SPIRE-ALC-REP-002349

HERSCHEL / PLANCK

System Design Report for PDR

Product Code : 000000

Rédigé par/*Written by*	Responsabilité-Service-Société *Responsibility-Office -Company*	Date	Signature
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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 Preliminary Design Review (PDR).

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).

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.

Section 6 presents the overall system design of the Herschal and Planck satellites. It begins by a summary of the main trade-offs conducted to arrive at the present design. Then the main system constituents of the system design are presented.

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 present Preliminary Design Review will be initiated on 02/07/02 and will last up to 04/10/02, planned date of the ESA Board meeting.

As a major task of the phase B, the procurement process is running as expected and to be completed by September 2002.

Further formal reviews are planned as follows:

- CDR: December 2003

- QR: December 2004
- AR: September 2006

The Launch date is scheduled on February 2007.

1.3.2 Phase B main achievements

Since the SRR a major spacecraft design consolidation has been made. In relation to the procurement process which is nearing completion, some open points are still existing at equipment level (selection of ACMS equipment supplier for instance). But thanks to the subsystem work and the use of consolidated assumptions or data coming from potential supplier, these open points are not invalidating the system level configuration, design and performance.

In this report a baseline design is defined. It refers to similar module design reports which provide further detail on their respective configuration, design and performance justification.

Initiated by ESA before the industrial Phase B start, the definition of the interfaces between the 5 instruments and the 2 spacecraft has achieved a major step of consolidation during this Phase B. Some refinement are still to be made, as detailed in the relevant design report, but interface feezing is expected and needed very soon. The main area of concern being the actual delivery dates of the various models.

Other critical areas have been identified and associated plan of action have been defined as summarised in the next chapter.

The compliance with requirements has been analysed and justified in detail, where main areas of efforts are the overall mass & Herschel cryostat performance (lifetime, FPU temperature). Optimisation is running to achieve requirement compliance with margin.

The development and verification plans have been consolidated considering the model philosophy applied in the program from system to unit level. A baseline of the GSE (requirement and planned usage) is also presented together with the planned intergaration and test facilities.

Whereas some planning assumptions have to be consolidated by not yet selected suppliers, the schedule detail and credibility has increased. The initial launch date could be maintained despite the 6 months delay of all instruments deliveries, but flexibility and margin is now very reduced and any further instrument delivery delay will have impact on the achievable launch date.

1.3.3 Critical areas

Although the Phase B activities have produced a justified system baseline design, it also highlighted critical areas which will need further attention in the early phase C of the program. Each of these points will be further detailed as part of the relevant design report included in the PDR data package.

1.3.3.1 Design aspects

Launch Mass

Although several mass reduction campaigns have already been conducted on each main contributor (Herschel cryostat, SVM structure, Planck telescope and cryo structure), the present maximum mass exhibit a negative margin with regard to the specified launcher capability. In order to further investigate mass reduction potentialities a Tiger Team has been nominated. As main tasks, the Tiger Team shall analyse:

- The mass sizing requirements and their flow down from ESA requirement specification down to subsystem/equipment requirements,
- The mass margin philosophy required or adopted by each party and their coherence,
- The baseline design presented at the PDR and its justification,

- The justification of the mass margin with respect to development maturity,
- The completeness of the mass budgets and of the mechanical analyses (with the objective to assess the credibility of the proposed design).

Then the Tiger Team shall then define:

- The mass drivers pertinence and completeness,
- Potential mass saving areas by optimisation of the proposed PDR design (with associated order of magnitude),
- Potential requirement changes leading to a mass reduction, with associated risk identification when relevant,

Instruments interfaces

The spacecraft design progress and the start of detailed manufacturing documentation are now limiting the flexibility to changes of the instrument interfaces. This is particularly true for the mechanical and thermal aspects, but also for the electrical interfaces of the warm units.. In order to assess the maturity of these interfaces a summary table is provided at the end of the chapter (see Section 1.3.3.5)

Shock levels at equipment basis derived from ARIANE 5 requirements

The shock levels specified by Arianespace are generating high levels at the subsystem/equipment interfaces. Since according to equipment supplier these levels are above the qualification levels for recurring units or above their standard technology capability a work plan to consolidate the derived specified levels as well as the equipment capability has been initiated.

Cryostat

The PFM approach is based on the ISO heritage for its overall concept, some hardware, the design principles and basic performance. Nevertheless new design areas are also existing, introducing risks areas, such as the need to initiate detailed design and manufacturing ahead from the CDR. Risk assessment and mitigation plan shall be considered to minimise the overall program schedule & cost.

Software

The software requirement step has still to be finalised and the corresponding ITT issued to select the supplier.

ACMS

The Herschel + Planck ACMS contractors activities have just been initiated. Considering the high complexity of this subsystem due to the challenging technical requirements (pointing and autonomy) the ACMS development is regarded as critical. In addition, the design phase being very short Alcatel will follow with a particular attention these activities.

1.3.3.2 Performance aspects

Herschel cryogenic lifetime

An optimisation & refinement of the analysis together with design optimisation in particular of the harness thermalisation and of the HIFI coax cables are in progress to reach the required lifetime with sufficient margin.

Pointing

The budgets are based on preliminary equipment performance to be confirmed by the supplier (not yet selected). Nevertheless since the assumed equipment performance have been provided by potential suppliers as part of the requests for information made during the ACMS contractor proposal phase, a good confidence is existing in their validity. Another aspect of the pointing budget to be consolidated is the Herschel Startracker LOS stability.

Cleanliness

Cleanliness requirements and budgets have been consolidated with ESA and the instruments leading to commonly agreed specifications and plans. Nevertheless, the particulate contamination under fairing during launch is not yet agreed with Arianespace.

1.3.3.3 Verification aspects

Instruments verification

Taking into account the budgetary and schedule constraints dictating the instruments development, the present information on the completeness & representativity of the instrument level testing before satellite level AIT remain to be carefully assessed in particular for Planck cooler chain. Since the satellite CQM TV/TB test will be the first time that the whole cooler chain is assembled, proper configuration, instrumentation and test steps are necessary to maximise the probability of success of the CQM test.

Planck cryogenic testing

After the end of the feasibility study the detailed test configuration and facility performance (cooling power, induced vibration, Helium partial pressure, thermal screens, …) to reach 0.1K on HFI bolometers are to be consolidated with CSL (contract to be started in July)

RF Planck

The completion of the RF characterisation of the Planck telescope will be achieved on the RF QM. The detailed requirements for testing of the QM telescope up to 500GHz, if possible, have now to be established considering the outcomes of the RFDM tests performed in Alcatel Cannes in the frame of the Phase B using representative hardware based on the Archeops balloon reflectors.

AVM

Considering the key objective within the verification process of the AVM, the test bed development in terms of technical performance and schedule will need to be closely monitored.

1.3.3.4 Planning areas

The analysis of the present schedule status confirms the schedule criticality identified at the start of the program:

- Extremely tight delivery schedule for Planck STM elements (SVM and telescope / PLM structures)
- Tight delivery schedule for AVM equipment and tests
- Tight schedule for cryostat PFM manufacturing, integration and tests.

The instruments delivery dates have been frozen for PDR baseline schedule. Since about all the initial contingency margin is now consumed any further delay will have a direct impact on the launch date.

1.3.3.5 Instrument interfaces maturity status

In order to document the assessment of the maturity of the instrument interfaces as made by ALCATEL the table here below is providing a status of maturity of each individual item.

satellite	Instru ment	Loca tion	Type	Unit	Code		Design status	Manufacturing status	Drawing	Remarks
Herschel	HIFI	cryostat	FPU & Electronics	Focal Plane Unit	FH	FPU	Stable since IIDR, apart for internal cold boxes changed at IBDR, still not stable	Parts manufactured	Detailed external configuration drawing	Technical problems with chanel 6
Herschel	HIFI	SVM	FPU & Electronics	Focal Plane Control Unit	FH	FCU	Electrical & mechanical design completed		Detailed external configuration drawing	
Herschel	HIFI	SVM	FPU & Electronics	Instrument Control Unit	FH	ICU	Electrical & mechanical design completed	AVM box has been manufactured.	Detailed external configuration drawing	similar to other herschel instruments DPU's
Herschel	HIFI	SVM	FPU & Electronics	3dB Coupler Horizontal	FH	3DH	RF design, no mechanical design	TBD	No drawing	Moved recently from FPU, to FCU, and then to independant for accomodation reason
Herschel	HIFI	SVM	FPU & Electronics	3dB Coupler Vertical	FH	3DV	RF design, no mechanical design	TBD	No drawing	
Herschel	HIFI	CVV	Local Oscillator	Local Oscillator Unit	FH	LOU	Mechanical design complete (not fully satisfactory wrt mechanical integrity)		Detailed for interface plate, sketches for LOU	
Herschel	HIFI	SVM	Local Oscillator	Local Oscillator Control	FH	LCU			external config drawing	
Herschel	HIFI	SVM	Local Oscillator	Local Oscillator Source Unit	FH	LSU	design not complete. Only design report from CSA	NIL	Sketch	
Herschel	HIFI	SVM	Local Oscillator	Local Oscillator Radiator	FH	LOR	Responsibility still not frozen	NIL (concept)	No drawing	
Herschel	HIFI	SVM	High Resolution Spectrometer	HRS ACS Horizontal polarisation	FH	HRH	Electrical & mechanical design completed		Detailed external configuration drawing	responsibility CESR. Uses ASICS
Herschel	HIFI	SVM	High Resolution Spectrometer	HRS ACS Vertical polarisation	FH	HRV	as above	as above	as above	
Herschel	HIFI	SVM	Wide Band Spectrometer	WBS Electronics for Horizontal Polarisation	FH	WEH	Electrical & mechanical design completed		Detailed external configuration drawing	WBS has good experience from previous mission
Herschel	HIFI	SVM	Wide Band Spectrometer	WBS Electronic for Vertical Polarisation	FH	WEV	as above	as above	as above	
Herschel	HIFI	SVM	Wide Band Spectrometer	WBS Optic for Horizontal Polarisation	FH	WOH	Electrical & mechanical design completed		Detailed external configuration drawing	
Herschel	HIFI	SVM	Wide Band Spectrometer	WBS Optic for Vertical Polarisation	FH	WOV	as above	as above	as above	

satellite	Instru ment	Loca tion	Type	Unit	Code		Design status	Manufacturing status	Drawing	Remarks
Herschel	SPIRE	cryostat	FPU	Focal Plane Unit	HS	FPU	Mature, detailed interface drawings received. Bolometer assemblies (JPL) "critical" in terms of funding and delivery dates.	Intensive prototyping and test activities of various components & sub-systems. Potentially critical problems with some FPU components, especially mechanisms.	Detailed external configuration drawing	All CQM deliverables on critical path.
Herschel	SPIRE	cryostat	FPU	JFET (Spectrometer)	HS	JFP	Mature, detailed interface drawings received.	JFET fabrication engineer (JPL) has left. Manufacturing & testing of prototypes.	Detailed external configuration drawing	All CQM deliverables on critical path.
Herschel	SPIRE	cryostat	FPU	JFET (Photometer)	HS	JFS	Mature, detailed interface drawings received.	sama as above	Detailed external configuration drawing	All CQM deliverables on critical path.
Herschel	SPIRE	SVM	Warm units	Focal Plane Control unit	HS	FCU	Apparently good progress, but industry has poor visibility of this.	At IBDR, manufacturing of some prototype components only.	Detailed external configuration drawing	All CQM deliverables on critical path. Recognised funding problems, could lead to delays in schedule.
Herschel	SPIRE	SVM	Warm units	Detector Control unit	HS	DCU	Apparently good progress, but industry has poor visibility of this.	At IBDR, manufacturing of some prototype components only.	Detailed external configuration drawing	All CQM deliverables on critical path. Recognised funding problems, could lead to delays in schedule.
Herschel	SPIRE	SVM	Warm units	Digital Processing Unit	HS	DPU	Well advanced.	AVM box has been manufactured.	Detailed external configuration drawing	All CQM deliverables on critical path. Potential delays due to financing difficulties at IFSI.

