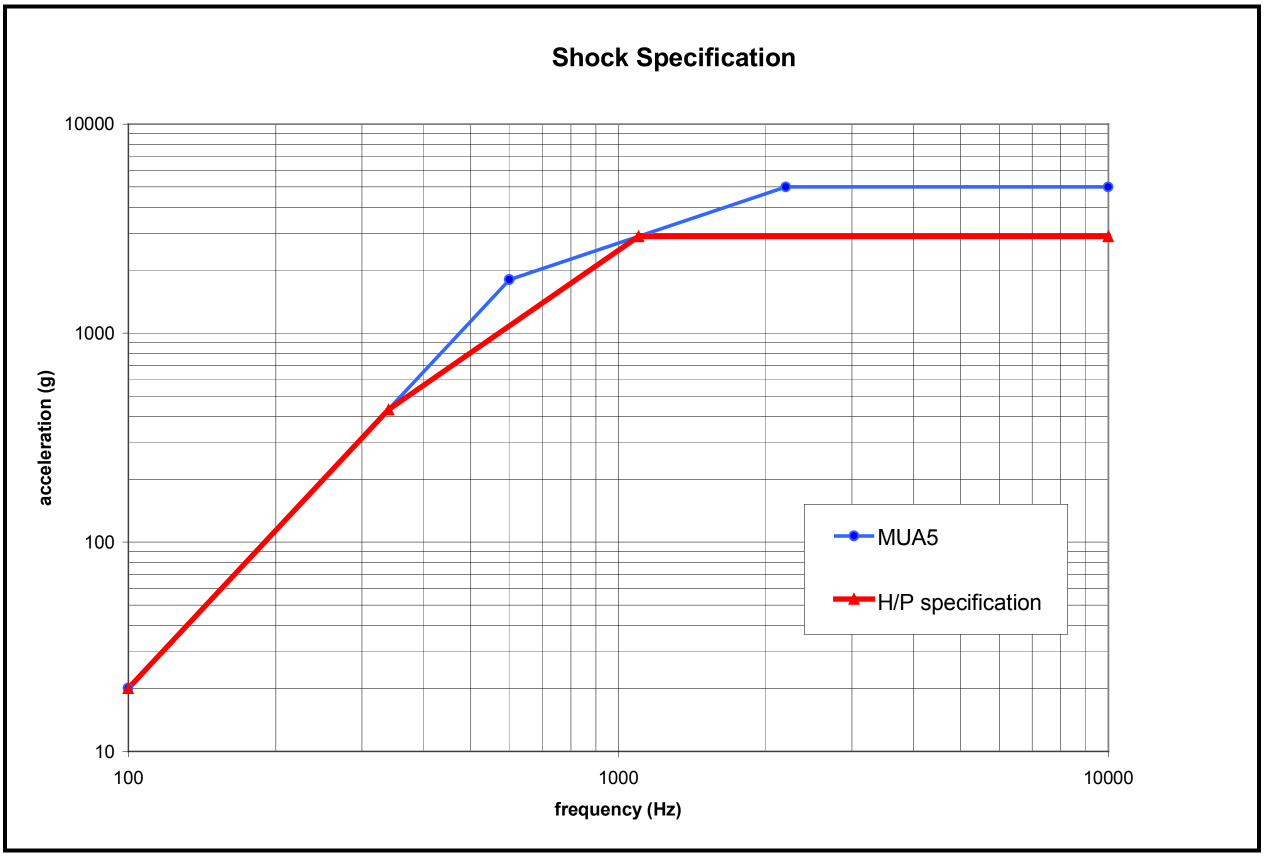


Figure 7.1-7 Herschel/Planck shock specifications at spacecraft interface

Herschel-PLM Shock evaluation

Only Launcher interface shock excitation is analysed in this section.

Shock attenuation inside sandwich panels due to the distance from the excitation source has been clearly identified from experimental tests. Considering this shock attenuation, shock levels at the interface with H-PLM strut support located at 970 mm from the launcher interface plane are reduced.

The estimated Herschel-PLM Shock interface levels are presented in the following table.

For the following shock specification, out of plane and In plane shock levels are supposed to be identical.

Frequency [Hz]	Shock Acceleration [g]
100	25
350	350
1000	2000
3000	2000
10000	1500

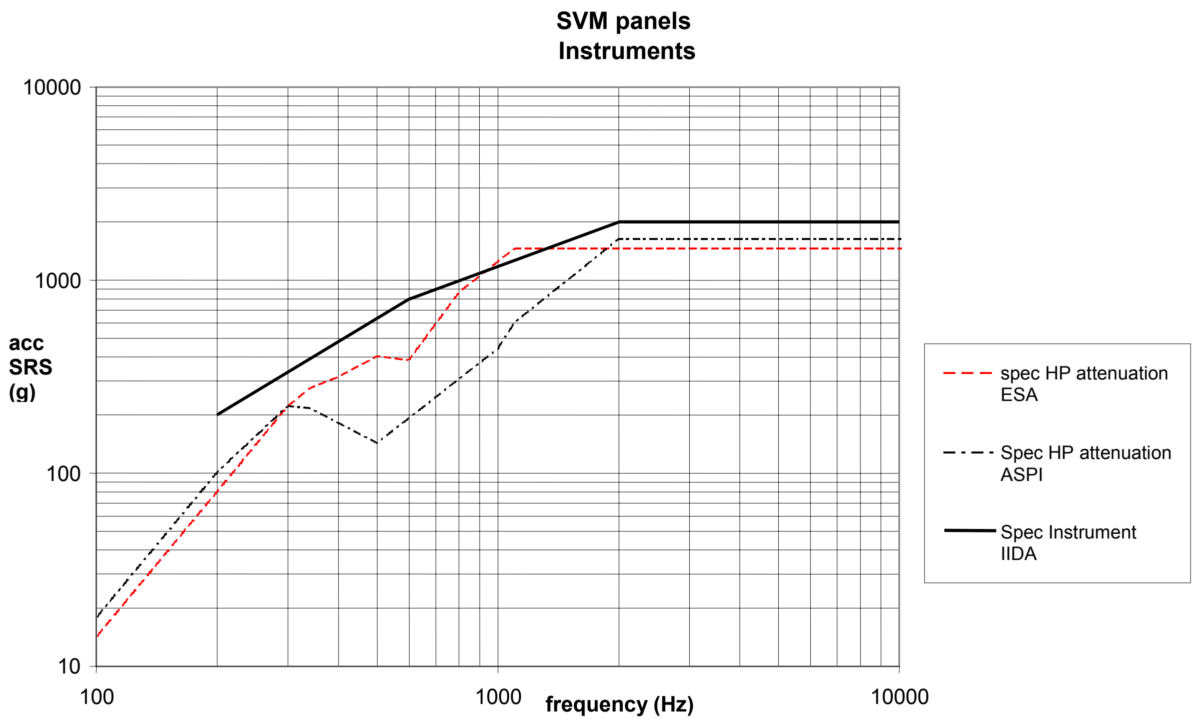
Table 7.1–23 H-PLM Interface shock response spectrum (SRS H-PLM, qualification levels)

Herschel SVM Shock specification

For SVM lateral panels shock levels are given in next tables, the proposal main results presented hereafter are considered unchanged. Out of plane and In plane shock levels are supposed to be identical.

Frequency (Hz)	Acceleration ASPI attenuation [g]	Acceleration ESA attenuation [g]	IIDA ref [AD04.1] [g]
100	15	20	
200			200
300	240	240	320
500	160	400	650
600	200	400	800
1000	500	1500	1200
2000	1800	1500	2000
10000	1800	1500	2000

Table 7.1–24 Shock response spectrum Sa 1 (qualification levels)



The IID-A specification is closed to the calculated ones. So, the IID-A (ref AD04.1) specification stays recommended.

7.1.6 Micro vibration analysis

7.1.6.1 Introduction

Details about this analysis are presented in the document "CDR Herschel MICRO-VIBRATION ANALYSIS REPORT" ref. [RD04.12].

The only instrument on Herschel concerned by microvibration is SPIRE. The SPIRE IID-B (AD04.2) is asking for the microvibration levels at FPU level, on a range between 30 Hz and 300 Hz.

The main source of perturbation identified are the four reaction wheels used to adjust the orientation of Herschel. They are operating at a rotating speed which may vary between 0 and 45 Hz. The wheels are characterised by their static imbalance that generate a radial force and by an axial force. They are both applied at the centre of Gravity of the wheel.

As Herschel spacecraft is supposed to be in the space environment, dynamic analyses are performed with spacecraft free boundary conditions.

7.1.6.2 Analysis

The model used for this analysis is presented in the § "Herschel Satellite mathematical model". The structural damping factor has been set to 0.5 % to consider a structural damping adapted to micro-vibration.

Each reaction wheel is represented by a rigid body connecting together its 4 interface points enabling introduction of interface disturbances (Figure 7.1-8).

Wheel number	Node ID	Analysis Coordinate System
1	17188	13003
2	17189	13002
3	17186	13004
4	17187	13001

The disturbance is modelled as a radial force and an axial force that are both applied at the centre of Gravity of the wheel.

A local rectangular co-ordinate system is attached to each wheel and defined as follows:

- Origin at the centre of gravity of the wheel
- Y direction parallel to the wheel rotation axis
- (X, Z) plane parallel to the wheel mounting plane.

The SPIRE optical instrument is represented by a point mass connected to the structure with a rigid body element. It is assumed that there is no mode local to the optical instrument below 350 Hz. Outputs of the computations are presented at its CoG. The node corresponding to the optical instrument is node 48301.

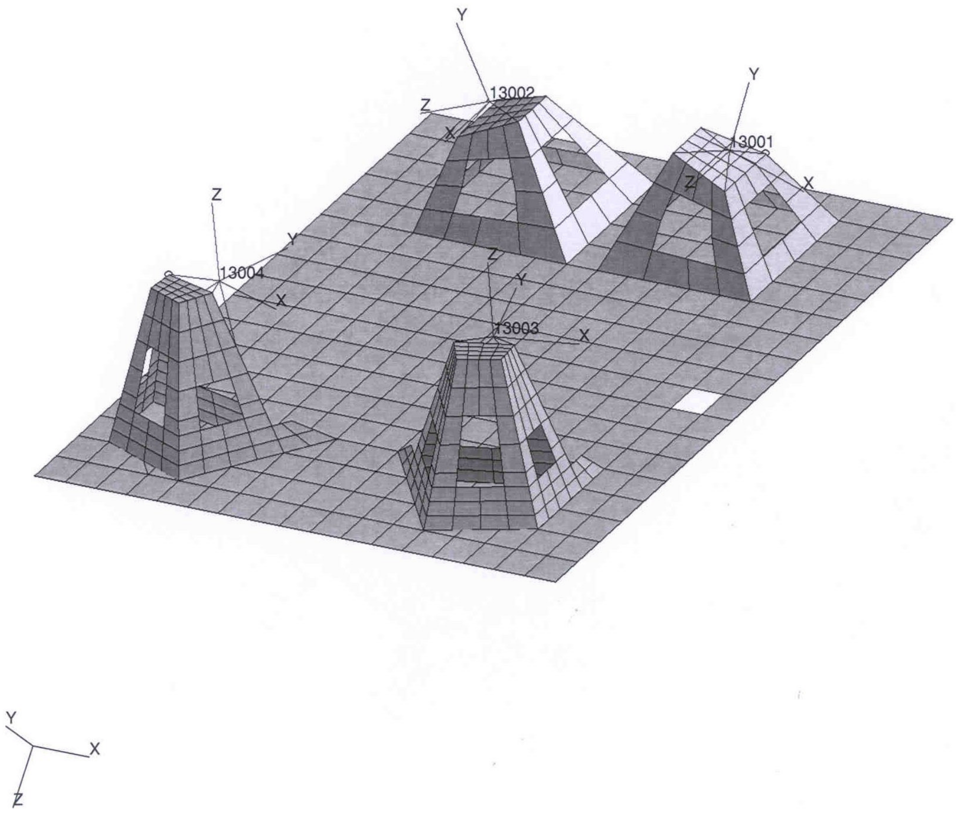


Figure 7.1-8 Model of reaction wheels mounted on Z+/Y- panel

7.1.6.3 NASTRAN analysis

The Nastran model used is the same as the one from sine analysis. Therefore the model is representative of the Herschel dynamic behaviour up to 140 Hz. Results at higher frequencies must be considered with caution. Nevertheless the main contribution to the Spire optical instrument, which dynamical behaviour is taken into account in the model with as spring-mass system, occurs below 120 Hz

7.1.6.4 MICROVISION analysis

The data required to perform the microvibration analysis are the following:

- A Nastran punch file containing the modes (up to 300 Hz) as well as modal displacements at the reaction wheels and at the Spire instrument location.
- Modal damping is set to 0.005.
- Characteristics of the wheels:
  - Rotating speed of the wheel: 0 to 45 Hz.
  - Static Imbalance: 2 e-5 kg.m for the first harmonic (guaranteed by TELDIX). Nine harmonics are taken into account for each excitation-axis. The harmonic 0.59 has been taken into account, it is typical of bearing cage excitation. According to previous studies, its amplitude is set to 2.487 e^{-6} kg.m.

Harmonic number	Radial excitation Static imbalance (kg,m)	Axial excitation Static imbalance (kg,m)
0,59	2,487E-06	2,487E-06
1	2,000E-05	2,000E-05
2	3,420E-07	4,559E-07
3	3,206E-07	4,328E-07
4	3,180E-07	4,266E-07
5	3,161E-07	4,187E-07
6	3,103E-07	4,116E-07
7	3,078E-07	4,104E-07
8	3,040E-07	4,053E-07
9	2,337E-07	2,922E-07

Table 7.1–25

- The axial excitation are not totally negligible. In conservative way, the radial static imbalance is considered for the 0.59 and 1 harmonic (see Figure 7.1-9).

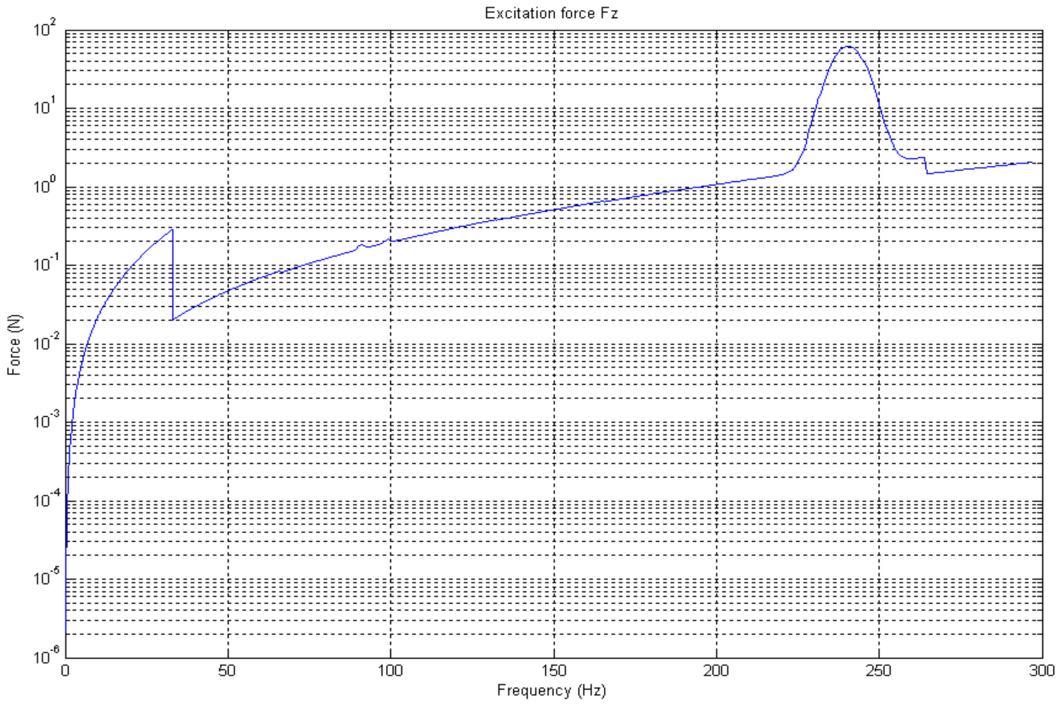


Figure 7.1-9 Axial excitation force input

– The first analysis is conducted wheel by wheel, for frequencies from 0 to 300 Hz and for wheel velocity varying from 0 to 45 Hz. Results provided below are the quadratic sum of the contribution of all harmonics whose frequency is below 300 Hz. (see excitation force input, Figure 7.1-10).

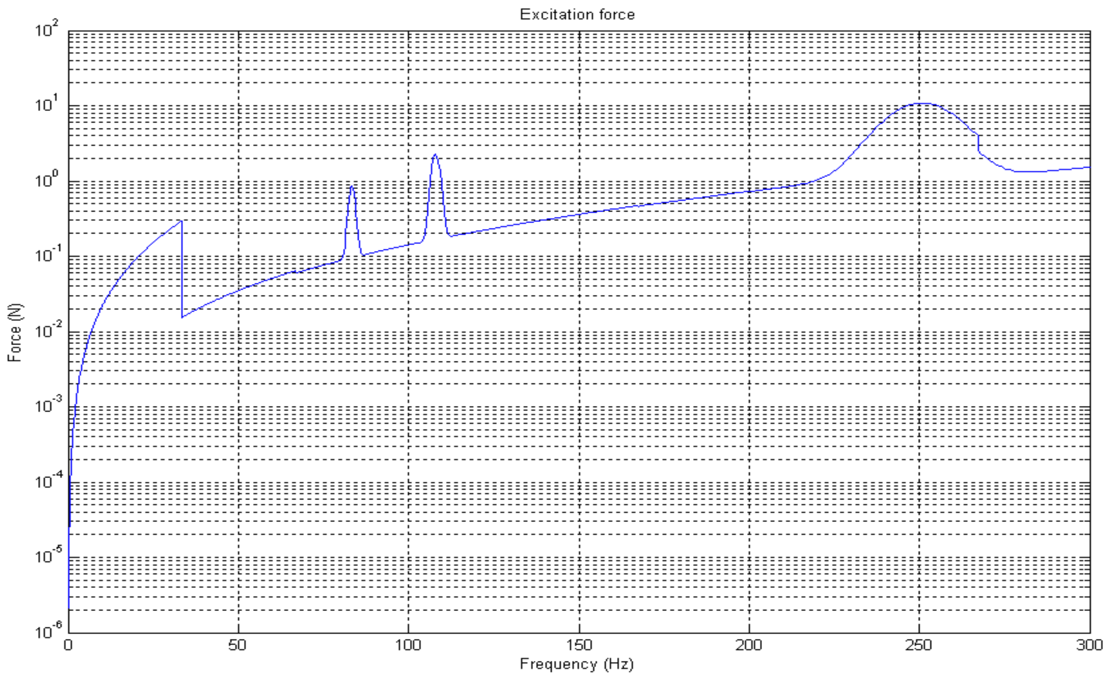


Figure 7.1-10 Radial excitation force input

- The second analysis is conducted with the four wheels rotating at the same time following the profile given Figure 7.1-11 to Figure 7.1-14. Result provided below is a time-acceleration representing the accelerations of the SPIRE CoG during a 5000 seconds phase.