satellite	Instru ment	Loca tion	Type	Unit	Code		Design status	Manufacturing status	Drawing	Remarks
Herschel	PACS	cryostat	FPU	Focal Plane Unit	FP	FPU	Almost complete.	Most CQM components should be manufactured by 07/2002.	Detailed external configuration drawing	ASPI insight into FPU design / manufacturing indicates a good level of maturity, and confidence with this unit. Industrial responsible = KT. Technologically "sensitive" FPU subsystems include : Chopper mechanism, Grating, Bolometers, 0.3 K Sorption Cooler.
Herschel	PACS	SVM	Warm units	Detector & Mechanism Control (DEC/MEC)	FP	DECMEC	Most electrical hardware designed or prototyped. Mechanical design still to be done S/W status between 30% and 100% Mechanical design poor : received updated connector I/Fs only	No known manufacturing, apart from prototype boards.	Only sketch	DECMEC design has evolved considerably in last 12 months (previously 4 units, now 1 single unit, etc.). Confirmation of agreed length of 560 mm still needed.
Herschel	PACS	SVM	Warm units	Bolometer Cooler Control unit	FP	BOLC	Well advanced.	Electronic prototypes and/or CQM boards manufactured, testing begun. Mechanical design less advanced.	Detailed external configuration drawing	Responsibilty with CEA/SAp. Recent decision to update design of BOLA, to include heaters : might introduce delays …
Herschel	PACS	CVV		Bolometer Buffer Amplifier	FP	BOLA	Similar to BOLC	Similar to BOLC	Similar to BOLC	Operating temperature 70K still TBC
Herschel	PACS	SVM	Warm units	Data Processing Unit	FP	DPU	Electronics & box : completed at IBDR	CQM electronics should be complete by ~ July 2002; mechanical + delivery by Oct 2002.	Detailed external configuration drawing	Responsibility with IFSI / Carlo Gavazzi. Good degree of coinfidence in this unit, although delays could arise from budgetary difficulties with IFSI.
Herschel	PACS	SVM	Warm units	Signal processing unit Nominal	FP	SPU1/2	DC/DC Electrical design consolidated. PCB design finished. Design presented at IBDR suggests "good" progress has been made.	Manufacture of some CQM components completed or underway at IBDR Modifications / breadboarding necessary.	Detailed external configuration drawing	Responsibility with IAC & CRISA. Poor insight into real progress. Allocated manpower at IAC ~ 1 person. Almost identical design as for LFI REBA. **Agreed change** with PACS : Nominal and redundant **SPUs should be stacked** : no official confirmation of this from IAC / PACS. At IBDR : *"Qualification and QM not started pending of receiving funds"* !

satellite	Instru ment	Loca tion	Type	Unit	Code		Design status	Manufacturing status	Drawing	Remarks
Planck	LFI	PPLM	Radiometer Array Assembly (RAA)	Front End Unit (FEU)	PL	FEU	design not complete		no updated drawing available at Alcatel, but we know that one is available	100GHz chanels not secured (funding)
Planck	LFI	SVM	Radiometer Array Assembly (RAA)	DAE Back End Unit (BEU)	PL	BEU	design almost complete	partial breadboard	draft under analysis	
Planck	LFI	SVM	Radiometer Array Assembly (RAA)	DAE Power Box	PL	CB	design complete	partial breadboard	draft approved	
Planck	LFI		Radiometer Array Assembly (RAA)	Wave Guides (WG)	PL	WG	WG design not complete, WG structure design not complete	Plastic breadboards	not complete drawing	
Planck	LFI	PPLM	Radiometer Array Assembly (RAA)	Heat switch	PL	A10	no design		no drawing	
Planck	LFI	SVM	Radiometer Electronics Box Assembly (REBA)	REBA	PL	REN&R	design complete	EM completed	drawing approved	similar to PACS SPU

satellite	Instru ment	Loca tion	Type	Unit	Code		Design status	Manufacturing status	Drawing	Remarks
Planck	HFI	PPLM	Detection	Focal Plane Unit (FPU)	PH	A	design not complete		no drawing	
Planck	HFI	SVM	Detection	Data Processing Unit (DPU) Nominal	PH	BA-N&R	design almost complete		draft approved	
Planck	HFI	PPLM	Detection	JFET Box	PH	CA	design not complete		sketch	
Planck	HFI	SVM	Detection	Pre-Amplifier Unit (PAU)	PH	CBA	design almost complete	partial breadboard	drawing under analysis	
Planck	HFI	SVM	Detection	Readout Electronics Unit (REU)	PH	CBC	design complete	partial breadboard	drawing approved (number of feet under analysis)	
Planck	HFI	SVM	4K Cooler	4K Cooler Compressor Unit (CCU)	PH	DA	design complete	off the shelf ?	draft under analysis	
Planck	HFI	SVM	4K Cooler	4K Cooler Ancillary Unit (CAU)	PH	DB	design almost complete		sketch + 3D model	
Planck	HFI	SVM	4K Cooler	4K Cooler Electronics Unit (4K-CDE)	PH	DC	design almost complete		drawing approved	
Planck	HFI	PPLM	4K Cooler	4K Cooler Cold End (CCE)	PH	DD	design not complete		no drawing	
Planck	HFI	SVM	4K Cooler	4K Cooler Current Regulator (CCR)	PH	DJ	no design		no drawing	
Planck	HFI	SVM	0.1K Cooler	0.1K Dilution Cooler 3He Tank	PH	EAA&B	design complete	off the shelf	drawing approved	
Planck	HFI	SVM	0.1K Cooler	0.1K Dilution Cooler Control Unit (0.1K-DCCU)	PH	EC	beginning of the design		no drawing	
Planck	SCS	SVM	SCC	Sorption Cooler Compressor	PS	M3 & R3	design almost complete	breadboard	drawing partially approved (hole tolerance)	
Planck	SCS	SVM	SCE	Sorption Cooler Electronic	PS	M4 & R4	design almost complete		draft approved	
Planck	SCS	PPLM	SCP	Sorption Cooler Pipes and Heat Exchangers	PS	M2 & R2	design not complete	breadboard	drawing for some parts	

From this status, it can be considered that most of the phisical interfaces between the instruments and the spacecraft (mechanical, thermal, electrical) are now mature enough to allow starting detailed design and manufacturing file initiation on spacecraft side.

Presently exceptions are identified as being:

- The Hercshel PACS DECMEC, the size of which having changed up to recently, a final freeze confirmation is necessary. It should be mentioned that any significant change with regard to the present assumption would have a severe impact on the SVM schedule
- The Planck 4K cooler pre regulator. A baseline interface definition is used. The electrical performance as well as the equipment volume is assessed to be sufficiently realistic to have confidence in the validity of the SVM architecture.

The Planck LFI RAA an associated waveguides. Since the IBDR has been postponed in next July, interfaces assumption have been defined for the spacecraft PDR. Considering the tight schedule of the telscope and cryo structure it is mandatory to keep unchanged the defined mechanical interfaces, whatever the final LFI instrument design is.

2. DOCUMENTS

2.1 ESA documents

2.1.1 Technical Specifications

AD01.1 Herschel/Planck System Requirements Specification (SRS)
SCI-PT-RS-05991, Issue 3.0

AD01.2 Planck Telescope Design Specification
SCI-PT-RS-07024, Issue 1.0
Superseded by H-P-3-ASPI-SP-0274, Issue 1.0

2.1.2 ESA Undertakings

AD02.1 Herschel Telescope Specification
SCI-PT-RS-04671, Issue 5.0

AD02.2 Planck Telescope Primary/Secondary Reflector and Inner Baffle Specification
SCI-PT-RS-07422, Issue 5.0

2.1.3 Satellite System Interface Specification

AD03.1 Herschel/Planck Operations Interface Requirement Documentation (OIRD)
SCI-PT-RS-07360, Issue 2.0

AD03.2 Herschel/Planck Space/Ground Interface Requirement Document (SGICD)
SCI-PT-RS-07418, Issue 2.1

AD03.3 Herschel/Planck Packet Structure ICD
SCI-PT-RS-07527, Issue 2.0

AD03.4 Launcher ICD
Not available at time of PDR Data Package issue. Inputs given in:

AD03.5 Demande d'Utilisation ARIANE
H-P-1-ASPI-IS-0066, Issue 1

2.1.4 Instrument Interface Specifications

AD04.1 Herschel/Planck IID Part A
SCI-PT-IIDA-04624, Issue 3.0

AD04.2 IID Part B: SPIRE
SCI-PT-IIDB/SPIRE-02124, Issue 2.2

AD04.3 IID Part B: HIFI
SCI-PT-IIDB/HIFI-02125, Issue 2.2

AD04.4 IID Part B: PACS
SCI-PT-IIDB/PACS-02126, Issue 2.1

AD04.5 IID Part B: HFI
SCI-PT-IIDB/HFI-04141, Issue 2.1

AD04.6 IID Part B: LFI
SCI-PT-IIDB/LFI-04142, Issue 2.1

2.2 Prime Documentation

2.2.1 Satellite System Specifications

AD05.1 General Design and Interface Requirements
H-P-1-ASPI-SP-0027, Issue 3.2

AD05.2 Environment and Test Requirements
H-P-1-ASPI-SP-0030, Issue 4.0

AD05.3 Cleanliness Requirement Specification
H-P-1-ASPI-SP-0035, Issue 2.0

AD05.4 EMC Specification
H-P-1-ASPI-SP-0037, Issue 3.0

AD05.5 Software Design Requirement Specification
H-P-1-ASPI-SP-0046, Issue 2.1

AD05.6 SVM Requirements Specification
H-P-4-ASPI-SP-0019, Issue 2.1

AD05.7 H-EPLM Requirements Specification
H-P-2-ASPI-SP-0250, Issue 1

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 3.0

AD07.2 H-EPLM Interface Specification
H-P-2-ASPI-IS-0039, Issue 2.1

AD07.3 P-PLM Interface and Applicability Specification
H-P-3-ASPI-IS-0070, Issue 2.0

AD07.4 Herschel MTICD
H-P-2-ASPI-ID-0258, Issue 1.0

AD07.5 Planck MTICD
H-P-3-ASPI-ID-0257, Issue 1.0

AD07.6 Herschel System Electrical ICD
H-P-2-ASPI-ID-0259, Issue 1.0

AD07.7 Planck System Electrical ICD
H-P-3-ASPI-ID-0260, Issue 1.0

AD07.8 MGSE Interfaces Specification
H-P-1-ASPI-IS-0120, Issue 3.0

AD07.9 EGSE Interfaces Requirements Specification
H-P-1-ASPI-IS-0121, Issue 2.0

2.3 Reference Documents

2.3.1 Design Reports

RD01.1 SVM Design Report
H-P-RP-AI-0005, Issue 2.0

RD01.2 H-EPLM Design Description
H-P-2-ASEP-RP0003, Issue 2.0

RD01.3 P-PLM Design Report
H-P-3-ASPI-RP-0312, Issue 1.0

2.3.2 Budget Reports

RD02.1 SVM Budget Report
H-P-BD-AI-0001, Issue 1.0

RD02.2 H-EPLM Budget Report
H-P-2-ASED-RP-004, Issue 1.0

RD02.3 System Budget Report
H-P-1-ASPI-BT-0264, Issue 1.0

2.3.3 Trade-offs, Technical Notes, Plans

RD03.1 Mass Reduction Plan
H-P-1-ASPI-PL-0332, Issue 1.0

RD03.2 Planck Cleanliness Control Plan
H-P-1-ASPI-PL-0253, Issue 1.0

RD03.3 EMC/ESD Control Plan
H-P-1-ASPI-PL-0038, Issue 3.0

RD03.4 Herschel System Alignment Plan
H-P-1-ASPI-PL-0276, Issue 1.0

RD03.5 Planck System Alignment Plan
H-P-3-ASPI-PL-0078, Issue 2.0

RD03.6 Herschel/Planck Functional Analysis
H-P-1-ASPI-AN-0074, Issue 1.1

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 2.0

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 1.0

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 1.0

RD03.17 Preliminary Safety Analysis
H-P-1-ASPI-TN-0283, Issue 1.0

RD03.18 Impact of propellant tank temperatures on wobble angles
H-P-1-ASPI-TN-0132, Issue 1.0

RD03.19 Impact of the Launcher Spin during the coast arc on Herschel PLM
H-P-2-ASPI-TN-0184, Issue 1.0

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

RD03.21 Herschel optical performances-contamination impact
H-P-2-ASPI-TN-0344, Issue 1.1

2.3.4 Analyses

RD04.1 PDR PLANK Mechanical analysis report
H-P-3-ASPI-RP-0265, Issue 1.0

RD04.2 Thermal analysis report
H-P-1-ASPI-RP-0266, Issue 1.0

RD04.3 EMC analysis
H-P-1-ASPI-AN-0202, Issue 1.0

RD04.4 Radiation analysis report
H-P-1-ASPI-RP-0267, Issue 1.0

RD04.5 ESD analysis
H-P-1-ASPI-RP-0268, Issue 1.0

RD04.6 End of Life Cleanliness analysis
H-P-1-ASPI-AN-0269, Issue 1.0

RD04.7 Herschel Random Environment Analysis
H-P-2-ASPI-AN-0112, Issue 2.0

RD04.8 Planck Random Environment Analysis
H-P-2-ASPI-AN-0113, Issue 2.0

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

RD04.10 PDR HERSCHEL Mechanical analysis report
H-P-2-ASPI-RP-0317, Issue 1.0

RD04.11 PLANK PLM Mechanical and Thermoelastic Analyses report
H-P-3-ASPI-RP-0329, Issue 1.0

2.3.5 Drawings

RD05.1 Herschel Grounding Diagram
H-P-2-ASPI-TN-0199, Issue 1.0

RD05.2 Planck Grounding Diagram
H-P-3-ASPI-TN-0200, Issue 1.0

RD05.3 Herschel Configuration and Interface Drawing File
H-P-2-ASPI-PL-0191, Issue 1.0

RD05.4 Planck Configuration and Interface Drawing File
H-P-3-ASPI-PL-0192, Issue 1.0

2.3.6 Subcontractors documentation

RD06.1 Herschel SVM FEM Description
H-P-4-CASA-RP-0008, Issue 1.0

RD06.2 Planck SVM FEM Description
H-P-4-CASA-RP-0030, Issue 1.0

RD06.3 Stability Analysis Report
H-P-4-CASA-RP-0007, Issue 1.0

RD06.4 H-EPLM FE Model Description
HP-2-ASED-TN-0025, Issue 1.0

RD06.5 H-EPLM Thermal Distortion Analysis
FE Model Description and Results
HP-2-ASED-TN-0046, Issue 1.0

RD06.6 HERCHEL TELESCOPE
Finite Element Model Description CDR Status
HER.NT.00190.T.ASTR, Issue 1.0

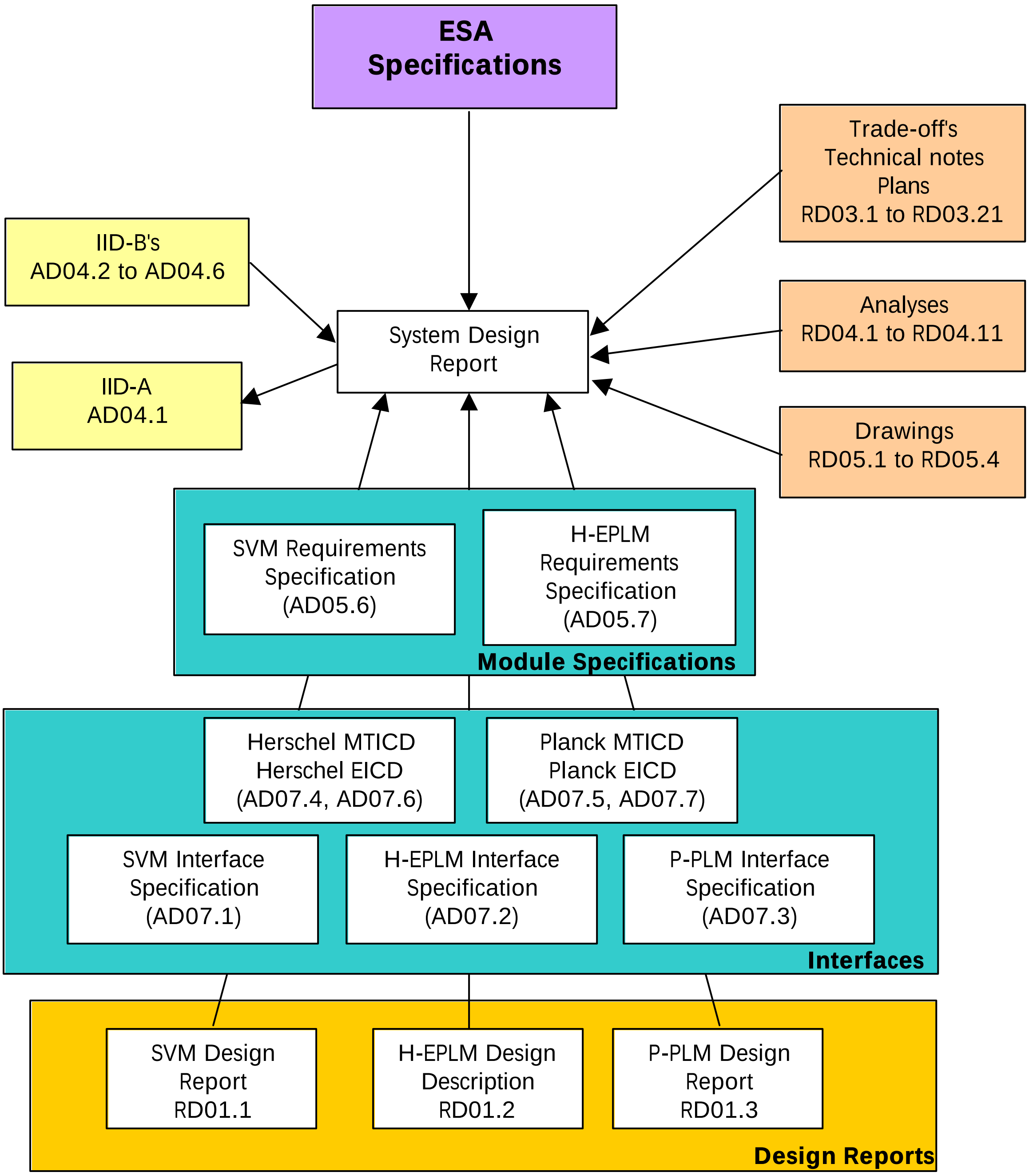
RD06.7 Herschel E-PLM Structural Analysis Report
HP-2-ASED-TN-0049, Issue 1.0

RD06.8 Herschel Alignment Concept
HP-2-ASED-TN-0002, Issue 1.0

RD06.9 SVM Structure Specification
H-P-SP-AI-0001, 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 data package 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.

The phase between SRR and PDR has been very active in refining the instrument interfaces. The instruments held their IBDR (Instrument Baseline Design Review) which allowed a better definition of their design and interfaces. Updated version of the IID-B's and of the IID-A have been produced for the PDR 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 ES/V with a launch capacity to L2 of 5310 kg, to which the mass of adaptors (SYLDA 5, 2624 adaptors, USF) have to be substracted. An overall ESA reserve of 148 kg has also to be kept.

The possibility to use the alternative ARIANE 5 ECA version has also been studied since SRR. The impact on design are various as it changes the launch window, imposes a larger Planck orbit to be compliant with increased ΔV requirements and has impact on the TTC design. The satellites are designed to be compliant with a launch on both ARIANE 5 ES/V and ECA

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 acheived with a margin of 10 % 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. Active thermal control might be necessary in some areas.

3.2 Evolution of system requirements since SRR

3.2.1 System Requirement Specification

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

- SRS 2.1 dated 21/12/2001
- SRS 3.0 dated 24/05/2002, which was received by mid-june, very close to the finalisation of the PDR data package.

The main updates of requirements are discussed in the following sections.

3.2.1.1 Evolution from SRS 2.0 to SRS 2.1

- Requirements coming from mission analysis are introduced in the SRS.
- No requirements on Planck orbit size. SGEN-060 gives the delta-V requirement for Planck as a function of the orbit size. This has allowed to optimise the Planck orbit size to the 15 deg orbit which is baselined for PDR (see trade-off in Section 4.2.4).
- Attitude constraints: the roll constraint has been reduced to ± 1 deg instead of ± 5 deg (MISS-110).
- Angles for straylight defined: 23 deg for Earth, 13 deg for Moon minimum angle with Herschel telescope axis (MISS-135/145).
- MISS-105/115. Clarification on peak-up: one attitude update per observation, maximum 10 arcsec amplitude around Y and Z.
- SGEN-100: clarification on testing of material or combination of materials. The minimum number of cycle has been set at 10 and qualification temperature shall be used. This modification has been flown down to the GDIR (AD05.1).
- Increase of average instrument data rate from 100 kbps to 130 kbps (SINT-040/045). This is the average data rate over 24 hours, including housekeeping and inclusive of formatting overheads. Burst rate now specified at 300 kbps during 30 minutes (SINT-047). These values are in accordance with the subframe allocation defined in RD03.11.
- § 5.5.5: clarification of the radiation environment to take into account. Radiation analysis shall take into account a launch in February 2007 and the nominal mission lifetime. Equipment sensitive to radiation (except the solar array) shall take into account a margin of 2 on top of the computed radiation dose.
- For solar array, the performance at the end of the nominal lifetime shall take into account the radiation fluence of 1 MeV electrons for the nominal lifetime duration. A margin of 10 % shall be taken on calculated power (SMSA-015). For extended lifetime, the radiation fluence for extended lifetime duration shall be taken into account and no additional margin shall be added.
- SCMD-140: clarification for high priority commands.
- SMAC-122: addition of requirement for gain and phase margin.
- SMRC-035/045/050: use of 2 separate branches not imposed to RCS. Eventually, the PDR baseline RCS design has 2 branches.

3.2.1.2 Evolution from SRS 2.1 to SRS 3.0

- Definition of the solid particle environment has been provided ("Solid Particle Environment for Herschel and Planck, EMA/02-027/GD/PLCK). This will be reflected in the EVTR (AD05.2). A CR has been sent to lower levels (ALENIA, Astrium, CSAG) for evaluation. No feedback has been received yet.
- MISS-035: the launch window is now optimised such that no eclipse occurs during transfer. This is a relaxation for power subsystem (BDR sizing) as well as for ACMS (no specific mode to be defined for eclipse).
- § 4.4: the instrument LoS is now clearly defined. The pointing requirements for Planck have been modified: it is now considered that the calibration is under instrument teams responsibility, so this part has been removed from the spacecraft requirements. This has led to reduce the AME LOS requirement from 1 arcmin to 0.5 arcmin with a goal reduced from 0.5 arcmin down to 0.2 arcmin. These new requirements have been taken into account in the pointing budgets.
- In addition the requirements for PRE (Pointing Reproducibility Error) around LOS have been removed. They will be covered by the APE around LOS.
- SGEN-200 and SGEN-202: the requirement SGEN-200 of 3 % transmission loss (as defined in SRS 2.1) has always been interpreted as being relative to the degradation of the telescope transmission under prime contractor control, i.e. contamination impact. The new wording of SRS 3.0 refers to the definition of relative spectral transmission as defined in AD02.1 which covers all contributors. In that case, the budget performed at system level is dependant on the performance of the telescope provided as a CFE by ESA. The change of requirement poses several problems:
  - For BOL (defined as cryo cover opening), no requirement exists in AD02.1 for telescope performance. Only transmission at acceptance and delivery of the telescope is specified.
  - Taking the specified transmission value at acceptance and delivery of telescope (0.97) lead to an allocation of only 0.5 % for the system contribution. As almost all contribution from contamination occurs before cryo cover opening, this requirement will be difficult to meet.
  - For EOL, no requirement exist for the telescope transmission in AD02.1. Only a goal of 0.95 is defined which is higher than the 4.2% transmission loss of SGEN-202. This means that the SRS and Herschel Telescope Specification are currently not consistent for this requirement.

  So, harmonisation is necessary between SRS and AD02.1:

  - To define telescope transmission requirements at BOL (cryo cover opening) and EOL, in line with SRS definitions,
  - To make the telescope specifications consistent with the SRS ones.

In addition, to build a telescope transmission budget including all contributors, ASPI/ASED will need to have full visibility on the transmission actual performance of the telescope.