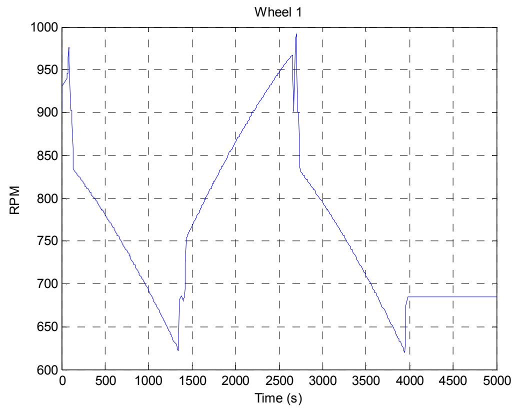


Figure 7.1-11 Speed profile wheel 1 (node 17188)

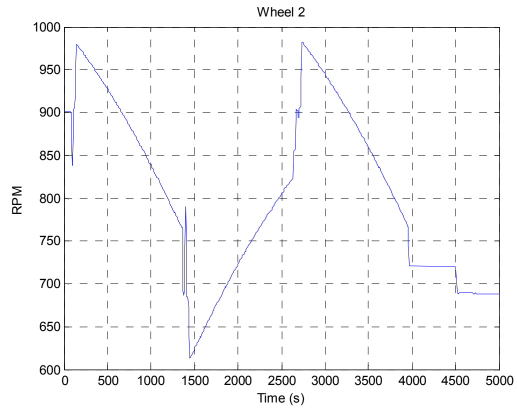


Figure 7.1-12 Speed profile wheel 2 (node 17189)

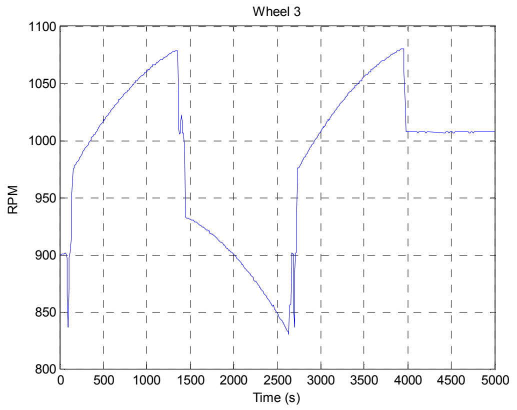


Figure 7.1-13 Speed profile wheel 3 (node 17186)

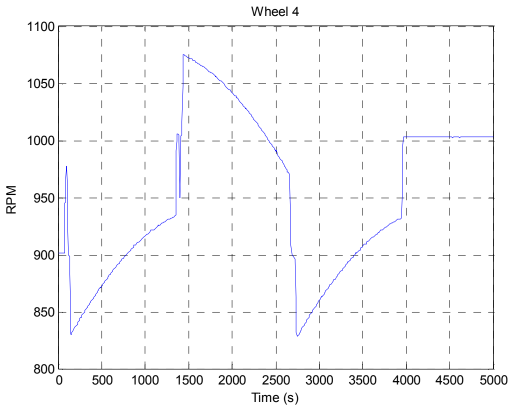


Figure 7.1-14 Speed profile wheel 4 (node 17187)

- Outputs are provided at node 48301, CoG of the SPIRE instrument. No specification was provided, therefore results are given in the spacecraft coordinate system.

7.1.6.5 Results

All results are expressed in the Spacecraft coordinate system.

7.1.6.5.1 Contribution of each Reaction Wheel separately

The maximum acceleration is due to Reaction Wheel 1:

Maximum acceleration occurs at 24.6 Hz with an amplitude of 29 mg in the X direction. This acceleration is mainly due to the radial wheel excitation (28 mg). Wheels 2 and 4 give almost the same level.

7.1.6.5.2 Sensitivity on the damping factor

To estimate a possible damping evolution at cryo temperature, the structural damping factor has been reduced to 0.05 % (very unfavourable).

The main response is due to a mode at 98.3 Hz. A previous strain energy analysis has shown that most of the energy of that mode comes from the CVV_FRAME (see detail in the document ref RD04.12)

The results show that the two maximal amplifications have been multiplied by almost a factor 3. (w.r.t. the analysis with a damping factor of 0.5 %)

It means that the choice of the damping factor values, at least for the modes which concern the coldest areas of the satellite, has to be made carefully.

It is show in RD04.21 that the results obtained with a 0.5 % damping also cover the case with a damping factor of 0.05 % for modes which concerns the cold areas of the H-PLM.

7.1.6.5.3 Results for the four wheels simultaneously

As no statistical analysis has been conducted between each wheel, they are considered in phase. The results are shown in the following figure.

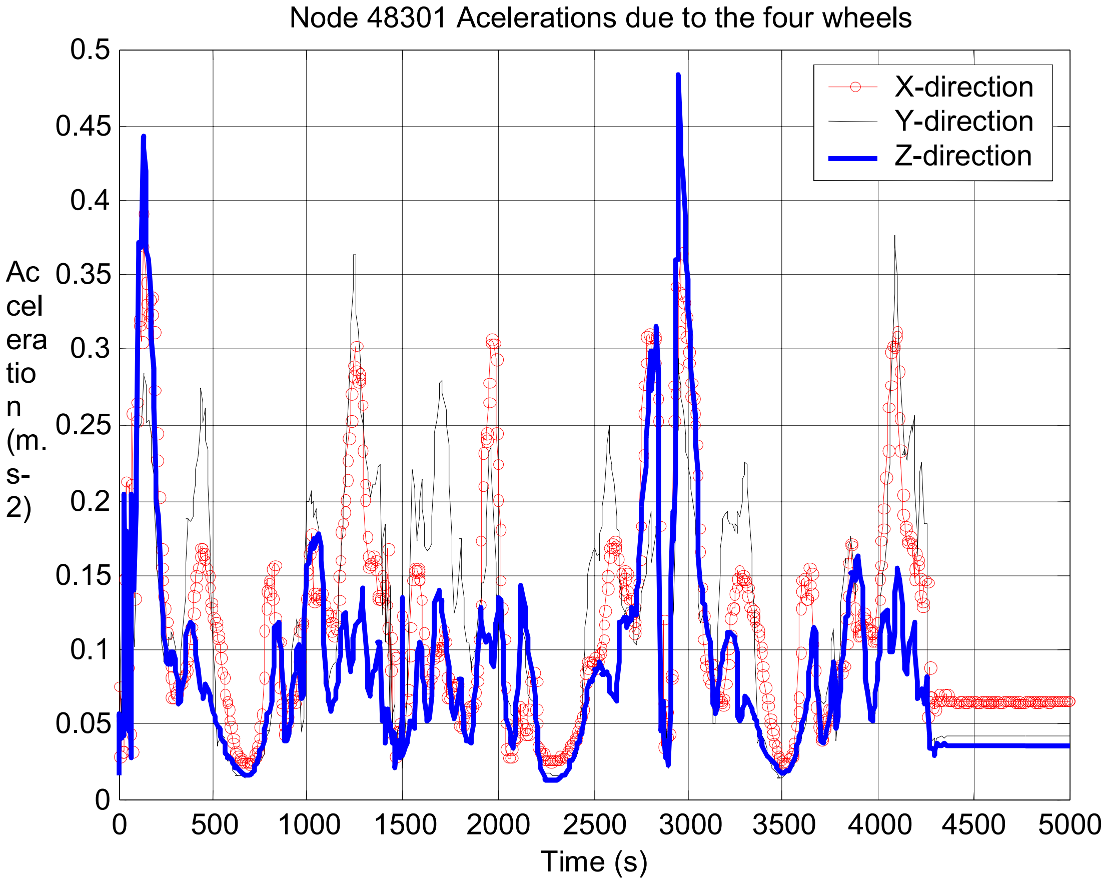


Figure 7.1-15

The maximal acceleration occurs after 125 s and has an amplitude of **39 mg** in X-axis direction.

The maximal acceleration occurs after 4087 s and has an amplitude of **37 mg** in Y-axis direction.

The maximal acceleration occurs after 2950 s and has an amplitude of **48 mg** in Z-axis direction.

7.2 Herschel thermal analyses

7.2.1 Introduction

The calculation detail is presented in the document RD04.2 "CDR Thermal analysis report".

A global Thermal Mathematical Model was developed and thermal analyses have been prepared and used to validate the thermal interfaces between the modules (SVM and PLM).

Non compliances w.r.t instrument or subsystem interfaces and ways to recover will be presented in this chapter.

7.2.1.1 H-SVM status

No non compliance have been identified on the instrument/SVM interfaces.

7.2.1.2 H-PLM status

Three non compliances are identified on H-PLM wrt PACS, HIFI and SPIRE. Table 7.2–1 summarise the deviations.

	Interface	I/F Requirement		Analysis Results
		Heat Load	Temperature	2.2 mg/s
Level 0	PACS Cooler Pump	500 (peak)	1.6 K … 10 K	12.0 K ±0.06K
	HIFI Detector	6.8 mW	< 2 K	1.96 K ±0.06K
Level 3	SPIRE PM-JFET	50 mW	< 15 K	15.1 K ±0.5K

Table 7.2–1 Non Compliances on H-PLM

An RFD (H-P-2-ASED-RD-0020) has been issued by ASED to cover the non compliances.

7.2.1.3 SVM/ PLM I/F status

Three requirements concerning the MLI temperature are not fulfilled. The non compliance is covered at system level.

The non compliance is covered at system level.

Requirement

ITP-100-H: "The blankets installed on top of the SVM upper panels and on top of the PLM sub-platform shall ensure an external layer temperature average (weighted by areas) < 220 K for any Pitch in the range [-30°,0°] (sun on +X side)".

Non conformance

SVM averaged temperature on MLI is –43.2° C (229.95° K) for winter season, EOL conditions with a Pitch of 0° and using TELECOM mode 1 dissipation.

Requirement

ITP-120-H: "The temperature of the CVV truss attachment points onto the SVM shall be lower than 293 K for any Pitch in the range [-30°, 0°] (i.e. sun on +X side)".

Non conformance:

For winter season, EOL conditions with a Pitch of 0° and using TELECOM mode 1 dissipation, the SVM averaged temperature on CVV truss is 25.65° C (298.8° K), the extreme temperatures range between 289 K and 304.7 K.

Requirement

ITP-130-H: "The temperature at the SVM shield attachment point shall be lower than 293 K for any Pitch in the range [-30°, 0°] (i.e. sun on +X side)".

Non conformance

For winter season, EOL conditions with a Pitch of 0° and using TELECOM mode 1 dissipation, the SVM averaged temperature on SVM shield attachment points is 22.56°C (295.71 K), the extreme temperatures range between 288.7 K and 300.4 K.

Recovery action

Assumptions taken into account by ASED for CDR (see E-PLM thermal model and analysis, RD06.11) are close to the maximum values guaranteed by ALENIA: 230 K (ALS=229.6 K) for radiative interface, and 293 K (ALS=294.1 K to 297.3 K) for conductive interface.

RFD have been issued by ALS to cover the non conformances:

- H-P-300000-ALS-RD-0009, Issue 1 for the requirement ITP-100-H
- H-P-300000-ALS-RD-0029, Issue 1 for the requirement ITP-120-H and ITP-130-H.

A dedicated sensitivity analysis was performed at system level to verify the impact of the out of specification.

ALS conductive temperatures have been introduced as new boundary conditions in the E-PLM thermal model using worst hot case with a Pitch at 0° (see Thermal analysis report, RD04.2).

The results show a limited impact of 6.7 days on the life time for the worst case, considering that the average thermal environment throughout orbit life is much cooler than worst hot conditions the real impact on life time is even lower than one week, consequently these non compliances are accepted at system level.

Remark: in the "CDR thermal analysis report" (RD04.2), computations where performed based on the results of "SVM TCS thermal analysis report" at issue 2. Slight differences appears between issue 2 and issue 3 for the MLI temperature. Nevertheless, in the system analysis, the SVM top MLI temperature taken into account is the value obtained at system level (235.9 K) whereas the Issue 3 value is 229.95K. The analysis of RD04.2 is hence conservative.

7.3 Radiation Analyses

7.3.1 Purpose

This analysis permits to evaluate the equivalent satellite shielding provided by the whole structure and appendages in terms of equivalent aluminium thickness. Details of the calculation shall be found in RD04.4, the present chapter is just a summary.

The Subcontractors have been required to add the standard (minimum) satellite shielding specifications given in Radiation Requirements (AD06.1) (cubical aluminium box of 0.8 mm for equipment inside the spacecraft and 0.1/1.6 mm for equipment outside) to their equipment radiation model in order to demonstrate the compatibility of the parts with Herschel mission.

This analysis demonstrates that the minimum shielding specified in [AD06.1] is verified for all Herschel equipment.

This analysis also provides an estimation of the cumulated dose at the center of each electronic equipment.

7.3.2 Radiation environment

The space radiation environment consists of trapped particles (electrons and protons from the transfer orbit to L2), solar protons and cosmic rays. The mission dose depth curve is presented in Figure 7.3-1 and evidence a very quiet radiation environment.

Erreur! Des objets ne peuvent pas être créés à partir des codes de champs de mise en forme.

Figure 7.3-1 Mission dose depth curve

7.3.3 Herschel modelling

The main structure thickness considered in the analysis are as follows:

Herschel	NIDA		SKINS	
	Material	**Thickness (mm)**	**Material**	**Thickness (mm)**
Equipment panels	NIDA 3-16	35	Al	0.3
Platform panels	NIDA 3-16	20	C	0.4
Subplatform panel	NIDA 3-16	20	C	0.3
RCS panel	NIDA 3-16	20	C	0.3
Central cone	NIDA 3-16	15	C	0.76
Shears panels	NIDA 3-16	15	C	0.76
Sunshade/Sunshield	NIDA 3-16	50	C	0.18
CVV	3mm Al			
Telescope	3mm Sic			

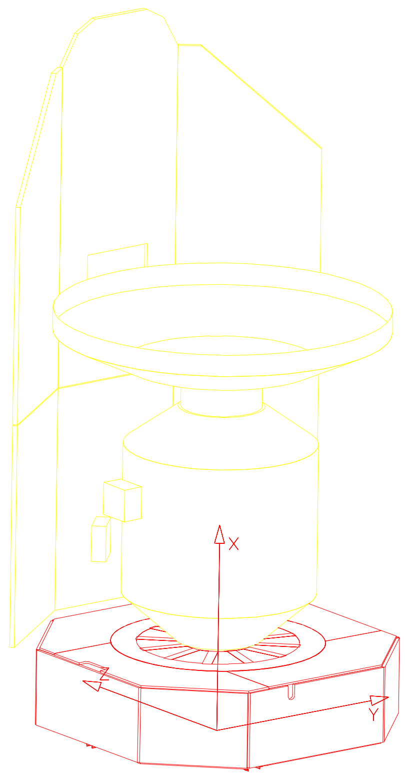


Figure 7.3-2 CATIA/NOVICE of Herschel satellite

7.3.4 Shielding analysis and Deposited dose calculations

Ray tracing analysis has been performed to evaluate the equivalent satellite shielding and to calculate an upper estimation of the dose received at the center of the target equipment.

For shielding calculations (normal path), the walls thickness of the target equipment are not taken into account and the detector point is located at the center.

This analysis demonstrates that for all the Herschel equipment, standard satellite shielding specifications in [AD06.1] are verified.

For cumulated dose calculations (slant path), the target equipment is modelled as a 0.8 mm thick aluminium box and the detector point is located at the center.

Equipment	Dose (kRad (Si))	Equipment	Dose (kRad (Si))
ACC	1.93	FPBOLC	2.30
S.T.R.E.	1.67	FPDPU	2.17
GYRO	1.85	FPSPU	2.24
RWDE	1.77	FPMEC+FPDEC	2.27
RWL	1.96	HSDCU	2.14
CRS	2.12	HSDPU	2.16
		HSFCU	2.31
CDMU	2.15	FHICU	2.34
PCDU	1.95	FHWEV	2.05
BATTERY	1.90	FHHRV	2.02
TRANSPONDERS	2.16	FHFCU	2.19
TWTA	1.83	FHWOV	2.01
RFDN	2.09	FHWEH	2.18
CCU	2.31	FHHRH	1.68
LOU	4.81	FHLSU	2.25
BAU	3.00	FHLCU	1.97
Focal Plan Unit	1.56	FHWOH	2.23

7.3.5 Conclusion

This analysis provides an estimation of the dose levels within Herschel units and shows that no major issues are expected, in accordance with the smooth radiation environment in L2. The radiation levels for EEE parts are low and, even including a Radiation Design Margin of 2, will all be lower than 10 krad(Si) which is the hardness threshold required for EEE parts selection.

7.4 ESD Analyses

The ESD analyses are presented in document RD04.5.

The different electrostatic environments met by Herschel and Planck satellites during their Mission are described in this document. Each environment implies different electrostatic interactions. The only dangerous part of the mission is the way through the internal magnetosphere around the geostationary orbit after Launch. The geomagnetic storms are known to create electrostatic charging and discharges that can lead to failures. This is why, even if the satellites will stay only a few minutes in this environment once in their life, the same precautions as for geostationary satellites, are generally applied.

Herschel satellite charging analysis is performed with NASCAP software. The ESD analysis document describes and justifies the rules used to minimise the occurrence of ElectroStatic Discharges in orbit, and to prevent any malfunction due to the still possible discharges because of the severe environment around the geostationary orbit: if a geomagnetic substorm would occur during transfer, the satellite absolute electrostatic charging should be highly negative and harmless electrostatic discharges are expected on the solar array. The use of a non-conductive coating on the CVV could lead to negative differential charging (difficult to quantify because of uncertainties on secondary electron emission parameters). Probability of discharge remains limited, however it remains desirable to quantify the discharge threshold of the selected coating by ground testing.

7.5 EMC Analyses

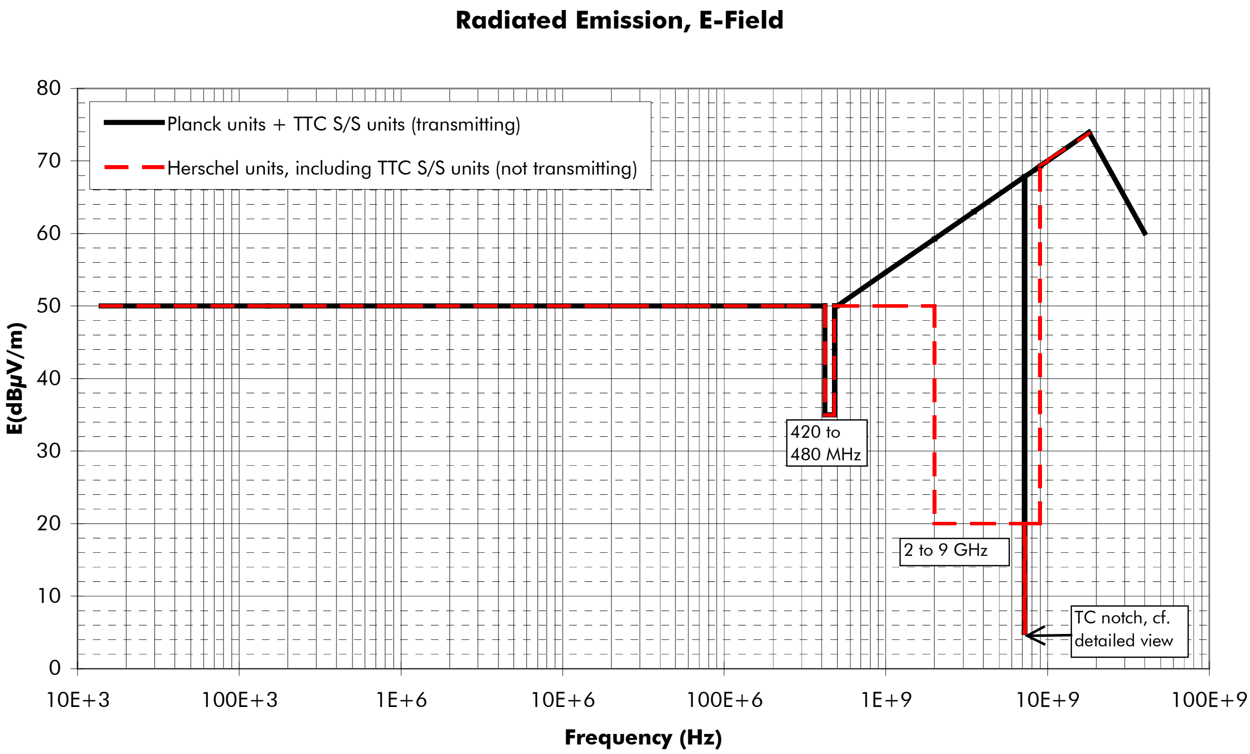
The detailed EMC analyses can be found in document "H/P EMC analyses", RD04.3. This section summarises the main issues.

The main identified EMC issue on Herschel is the Instruments detection chains sensitivity to common mode (bias lines included), which is analysed from a general point of view in the RD04.3, § 5.

Concerning HIFI radiated susceptibility in the [4 – 8 GHz] "IF" band, a ~ 20 dB positive margin between the SVM units RE and HIFI FPU RS is expected, with the available hypotheses (cf. RRD04.3, § 4.1.2.1), considering in particular a spacecraft X-Band receiver compliant with its RE specification. HIFI self compatibility (compatibility between the warm units and the FPU in radiated mode in IF band) seems to be the dimensioning case as far as units shielding efficiencies on either side are concerned.

To further attempt to define the RE/RS margin between the HIFI FPU inside the cryostat and the SVM mounted equipment, an extensive analysis has been performed using the MGTD/PO/GTD based 'GRASP 8' software (ref. H-P-2-ASPI-TN-0177). The result of this analysis clearly indicates an RE/RS margin of > 30dB between the HIFI FPU radiated susceptibility levels and the SVM radiated emission levels.

A modification to the RE specification template, in the 500 MHz to 9 GHz frequency range for Herschel units has been agreed (cf. next figure) and included in the changes at Issue 4 of the EMC specification (ref. H-P-1-ASPI-SP-0037).



7.6 Disturbance torques on Herschel

This section summarises the disturbing torques applied on Herschel.