- SPER-045: the Delta-V manœuvre accuracy of 1 % is limited to large manœuvres (above 10 m/s). For small manœuvres, only 5 % accuracy is required. This is a relaxation for the ACMS.
- SINT-035: the margins on power dissipation is now referring to the IID-B's without any reference of Issue (reference to Issue 2 was introduced in SRS 2.1). This margin is understood to cover evolution of instrument dissipation along the course of the programme and progressive release of the margin will have to be implemented. For the PDR, the nominal values in AD04.2 to AD04.6 have been taken to make the thermal design of the SVM and the 10 % variation has been assessed through a sensitivity analysis.
- SINT-050: OTF and spin reference message are not anymore required to be sent to instruments.

- SCMD-085: the ESA reserve has been decreased to 148 kg. This takes into account increase of the Herschel telescope allocation, increase of Planck reflectors allocation and inclusion of Herschel telescope interface frame in the spacecraft share.
- SCMD-088: these alignment requirements have been agreed in the Herschel Optical System Working Group (11/03/2002). Since that date, HIFI requirements have been relaxed (and HIFI internal contribution has increased), leading to the following system requirements for HIFI:
  - Defocus: +/-8.5mm
  - Pupil mismatch: +/-17mm.

  Update of HIFI requirements should be included in the next issue of the SRS.
- Annex 1, Herschel pointing modes:
  - For raster pointing, line scanning and position switching, the angle φ which determines the rotation of the pattern axis w.r.t. local instrument axes is now specified to be in the range 0-180 deg instead of 0-90 deg. This means the the raster or scan pattern can be reversed. This is considered to be compatible with current design.
  - For line scanning, the minimum length of a line has been reduced from 1 arcmin down to 20 arcsec with a resolution of 5 arcsec instead of 1 arcmin. This should be compatible with the current ACMS design but has to be confirmed by SVM/ACMS contractors.

3.2.2 Space to Ground ICD (SGICD)

The Issue 2.1 of the SGICD was release before PDR. The main evolutions are:

- Update of the requirement for medium data rate: in order to be consistent with instrument data rate increase to 130 kbps, ESA has increased to 140 kbps the requirement on medium data rate to allow real time downlink of instrument data. In order to have a medium rate which corresponds to an integer division of the CDMU and transponder clocks, the final value used in the design is 150 kbps.
- Selection of the modulation scheme. Two options were available up to now: OQPSK and GMSK. The GMSK modulation has been selected and is implemented as the baseline.
- The ranging tone frequency has been selected to be between 600 kHz and 700 kHz.
- Some additional case to be taken into account in the link budgets have been defined:
  - Medium rate communication with New Norcia: this is used at the beginning and end of DTCP to perform a ranging session which cannot be performed at high rate. For Planck, this has to be done without disturbing science observation which means that the maximum angle between spin axis and Earth direction to take into account is 15 deg.
  - For medium rate communication with Kourou, the maximum angle between spin axis and Earth direction to take into account is 10 deg. This is justified by the fact that this link is not used during nominal scientific operation but rather during commissionning and performance verification which allows to repoint the spacecraft toward Earth for communication.

Update of virtual channel definition: an additional Virtual Channel (VC4) has been added and priority scheme redifined accordingly. Since the issue of the SGICD 2.1, the virtual channel definition has been refined with ESA. The outcome of these discussion is the virtual channel definition presented in Section 6.3.1. SGICD should be updated to fully reflect latest agreement.

4. HERSCHEL/PLANCK MISSION OVERVIEW

4.1 Introduction

4.1.1 Lissajous orbit around L2

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.

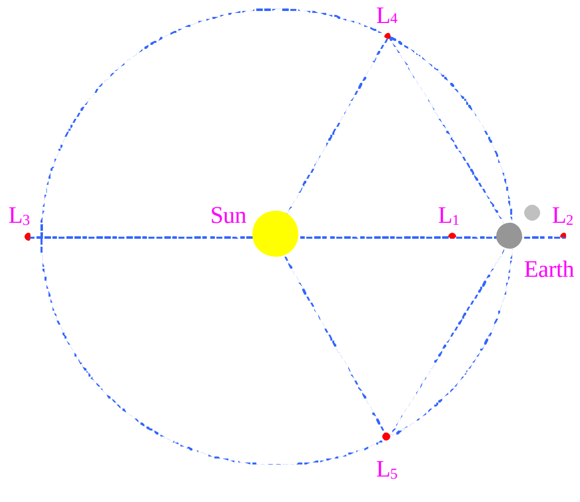


FIGURE 4.1-1 LISSAJOUS ORBIT AT L2 LAGRANGE POINT

Both spacecraft are not sitting 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 uses the same spatial scale.

Table 4.1-1 details the operational lifetime requirements for HERSCHEL and PLANCK mission. Note that the trajectories provided by ESOC are propagated over a time horizon which is smaller (respectively greater) than the required extended lifetime for HERSCHEL (respectively PLANCK).

Operational Lifetime	HERSCHEL	PLANCK
Required Standard Lifetime	3.5 years	1.75 years (21 months)
Required Extended Lifetime	6.0 years	2.5 years
Time Horizon of ESOC Orbit Data	4.75 years	2.75 years

TABLE 4.1-1 REQUIRED OPERATIONAL LIFETIME FOR HERSCHEL AND PLANCK MISSIONS

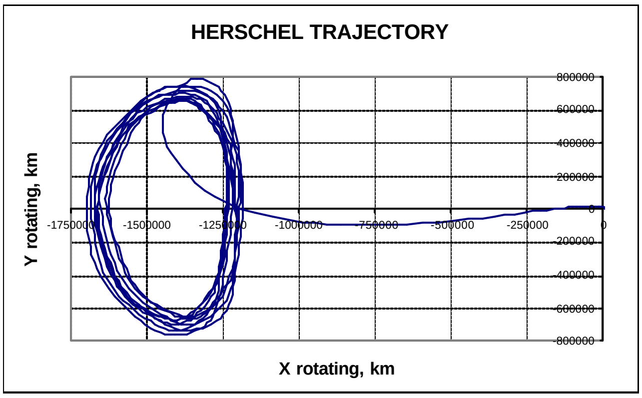
4.1.2 HERSCHEL operational orbit

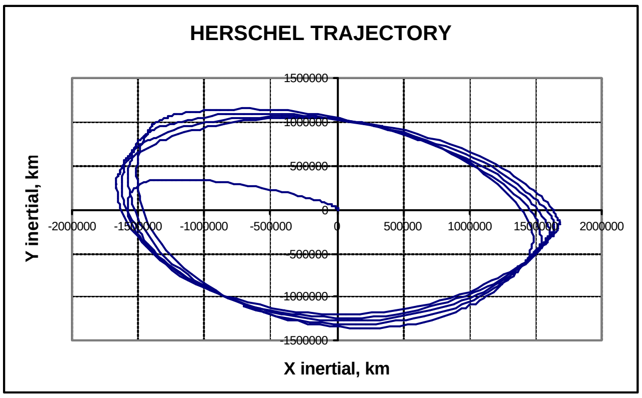
A large Lissajous orbit has been selected for HERSCHEL, its main characteristics are large amplitudes: up to 800000 km amplitude in Y direction (as referenced in Figure 4.1-1), up to 500000 km amplitude out of ecliptic plane (Z direction).

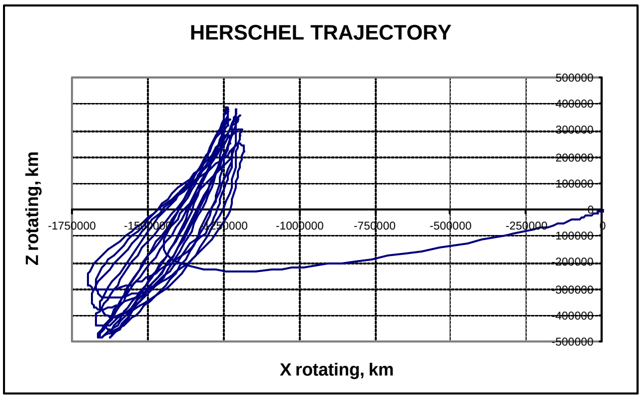
Figure 4.1-2 shows the orbit evolution of HERSCHEL from launch on the 15th Feb 2007 at 17:50 UTC, to 4.75 years of propagation in Earth centred XYZ rotating axis. The large amplitudes implies that the maximum Sun-Satellite-Earth angle can reach values above 30 deg (MISS-081 from the SRS specifies 40 deg) and that the declination to Earth can be up to 40 deg.

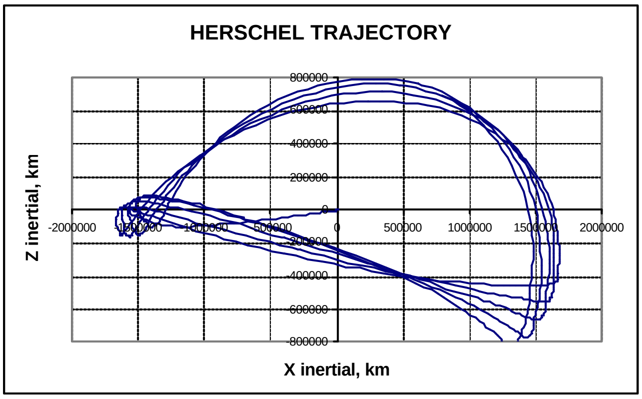
This orbit can be reached without insertion manoeuvre.