The disturbing torques are of two types:

- **external torques**: these torques cause both an accumulation of the total angular momentum of the spacecraft that has to be off-loaded later, and a potential degradation of the pointing performance
- **internal torques**: these torques cause only a potential degradation of the pointing performance.

The external and internal torques are distinguished hereunder.

7.6.1 External disturbance torques on Herschel

The external torques are due to:

- solar pressure
- helium exhaust
- use of reaction control thrusters (then non permanent)
- gravity gradient
- geomagnetic
- aerodynamics.

The first two torques, i.e. solar pressure and helium exhaust are the two main permanent torques. The basic idea is to balance these two torques by an adequate accommodation of the helium nozzles. This will lead to a reduced angular momentum accumulation, so that the reaction wheels will be off-loaded at most once per day, according to requirements SMAC-115 and MOOF-010 of the System Requirements Specification.

The reaction control thrusters are used in part to create the torque necessary to off-load the angular momentum accumulated in the wheels.

The last three torques, i.e. gravity gradient, geomagnetic and aerodynamics are negligible for Herschel mission.

7.6.1.1 Solar torques

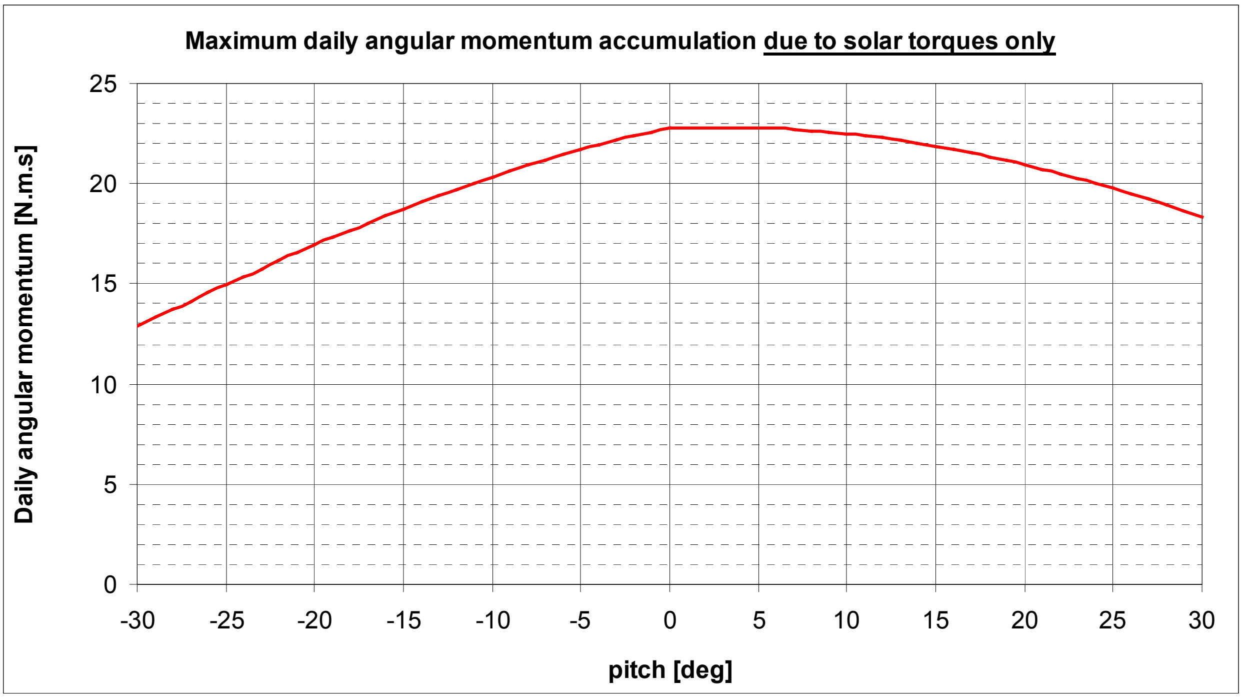
A dedicated TN is written on this subject: "Calculation of Herschel solar forces and torques", H-P-1-ASP-TN-0088 Issue 2.

This note shows that the torque in the attitude operational domain is:

– +148 < Ty < 263 μN.m

– |Tx| and |Tz| are inferior to 3μ N.m.

After 24 hours of accumulation of this torque, the total angular momentum is the following (vs Pitch angle):



7.6.1.2 Helium exhaust torques

Two types of helium exhaust thrusters are used:

– in the early orbit phase, from separation to day 25, big nozzles (diameter 2.121 mm) are used to accelerate the H-PLM cool-down.

– after day 25, the will from big nozzles to small nozzles (diameter 1.011 mm) will take place.

7.6.1.2.1 Big nozzles (from day 0 to day 25)

In the early orbit phase, from launch to the closing of the big nozzle, the resulting torque is limited to 1000μ Nm (see "Nozzle position and performance", HP-2-ASED-TN-0075 Issue 1).

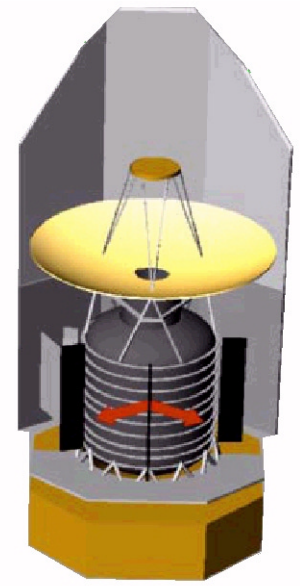
This torque is by far the most important one, but it applies mainly during periods controlled by thrusters, and when the spacecraft is still in commissioning phase with frequent contacts with ground.

Therefore, the off-loading, even if performed more than once per day (up to typically 5 times), can be done during ground contact.

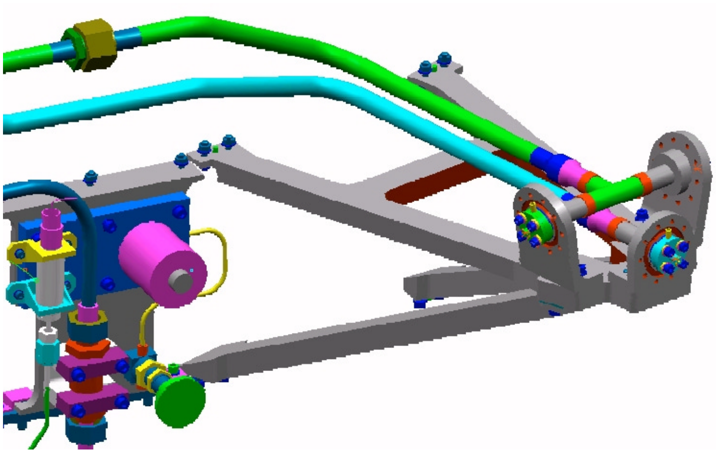
7.6.1.2.2 Small nozzles (after day 25)

Two helium exhaust nozzles are accommodated on the "nose" radiator of the H-PLM. A dedicated technical note explains the accommodation and the performance of this device: "Nozzle position and performance", HP-2-ASED-TN-0075 Issue 1.

The two nozzles are accommodated at: X=2083.1mm, Y=±103.8 mm (left/right), Z=-1410 mm, and oriented in the XY plane, 8 degrees below ± Y.



Helium nozzle accommodation



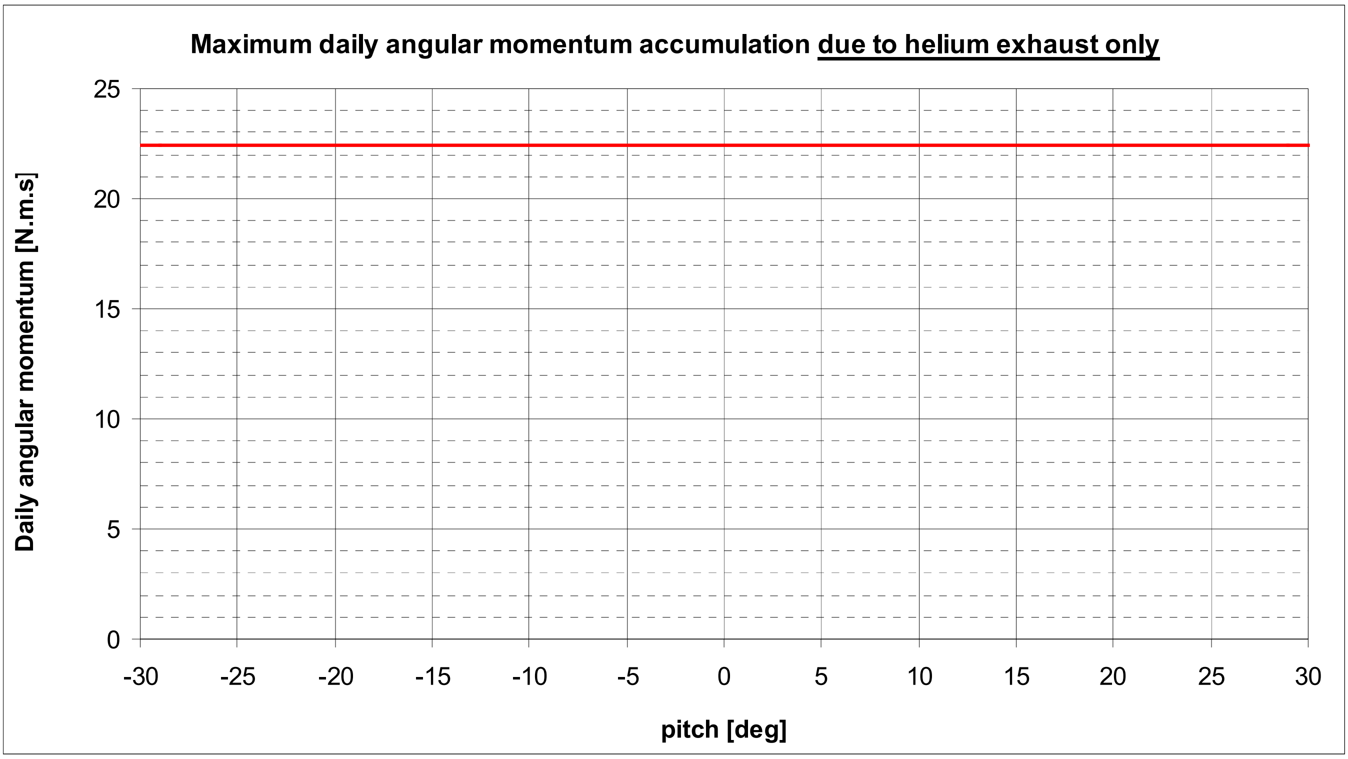
Helium nozzle bracket

This device meets the requirement during the mission phase:

- $-50 < T_x < +50\ \mu$ N.m
- $-250 < T_y < -150\ \mu$ N.m
- $-50 < T_z < +50\ \mu$ N.m.

It must be noted that following a RID at the H-PLM CDR, EADS is currently studying the plume impingement effect of these nozzles, in particular on the CVV, the "ear" radiators, the SVM shield and to a lesser degree the telescope. Since they have a large capacity of orientation, the optimised orientation will be easy to implement after this analysis is performed.

After 24 hours of accumulation of this torque (quadratic sum of 250, 50 and 50 μ Nm), the total angular momentum is the following (constant vs Pitch angle):



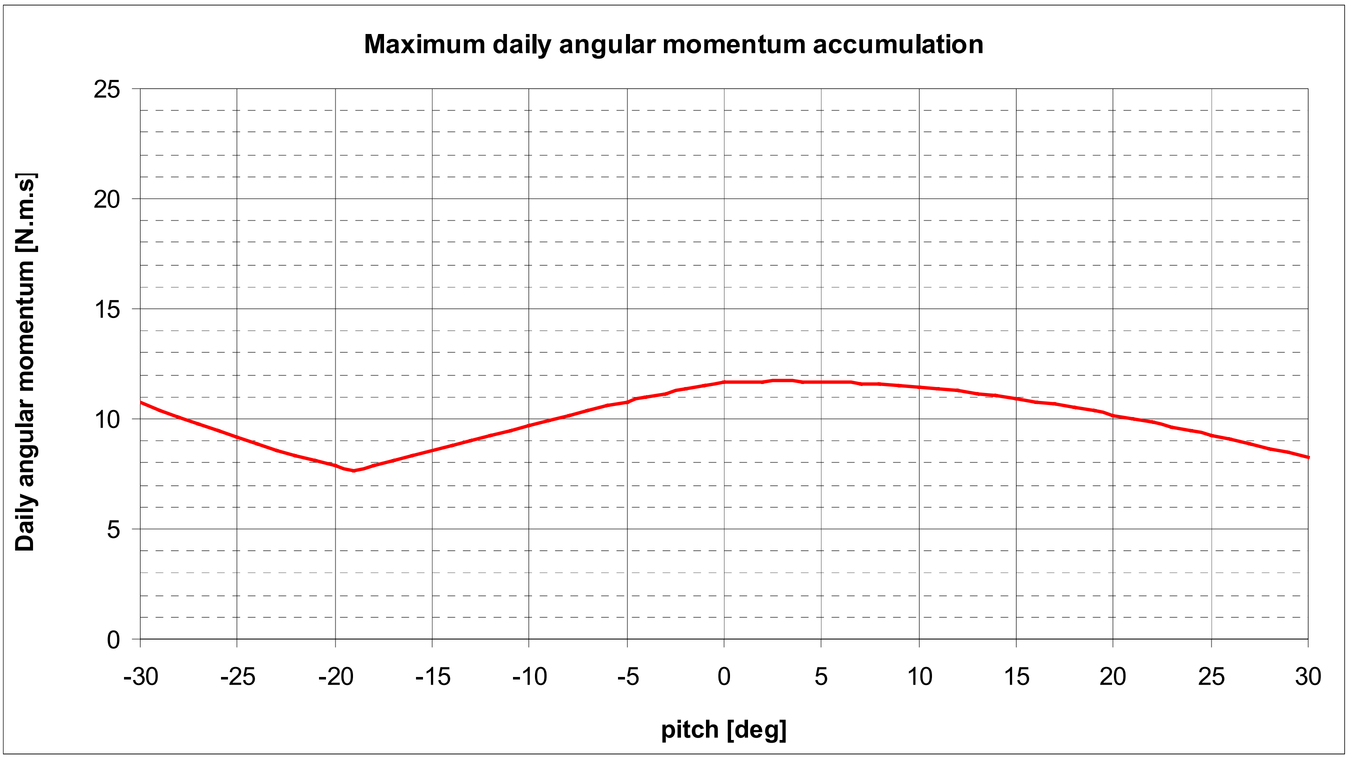
7.6.1.3 Combined solar torques and helium exhaust torque

The combination of solar torques and helium exhaust torques reduce highly the angular momentum, the combined result being dimensioned by the uncertainties:

- 22.8 N.m.s (solar) + 22.5 N.m.s (Helium) = **11.7 N.m.s (solar + Helium).**

It must be noted that the this worst case can only be reached if the spacecraft remains in the same inertial attitude during one day. Any slew will tend to reduce the total accumulation.

After 24 hours of accumulation of this combined torque, the total angular momentum is the following (vs Pitch angle):



The total accumulation is largely within the reaction wheel assembly capacity.

The reaction wheels are therefore mainly dimensioned by the transient momentum due to slews. The maximum inertia is around Z (nominally 8700 kg.m²), the momentum at the maximum slew rate (7°/min) will be 18 Nms around Z, which can be handled by the reaction wheel assembly.

7.6.1.4 Thruster torques

The section 6.4.3 of the present Design Report and the technical note "Thruster Utilisation" (H-P-1-ASP-TN-0689 issue 1) show that the torques created by thrusters:

- can be created in any direction, in particular whatever the spacecraft attitude is
- are <u>5 orders of magnitude</u> higher than the permanent disturbance.

In addition, the effect of thruster misalignments, differential forces between thrusters, and motion of the centre of mass during the mission create equivalent lever arms that are negligible with respect to the nominal lever arms of the "C" thrusters, i.e. at least 2.15 m.

As a result of the above, the thruster can:

- off-load the reaction wheels, the total thrust time being 5 orders of magnitude less than a day (typically a few seconds, spread over typically 10 minutes to let Herschel stabilise after each thrust)
- compensate the disturbance they create themselves during the thruster controlled modes.

7.6.1.5 Negligible torques

The following external torques are negligible:

- gravity gradient
- geomagnetic
- aerodynamics.

Indeed, Herschel is separated at an altitude above 1400 km and will later never get any closer from the Earth.

At this altitude and above, the atmosphere is tenuous not to create any aerodynamic torque.

In this early phase, Herschel attitude is controlled by thrusters, and after the 6 hours required to perform the first manoeuvre (SMAC-015 of the SRS), its altitude will be roughly 80000 km. At this altitude:

- the gravity gradient is inferior to $K_{Eartth}.(Imax-Imin)/(2.r^3) < 2\ \mu N.m$, i.e. 2 orders of magnitude less than the solar torque.
- the geo-magnetic field B is lower than 0.02 μT. The effect on the spacecraft will be negligible.

7.6.2 Internal disturbance torques on Herschel

The internal torques are due to:

- reaction wheels imperfections (friction, static unbalance, dynamic unbalance, resonance)
- propellant and helium sloshes.

The reaction wheels imperfections are accounted by the ACMS supplier in the pointing budget.

The propellant slosh and helium slosh effects are accounted by the ACMS supplier, using with pendulum models for both effects, as explained in "Herschel RWS Controller Design Report", H-P-4-ANA-TN-005 issue 4.

They create no issue, neither on the spacecraft stability, nor on the pointing performance.

8. PLANCK SYSTEM ANALYSES

8.1 Mechanical analyses

8.1.1 Introduction

For the dynamic and sine analyses, the calculation details are in the document RD04.1 "CDR Planck dynamic analysis and sine test prediction report".

Several mathematical models (FEM) and mechanical analyses have been prepared and carried out in order:

- to assess the ability of the structural concept of Planck satellite (Launcher requirements)
- to verify and update subsystem (P-PLM and SVM) structural requirements
- to perform a sine prediction with ARIANE V level. From the computed accelerations, equipment and subsystem qualifications levels are evaluated as well as primary and possible secondary notching levels are investigated.

Planck mathematical model has been prepared from SVM FE model delivery coming from ALENIA and P-PLM FE model coming from CONTRAVES.

For the random/vibro-acoustic analyses, the calculation details are in the document "Planck Random environment Analyses" ref. [RD04.8].

For the shock analyses, the calculation details are in the document in the document "Shock Evaluation Results, Launcher Shock" reference [RD04.9].

For the micro-vibration analyses, the calculation details are in the document " CDR Planck MICRO-VIBRATION ANALYSIS REPPORT" reference [RD04.13].

8.1.2 Analysis of Planck satellite dynamic behavior

8.1.2.1 Planck satellite mathematical model

The mathematical model of the whole Planck satellite is assembled using the models of the various subsystems: service module, and PLANCK payload module (see FEM description in the document RD04.1 "CDR Planck DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT").

Planck model characteristics

The SVM and P-PLM models are connected to each other with CELAS elements (spring elastic elements). The main characteristics of the Planck satellite mathematical model are:

- number of physical nodes: 44731
- number of elements: 47350
- total number of degrees of freedom: 268386.

The files used in the present analysis have been stored on the disks of the ALCATEL servers.

The main directory where analyses have been performed are referenced in [RD04.1].

Mass budget

The following table presents the mass budget of Planck satellite.

SUBSYSTEM	MASS IN THE MODEL [Kg]
P-PLM	388
SVM	1538
Total mass	**1926**

The inertia and CoG properties of the FEM model are listed hereafter from a NASTRAN computation.

```
DIRECTION
      MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
              X           1.925617E+03     -1.153109E-19  2.545921E-02  1.383099E-02
              Y           1.925617E+03      7.947787E-01 -1.106985E-17  1.283057E-02
              Z           1.925617E+03      7.947787E-01  2.543114E-02  1.291482E-17
                                          I(S)
                       *  3.201557E+03 -2.019816E+01 -1.255983E+01 *
                       * -2.019816E+01  2.562122E+03 -6.069899E+01 *
                       * -1.255983E+01 -6.069899E+01  2.743759E+03 *
                                          I(Q)
                       *  2.543331E+03                             *
                       *               2.761451E+03                *
                       *                             3.202657E+03 *
                                           Q
                       *  2.386995E-02  4.053060E-02  9.988931E-01 *

                       * -9.572143E-01 -2.873124E-01  3.453182E-02 *
                       *  2.883939E-01 -9.569790E-01  3.193834E-02 *
```

The total mass of the spacecraft is 1925.67Kg including 114 kg of ergol per tank. This is well in line with the document “system budget report” ref. [RD02.3] which is between 1866kg (nominal mass) and 2001kg (mass max) with 115 kg of ergol per tank.

The cog of the FEM is at 0.795m in X direction, which is well in line with the document “system budget report” ref. [RD02.3], where it is at 0.792m.

Lateral views of the Planck spacecraft are shown on the following pictures.

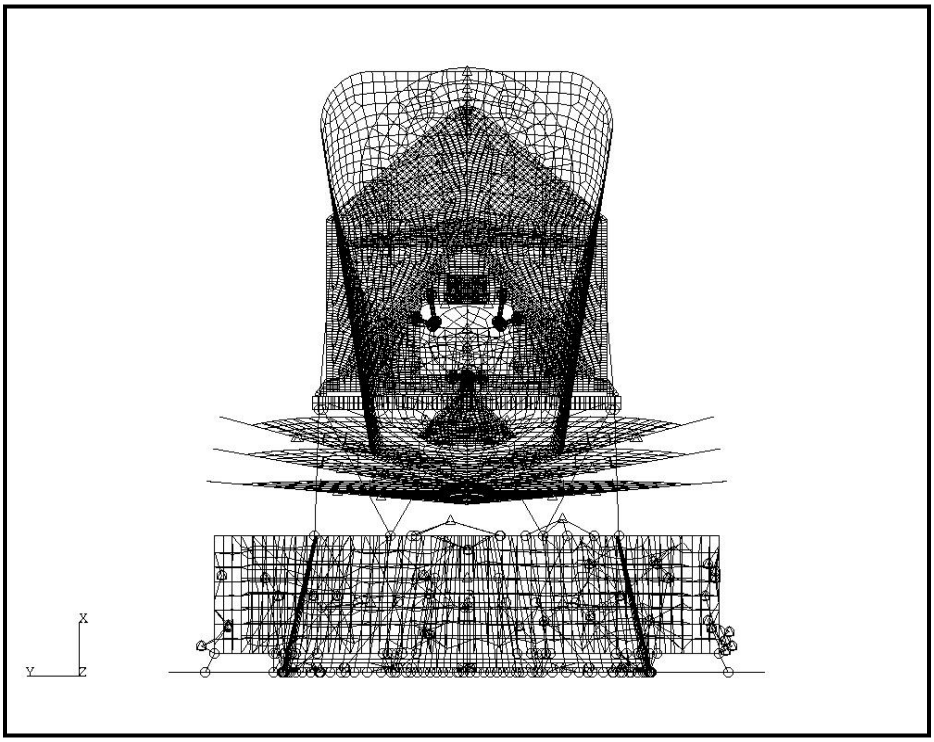


Figure 8.1-1 Planck spacecraft Y-view

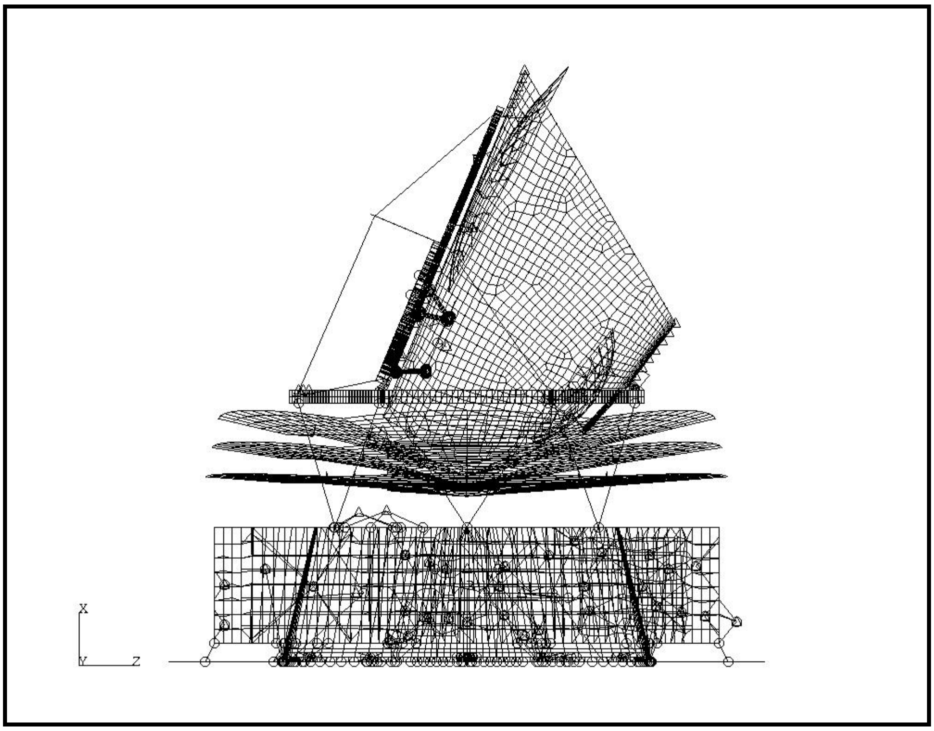


Figure 8.1-2 Planck spacecraft Z-view

8.1.2.2 Overall system mechanical analyses

8.1.2.2.1 General

Planck system-level analyses have been performed in two different steps:

- An overall modal analysis is performed with NASTRAN software in order to identify the main modes and associated effective masses and check if any modal coupling between subsystems exists.
- A sine analysis is performed to predict acceleration levels during ARIANE V launch. From the computed accelerations, equipment and subsystem qualifications levels are evaluated as well as primary and eventual secondary notching levels are investigated.

8.1.2.2.2 Planck Satellite overall dynamic analyses

Modal analysis has been performed up to 140Hz. This value corresponds to the frequency bandwidth of the sine vibration tests.

Simply boundary conditions (123 degrees of freedom) are applied at the spacecraft-launcher interface.

Modes with associated effective mass greater than 2 % of spacecraft total mass (corresponding to about 20kg) are listed in the following table.

Mode Nr	Freq. Hz	Mxx Kg	Myy Kg	Mzz Kg	Mode Description
7	18.027	0.000	181.363	0.008	PLM 1st Y-Lateral Mode
11	24.616	2.374	0.031	264.038	PLM 1st Z-Lateral Mode
24	31.664	0.019	45.369	0.037	2nd Y PLM lateral mode + PLM Groove#1 (Bending about 3 in-plane local axes)
25	31.986	0.071	76.572	0.188	PLM 2nd Y-Lateral Mode: In-phase Opposition Coupling between PLM Groove#1 (Bending about 3 in-plane local axes) & PLM Groove#2 (Bending about 3 in-plane local axes)
27	32.824	2.778	71.944	25.035	PLM 2nd Y-Lateral Mode: PLM Baffle (Combined Bending and Torsion Mode) + PLM Groove#2 (Bending about 3 in-plane local axes)+ Inner SA Breathing Mode
28	32.910	8.759	22.636	96.457	PLM 2nd Z-Lateral Mode: PLM Baffle (Breathing Mode) + PLM Groove#2 (Bending about 3 in-plane local axes) + Inner SA Bending Mode
29	34.291	34.496	0.019	0.405	PLM Groove#3 (Breathing Mode)
33	37.011	20.423	76.387	2.285	SVM Panel +Y (Out-of-plane Bending Mode)
40	41.875	73.467	22.030	3.145	PLM Baffle (Bending about local Y and Z axes in CORD20000) + PLM Primary_Reflector (Bending about global Y-axis) + SVM Octogonal Box (Bending Mode about global Z-axis) + SVM Panel+Y (Out-of-plane Bending Mode)
41	42.129	50.654	0.361	0.487	PLM Baffle (Bending about local Y and Z axes in CORD20000) + PLM Primary_Reflector (Bending about global Y-axis)
45	45.083	190.093	0.240	41.621	SVM 2nd Box Mode
47	47.731	17.205	0.044	4.476	Coupling between PLM Baffle (Bending about global Y-axis on the reflector I/F side) + PLM Groove3 (Bending about 3 in-plane local axes) + PLM Primary_Reflector (Bending about global Y-axis)
50	49.230	2.437	2.612	21.796	PLM Groove#1 (Bending about 3 in-plane local axes)
51	49.495	0.133	37.358	7.773	SVM Panel -Y+Z (Out-of-plane Bending Mode)
52	50.280	65.371	2.922	207.547	1st SVM Z-Lateral Mode
54	51.167	0.076	54.255	1.788	PLM Baffle (Bending about local Y and Z axes in CORD20000) + PLM Primary_Reflector (Torsion about local X-axis in CORD20000) + PLM Groove#2 (Bending about 3 in-plane local axes) + In-Phase Opposition SVM Tanks#2&3 Bending Mode
55	52.064	0.016	25.999	25.081	SVM Tank#2 (1st Lateral Mode)
56	52.207	0.120	88.265	13.629	SVM Tank#3 (1st Lateral Mode)

Mode Nr	Freq. Hz	Mxx Kg	Myy Kg	Mzz Kg	Mode Description
58	53.698	72.493	0.822	14.429	PLM 1st Longitudinal Mode + PLM Baffle Out-of-Plane Mode
59	53.957	0.016	2.153	26.410	SVM Octagonal Box (Combined Bending about global Y and Z axes)
61	55.659	4.268	4.184	53.910	SVM Panel +Z (Out-of-plane Bending Mode)
64	57.706	23.261	0.111	0.031	PLM Groove#1 (Bending about 3 in-plane local axes)
69	61.714	0.000	173.175	2.979	SVM Octagonal Box (Combined Bending about global Y and Z axes)
70	62.026	0.866	70.562	3.151	1st SVM Y-Lateral Mode
71	62.701	40.671	53.447	35.842	SVM Shear Panels +Y +Z (Bending about Out-of-plane local axes) + PLM Baffle (Breathing Mode)
72	62.954	162.077	5.377	19.816	PLM Main Longitudinal Mode
73	63.114	31.222	29.725	14.210	SVM Panel -Y (Out-of-plane Bending Mode) + PLM Groove#3 (Bending about 3 in-plane local axes)
74	63.511	4.144	24.648	5.374	PLM Struts_Blades_Brace (Bending about global Z-axis) + PLM Grooves In-phase Bending Mode
75	64.206	5.098	21.782	84.038	PLM Baffle (Bending about global Y-axis) + PLM Primary_Reflector (Bending about global Y-axis)
76	64.425	20.809	19.929	8.092	PLM Baffle (Bending about global Y-axis) + PLM Primary_Reflector (Bending about global Y-axis)
78	66.476	4.674	10.429	117.016	SVM Shear Panels +Y +Z (Bending about global X-axis)
79	67.513	2.725	13.529	82.734	SVM Shear Panel +Y +Z (Bending about global X-axis)
80	68.264	18.791	0.060	53.131	SVM Shear Panel -Y -Z (Bending about global X-axis) + SVM Shear Panel +Y +Z (Bending about global X-axis)
85	70.641	16.147	5.900	1.921	SVM Lower_Closing_Panel (Local Bending -Y+Z due to Equipments and Connector Brackets resonance)
87	71.300	61.163	9.064	7.328	SVM Lower_Closing_Panel (Local Bending -Y+Z due to Equipments and Connector Brackets resonance)
88	71.472	15.814	4.904	1.365	PLM Groove#1 (Bending about 3 in-plane local axes) + PLM Baffle (Bending about local Y and Z axes in CORD20000 + Torsion about local longitudinal axis in CORD20000)
90	72.111	7.401	11.765	2.674	SVM Inner Solar Array (Bending about global Z-axis)
96	74.379	107.404	6.125	0.235	SVM Tank#3 (Longitudional Mode)
97	75.078	15.399	2.136	0.331	PLM Baffle (Bending about local Y and Z-axes in CORD20000)
98	75.860	42.690	14.113	16.098	PLM Groove#1 (Bending about global Y-axis)
99	76.316	4.814	21.909	18.795	PLM Groove#1 (Bending about 3 in-plane local axes)
100	77.173	115.721	18.430	5.073	SVM Octagonal Box (Combined Bending about global Y and Z axes)
101	77.426	13.724	38.495	0.439	SVM Shear Panel -Y +Z (Bending about global X-axis)
102	77.584	8.764	8.790	1.557	PLM Groove#3 (Bending about 3 in-plane local axes)
104	79.038	16.108	31.914	1.662	SVM Tank#1 (Longitudinal mode)
111	82.329	0.008	36.729	76.847	SVM Subplatform Mode
113	83.752	2.373	7.969	26.046	SVM Outer Solar Array (Bending about global Z-axis)
114	84.423	2.181	9.425	11.932	SVM Lower_Closing_Panel (Panels +Y-Z & -Y-Z Local Bending)
119	87.073	0.671	22.366	0.460	SVM Lower_Closing_Panel (Panel +Y+Z Local Bending)
122	87.843	0.012	29.616	0.609	SVM Shear Panel -Y +Z (Bending about global X-axis)
129	89.948	12.531	17.097	1.882	PLM Groove#2 (Breathing Mode)
132	91.382	19.708	0.222	10.299	SVM Lower_Closing_Panel (Panel +Y+Z Local Bending)
236	131.802	0.074	26.018	0.234	SVM Inner Solar Array (Bending about global Y and Z-axes)
249	136.827	0.146	0.035	19.229	SVM Inner Solar Array (Bending about global Y and Z-axes)

Table 8.1-1 Planck satellite modal analysis results

Comments

The Planck S/C dynamic behavior is compliant with the launcher requirements, see table below.

Modes	Frequencies	ARIANE V Launcher spec
1st Lateral Y mode	18 Hz	9 Hz
1st Lateral Z mode	24 Hz	9Hz
1st Longitudinal mode	45Hz	31Hz

The 1st SVM lateral modes in the Z and Y-directions have been computed respectively at **50.28Hz/52Hz** and **62.06Hz**. The 1st SVM longitudinal mode is located at **45.08Hz**.

The 1st lateral modes of the SVM propellant tanks are located at 52.06 Hz (tank#2) and 52.21 Hz (tank#3).

The 1st longitudinal modes of the SVM propellant tanks are located at:

1. 79.04 Hz (tank#1),
2. 72.57 Hz (tank#2).
3. 74.38 Hz (tank#3).

Lateral modes of the tanks are coupled with the first SVM lateral modes (around 52Hz). However, levels calculated on the tanks are compatible with the tank quasi static specifications. Thus this is acceptable.

The 1st SVM Inner Solar Array mode is located at 32.82 Hz and it is an out-of-plane mode. This mode is decoupled from the main SVM modes.

The 1st PLM lateral modes have been computed at **18.03**Hz in Y-direction and **24.62**Hz in the Z-direction. The main PLM longitudinal mode is at **62.96**Hz. The 2nd PLM lateral modes are located around **32Hz** for Y (separated in 3 modes) and **32.9 Hz** for Z.

A closer look to longitudinal mode at **62.96**Hz, generating high equipment responses, has been done in order to assess the risk of coupling between SVM and PPLM. Strain energy calculation on this mode shows that PPLM participation is about 70 %, and SVM 30 %. Participation factor for this mode is 2.3, which shows that no strong coupling occur between the 2 structures (usual minimum value for identifying high coupling is 3). As a consequence, impact of SVM modes around 60Hz on PPLM equipment responses on this mode is rather low, and this issue can be treated at PPLM level.

8.1.3 Dynamic Sine Response analyses

Methodology

The dynamic response analysis is performed using the input qualification levels specified by ARIANE5 user's manual referenced in the document GDIR [AD05.1]:

- ***Longitudinal axis:** ±1.25g from 5Hz to 100Hz,
- ***Lateral axis:** ±1.00g from 5Hz to 25 Hz,
  ±0.80g from 25Hz to 100Hz.

These qualification levels are applied at the base of the spacecraft.

<u>The reduced damping factor considered in this analysis is 2 % for all the whole spacecraft except that for propellant tanks which have a 5 % damping in longitudinal direction.</u>

A uncertainty factor of 1.2 has been applied to all the sine responses presented in this document as well as primary notching levels.

Notching on main modes

Analyses and primary notching level evaluation have been performed from the main ARIANE V quasi-static loads referenced in the document GDIR [AD05.1] which are summarised in the following table.

Flight Event	Long. Flight Level [g]	Lat. Flight Level [g]	Long. Qualif Level [g]	Lat. Qualif Level [g]
Max Dynamic Pressure	-3.2	±2.0	-4.0	±2.5
SRB End of Flight	-6.0	±1.0	-7.5	±1.25
Max Tension Case	2.5	±0.9	3.13	±1.13

Table 8.1-2 ARIANE V quasi-static loads

Compression quasi-static launcher loads have been held as the most severe loading conditions.

Notching Levels

For each excitation axis, the following tables present:

- the primary notching levels and frequencies where they occur,
- the notched qualification maximum loads at the launcher interface.

Notched Level [g]	Freq. [Hz]	Notched I/F Loads [N/Nm]					
		Fx	Fy	Fz	Mx	My	Mz
0.72	42.1	32850	6883	5012	5297	10486	**37544**
0.57	45.2	30217	1787	14249	4513	**37544**	21101
0.96	49.5	24611	2402	27377	14931	**37544**	7038

Table 8.1-3 Primary notching peaks – X drive

Notched Level [g]	Freq. [Hz]	Notched I/F Loads [N/Nm]					
		Fx	Fy	Fz	Mx	My	Mz
0.31	18.0	26	14924	91	855	315	**37544**
0.55	31.8	759	25992	858	4490	963	**37544**
0.53	61.7	1360	47226	12352	24772	3130	19352

Table 8.1-4 Primary notching peaks – Y drive

Notched Level [g]	Freq. [Hz]	Notched I/F Loads [N/Nm]					
		Fx	Fy	Fz	Mx	My	Mz
0.23	24.6	1526	166	15329	255	**37544**	497
0.61	50.4	17497	6371	35686	20339	**37544**	6552
0.74	66.2	6579	12977	**47226**	49247	11713	10303

Table 8.1-5 Primary notching peaks – Z drive

Bold-marked values indicate just quasi-static launcher qualification interface loads. That is to say the excitation profiles have been notched with respect to that load.

Maximum I/F flux at launcher I/F

For each excitation axis, the flux at launcher interface has been computed at frequency, which leads to minimum notching level for every excitation drive.

X-DRIVE			Y-DRIVE			Z-DRIVE		
Freq [Hz]	**Max Flux [N/m]**	**Frame Angle [°]**	**Freq [Hz]**	**Max Flux [N/m]**	**Frame Angle [°]**	**Freq [Hz]**	**Max Flux [N/m]**	**Frame Angle [°]**
42.1	35296	5.76	18.0	3286	162.74	24.6	19480	58.87
45.2	26130	95.76	31.8	3211	17.27	50.4	18701	111.23
49.5	30660	45.00	61.6	9107	-104.39	66.2	30652	58.87

The highest flux value is **35.3 N/mm** at ~6°, close to propellant tank#2 angular position. It occurs at ~42 Hz for the X-drive excitation.

Dimensioning flux computed by CASA is **102.5 N/mm**.

Computed flux is lower than dimensioning flux**.**

8.1.3.1 Secondary notching due to SVM and PLM specifications

Dynamic loads and mechanical environments of structures and instruments have been evaluated during PDR and specified through EVTR and GDIR specifications. The following chapter gives a comparison of the loads found during CDR analyses and the mechanical requirements applicable to subsystems.

Possible secondary notching requirements are investigated in this paragraph. Sine specifications and quasi-static loads of subsystems, equipments or instruments may cause to notch the excitation profile injected at the base of the spacecraft.

The following subsystems have been considered:

- SVM Short & Long Panels
- SVM Shear Panels
- SVM Equipments
- SVM Upper & Lower Closure Panels
- SVM Internal & External Solar Array
- SVM Propellant tanks
- PLM Instruments

They shall withstand the quasi-static load and sine environment requirements as defined in the following paragraphs.

– Subsystem Quasi-Static Loads specs.