Earth rotating coordinate system **Inertial coordinate system**









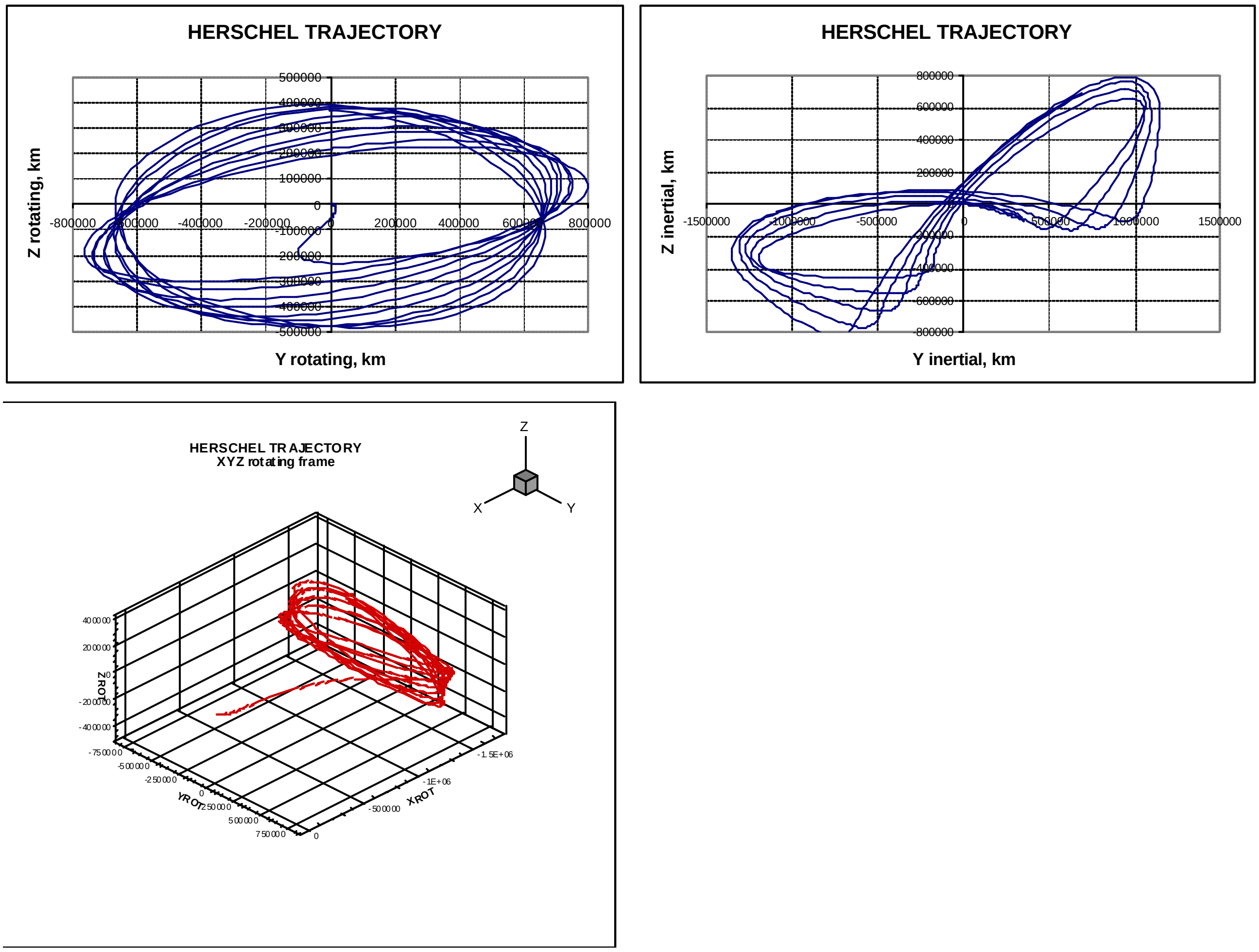


FIGURE 4.1-2 HERSCHEL LARGE LISSAJOUS ORBIT AROUND L2

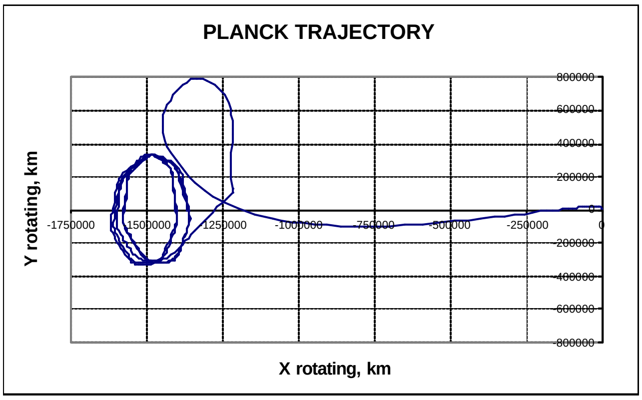
4.1.3 PLANCK operational orbit

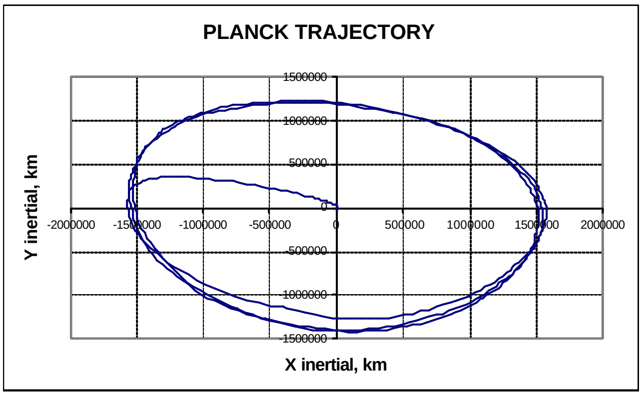
PLANCK is a Sun-pointed spacecraft with little manoeuvrability. In order to prevent the Earth to enter the PLANCK field of view and generate unacceptable straylight, the chosen baseline is a Small Lissajous orbit with a Sun-Satellite-Earth angle limited to 15 deg. This imposes an insertion manoeuvre at the arrival at L2 to reduce orbit amplitude. This manoeuvre has a magnitude of 180 m/sec, which is acceptable.

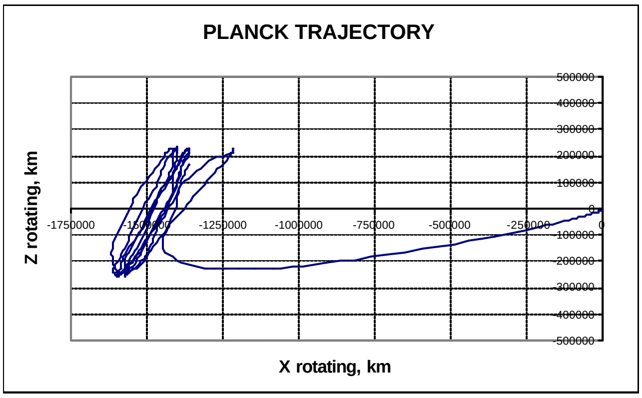
Figure 4.1-3 shows an example of a 15 deg Lissajous orbit from launch on the 15th Feb 2007 at 17:50 UTC, to 2.75 years of propagation in Earth centred XYZ rotating axes. The Y amplitude is 330000 km, and the Z amplitude is 250000 km.

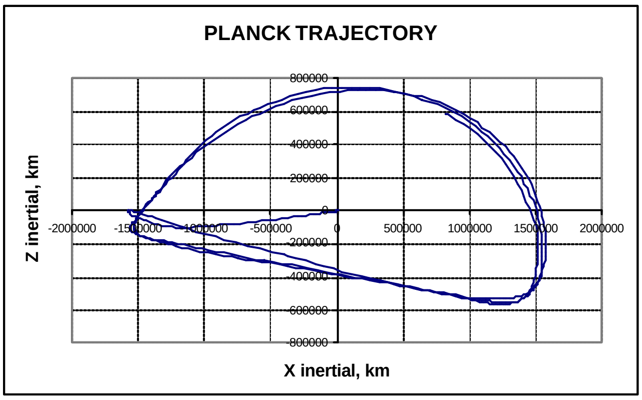
Earth rotating coordinate system

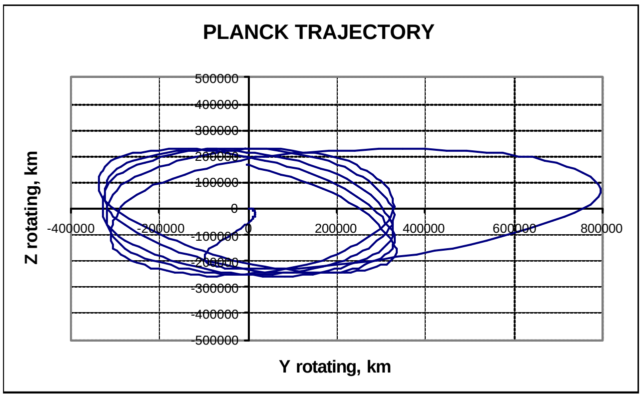
Inertial coordinate system

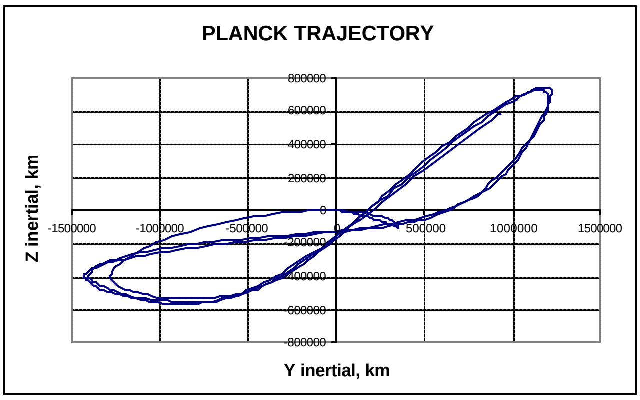












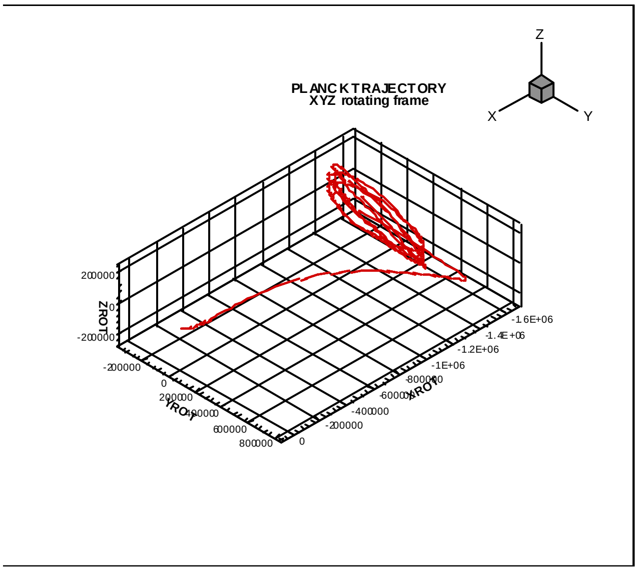


FIGURE 4.1-3 PLANCK SMALL LISSAJOUS ORBIT AROUND L2

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

4.2 Mission trade-offs

4.2.1 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. The advantages are the following ones:

- Higher launcher performances as illustrated in Figure 4.2-1. For example, targeting an apogee altitude of 500000 km (instead of 1300000 km) could lead to an additional performance of about 150 kg which gives a total launch mass of 5460 kg
- Possibility to have compatibility with A5-ECA. The main drawback with A5-ECA is that with a nominal injection strategy the Sun is along the telescope axis at fairing separation. The parking orbit strategy is a possibility to increase the Sun aspect angle at fairing separation. During this orbit, with a 30 days period, the Sun rotates 30 deg and the Sun aspect angle can be 30 deg higher than in the case of direct injection to L_2.

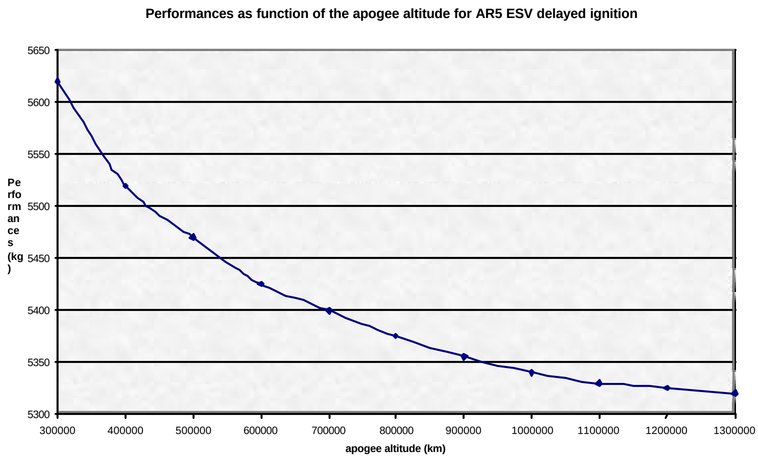


FIGURE 4.2-1 A5-ESV PERFORMANCE VS APOGEE ALTITUDE WITH A DELAYED IGNITION

System and mission analysis impacts are described in table 4.2-1. Possible parking orbit apogee altitudes is in the 500000 - 700000 km range, which increases the transfer duration by 15 to 25 days (3 weeks in average).

<table>
<tr><th>Satellite</th><th>HERSCHEL</th><th>PLANCK</th></tr>
<tr><td>Impact on transfer timeline</td><td>Additional perigee passage after one revolution on the highly elliptical orbit, which increase the duration of telescope cool-down operation by 0-2 days, and CVV cool-down operation by 1-7 days</td><td>3 weeks impact on timeline, still compatible with 6 months transfer phase</td></tr>
<tr><td>Impact on orbit correction manoeuvres</td><td colspan="2">Additional manoeuvres.
<u>Advantages</u>
(1) the main orbit correction manoeuvre removing the launcher dispersions is combined with the perigee manoeuvre for the injection towards L_2. No time criticity of the launcher dispersion removal manœuvre at day 2
(2) reduced sensitivity of the manoeuvres with respect to the launcher dispersions
(3) solution close to the optimum Delta-V, so little de-optimisation of the manoeuvre strategy for Sun aspect angle constraint satisfaction
<u>Drawbacks</u>
(1) optimum targeted apogee altitude depends on launch day and hour (strong constraint on launcher)
(2) Sun aspect angle constraint reduces the range of possible manoeuvre orientations during the additional manoeuvres
(3) important gravity losses during the perigee manoeuvre, which implies a modified thruster configuration (20 N thrusters)
(4) requires an accurate perigee manoeuvre</td></tr>
<tr><td>Impact on environment conditions</td><td colspan="2"><u>Drawbacks</u>
(1) increased PLM temperature around perigee pass
(2) radiation belts crossed two more times</td></tr>
<tr><td>Impact on launch window</td><td colspan="2"><u>Drawbacks</u>
(1) Two months seasonal launch window around equinoxes (instead 3 months) for a maximum Delta-V of 320 m/sec
(2) Three months seasonal launch window feasible with a Delta-V overcost of 20 m/sec</td></tr>
</table>

TABLE 4.2-1 SYSTEM IMPACTS OF THE PARKING ORBIT INJECTION SCENARIO

However, more detailed studies showed that in the A5-ECA case, 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.

Also the complicated and more risky LEOP operations were not appreciated.

In conclusion, the parking orbit injection scenario has major drawbacks (in particular, an increased number of manoeuvres, and an increased transfer duration), and its feasibility status is not ensured (in particular, the accuracy of the perigee manoeuvre and compatibility with A5-ECA). For these reasons, this scenario is no more considered as an open option at PDR time.