SVM Substructure	Equipment	Quasi-Static Loads [g]		
		⊥	//	// ≡ X_{SAT}
SubPlatform	BEU	25	25	25
	PAU	25	25	25
	DAE	25	25	25
Panel +Y	REU	25	20	20
	4KCDE	25	20	20
	4KCAU	25	20	20
	4CCU	25	20	20
Panel +Y-Z	SCC	16	6	16
Panel –Z	SCE	25	20	20
Panel -Y-Z	SCC	16	6	16
Panel -Y	SREM	25	20	20
Panel +Z	DPU 1	25	20	20
	DPU 2	25	20	20
Panel +Y+Z	DCCU-FV	25	20	20
	REBA 1	25	20	20
	REBA 2	25	20	20
Shear Panel +Y-Z	4CRU	25	20	20
Shear Panel +Y+Z	GEU	25	20	20
	ICU	25	20	20

Table 8.1-6 SVM instruments and CFE quasi-static loads

SVM Substructure	Platform Equipment	Quasi-Static Loads [g]		
		⊥	//	// ≡ X_{SAT}
Panel –Y	EPC 1	42.5	25	25
		25	35	25
		25	25	35
Panel –Y	EPC 2	42.5	25	25
		25	35	25
		25	25	35
Panel -Y	XPND 1	35	25	25
		25	30	25
		25	25	30
Panel -Y	XPND 2	35	25	25
		25	30	25
		25	25	30
Panel -Y	RFNRD	33.5	25	25
		25	28.5	25
		25	25	28.5
Panel –Y	TWTA 1	48.5	25	25
		25	38.5	25
		25	25	38.5
Panel –Y	TWTA 2	48.5	25	25
		25	38.5	25
		25	25	38.5
Panel -Y+Z	PCDU	34.5	25	25
		32	27	25
		32	25	27
Panel -Y+Z	ACC	37	25	25
		32	28	25
		32	25	28
Panel -Y+Z	BAT	38.5	25	25
		32	29.5	25
		32	25	29.5
Panel -Y+Z	CDMU	37	25	25
		32	28	25
		32	25	28
Panel +Z	STR 1&2	28	32	32
		25	32	32
		25	32	32
Shear Panel -Y-Z	QRS	57.5	25	25
		32	42.5	25
		32	25	42.5
Shear Panel -Y+Z	QRS 1	57.5	25	25
		32	42.5	25
		32	25	42.5
Shear Panel -Y+Z	QRS 2	57.5	25	25
		32	42.5	25
		32	25	42.5

Table 8.1-7 SVM platform equipments quasi-static loads

SVM Substructure	Quasi-Static Loads (+/-) [g]		
	⊥	//	// ≡ X_{SAT}
Short Panels	17	15	21
Long Panels	21	10	11
Shear Panels	43	10	10
Lower Closure Panel	17	10	10
Upper Closure Panel	71	10	10
Inner Solar Array	40	10	10
Outer Solar Array	57	14	10
	24	35	10
	24	14	32

Table 8.1-8 SVM substructures quasi-static loads

PLM Substructure	Quasi-Static Loads (+/-) [g]			Coordinate Frame Description
	X_{loc}	Y_{loc}	Z_{loc}	
Telescope	16.5	-	6	// to Spacecraft Coordinate Frame
	-	13	-	
	5	-	13	
Primary Reflector	20	4	20	RDP (Z-Axis Out-of-Plane)
	3	13	3	
Secondary Reflector	16	8	37	RDP (Z-Axis Out-of-Plane)
	26	12	27	
	8	18	3	
Cryo-structure	16	-	1	// to Spacecraft Coordinate Frame
	10	-	6	
	-	11	-	
	2	-	10	
Focal Plane Unit (FPU)	20//	20//	15⊥	RDP (Z-Axis Out-of-Plane)
Junction Field Effect Transistor (J-FET) box	15//	15//	30⊥	

Table 8.1-9 PLM quasi-static loads

– Subsystem Mechanical Environment.

SVM Substructure	Freq. [Hz]	⊥[1] Acc. [g]	Freq. [Hz]	//[2] Acc. [g]
Panel +Y	5-100	25	5-100	20
Panel +Y-Z	5-100	25	5-100	20
Panel –Z	5-100	25	5-100	20
Panel –Y-Z	5-100	25	5-100	20
Panel –Y	5-100	25	5-100	20
Panel +Z	5-100	25	5-100	20
Panel +Y-Z	5-100	25	5-100	20
Shear Panel +Y-Z	5-100	25	5-100	20
Shear Panel +Y+Z	5-100	25	5-100	20
SubPlatform	5-100	25	5-100	20

Table 8.1-10 SVM instruments and CFE sine environment requirements

Sine environment requirements of the ALENIA SVM equipments are reported in the following table.

SVM Substructure	Freq. [Hz]	Old Spec ⊥ Acc. [g] (1)	New Spec ⊥ Acc. [g] (2)	Freq. [Hz]	Old Spec // Acc. [g] (1)	New Spec // Acc. [g] (2)
Panel –Y	5-70	14		5-100		
	70-90	30.5	35		16	20
	90-100	47				
RFDN on Panel -Y	5-100		22	5-100		20
TWT on Panel -Y	5-100		20	5-100		20
STR on +Z Panel	5-100		27	5-100		20
Panel -Y+Z	5-100	19	19	5-100	12	22
Shear Panels	5-100	6	20	5-100	11	15

Table 8.1-11 SVM platform equipments sine environment requirements

(1) **Old spec**: SVM Mechanical Environment and Test Specification
H-P-SP-AI-0033, Issue 2.0

(2) **New spec:** SVM CDR data Package Review - Mechanical Splinter
H-P-ASP-MN-5074, dated 17&18/06/04

[1] Perpendicular to equipment mounting panel
[2] Parallel to equipment mounting panel

– Secondary notching.

In order to not exceed the specifications here above for SVM and PLM equipments/structure, the following secondary notching have to be applied on the excitation profile injected at the basis of the spacecraft.

Substructure	Axis Driven	Input [g]	Notching Level [g]	Frequency [Hz]	Requirement	Max level	Spec
SVM Panel –Y+Z	// ≡ X_{SAT}	1.25	**0.81**	**44.00**	Panel QS load	15.1g	11g
SVM Panel +Y-Z	// ≡ X_{SAT}	1.25	**0.86**	**41.02**	Panel QS load	15.9g	11g
PLM Secondary Reflector	//	1.25	**0.60**	**63.09**	Equipt QS load	54.3g	26g
CRS1 I/F (Shear web -Y+Z)	⊥	1.25	1.13	77.14	Equipt I/F sine	22.1g	20g
CRS2 I/F (Shear web -Y+Z)	⊥	1.25	**1.05**	**77.14**	Equipt I/F sine	23.7g	20g
CRS I/F (Shear web -Y-Z)	⊥	1.25	**0.7**	**72.87**	Equipt I/F sine	35.7g	20g

Table 8.1-12 Secondary Notching Levels (X-drive)

Substructure	Axis Driven	Input [g]	Notching Level [g]	Frequency [Hz]	Requirement	Max level	Spec
SVM Panel –Y	⊥	0.61	0.41	62.52	Panel QS load	25.5g	17g
SREM (-Y panel)	⊥	0.61	0.41	62.52	Equipt QS load	38g	25g
SCC (-Y-Z panel)	//	0.80	0.67	76.26	Equipt QS load	7.2g	6g
CRS (Shear web –Y-Z)	//	0.80	0.66	72.64	Equipt QS load	30.3g	25g
RFNRD-TWTA1 I/F (-Y panel)	⊥	0.61	0.45	62.52	Equipt I/F sine	27.3g	20g
RFNRD-EPC1-XPND1 I/F (-Y panel)	⊥	0.61	**0.34**	**62.52**	Equipt I/F sine	36.2g	20g
RFNRD-EPC2-XPND2-SREM I/F (-Y panel)	⊥	0.61	0.49	62.52	Equipt I/F sine	27.4g	22g
RFNRD-TWTA2 I/F (-Y panel)	⊥	0.61	0.34	62.52	Equipt I/F sine	36.2g	20g
PCDU-ACC-BAT-CDMU I/F (-Y+Z)	⊥	0.80	**0.72**	**49.47**	Equipt I/F sine	21g	19g
GEU I/F (shear web +Y+Z)	⊥	0.80	**0.60**	**64.39**	Equipt I/F sine	33.4g	25g
ICU I/F (shear web +Y+Z)	⊥	0.80	0.70	64.39	Equipt I/F sine	28.5g	25g
CRS1 I/F (shear web -Y+Z)	⊥	0.80	0.72	76.93	Equipt I/F sine	22.1g	20g
CRS2 I/F (shear web -Y+Z)	⊥	0.80	**0.67**	**76.93**	Equipt I/F sine	24.2g	20g
CRS I/F (shear web -Y-Z)	⊥	0.80	**0.4**	**72.74**	Equipt I/F sine	40.2g	20g

Table 8.1-13 Secondary Notching Levels (Y-drive)

Substructure	Axis Driven	Input [g]	Notching Level [g]	Frequency [Hz]	Requirement	Max level	Spec
SVM Panel +Z	⊥	0.80	0.64	55.86	Panel QS load	21.3g	17g
SVM Panel –Z	⊥	0.80	0.42	67.76	Panel QS load	32.5g	17g
SCC (-Y-Z panel)	//	0.80	**0.43**	**65.71**	Equipt QS load	11.1g	6g
CRS (shear web –Y-Z)	//	0.80	0.52	67.76	Equipt QS load	38.8g	25g
SCE I/F (-Z panel)	⊥	0.80	0.68	67.76	Equipt I/F sine	29.3g	25g
STR 1& 2 (+Z panel)	⊥	0.80	0.75	55.62	Equipt QS load	30g	28g
STR 1& 2 I/F (+Z panel)	⊥	0.80	0.68	55.86	Equipt I/F sine	31.55g	27g
DPU1-DPU2 I/F (+Z panel)	⊥	0.80	**0.54**	**55.86**	Equipt I/F sine	37.3g	25g
GEU I/F (shear web +Y+Z)	⊥	0.80	0.59	65.71	Equipt I/F sine	33.9g	25g
ICU I/F (shear web +Y+Z)	⊥	0.80	0.71	65.71	Equipt I/F sine	28.0g	25g
CRS I/F (shear web -Y-Z)	⊥	0.80	**0.33**	**67.76**	Equipt I/F sine	47.8g	20g

Table 8.1-14 Secondary Notching Levels (Z-drive)

Bold-marked values represent the notching levels necessary to define the secondary notching profiles.

The results show that the first S/C modes are compliant with Arianespace requirement. The sine S/C input levels are considered compatible with ARIANE V as these levels are higher than the CLA preliminary ones ref. [RD04.20].

8.1.3.2 Global SVM/PLM interface loads

Global SVM interface loads have been calculated by CASA with the specification given in the document "Performance analysis report" ref. H-P-4-CASA-RP-0012, Iss. 4 to design the interfaces. A comparison between loads found during system analyses and the design loads has been performed. For the details, see document RD04.1 "CDR Planck DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT".

Envelopes of loads at the SVM/PLM Interfaces are presented here below

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	644.16	706
T	3430.24	10854
X (Long.)	10098.96	17417
Mr	84.64	43
MT	50.62	37
MX	18.36	4

Table 8.1-15 Interface load for X drive

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	911.51	706
T	8016.03	10854
X (Long.)	15780.37	17417
Mr	252.04	43
MT	116.07	37
MX	22.01	4

Table 8.1-16 Interface load for Y drive

Direction	Max sine load [N/Nm]	Interface design load [N/Nm]
R	768.59	706
T	7452.38	10854
X (Long.)	9721.55	17417
Mr	182.70	43
MT	110.07	37
MX	9.18	4

Table 8.1-17 Interface load for Z drive

However, it is specified in RD06.9 that minimum values have to be taken for moments for the design loads at the SVM interfaces:

- Mr 195 Nm
- Mt 215 Nm
- Mx 55 Nm.

Taking these moments in consideration, levels found during system analyses are lower than design loads except for Mr (Y drive), which is of 252Nm (at 32.89Hz). **A notching of 0.62 at 32.89Hz is then necessary in order to stay within the design load for the Y Drive.**

Moreover, it has been verified that the maximum loads seen at each strut end fitting of the struts are largely covered by CSAG sizing loads for struts. (for more details, see document "PLANCK PLM Mechanical and Thermoelastic Analyses" ref. [RD04.22])

8.1.3.3 Conclusion

The main results of the dynamic analysis are:

- The Planck first modes are compliant with Arianespace requirement.
- The spacecraft interface dynamic flux is covered by the required flux for the SVM static test.
- The primary notching on the launcher quasi-static loads have been defined in the following Table 8.1-1, Figure 8.1-3 and Figure 8.1-4.
- The sine responses on substructures and equipments/instruments are compliant with their quasi static and sine requirement. For instruments the specified levels are those of the document referenced IID Part A [AD04.1]. Some discrepancies were found which are covered by the following secondary notching (Table 8.1-1 to Figure 8.1-4).

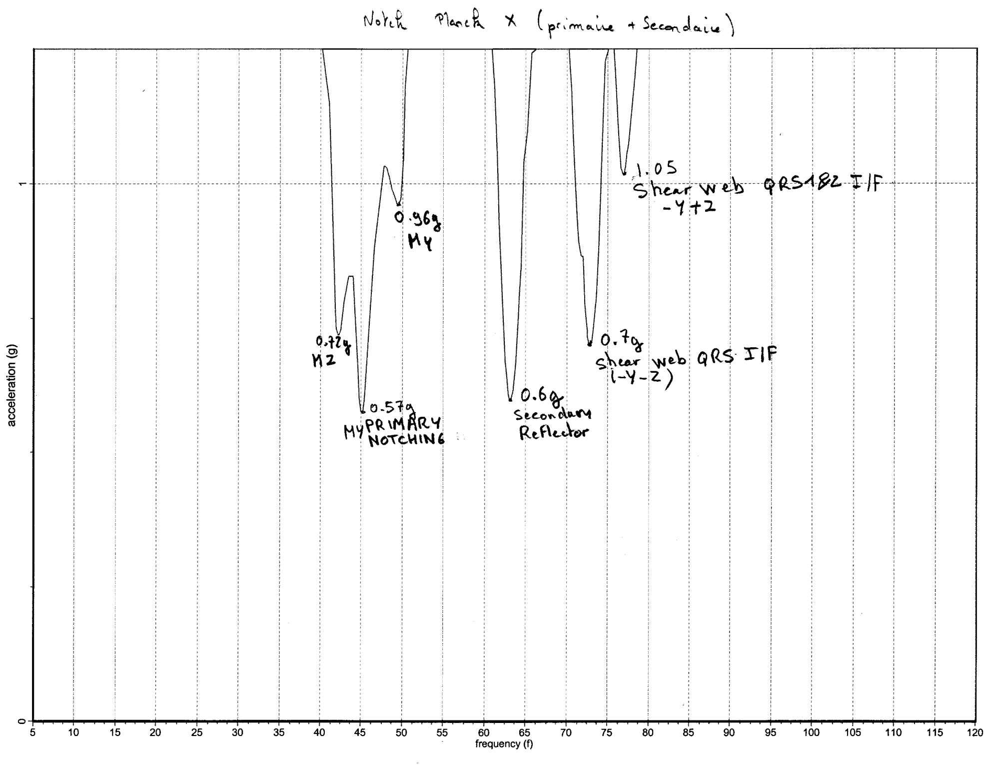


Figure 8.1-3 Secondary Notching Profile (X-drive)

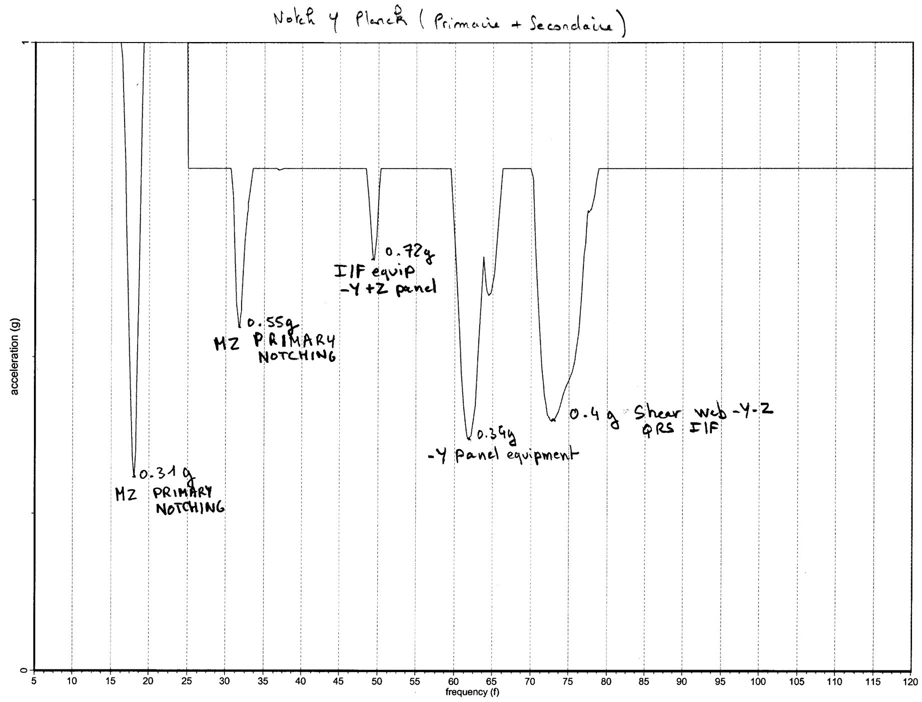


Figure 8.1-4 Secondary Notching Profile (Y-drive)

__Remark__: a notching of 0.62 at 32.89Hz shall be added to this picture in order to be within the design loads for the SVM interface loads.

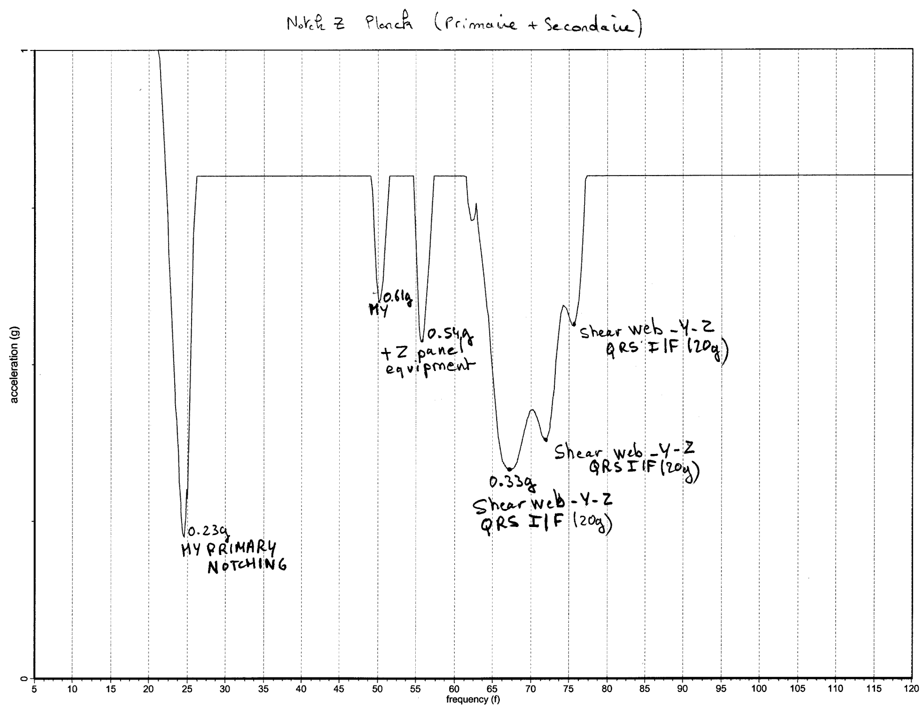


Figure 8.1-5 Secondary Notching Profile (Z-drive)

The sine S/C input levels are considered compatible with ARIANE V. The levels are generally higher than the minimum ones asked by ESA excepted at 62 Hz in Y direction (0.34g) and 67 Hz in Z direction (0.33g). But these levels are higher than the CLA preliminary ones (see document "ARIANE V ECA/Planck preliminary coupled load analysis evaluation" ref. [RD04.20]).

SVM lateral panels load reduction

Following the mass problem of the SVMs (about 50kg too much for each SVM), it has been asked by ESA to lower the Quasi-Static Loads specifications for lateral panels of both SVM taking into account a possible reduction of the launcher spectrum. (see document RD04.1 "CDR Planck DYNAMIC ANALYSIS AND SINE TEST PREDICTION REPORT" for details).

This exercise lead to the following QS loads for the lateral panels of the equipments. (See M.O.M. "Revision of DLL for SVM structure – convergence meeting" ref. H-P-ASP-MN-4812, dated 23/04/04).

Loads taken separately

	R	L	T
Short Panels +Z; -Z	15g	10g	16g
Short Panels +Y; -Y (1)	17g	10g	16g
Long Panels +-/Y+/-Z	15g	10g	16g

If out of plane mode > 50Hz

The new QS loads on the SVM lateral panels found after the mass reduction exercise have not been taken into account in the preceding §. I/F sine S/C levels found with these new QS lateral panel loads are presented in Appendix 4 document ref. [RD04.1]. The levels are generally higher than the minimum ones asked by ESA.

8.1.4 Planck Random vibration analyses

Methodology

Levels presented here-after have been derived from the theoretical ESA PSS formulae, from experimental results coming from XMM tests and from acoustic analyses performed with the ASTRYD software. Description of the different methods is included in the document "Planck Random environment Analyses" ref. [RD04.8].

PPLM equipment levels have been derived using acoustic analyses and SVM equipment have been derived using results coming from XMM with a comparison with the ESA PSS curves.

Planck SVM equipment random vibration specification

Proposed Specifications for SVM equipment are the following:

- 20 – 100 Hz +3 dB/octave
- 300 – 2000 Hz - 5 dB/octave.

Item	Mass Nom [Kg]	Mounted Panel	Panel mass/surf [Kg/m²]	Out of Plane Level [g²/Hz]	In plane Level [g²/Hz]
SCC/HP	41.8	-Z+Y	80	0.2	0.1
SCC	41.8	-Z-Y	80	0.2	0.1
4K CAU	7	+Y	85	0.2	0.1
4K CDE	6.5			0.2	0.1
4K CCU	14.2			0.2	0.1
LGA	0.45			0.2	0.1
REU	33.5			0.2	0.1
Battery	7	+Z-Y	110	0.2	0.1
PCDU	27.7			0.2	0.1
ACC	13.3			0.2	0.1
CDMU-A	15			0.2	0.1
DCCU	25	+Y+Z	48.5	0.2	0.1
REBA	4.1*2			0.2	0.1
SREM	2.57			0.69	0.22
RFDN	5.48	-Y	36	0.4	0.2
X/B transponders	2*3.98			0.4	0.2
TWTA	2*0.79			0.4	0.2
LGA	0.45			0.4	0.2
EPC	2*1.43			0.4	0.2
DPU	2*6.9	+Z	31.6	0.3	0.15
STR assy	2*1			0.3	0.15
SCCE/+HP	8.5	-Z	33.5	0.3	0.15
BEU	30.6	Platform +X	>50	0.3	0.15
PAU	10	Side -Z		0.3	0.15
DAE power box	6.4	Platform -X Side +Z	30	0.3	0.15
FOG [3]	7.5	Web (+Y+Z)	20	1	0.5
4K CRU [4]	2.2	Side +Z		0.3	0.15
CRS	2	Web (-Y-Z) Side -Y	11.3	0.6	0.3
CRS	2*2	Web (-Y+Z)Side -Y	14	0.6	0.3

Table 8.1-18 Qualification random levels for SVM equipment (CDR configuration)

[3] FOG spec is largely covering levels found by analyses
[4] 4KCRU moved on FOG web according to SVM PM#21

Helium Tank random acceleration specifications

Level presented hereafter come from the vibration report of the 51L Space Use Pressurant Tank, "PFM Vibration Report" ref. RS KT 051-A-NT04, Iss. 1 dated 03/10/94].

Orthogonal to pole axis

20-100Hz	+6dB/oct
100-1100Hz	0.1 g^2/Hz
1100-2000Hz	-6dB/oct
Global: 13 gRMS	

// to pole axis

20-150 Hz	+6dB/oct
150-470 Hz	0.3 g^2/Hz
470-550 Hz	0.01 g^2/Hz
550-700Hz	0.3g^2/Hz
700-1100Hz	0.15 g^2/Hz
1100Hz-2000Hz	-6dB/oct
Global: 17gRMS	

Planck PLM random vibration specification

Specification for V-groove 1 for 20K pipes

Out of plane		**In plane**	
10-50Hz	+3dB/Oct	10-70Hz	+6dB/Oct
50-300Hz	6 g^2/Hz	70-250Hz	0.4 g^2/Hz
300-1000Hz	-6dB/Oct	250-400Hz	1 g^2/Hz
		400-1000Hz	-6dB/Oct
gRMS	54	gRMS	21

Specification for V-groove 2 for 20K pipes

Out of plane		**In plane**	
10-60Hz	+6dB/Oct	10-70Hz	+6dB/Oct
60-200Hz	4 g^2/Hz	70-300Hz	0.3 g^2/Hz
200-300Hz	6 g^2/Hz	300-1000Hz	-6dB/Oct
300-1000Hz	-6dB/Oct		
gRMS	50	gRMS	11.8

Specification for V-groove 3 for 20K pipes

Out of plane		**In plane**	
10-70Hz	+6dB/Oct	10-70Hz	+6dB/Oct
70-170Hz	8 g^2/Hz	70-250Hz	0.4 g^2/Hz
170-350Hz	10 g^2/Hz	250-350Hz	1.3 g^2/Hz
350-1000Hz	-6dB/Oct	350-1000Hz	-6dB/Oct
gRMS	71.2	gRMS	22.5

FPU and J-FET

Proposed Specifications for FPU and JFET are the following:

- 20 – 100 Hz: +3 dB/octave,
- 300 – 2000: -5 dB/octave.

FPU

0.1 g²/Hz on the range [100,170] Hz 0.25 g²/Hz on the range [170,300] Hz	11.2 gRMS	X Axis (in plane)
0.1 g²/Hz on the range [100,300] Hz	7.6 gRMS	Y Axis (in plane)
0.4 g²/Hz on the range [100,200] Hz 0.2 g²/Hz on the range [200,300] Hz	12 gRMS	Z Axis (out of plane)

JFET

0.2 g²/Hz on the range [100,300] H	10.7 gRMS	X Axis (in plane)
0.2 g²/Hz on the range [100,300] Hz	10.7 gRMS	Y Axis (in plane)
0.4 g²/Hz on the range [100,300] Hz	15.1 gRMS	Z Axis (out of plane)

All levels presented in this document are in line with the levels presented for the PDR (Table 8.1-3) except for the DPU whose spec has been raised (as the panel on which they are located is lighter due to the displacement of the REU to another panel) and the 4K CAU/4K CDE/4K CCU whose spec has been lowered (as the panel on which they are located is heavier due to the displacement of the REU).

All levels presented are covered by the instrument specification (AD04.1)

8.1.5 Planck Shock analyses

General

A shock analysis is performed in order to evaluate the shock environment of PLANCK equipment inside P-PLM and SVM. PLANCK spacecraft position is the lower SC position on the Launcher.

Shock excitation assumptions

At the spacecraft interface, the shock response spectrum of shock excitation is supposed to be similar to the shock response spectrum presented in Figure 8.1-6 and called "HP specification". The comparison of the present Herschel/Planck specification with those agreed for SPACEBUS Family and for MSG-2 shows that for Herschel/Planck the level remains especially high and might be still very conservative. The main results are presented in the document RD04.9 " Shock Evaluation Results, Launcher Shock".

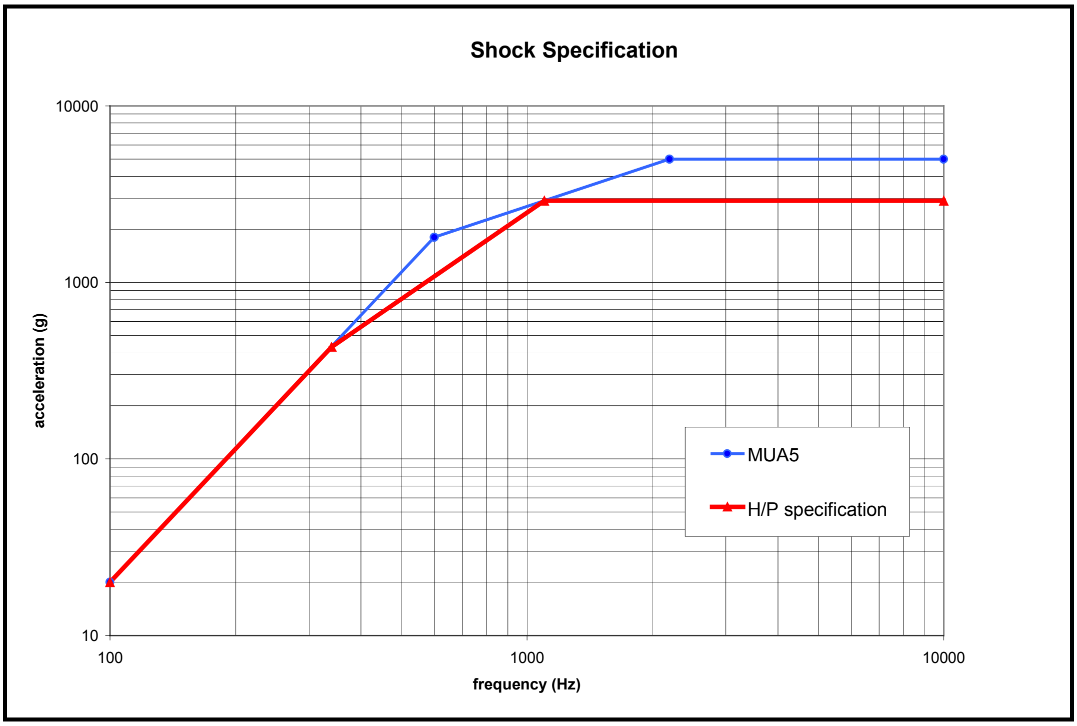


Figure 8.1-6 Herschel/Planck shock specifications at spacecraft interface

The interface shock response spectrum is defined by the following shock acceleration levels (see Table 8.1-19).

FREQUENCY [Hz]	SHOCK ACCELERATION [g]
100	20
600	1000
10000	3600

Table 8.1-19 Launcher shock interface response spectrum (SB 1)

Planck-PLM Shock evaluation

Only Launcher interface shock excitation is analysed in this section.

A shock attenuation inside sandwich panels due to the distance from the excitation source has been clearly identified from experimental tests. Considering this shock attenuation, shock levels at the interface with P-PLM strut support located at 970 mm from the launcher interface plane are reduced also like on Herschel satellite.

The estimated Planck-PLM Shock interface levels are presented in the following table.

For the following shock specification, out of plane and In plane shock levels are supposed to be identical.

FREQUENCY [Hz]	SHOCK ACCELERATION [g]
100	25
350	350
1000	2000
3000	2000
10000	1500

Table 8.1-20 P-PLM interface shock response spectrum (SRS P-PLM) (qualification level)

BEU Shock specification

P-PLM EQUIPMENT	Shock Specification
BEU	SRS P-PLM

Table 8.1-21 Planck PLM equipment shock specification

For Telescope, Vgroove and Planck_PLM structures, the interface shock specification is presented hereafter.

P-PLM STRUCTURE	SHOCK SPECIFICATION
Telescope	SRS P-PLM
V-groove	SRS P-PLM
P –PLM	SRS P-PLM

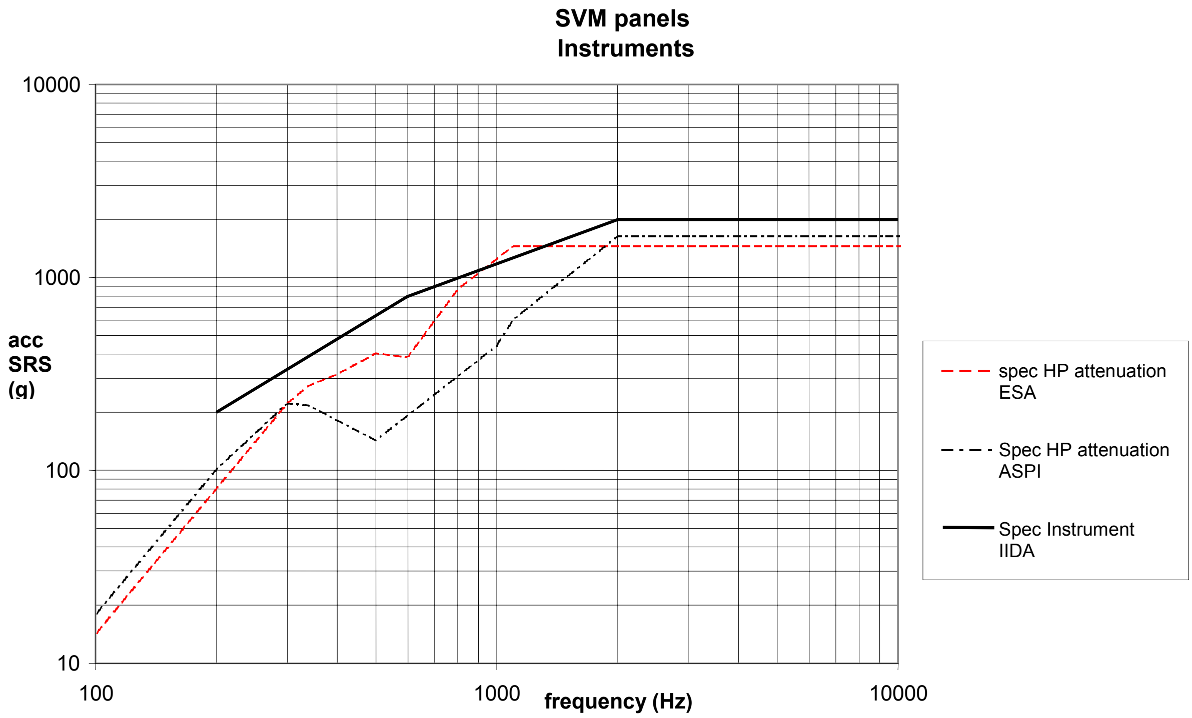
Table 8.1-22 Planck PLM structure shock specification

Planck SVM Shock specification

For SVM lateral panels shock levels are given in next tables. Out of plane and In plane shock levels are supposed to be identical.

FREQUENCY (Hz)	ACCELERATION ASPI ATTENUATION [g]	ACCELERATION ESA ATTENUATION [g]	IIDA ref. [AD04.1] [g]
100	15	20	
200			200
300	240	240	320
500	160	400	650
600	200	400	800
1000	500	1500	1200
2000	1800	1500	2000
10000	1800	1500	2000

Table 8.1-23 Shock response spectrum SB 2 (qualification levels)



The IID-A specification is closed to the calculated ones. So, the IID-A specification stays recommended.

8.1.6 Micro Vibration analyses

8.1.6.1 Introduction

Details about this analysis are presented in the document "CDR Planck Micro-Vibration Analysis Report" ref. (RD04.13].

The HFI instrument is sensitive to vibrations. The main source of perturbation identified for the Planck spacecraft is the 4 K cooler compressor. It is operating at 40 Hz (+/- 5 Hz, adjustable in flight). The Low Vibration Drive Electronic (LVDE) minimises the force generated by the compressor, thus limiting the perturbation to a force of amplitude up to 40 mN on all harmonics up to 200 Hz.

The purpose of this analysis is to investigate the effects, in terms of acceleration levels, occurring at the support interfaces of the FPU. Computed acceleration levels are then compared to specification requirements (see IID part B ref. [AD04.5]).

As Planck spacecraft is supposed to be in the space environment, dynamic analyses are performed with spacecraft free boundary conditions.

8.1.6.2 Analysis

8.1.6.2.1 Model

The model used for this analysis is presented in Section 8.1.2.1.3.

However, it has been modified in the following way for the purpose of this analysis:

- stiffening of the SVM Panel +Y where 4K Cooler is mounted on (reinforcement by changing the sandwich panel skin thickness from 0.3 mm to 0.6 mm, thus the frequency of first mode shifts from 37.50Hz to 44.80Hz) to put in line the model with the latest design
- modifying spacecraft damping from 2 % (CDR analysis finite element model) to 0.5 % to consider a structural damping adapted to microvibration.

FPU is hinged (RBE2 123) at the primary reflector support panel level (see Figure 8.1-7) by six interfaces.

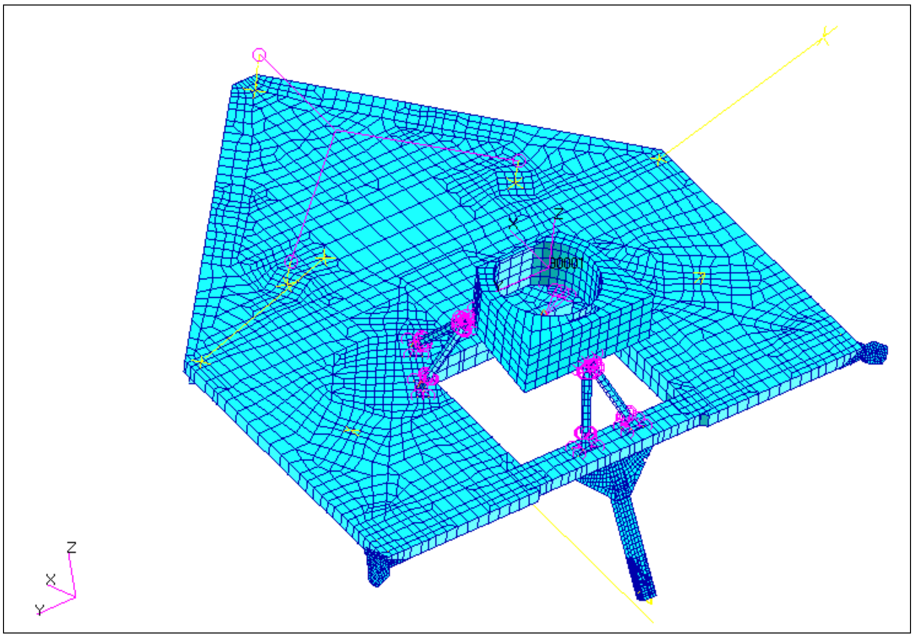


Figure 8.1-7 PR panel & FPU fem view

Sine response levels are computed at the central node of the 4-node rigid element (RBE2) shown in the figure above as required by specification requirements.

The 4K Cooler is mounted on SVM Panel +Y and is modelled by a rigid element (MSC/NASTRAN RBE2) with a lumped mass (CONM2 MSC/NASTRAN element). A view of SVM Panel +Y is shown in Figure 8.1-8.

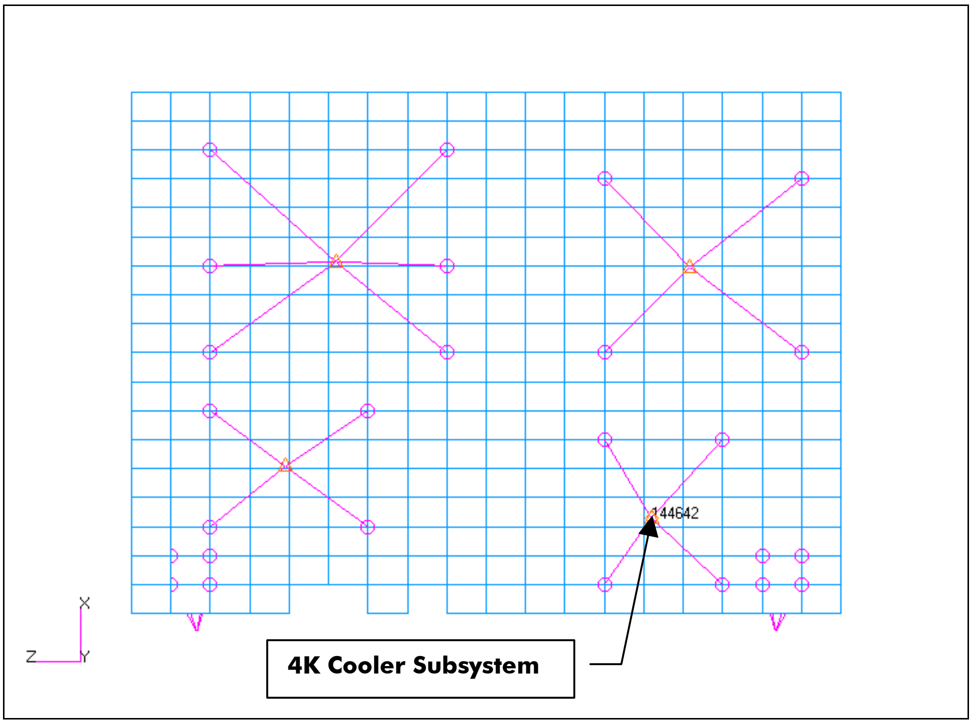


Figure 8.1-8 4K Cooler view (SVM Panel +Y)

The 4K Cooler is hinged (RBE2 123 MSC/NASTRAN rigid element) at the SVM Panel +Y (see Figure 8.1-7) by 4 interfaces and aligned with spacecraft Z-axis.

During its working, the 4K Cooler generates a dynamic load along the Spacecraft Z-axis. The load magnitude is 40 mN at the 4K Cooler fundamental frequency and harmonics up to 200 Hz. Load amplitude above 200Hz is assumed to be 0. Noise outside the fundamental and harmonics is assumed to be 0.

The 4K Cooler fundamental frequency may be adjusted in between 35Hz and 45Hz.

The dynamic load is applied to the 4K Cooler center of gravity (node 144642).

8.1.6.2.2 Specifications

The FPU interfaces should withstand the specification requirements reported in Table 8.1-24.