4.2.2 Three-axis versus BBQ

ARIANESPACE offers two options of attitude control during the launch phase coast arc ([H2, K2.1]):

- BBQ with a rotational speed of maximum +/- 2°/s around $X_{Launcher}$
- 3-axis control.

During this phase, PLANCK is protected from the Sun by SYLDA5. The consequences of both options are therefore to be assessed for HERSCHEL only.

As shown on the table below, the trade-off between the "BBQ" and the "3-axis control" relies on 3 parameters:

- thermal impact on HERSCHEL
- "A5 ESV with delayed ignition" performance
- injection accuracy.

	BBQ	**3-axis control**
Thermal impact on HERSCHEL	high (see §4.2.2.1) => unacceptable option	Local adaptation of the H-EPLM thermal protection (see §4.2.2.2)
"A5 ESV with delayed ignition" performance	not impacted	Possible launcher performance reduction of 150 kg (due to the additional consumption of Hydrazin during the ballistic phase [H2, K2.1]). ARIANESPACE finally confirmed the 5310 kg performance with 3-axis control.
Injection accuracy	not impacted	ARIANESPACE confirmed no impact on injection accuracy.

4.2.2.1 Thermal impact on HERSCHEL if BBQ with A5 ESV upper stage during [H2, K2.1]

BBQ does not allow to satisfy the saa constraints required by Herschel.

Thermal computations made (see RD03.19) indicate that the HERSCHEL MLI can reach temperatures up to 300° C, close to the maximum MLI design temperature of 350° C. As there is a high uncertainty on the modelling and as the small scale effects are not covered by the analysis performed, ASPI considers that the margin of + 50° C is not enough.

As a conclusion:

- The H-EPLM current design is not compatible with a BBQ imposed by the A5 ESV upper stage during [H2, K2.1].
- An alternative design could be the use of cold coating on the MLI outer foil (eg white paint or Kapton). ASED assessed that the use of a cold coating like Kapton would lead to a lifetime reduction of about 200 days.
- **The BBQ with the A5 ESV upper stage during [H2, K2.1] has a strong thermal impact which does not make it a feasible option.**

4.2.2.2 Thermal impact on HERSCHEL if 3-axis control

ARIANESPACE confirmed since SRR that with a 3-axis control during [H2, K2.1]

- the nominal roll attitude is 0° +/- 3° saa throughout the complete 45 min daily launch window
- the maximum excursions from the nominal roll attitude are +/- 13°.

This remains within the ± 23 deg roll allocation during launch phase.

However, this lead to partial illumination of the H-EPLM during this phase, and locally high temperature of the H-EPLM thermal protection. Three solutions have been investigated to protect the H-EPLM from the Sun during [H2, K2.1]:

1. addition of telescope flap
2. SSH/SSD extension of 120 mm
3. local modification of H-EPLM thermal protection by replacing the outer layer by e.g. Kapton.

The best compromise has been found to be the 3^{rd} one.

4.2.2.3 Conclusion

The baseline scenario is based on an A5 ESV upper stage with **3-axis control during [H2, K2.1].**

4.2.3 Compatibility with A5-ECA

The baseline option is the direct injection of HERSCHEL and PLANCK to the L_2 transfer orbit using the A5-ESV launcher (delayed ignition of upper stage).

This section deals with another option of using the A5-ECA launcher for HERSCHEL and PLANCK direct injection. The A5-ECA does not provide the facility of delayed ignition or upper stage. With the nominal A5-ECA ascent trajectory, this results in having the Herschel telescope Sun pointed at fairing separation which was 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 at fairing separation which can be above 60 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 about 1800 kg higher than the one of A5-ESV, providing some margin to cover the effect of the non optimality of the ascent trajectory.

The A5-ECA launcher capability to reach a target orbit as required for the L_2 transfer, by turning the line of apsides in the Earth fixed frame by 15 deg, with an acceptable loss in the final injected mass, has been evaluated.

Note that the Sun aspect angle at fairing separation is a function of two different contributions: the launch time and the launcher axis orientation relative to KOUROU at Fairing ejection. The main parameters of the ascent trajectory for the case of a 15 deg Eastwards shift of the perigee are listed in Table 4.2-2.

Target obit	h_a, km	h_p, deg	inc, deg	ω, deg	Ω_K, deg	mass, kg
Sub-optimum, 15 deg shift	1300000	114	12.7	189	210	6267

TABLE 4.2-2 MAIN PARAMETERS OF THE SUB-OPTIMUM A5-ECA LAUNCH STRATEGY FOR A 15 DEG PERIGEE DISPLACEMENT

For the case of a 15 deg Eastwards shift of the perigee, a full year launch window is open, except for the Equinox periods cut out by the eclipses during transfer.

A six month launch window would require an allocation of about 325 m/sec for the 15 deg Sun-Satellite-Sun angle orbit. Table 4.2-3 summarises the Delta-V allocation for several cases of Sun-Satellite-Sun angle orbits.

Maximum Sun-Satellite-Sun angle, deg	10	**15**	20
Required Delta-V for a 6 months launch window, m/sec	375	**325**	250

TABLE 4.2-3 DELTA-V ALLOCATION OF THE SUB-OPTIMUM A5-ECA LAUNCH STRATEGY FOR A 15 DEG PERIGEE DISPLACEMENT

In conclusion, direct injection by A5-ECA with a perigee shift of 15 deg is an alternative launch strategy which manage the Sun aspect angle constraint imposed by the HERSCHEL payload after fairing separation. An acceptable launch window can be reached for an H155 impact in the Atlantic Ocean with a launch capacity of 6267 kg, and a deterministic propellant allocation of 325 m/sec for PLANCK.

4.2.4 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 backup 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 backup A5 ECA.	None
Allowed propellant growth (SMRC-025 requires at least 20%)	Allowed propellant growth increases: – until 53 % for a baseline 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 a backup A5 ECA launch and a baseline Planck design based on 3 tanks. A Planck design based on 2 tanks would not however make the backup 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 backup 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 for the PDR**.

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/SV (A5-ESV), backup launch vehicle is ARIANE 5 Evolution/CA (A5-ECA).

The driving system constraints are the overall transfer cost and spacecraft mass, the Sun-Satellite-Earth angle, the eclipse avoidance strategy, and the sensitivity with respect to launch day and hour.

4.3.1 Baseline with A5-ESV

Transfer phase baseline is a direct injection on L2 transfer orbit for both spacecraft, launched by A5-ESV in dual launch.

4.3.1.1 Launch Phase Operation Timeline

The baseline ARIANE 5 Launcher is the A5-ESV with a delayed ignition of the EPS upper stage, which can bring 5310 kg in transfer orbit (including adapters). After burn-out of the lower composite, the upper stage and the satellites perform a ballistic phase around Earth of about 107 mn. The upper stage is fired during 17.2 mn at the end of the coast arc to inject successively HERSCHEL and PLANCK towards L_2. Table 4.3-1 gives a timetable for the launch sequence.

TIME	EVENT	DESCRIPTION
T_0	Lift-off (H_0)	
T_0 + 144.9 sec	Acceleration threshold detection (H_1)	
T_0 + 145.7 sec	Booster jettisoning (H_1 + 0.78 sec)	
T_0 + 196.3 sec	Fairing jettisoning (FJ)	HERSCHEL Sun solar aspect constraint applies
T_0 + 539.2 sec	End of EPC thrust phase (H_2)	
T_0 + 545.2 sec	Lower composite jettisoning (H_2 + 6 sec)	
T_0 + 116 mn	End of the coast arc Upper stage ignition ($K_{2.1}$)	Eclipses during coast arc
T_0 + 133.2 mn	Spacecraft separation (H_3)	HERSCHEL is separated in three axis mode, PLANCK is separated in spin mode

TABLE 4.3-1 A5-ESV LAUNCH SEQUENCE

The orbit targeted apogee altitude is around 1300000 km.

For a dual launch, the sequence of events for the spacecraft separations is:

- HERSCHEL separated in three axis mode with Z_S pointed to the Sun
- ARIANE 5 upper stage re-orientation to have $-X_S$ axis Sun pointed
- SYLDA 5 separation

– PLANCK spin-up and ejection.

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 4.4.

Eclipse duration

The maximal eclipse duration during launch is expected to be about 43 min maximum during the coast phase.

Collision analysis

One other important point will be the trajectory analysis of HERSCHEL and PLANCK after the separation, in particular a collision risk analysis will demonstrate that there is no risk of collision between both spacecraft.

A slight and sufficient difference in the semi-major axis will be have to be introduced by the launcher spring separation system. First assessment indicates that, according to the semi-major axis differences, the ejection Delta-V and to the instability of the target point, there is no risk of collision between both spacecraft.

Injection Accuracy

The ARIANE 5 launcher dispersions are determinant for the navigation study. 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.

A first Analysis shows that true anomaly is the driving parameter for inaccuracy due to the Schüler effect. Table 4.3-2 synthesises the results issued from ARIANESPACE which has taken 20% margin on its results. The injection accuracy is the driving parameter, as it dimensions the first orbit correction manoeuvre which takes place two days after the separation. The amplitude of this correction has been estimated to 43.3 m/sec with an updated method generating a Monte-Carlo simulation with re-optimisation of the transfer (save in Delta-V of 20 m/sec compared to a classical navigation study). For the budget, a round-up value of 52 m/sec will be considered for the first orbit correction.

Classical Orbit parameters	Orbit parameters	Estimated dispersions	Estimated dispersions with 20% margin
Semimajor axis a (km)	656493.132	47510	57010
Eccentricity e	0.99	0.000602	0.0007221
apogee (km)	1299995	95010	114020
perigee (km)	235	0.52	0.62
Inclination i (°)	6.107	0.01462	0.01755
Argument of perigee w(°)	110.129	0.249	0.2988
Right ascention of the ascending node W(°)	-120.914	0.2373	0.2847
Mean anomaly M	0.028	0.002521	0.003025

TABLE 4.3-2 A5-ESV INJECTION ACCURACY

4.3.1.2 Attitude during launch (Roll and Pitch control)

One major constraint during the launch is the Sun aspect angle (angle between the Sun and the launcher axis) which must be such as to avoid lighting of the Herschel PLM by the Sun. As soon as the fairing is jettisoned, the point is to ensure that HERSCHEL does not receive any Sun light out of its acceptable range during the launch phase.

Two aspects must be considered:

- the Sun must be close to HERSCHEL [X_S, Z_S] plane to meet the requirement around X_S. This imposes a Roll law for the launcher
- the Sun must be at more than 60 deg from the X_S axis to avoid illumination of the telescope: once proper Roll has been achieved and during propulsive phases, the Sun angle from the X_S axis is imposed by launcher attitude which is derived from mission analysis. During ballistic phase, the launcher is 3-axis stabilised and it is possible to chose the Sun aspect angle.

Until EAP separation which occur before fairing separation, the roll angle is imposed by the launcher. After boosters jettisoning, the payload can impose its Roll Law, allowing correct orientation at fairing jettison. The driving launcher Roll constraint occurs 30 sec before EPC extinction: the EPC attitude must be oriented in order to ensure its atmospheric reentry. The chosen strategy is that, from fairing jettison up to spacecraft separation, the launcher roll is closed to the EPC constraint. Then, the judicious choice of the clocking of the Herschel satellite will ensure the compatibility of this launcher constraint with respect to HERSCHEL constraint.

For a given launch date and hour, the Sun aspect angle constraint can be solved by the Roll law optimisation of the launcher. For a different launch date and launch hour, the roll law is not optimised which introduces a bias with respect to nominal Sun pointing. Last contribution is the Roll attitude control of the EPC. It is controlled inside a deadband which has a nominal width of 25 deg, with a target 13 deg. It was agreed with ARIANESPACE that, over the complete 45 minute daily launch window, the roll control will be such that:

- the nominal roll attitude is 0 $\pm$ 3 deg Sun aspect angle throughout a daily 45 minutes daily launch window
- the maximum excursions from the nominal roll attitude shall be $\pm$13 deg.

This means that the total rotation of the Sun around X_S is 16 deg. This is below the value of 23 deg specified in the EVTR (AD05.2).

Concerning pitch attitude control, the agreement with ARIANESPACE is that:

- Nominal pitch attitude during ballistic phase is 90 deg Sun aspect angle with an allowed range of 90-105 deg through a 45 minutes daily launch window.
- The maximum excursion from the nominal pitch attitude shall be $\pm$ 20 deg.

This ensures that the Sun aspect angle remains between 70 and 125 deg which is compatible with the H-PLM protection by the Sunshield/Sunshade.

4.3.1.3 Launch window and HERSCHEL clock angle definition

4.3.1.3.1 Launch window

The launch window has also been subject to many analyses. As both satellites are launched together, the launch window must be compatible with HERSCHEL and PLANCK, but only PLANCK does really constraint the launch window. HERSCHEL does not introduce any launch window constraint.

The main constraints satisfied by the launch window are described:

- Minimisation of the injection Delta-V on the Lissajous orbit: for PLANCK which needs a reduction manoeuvre to reach the small Lissajous orbit, the Delta-V is limited to 180 m/sec assuming an injection on a Lissajous orbit with a maximum Sun-Satellite-Earth angle of 15 deg.
- The eclipse occurrence on the Lissajous orbit shall be avoided, as they are correlated with injection point on the Lissajous orbit and an eclipse avoidance manoeuvre which is included in the injection Delta-V budget of 180 m/sec
- No eclipse during transfer phase

– ARIANE 5 performance compatibility.

The launch window for a 15 deg orbit is presented in Figure 4.3-1. It has been computed for the whole year 2007 (Jan to Dec). Two periods around Equinoxes are favourable due to the small angle between the transfer orbit inclination and the ecliptic plane:

– from Feb to May 2007

– from Jul to Oct 2007.

The launch window is closed few days around Equinox due to eclipses occurrence. The eclipses occurs during about 30 days for the worst launch hour cases.

The launch window sensitivity for the value of 180 m/sec is greater in terms of hours within a day rather than from a day to another one, due to the relative rotation velocity of the Earth.

The launch hour is between 16:00 and 18:00 UTC, which corresponds to 13:00 to 15:00 in KOUROU local time. The launch window which is compatible with the ARIANE 5 standard launch window daily slot of 45 min. This constraint is satisfied for all the possible days of year 2007.

<u>Summary</u>

A six months launch window is ensured between Feb and Oct 2007. The date and hour of the launch drive the following parameters of HERSCHEL and PLANCK mission:

– the perigee velocity

– the maximum Sun-Satellite-Earth angle in orbit

– the exact time of the insertion manoeuvre for PLANCK

– the date and the amplitude of the eclipse avoidance manoeuvre

– and finally, the size of the reached Lissajous amplitude orbits (in Y and Z).

Thus the overall mission will be strongly dependent on the selected launch date andhour.

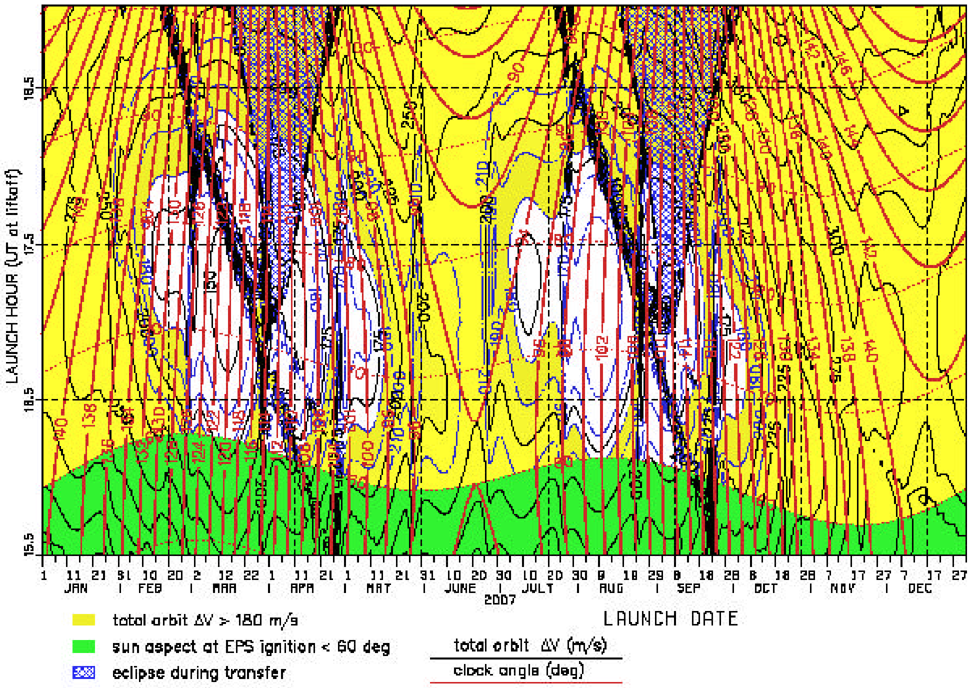


FIGURE 4.3-1 YEAR 2007 LAUNCH WINDOW FOR HERSCHEL AND PLANCK (A5-ESV, 15 DEG ORBIT)

4.3.1.3.2 HERSCHEL clock angle definition

For PDR, a preliminary value for the clock angle of the HERSCHEL spacecraft was defined before full data was received from ESOC.

During launch, the main driver for attitude control in roll is the EPC separation at H_2 time, for which a fixed launcher attitude is imposed to ensure proper EPC re-entry in the Earth atmosphere. The roll control will be such that, from fairing separation up to spacecraft separation, the roll attitude will remain close to the one at H_2. The Figure 4-3.2 explains the clock angle configuration (Y_L and Z_L denotes the launcher axes, while Y_S and Z_S denotes the HERSCHEL spacecraft axes).

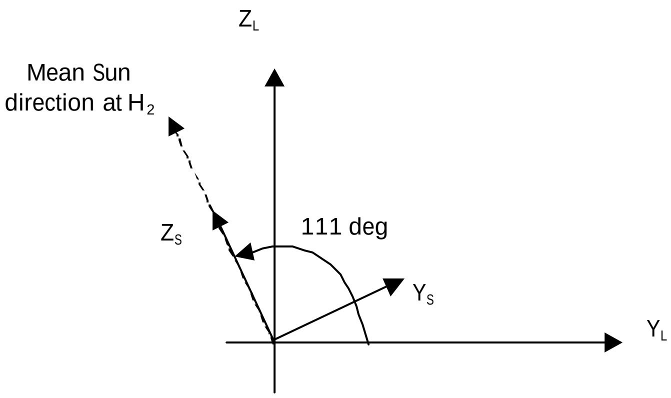


FIGURE 4.3-2 CLOCK ANGLE DEFINITION

Table 4.3-3 presents preliminary results given by ARIANESPACE, concerning the clock angle between launcher Y axis (Y_L) and the Sun at H_2 event. In order to ensure proper protection of the PLM during launch, the spacecraft Z axis (Z_S) has to be oriented in the Sun direction at H_2. Values are provided for the Feb-Apr 2007 launch window, but not for the Jul-Oct 2007 launch window. Note that the quoted value for May 2007 has been linearly extrapolated. A preliminary clock angle value can be defined as the average value 111 deg. This value is the baseline for PDR.

CLOCK ANGLE BY LAUNCH DATE	VALUE AT BEGINNING OF WINDOW	VALUE AT END OF WINDOW
15 Feb 2007	130 deg	125 deg
15 Mar 2007	120 deg	115 deg
15 Apr 2007	108 deg	103 deg
15 May 2007	97 deg	92 deg
Average value over period	114 deg	109 deg

TABLE 4.3-3 CLOCK ANGLE AT H2 EVENT FOR THE FEB-MAY 2007 LAUNCH WINDOW

4.3.1.3.3 A posteriori analysis of the clock angle variation over launch window

The value for clock angle computed by ESOC are given in Figure 4.3-1. It shows that the clock angle varies:

- from 134 down to 98 deg for the Feb-May 2007 launch window
- from 94 up to 124 deg for the Jul-Oct 2007 launch window.

Over the whole launch window, the clock angle varies from 94 to 134 deg, the average value being 114 deg. The baseline defined in previous section (clock angle of 111 deg) fits quite well with this value.

As the iso-clock angle lines are almost vertical, it is difficult to compensate the clock angle variation through launch date by a variation of the launch hour.

A tolerance of ± 23 deg is defined for the roll angle during launch phase. A 114 deg clock angle covers angles from 91 to 137 deg. This means that 3 deg for attitude control at H_2 is available.

4.3.2 Backup with A5-ECA

Transfer phase backup is a direct injection on L_2 transfer orbit for both spacecraft, launched by A5-ECA in dual launch.

4.3.2.1 Launch Phase Operation Timeline

The backup ARIANE 5 Launcher is the A5-ECA, which can bring 7100 kg in transfer orbit (including adapters). The upper stage is fired during 15.7 mn at the end of the coast arc to inject successively HERSCHEL and PLANCK towards L_2. Table 4.3-4 gives a timetable for the launch sequence.

This launch sequence is applicable for an optimised orbit without perigee shift, and shall be refined for the sub-optimal orbit with a 15 deg perigee shift, with a corresponding launch mass of 6267 kg (including adapters).

TIME	EVENT	DESCRIPTION
T_0	Lift-off (H_0)	
T_0 + 141.9 sec	Acceleration threshold detection (H_1)	
T_0 + 142.6 sec	Booster jettisoning (H_1 + 0.78 sec)	
T_0 + 182.6 sec	Fairing jettisoning (FJ)	HERSCHEL Sun solar aspect constraint applies
T_0 + 538.6 sec	End of EPC thrust phase (H_2)	
T_0 + 544.6 sec	Lower composite jettisoning (H_2 + 6 sec)	
T_0 + 551.6 sec	Upper stage ignition (H_2 + 13 sec)	
T_0 + 1493.9 sec	Spacecraft separation (H_3)	HERSCHEL is separated in three axis mode, PLANCK is separated in spin mode

TABLE 4.3-4 A5-ECA LAUNCH SEQUENCE (TYPICAL, WITHOUT PERIGEE SHIFT)

4.3.2.2 Attitude during launch (Roll and Pitch control)

The attitude control constraints for ECA are similar to the one of ES/V. However, due to the absence of ballistic phase, the attitude control in pitch will be imposed by the launcher all along the ascent. Concerning roll control, the same requirements apply as for ES/V:

- the nominal roll attitude is 0 ± 3 deg Sun aspect angle throughout a daily 45 minutes daily launch window
- the maximum excursions from the nominal roll attitude shall be ±13 deg.

from fairing jettison till launcher separation.

4.3.2.3 Launch window and HERSCHEL clock angle definition

4.3.2.3.1 Launch window

The launch window for a 15 deg orbit is presented in Figure 4.3-3. It has been computed for the whole year 2007 (Jan to Dec). As for the A5-ESV case, the Delta-V shading limit in this figure has been taken to represent a 6 month launch window. Four periods are favourable:

- From Jan to Mar 2007
- From Apr to Aug 2007
- From Sep to Oct 2007
- From Nov to Dec 2007.

The launch window is closed few days around Equinox due to eclipses occurrence. The eclipses occurs during about 45 days for the worst launch hour cases.

The launch window sensitivity for the value of 325 m/sec is greater in terms of hours within a day rather than from a day to another one, due to the relative rotation velocity of the Earth.

The launch hour is between 15:00 and 17:00 UTC, which corresponds to 12:00 to 14:00 in KOUROU local time. The launch window which is compatible with the ARIANE 5 standard launch window daily slot of 45 min, but this constraint is not satisfied for all the possible days of year 2007.