Specification Nr.	Frequency Range [Hz]	Acceleration Level [g]	Output Acceleration Description
#2	30-200	2.0E-03	XYZ-Axis Resultant (RMS Value)
#3	50-70	0.2E-03	XY-Axis Resultant (RMS Value)
#4	120-160	0.2E-03	Z-Axis (RMS Value)

Table 8.1-24 Micro-vibration Specification Requirements

8.1.6.3 Results

For this analysis, the damping factor has been set to 0.5 %. However, it is difficult to assess accurately the damping factor for parts under cryo-temperature. A sine analysis has shown that there is one mode at 127Hz generating high levels on the FPU that is occurring on the Primary Reflector panel, which is under cryo temperature. All other modes impacting the FPU occur on parts of the structure which are not under cryo temperature.

To estimate an eventual damping evolution at cryo temperature for the PR panel, a run has been performed with a **structural damping factor** of **0.05 % for** the primary reflector support panel **(very unfavorable).**

Both results with a damping factor of 0.5 % (for the whole structure) and 0.05 % (for the PR panel and 0.5 % for the rest of the structure) are presented here-below.

Node ID	***Description***	***SPECIFICATION #2 [30Hz-200Hz] [mg]***	***PR SUPPORT PANEL DAMPING 0.5 %***		***PR SUPPORT PANEL DAMPING 0.05 %***	
			Max Acceleration Level [mg]	***4K Cooler Working Frequency [Hz]***	***Max Acceleration Level [mg]***	***4K Cooler Working Frequency [Hz]***
69010	+X+Y TOP I/F	2	0.21	39.0	0.22	39.0
69011	+X-Y TOP I/F		0.19	38.8	0.21	38.8
69012	+X+Y BOTTOM I/F		0.22	37.3	0.24	37.3
69013	+X-Y BOTTOM I/F		0.19	35.0	0.22	37.4
69017	-X RIGHT I/F		0.20	35.0	0.24	35.0
69018	-X LEFT I/F		0.21	35.0	0.24	35.0

Table 8.1-25 Results (Specification #2)

Node ID	***Description***	***SPECIFICATION #3 [50Hz-70Hz] [mg]***	***PR SUPPORT PANEL DAMPING 0.5 %***		***PR SUPPORT PANEL DAMPING 0.05 %***	
			Max Acceleration Level [mg]	***4K Cooler Working Frequency [Hz]***	***Max Acceleration Level [mg]***	***4K Cooler Working Frequency [Hz]***
69010	+X+Y TOP I/F	0.2	0.02	35.0	0.03	35.0
69011	+X-Y TOP I/F		0.03	35.0	0.03	35.0
69012	+X+Y BOTTOM I/F		0.02	35.0	0.03	35.0
69013	+X-Y BOTTOM I/F		0.03	35.0	0.03	35.0
69017	-X RIGHT I/F		0.03	35.0	0.03	35.0
69018	-X LEFT I/F		0.03	35.0	0.03	35.0

Table 8.1-26 Results (Specification #3)

Node ID	***Description***	***SPECIFICATION #4 [120Hz-160Hz]***	***PR SUPPORT PANEL DAMPING 0.5 %***		***PR SUPPORT PANEL DAMPING 0.05 %***	
			Max Acceleration Level [mg]	***4K Cooler Working Frequency [Hz]***	***Max Acceleration Level [mg]***	***4K Cooler Working Frequency [Hz]***
69010	+X+Y TOP I/F	0.2	0.16	40.0	0.17	40.0
69011	+X-Y TOP I/F		0.14	40.0	0.15	40.0
69012	+X+Y BOTTOM I/F		0.17	40.0	0.18	40.0
69013	+X-Y BOTTOM I/F		0.14	40.0	0.15	40.0
69017	-X RIGHT I/F		0.08	40.0	0.09	40.0
69018	-X LEFT I/F		0.09	40.0	0.09	40.0

Table 8.1-27 Results (Specification #4)

Reduction of the damping factor does not produce significant changes in the resultant levels.

The results are fully compliant for all the specifications.

8.2 Planck thermal analyses

8.2.1 Introduction

The calculation detail is presented in the document RD04.2 "CDR Thermal analysis report".

A global Thermal Mathematical Model was developed and thermal analyses have been prepared and used to validate the thermal interfaces between the modules (SVM and PLM).

Non compliances and ways to recover will be presented in this chapter.

8.2.1.1 P-SVM status

Some non compliances are present on the instrument/SVM interfaces. They are presented hereafter.

The uncertainty used for units temperature prediction is around 10° C, as a general recovery action it is expected to reduce this level of uncertainty after PFM thermal balance test (end of 2005). It is also suggested to replace some critical PFM units by thermal dummies (already available) to avoid damaging any flight hardware.

Nevertheless some design improvement have to be undertaken in order to remove non compliances before the test at PFM level:

4K WU

Requirement

"CRU/CEU/CCU maximum operating temperature at the interface of the instrument unit with the mounting platform shall not exceed **40° C**"

Non conformance: (TCS CDR analyses)

For winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation, the CRU/CCU maximum temperatures are respectively **41.7° C** and **40.6° C.**

Recovery action: (CDR close-out)

The present calculation has been run with the CRU (dissipation 20W) on the FOG web (DPU/STR enclosure) with the following effects:

- the CEU/CCU temperatures are reduced to 39.8° for CEU which meets the requirement and to 40.6° C for CCU still slightly out of specification (see here under specific consideration for 4K CCU).
- need to open new radiative area of about 1600 cm^2 on the +Z/+Y panel to reduce temperature to 38.9° C for FOG which meets the requirement and to 40.0° C for CRU still slightly out of specification.
- need to introduce a dedicated heating line of 12.8 W for CRU (enable in survival mode only) with some minor impacts on DPU/STR survival heating budgets:
  - DPU consumption increases from 12.4W to 19.2W
  - STR consumption increases from 0.9W to 1.5W.

Specific consideration for 4K CCU: the latest internal design update of the CCU has not been forwarded to ALS because the thermal model is not correct and must be validated by RAL thermal test. The last model has an enhanced coupling between the compressor head and the strap with the following effects:

- strap temperature (where interface requirement is specified) will increase by 5° C (TBC), which is acceptable since the real need for CCU is located on the compressor heads.
- as a possible side effect of strap temperature increase, CEU temperature might increase to also due to its proximity with CCU straps.
- compressor head temperature will decrease by 9° C to ~52° C (TBC), reliability and thermodynamic performances require maximum temperature of 50° C on these parts.
- Removal of the magnetic shield on CCU unit would lead to an additional decrease of the compressor head temperature by 3° C to ~49° C.

ALS will issue an RFD for the out of specification on CRU and CCU.

SCC

Requirement

"SCS maximum operating temperature at the interface on the spacecraft side (on top of the heat pipes) shall not exceed **280°K**"

"The radiator interface will also maintain the following levels of temperature stability under the absorbing compressor elements adjacent to the cooling compressor element:

- first adjacent element: **3°** peak/peak
- next adjacent element: **1°** peak/peak
- next most element: **0.5°** peak/peak".

A requirement with 7° C/4.7° C/4.7° C is proposed in Iss. 3.0 of AD04.6

Non conformance

For winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation, the vertical heat pipes maximum temperature is 6.7° C (**280° K**). Requirement is met with little margin.

For winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation, the absorbing bed outer shell temperature fluctuation is respectively **7.9°/2.2°/2.2°**

Recovery action

Flight design improvements are not envisaged because the radiators are already sized to the maximum extent and the mass increase for stability would be prohibiting.

On the other hand, the non compliances are enhanced on ground during test (see H-P-ASP-LT-4819 is2), therefore it is suggested to test the SCC on PFM only in cold conditions (minimum dissipation, minimum temperature on solar array), this will avoid to damage flight hardware.

PAU

Requirement

"PAU maximum operating temperature at the interface of the instrument unit with the mounting platform shall not exceed **30°C**".

Non conformance

For winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation, the PAU maximum temperature is **30.9° C**

Recovery action

An RFD “H-P-300000-AI-RD-0010, issue2” has been issued and is under evaluation.

FOG

Requirement

“FOG ICU minimum operating temperature shall not be below **0° C**”.

Non conformance

For summer season, BOL conditions with a sun aspect angle of 10° on the solar array and using minimum dissipation, the FOG ICU temperature is **– 2.8° C**.

Recovery action

The CRU heater can be switched ON. The FOG ICU temperature is then above 0° C, uncertainties included.

8.2.1.2 P-PLM status

Non compliances wrt minimal operating or non operating temperature arise in cold case for the grooves and the FPU.

Table 8.2-1 recalls all the non compliances on the P-PLM.

Item	Operating minimum temperature (K)		Non operating minimum temperature (K)	
	requirement	Worst estimated	requirement	Worst estimated
V-groove 1	150	133.1	150	121
V-groove 2	100	79.7	100	69
V-groove 3	45	42.2	40	31
FPU	40	38.7		

Table 8.2-1 Summary of non compliances on P-PLM

These non compliances have not been identified as a major issue in the P-PLM CDR. The corresponding RFD’s are to be issued.

8.2.1.3 SVM/PLM I/F status

Three requirements concerning the MLI temperature are not fulfilled. The non compliance is covered at system level.

One requirement concerning stability the MLI temperature is not fulfilled. The non compliance is covered at system level.

Requirement

ITP-150-P: “The blankets installed on top of the SVM upper panels and on top of the PLM sub-platform shall ensure an external layer temperature < **220 K** (averaged out by areas)”.

Non conformance

SVM averaged temperature on MLI is – 41.65° C (**231.5 K**) for winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation.

Requirement

ITP-180-P: "The blankets installed on sub-platform instruments units shall ensure an external layer temperature < **235 K** ".

Non conformance

PAU and BEU MLI temperatures are respectively – 29.2° C (**243.95 K**) and – 35.6° C (**237.55 K**) for winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation.

Requirement

ITP-200-P: "The blankets mounted on the back side of the solar array shall ensure an external layer temperature < **300 K**".

Non conformance

For winter season, EOL conditions with a sun aspect angle of 0° on the solar array and using maximum dissipation, the MLI temperature on SA back side ranges between **311.05 K** and **312.65 K**.

Recovery action

P-PLM CDR thermal analysis (RD06.10) were performed using conservative boundary conditions in terms of flux from SVM to 1st V-groove:

- PAU/BEU radiative loads have been set to 3.8 W instead of 2.25 W (system level result)
- MLI radiative loads have been set to 8.2 W instead of 5.8 W (system level result).

The discrepancy on temperature is hence covered as the total flux on groove 1 is lower than the assumption for P-PLM performance. No recovery action is foreseen.

Remark: in the "CDR thermal analysis report" (RD04.2), computations where performed based on the results of "SVM TCS thermal analysis report" at issue 2. Slight differences appears between issue 2 and issue 3 for the MLI temperature. Nevertheless, in Issue 3, the MLI temperature are always colder than in Issue 2, making the system analysis conservative.

Requirement

ITP-230-P: "The SVM TCS shall ensure the following interface temperature stability performances at radiative panels level: component at 1/60 Hz of temperature < **0.01 K.Hz$^{-1/2}$**".

Non conformance

For summer season, BOL conditions with a sun aspect angle of 10° on the solar array and using minimum dissipation, the SCC panels stability are **0.06** (on +Y-Z), **0.11** (on –Z)**, 0.04 K.Hz$^{-1/2}$** (on –Y-Z).

Recovery action

Straylight analysis has been performed using an Amplitude Spectral Density of 0.128 K.Hz$^{-1/2}$ on all SVM lateral panels (see Planck PLM RF performance analysis, RD04.18). The results show that RF performances still meet their requirements, consequently no recovery action is foreseen.

8.3 Radiation analyses

8.3.1 Purpose

This analysis permits to evaluate the equivalent satellite shielding provided by the whole structure and appendages in terms of equivalent aluminium thickness. Details of the calculation shall be found in RD04.4, the present chapter is just a summary.

The Subcontractors have been required to add the standard (minimum) satellite shielding specifications given in Radiation Requirements (AD06.1) (cubical aluminium box of 0.8 mm for equipment inside the spacecraft and 0.1/1.6 mm for equipment outside) to their equipment radiation model in order to demonstrate the compatibility of the parts with Herschel mission.

This analysis demonstrates that the minimum shielding specified in [AD06.1] is verified for all Herschel equipment.

This analysis also provides an estimation of the cumulated dose at the center of each electronic equipment.

8.3.2 Radiation environment

The space radiation environment is illustrated in Paragraph 7.4.2 which shows a very smooth environment.

8.3.3 Planck modelling

The main structure thickness considered in the analysis are as follows:

PLANCK	NIDA		SKINS	
	Material	Thickness (mm)	Material	Thickness (mm)
Equipment panels	NIDA 3-16	35	Al	0.3
Platform panels	NIDA 3-16	20	C	0.4
Subplatform panel	NIDA 3-16	19.2	C	0.4
Central cone	NIDA 3-16	15	C	0.76
Shears panels	NIDA 3-16	15	C	0.76
Baffle	NIDA 3-16	19.46	Al	0.27
Groove 1 (-X)	NIDA 3-16	16.6	Al	0.2
Groove 2	NIDA 3-16	16.6	Al	0.2
Groove 3 (+X)	NIDA 3-16	16.46	Al	0.27
Primary Reflector	NIDA 3-16	76.46	C	1.77
Secondary Reflector	NIDA 3-16	61.46	C	1.77
External Solar Array	NIDA 3-16	20	C	0.24
Internal Solar Array	NIDA 3-16	15	C	0.18

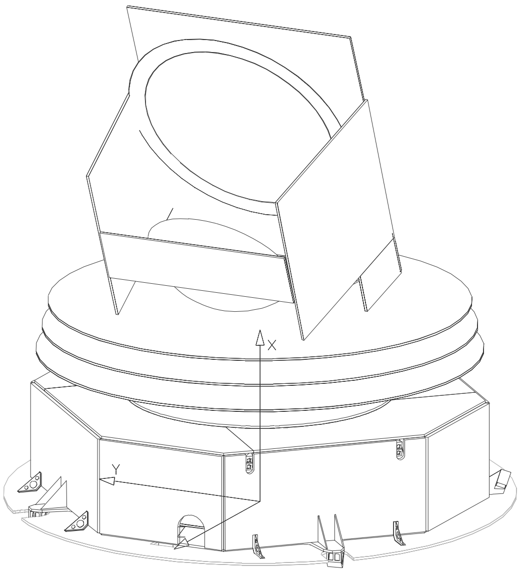


Figure 8.3-1 Catia/Novice of Planck satellite

8.3.4 Shielding analysis and Deposited dose calculations

Ray tracing analysis has been performed to evaluate the equivalent satellite shielding and to calculate an upper estimation of the dose received at the center of the target equipment.

For shielding calculations (normal path), the walls thickness of the target equipment are not taken into account and the detector point is located at the center.

This analysis demonstrates that for all the Planck equipment, standard satellite shielding specifications in [AD06.1] are verified.

For cumulated dose calculations (slant path), the target equipment is modelled as a 0.8mm thick aluminium box and the detector point is located at the center.

EQUIPMENT	DOSE (kRad (Si))	EQUIPMENT	DOSE (kRad (Si))
ACC	1.78	Focal Plan Unit	10.0
CRS	1.21	PAU	2.34
STR. ELEC	1.81	REU	2.04
CDMU	1.78	DPU	1.75
PCDU	1.73	4K COMPRESSOR	2.06
BATTERY	1.63	4K CAU	2.60
TRANSPONDERS	2.11	4K CEU	1.91
TWTA	1.57	DAE	1.46
RFDN	1.77	REBA	1.61
BEU	2.75	LFI2D (SCE)	1.61
DCCU	1.80	LFI2C (SCC)	1.27

8.3.5 Conclusion

This analysis provides an estimation of the dose levels within Planck units and shows that no major issues are expected, in accordance with the smooth radiation environment in L2. The radiation levels for EEE parts are low and, even including a Radiation Design Margin of 2, will all be lower than 10 krad(Si) which is the hardness threshold required for EEE parts selection.

8.4 ESD analyses

The ESD analyses are presented in document RD04.5.

The different electrostatic environments met by Herschel and Planck satellites during their Mission are described in this document. Each environment implies different electrostatic interactions. The only dangerous part of the mission is the way through the internal magnetosphere around the geostationary orbit after Launch. The geomagnetic storms are known to create electrostatic charging and discharges that can lead to failures. This is why, even if the satellites will stay only a few minutes in this environment once in their life, the same precautions as for geostationary satellites, are generally applied.

Planck satellite charging analysis is performed with NASCAP software. The ESD analysis document describes and justifies the rules used to minimise the occurrence of ElectroStatic Discharges in orbit, and to prevent any malfunction due to the still possible discharges because of the severe environment around the geostationary orbit: if a geomagnetic substorm would occur during transfer, the satellite absolute electrostatic charging should be highly negative and harmless electrostatic discharges are expected on the solar array. The use of a conductive paint on the PPLM has been chosen to reduce this risk.

8.5 EMC analyses

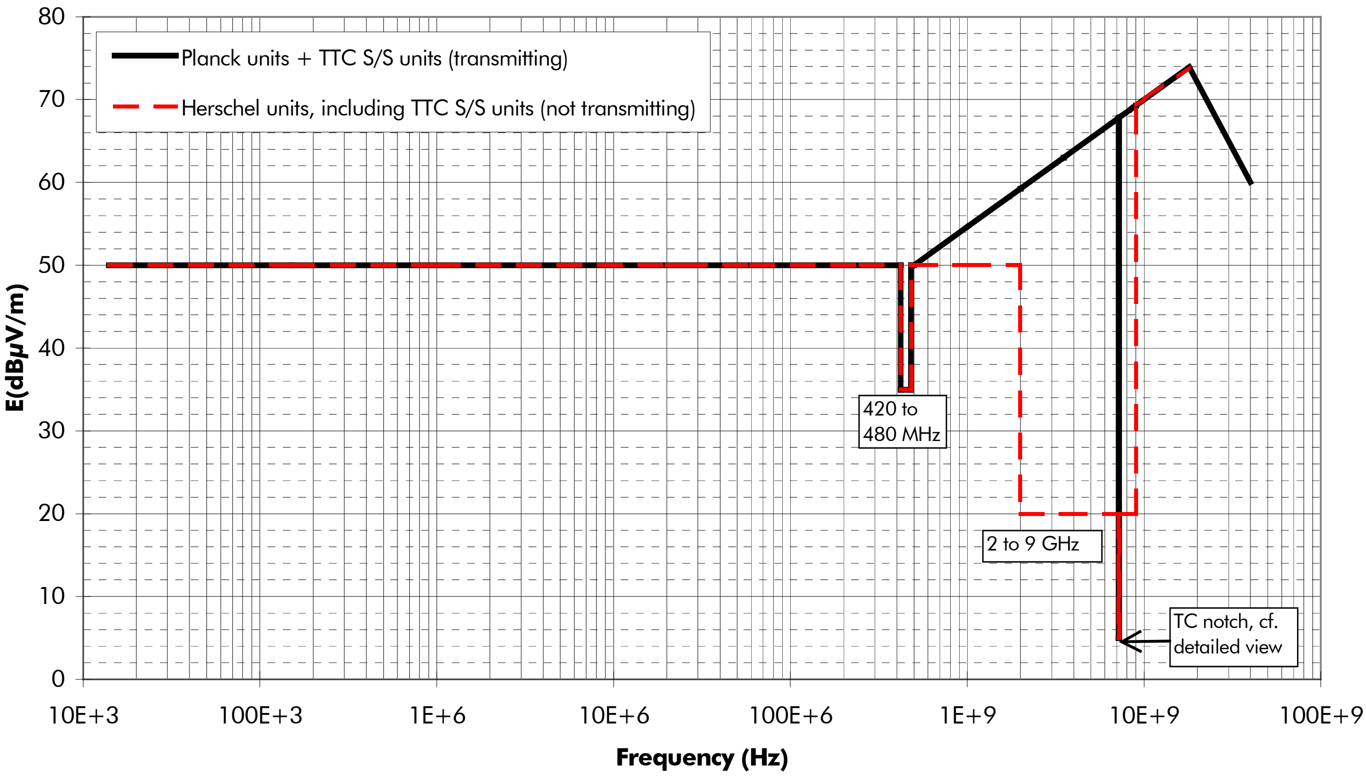
The detailed EMC analyses can be found in document "H/P EMC analyses", RD04.3. This section summarises the main issues.

The main identified EMC issue on Planck is the Instruments detection chains sensitivity to common mode (bias lines included), which is analysed from a general point of view in the RD04.3, § 5.

- Concerning the RF coupling between the TTC antenna and LFI horns during the telecommunication periods: the analysis is reproduced in RD04.3 § 4.1.3.1 and shows comfortable margins (> 50 dB).
- Another coupling mode that may be considered is a direct radiated coupling between the TWTA unit radiated emission and LFI Back End Unit (BEU).
- The EMC specification (H-P-1-ASPI-SP-0037) requires to test the TTC units (XPND and TWTA) in RE up to 40 GHz.

An extension of the RE specification template up to 40 GHz has been agreed with ALS (cf. next figure).

Radiated Emission, E-Field



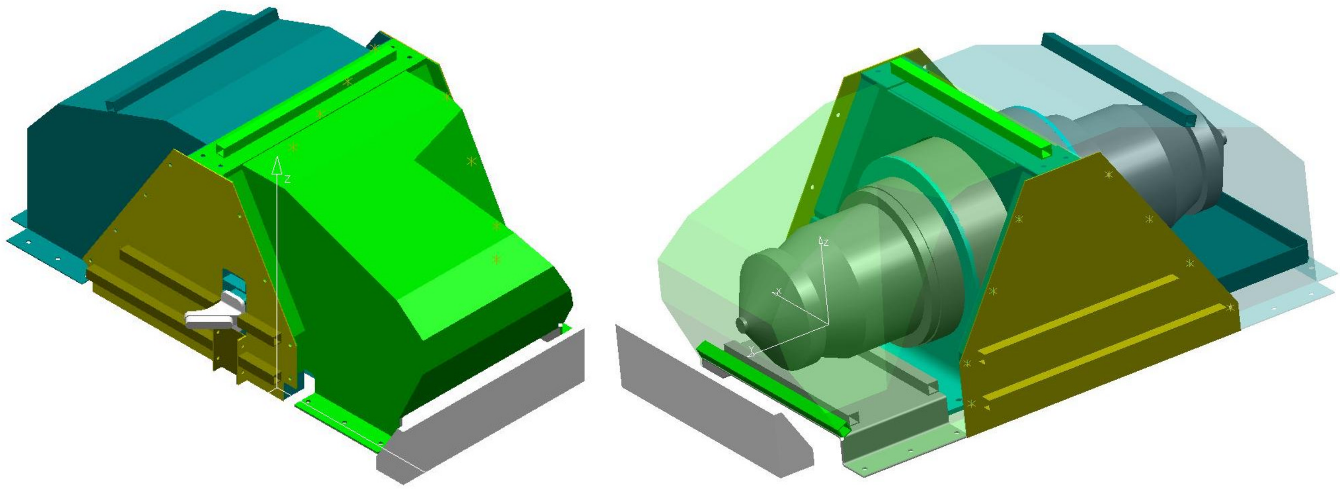
If the emission from the TWTA at the TM frequency 4th harmonic is compliant with the requirement (~ 2 mV/m at 33.8 GHz), then considering a distance of 1 m between the TWTA and the BEU, a Shielding Efficiency of the BEU of ~ 45 dB is enough to reduce the spurious power to – 147 dBm (power variation corresponding to LFI required sensitivity, cf. again RD04.3, § 4.1.3.1).

The additional shielding due to the SVM structure (the TWTA being inside the SVM and the BEU on top of the SVM subplatform) together with the modest shielding efficiency needed from the BEU (achievable by any RF unit) are enough to demonstrate a positive System margin with a good confidence.

A measurement of the spectral content at TWTA output in "conducted" (guided) mode is foreseen on the SVM AVM in order to check the impact of the TWTA non-linearity on the spectral content at TTC subsystem level, and thus to confirm the RF compatibility.

The HFI REU and the 4 K Cooler, which were initially on different panels within the SVM have now been located in a close proximity to each other on the same panel (due to centre of gravity reasons). During its operation it is known that the 4 Kcooler compressor generates high levels of low frequency AC magnetic field which if the HFI REU fails to comply with its RS-H specification could result in a compatibility problem. To minimise this risk, a magnetic shield has been designed for the 4 KCC which analysis indicates will reduce the levels of its radiated magnetic field by approximately 30 dB. This shield will only be installed if testing indicates that it is necessary, the specified shielding effectiveness being 20 dB.

The following figures are showing the implementation of the magnetic shield.



8.6 Disturbance torques on Planck

This section summarises the disturbing torques applied on Planck.

The disturbing torques are of two types:

- **external torques:** these torques cause both an accumulation of the total angular momentum of the spacecraft that has to be off-loaded later, and a potential degradation of the pointing performance
- **internal torques:** these torques cause only a potential degradation of the pointing performance.

The external and internal torques are distinguished hereunder.

8.6.1 External disturbance torques on Planck

The external torques are due to:

- solar pressure
- Helium exhaust
- use of reaction control thrusters (then non permanent)
- gravity gradient
- geomagnetic
- aerodynamics.

The first two torques, i.e. solar pressure and Helium exhaust are the two main permanent torques.

The reaction control thrusters are used in part to create the torque necessary to off-load the angular momentum in excess accumulated in Planck spacecraft body.

The last three torques, i.e. gravity gradient, geomagnetic and aerodynamics are negligible for Planck mission.

8.6.1.1 Solar torques

Due to the shift of Planck centre of mass from the X axis, and the maximum tilt of 10° from the Sun, the solar force has a lever arm with respect to the CoG and therefore creates a torque.

However, the Solar Pressure torque is rather reduced due to the quasi Sun Pointing attitude and the limited shift of the CoG.

8.6.1.1.1 Solar transverse torque

To assess the impact of the torque, one must distinguish between:

- the torques that accumulate over one revolution: they are caused by the angle between the Sun line and Planck –X axis
- the torques that are averaged out over one revolution: they are caused by the CoG shift from X, which is considered maximised by 30 mm, as required by the ARIANE User's Manual.

Sun exposed Surface	$S = 14.0\ m^2$
The force can be considered as having one component along the Sun direction and one along the SA outer normal:	
Force along the Sun direction (**Σ**) = $-P \times S \times \cos SAA \times (Ca+Cd)$ typical SA coeffs: Ca = 70 %, Cd = 24 %, Cs = 6 %	F_{Σ} # -61 µN
Force along the array outer normal (**N**) = $-2 \times P \times S \times \cos(SAA) \times (Cd/3 + Cs \times \cos(SAA))$	F_N # -18 µN
The force can <u>also</u> be considered as having one component in the SA plane (tangential) and one perpendicular to the array (axial):	
Tangential force = $F_T = F_N \times \sin(SAA)$	$\lvert F_T \rvert < 3.1$ µN (SAA = ± 10°)
Axial force = $F_A = F_{\Sigma} + F_N$	F_A # -79 µN
"fixed" Lever Arm < sin(10°) × height of CoG	lever arm < 145 mm
Resulting maximum Transverse torque (not averaged out over one revolution)	**T < 0.45 µNm** (3.1µN × 145mm)
"Spinning" Lever Arm < CoG shift from X axis	lever arm < 30 mm
Resulting maximum Transverse torque (averaged out over one revolution)	**T < 2.4 µNm** (79µN × 30mm)

The torque that accumulates inertially is at worse **0.45 µNm**. When Planck inertia around X is minimum (2600 $kg.m^2$), the angular momentum is **272 Nms**.

This corresponds to a maximum drift of Planck angular momentum axis of:

- 0.45 µN.m/272 N.m.s = 1.7 × 10-9 rad/s = **0.02 arcmin/55 min.**

The corresponding nutation is at worse double, and this effect is negligible with respect to the RPE requirement (1.5 arcmin/55 min), and on other pointing requirements.

8.6.1.1.2 Solar longitudinal torque

Due to the CoG shift from X axis, there is also a limited torque around Planck X axis:

$$|Tx| < P \times S \times (Ca+Cd) \times \sin(10°) \times 30\ mm = 0.3\ \mu Nm.$$

Since it is averaged out after one revolution, it has absolutely no impact on any pointing requirement or rate stability.

The windmill torque due to Solar Array external quarters mounting tolerance and flatness is even more negligible:

- average lever arm: d = 2m
- external quarters total area: S = 8.6 m^2
- 1mm (worst case) on 1.5m: θ = 0.04 deg.

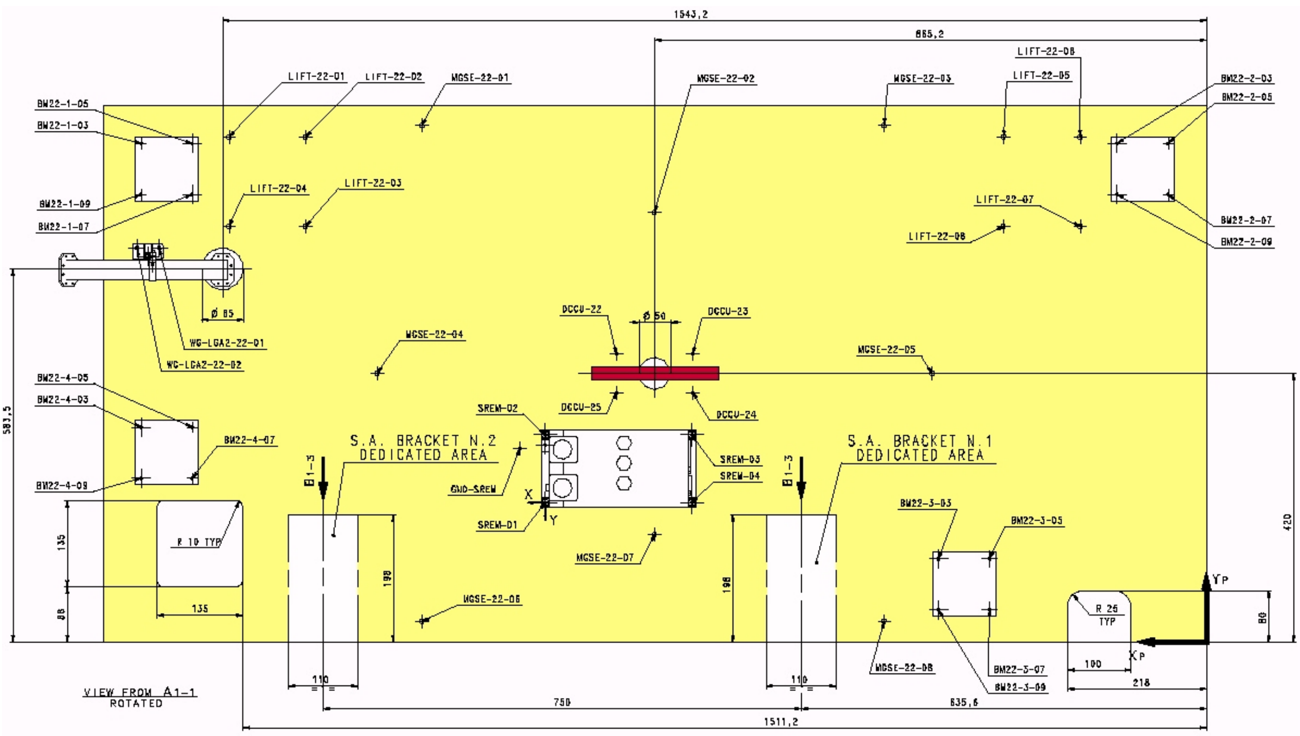
This provides the torque T = P × S × (Ca+Cd) × d × θ = 0.05 μNm.

The mounting of the solar cells will be statistically cancelled by average on 2835 cells.

8.6.1.2 Helium exhaust torques

A T-shape exhaust is accommodated on the +Y +Z panel, behind the DCCU. From the DCCU, a single exhaust tube is routed outside the spacecraft though a panel cut-out. When outside, it is split in two end branches (forming a "T"), that are nominally oriented parallel to the YZ plane.

As shown in Sections 8.6.1.2.2. and 8.6.1.2.3., the only issue generated by the Helium exhaust is the spin-up or -down torque. The torque in YZ plane contribute very negligibly to the wobble angles of the spacecraft, and therefore to the APE of LoS and around LoS.



DCCU Helium exhaust accommodation on +Y+Z panel

In order to reduce the asymmetry of the forces on the panel, the Helium exhaust has been located at equal distance from both lateral edges, and the appendices (SREM, balancing masses, RF wave guide, Solar Array brackets) limited to the minimum, or placed as far as possible symmetrically.

8.6.1.2.1 Assumptions

The evaluation of the force produced by the Helium exhaust on the panel is described in HFI technical note "Evaluation of the force induced on the SVM by the dilution ejection flow" (TN-PHEBA-300270-CRTBT, Issue 1.1).

8.6.1.2.1.1 Longitudinal force

The total longitudinal force is evaluated in HFI's above referenced tech note:

- He^3 flow = 8.5 μmol/s
- He^4 flow = 24 μmol/s
- exhaust velocity = velocity of sound of He @ 300K = 1260 m/s
- resulting total force: **F_L = 163 μN**.

8.6.1.2.1.2 Longitudinal force distribution

There is currently no analysis on the force distribution between the branches of the T.

A **1 % difference is assumed**, i.e. 50.5 % in one branch and 49.5 % in the other branch.

This results is a distribution of the longitudinal forces of:

- **F_{L1}** = 50.5 % × F_L = **82.31μN**
- **F_{L2}** = 49.5 % × F_L = **80.68 μN**.

8.6.1.2.1.3 Point of application of longitudinal forces

The longitudinal forces apply at a distance of the CoG of:

- **d_L = 1760 mm**.

8.6.1.2.1.4 Spin-up or -down torques produced by longitudinal forces

The total torque around X applied by F_{L1} and F_{L2} at Planck centre of mass is:

- **Tx** = $F_{L1} \times d_L - F_{L2} \times d_L$ = **2.87 μNm**.

8.6.1.2.1.5 Force perpendicular to the panel

The total force perpendicular to the panel is due to Helium reflections, and is evaluated in HFI's above referenced tech note:

- **F_P = 56.7 μN**.

8.6.1.2.1.6 Perpendicular force distribution

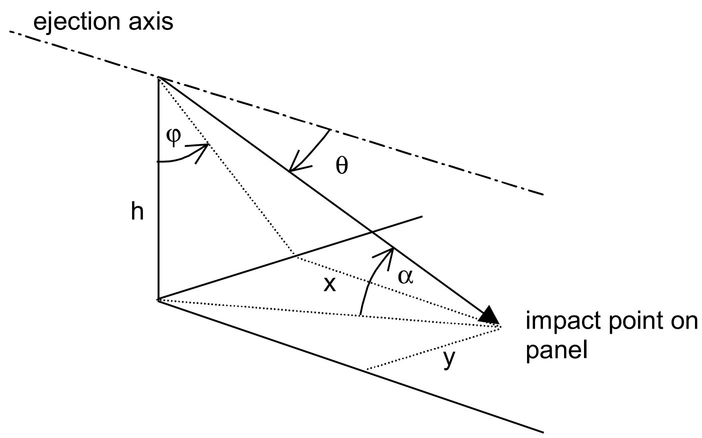
The distribution is assumed to be the same as for the longitudinal forces:

- **F_{P1}** = 50.5 % × F_P = **28.63 μN**

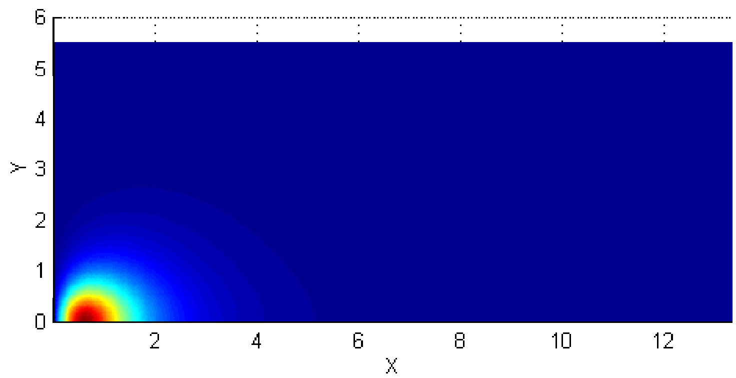
– $\mathbf{F_{P2}}$ = 49.5 % × F_P = **28.06 µN**.

8.6.1.2.1.7 *Point of application of forces perpendicular to the panel*

HFI techn note describes the distribution of pressure on the panel:



Helium exhaust geometry (h = height above the panel = 60mm)



Pressure distribution on the panel (in multiple units of h = 60mm)

The points of application of the perpendicular forces are assumed to be distant from the panel cut-out of:

– $\mathbf{d_P}$ = 100 mm (half length of the tube) + 3×h # **300 mm**.

8.6.1.2.1.8 *Spin-up or -down torques produced by perpendicular forces*

The total torque around X applied by F_{P1} and F_{P2} at the location of the panel cut-out, as well as at Planck centre of mass is:

– **Tx** = $F_{P1} \times d_P - F_{P2} \times d_P$ = **0.17 µNm**.

The effect of CoG shift is already accounted for separately, see table of Section 8.6.1.2.2.

8.6.1.2.1.9 Effect on the Solar Array, first V-groove, and appendices

These torques are neglected since:

- the force on the array and the groove will be more or less parallel to X and will therefore not create any torque around X
- the appendices on the panel cover a small solid angle view from the exhaust and will then contribute very little compared to the other effects.

8.6.1.2.2 Effect of X torque

The following table shows the different contributors to the X torque:

Cause	Force [µN]	Lever arm [mm]	Torque [µNm]
CoG shift Total force	56.7	30	1.70
Unbalance between branches (longitudinal forces)	+83.13 and –79.87	1760	2.87
Unbalance between branches (perpendicular forces)	+28.63 and 28.06	±300	0.17
TOTAL			**4.74**

The resulting spin-up (or -down) angular acceleration is, for the minimum spacecraft inertia:

- 4.74 µN.m/2600 kg.m² = 1.8×10^{-9} rad/s² = **0.63 10^{-4} rpm/h**.

This is within the required 10-4 rpm/hr during an observation period (1 hour) required by the requirement MOOF-055 of the SRS.

8.6.1.2.3 Effect of Y and Z torques

The total force of 56.7 µN on the panel is supposed to be applied at the cut-out, with a lever arm of:

- H = height of the Helium exhaust (420+106) – max height of the CoG (826) = -300 mm.

The resulting torque is:

- T_Y = +12.0 µNm
- T_Z = –12.0 µNm.

The impact on the wobble angles are:

- wobble LOS = -0.0003 arcmin
- wobble around LOS = -0.0018 arcmin.

This effects being constant, they only impact the APE, but are 4 orders of magnitude below the required pointing performance. They are then fully negligible.

Other torques, not evaluated, can be applied, as explained in Section 8.6.1.2.1.9. They will have a similar order of magnitude, and their effect will therefore be negligible for the pointing budgets.

8.6.1.3 Thruster torques

8.6.1.3.1 20-N thruster torques

The section 6.4.4 of the present Design Report and the technical note "Thruster Utilisation" (H-P-1-ASP-TN-0689 issue 1) show that the torques created by 20-N thrusters:

- can be created in any direction, in particular whatever the spacecraft attitude is,
- are <u>5 orders of magnitude</u> higher than the permanent disturbance.

In addition, the effect of thruster misalignments, differential forces between thrusters, and motion of the centre of mass during the mission create equivalent lever arms that are negligible with respect to the nominal lever arms of the "C" thrusters, i.e. at least 2.15m.

As a result of the above, the thruster can compensate the disturbance they create themselves during the thruster controlled modes.

8.6.1.3.2 1-N thruster torques

The Section 6.4.4 of the present Design Report and the technical note "Thruster Utilisation" (H-P-1-ASP-TN-0689 - Issue 01) show that the torques created by thrusters allow to:

- re-orient the spacecraft to any direction,
- damp the nutation by a 3-pulse strategy,
- maintain the spin rate of the spacecraft, by an adequate choice of the spin-up or spin-down thruster.

8.6.1.4 Negligible torques

The following external torques are negligible:

- gravity gradient
- geomagnetic
- aerodynamics.

Indeed, Planck is separated at an altitude above 2700 km and will later never get any closer from the Earth.

At this altitude and above, the atmosphere is tenuous not to create any aerodynamic torque.

After the 6 hours required to perform the first manoeuvre (SMAC-015 of the SRS), its altitude will be roughly 80000 km. At this altitude:

- the gravity gradient is inferior to $K_{Eartth}.(Imax-Imin)/(2.r^3) < 0.15\ \mu N.m$, i.e. 2 orders of magnitude less than the solar torque.
- the geo-magnetic field B is lower than 0.02 μT. The effect on the spacecraft will be negligible.

8.6.2 Internal disturbance torques on Planck

The internal torques are due to propellant and Helium sloshes.

The propellant slosh effects are accounted by the ACMS Supplier, using a pendulum model.

The Helium being gaseous and with a limited mass (7.69 kg maximum), its effect is negligible with respect to propellant.

The sloshes create no issue, neither on the spacecraft stability, nor on the pointing performance.