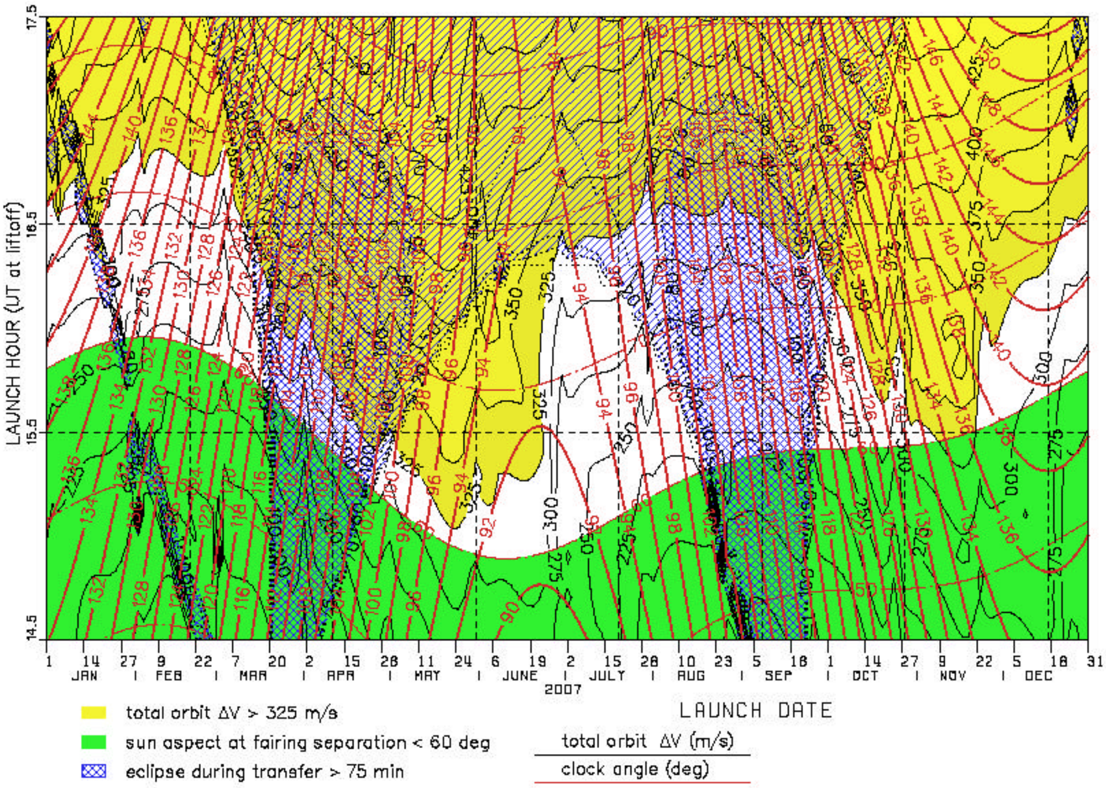


FIGURE 4.3-3 YEAR 2007 LAUNCH WINDOW FOR HERSCHEL AND PLANCK (A5-ECA, 15 DEG ORBIT)

4.3.2.3.2 A posteriori analysis of the clock angle variation over launch window

For the A5-ECA case, the situation is more complex than for A5-ESV. The launch window is split into four phases:

- Jan-Mar 2007: clock angle varies from 144 to 118 deg
- Apr-Aug 2007: clock angle varies between 90 and 102 deg
- Sep-Oct 2007: clock angle varies between 118 and 132 deg
- Nov-Dec 2007: clock angle varies between 132 and 144 deg.

So the variation range over the whole launch window is between 90 and 144 deg, which is larger than the A5-ESV case and above the ± 23 deg roll tolerance.

For A5-ECA it should be checked if the ± 23 deg can be slightly extended. Only a few degrees of additional tolerance can be expected due to, for instance, problems with lighting of LOU.

Also, the launch window covers today more than 6 months, it can also be trimmed with respect to the clock angle constraint.

4.4 Transfer and operational orbit phases

This phases covers the in-orbit phase of the satellites. It begins at satellite separation from launcher and covers the whole nominal lifetime of 3.5 years for HERSCHEL, and 21 months for PLANCK.

4.4.1 Attitude constraints

In this section, attitude modes used during HERSCHEL and PLANCK on-orbit phase are defined. Attitude modes during launch phase are described in Chapter 4.3.

4.4.1.1 HERSCHEL attitude constraints

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 4.4-1.

- 90 ± 30 deg from X_S axis around Pitch axis (Y_S axis)
- 1 deg around Roll axis (X_S axis is the telescope line of sight).

The sunshield 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 ones.

These constraints have top be met during the whole mission, from launcher separation. During launch, the launcher constraints leads to violation of the Sun aspect Angle requirements. Since the SRR, the allowed Sun direction in roll has been reduced from 5 deg down to 1 deg.

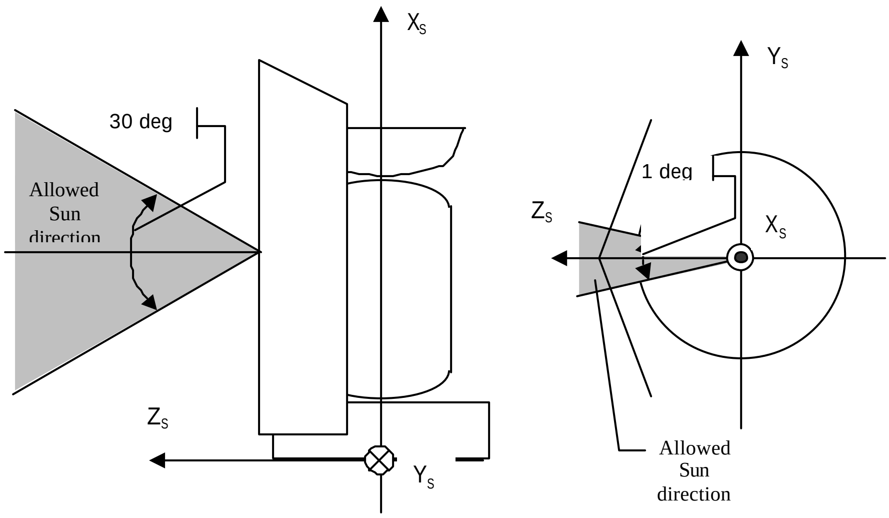


FIGURE 4.4-1 HERSCHEL ATTITUDE CONSTRAINTS

A ± 30 deg rotation is allowed in Pitch (Y_S), while ± 1 deg is allowed in Roll (X_S). The spacecraft is free to rotate around Z_S

4.4.1.2 PLANCK attitude constraints

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 in Figure 4.4-2, 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 in Figure 4.4-3.

Due to the fact that PLANCK is in orbit around L_2, 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 ($-X_S$) and the direction from satellite to Earth has to remain below 15 deg.

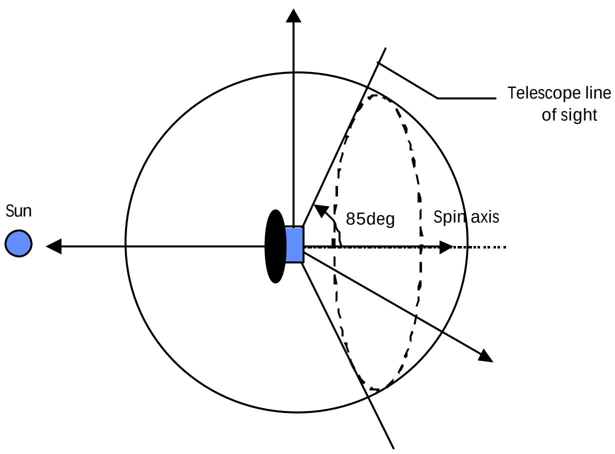


FIGURE 4.4-2 PLANCK OBSERVATION STRATEGY

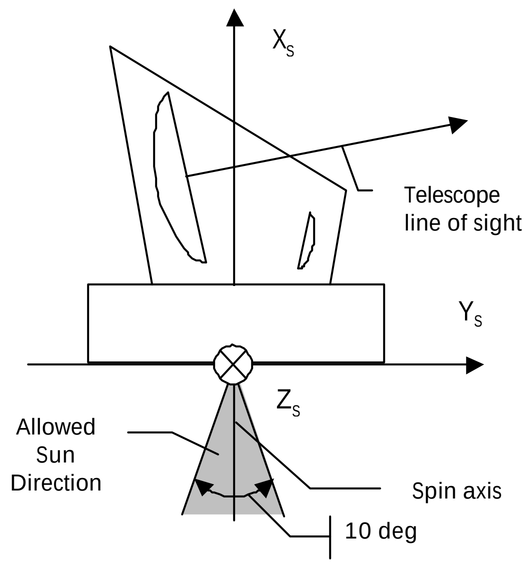


FIGURE 4.4-3 PLANCK ATTITUDE CONSTRAINTS: THE SUN IN CONSTRAINED TO REMAIN WITHIN 10 DEG FROM THE SPIN AXIS

4.4.2 Environment conditions

Environmental conditions are driving constraints for the HERSCHEL - PLANCK mission and operation.

4.4.2.1 Distance to Earth and Moon

Figure 4.4-4 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. The upper curves plots only the transfer phase (about 6 months), and the lower ones plots 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 manoeuvre on day 113 after separation.

HERSCHEL PLANCK

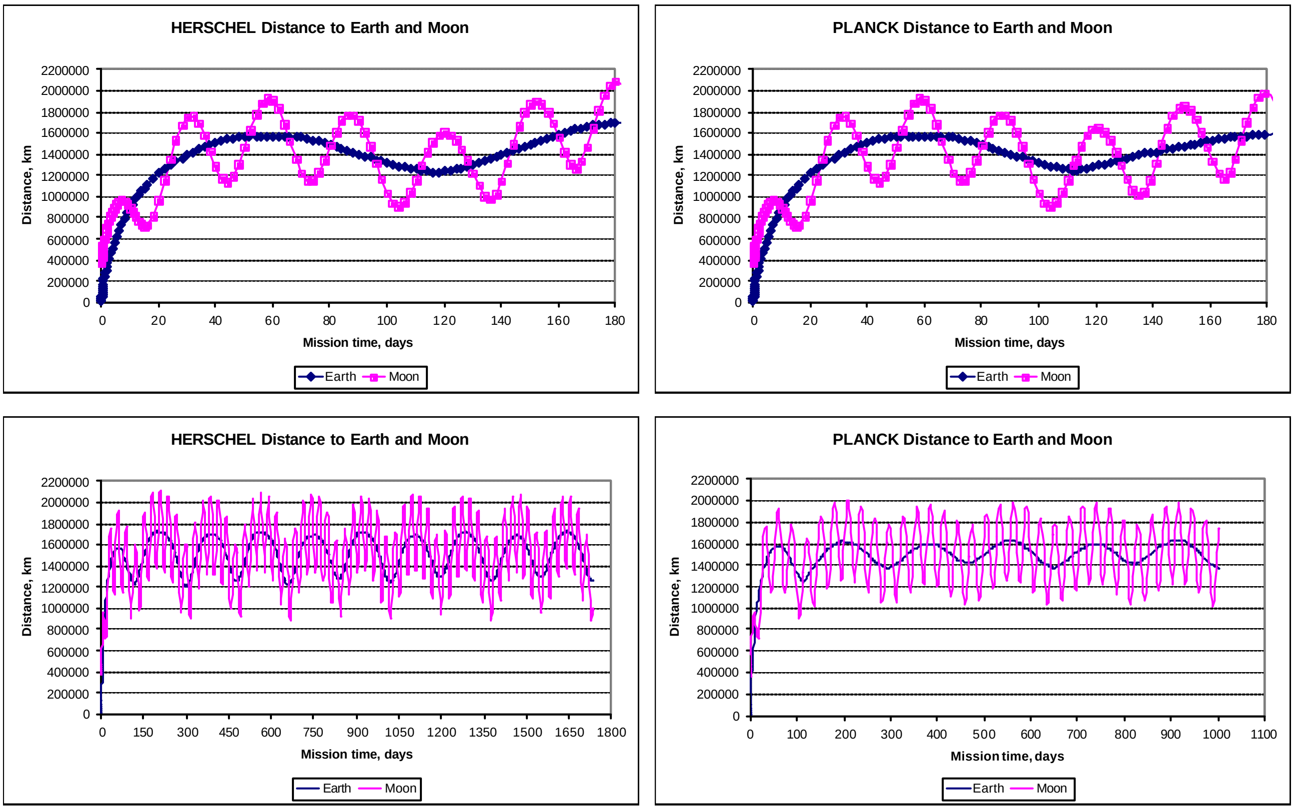


FIGURE 4.4-4 HERSCHEL AND PLANCK DISTANCE TO THE EARTH AND MOON DURING TRANSFER AND ON-ORBIT

4.4.2.2 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 equipments embarked. This angle has to be checked during all the phases of the mission and particularly during the transfer when it is submitted to big variations.

Figure 4.4-5 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.

More precisely, the 15 deg maximum constraint is violated during 72 days, from day 36 to day 108 after separation. The 25 deg maximum constraint is violated during 43 days, from day 54 to day 97 after separation.

HERSCHEL PLANCK

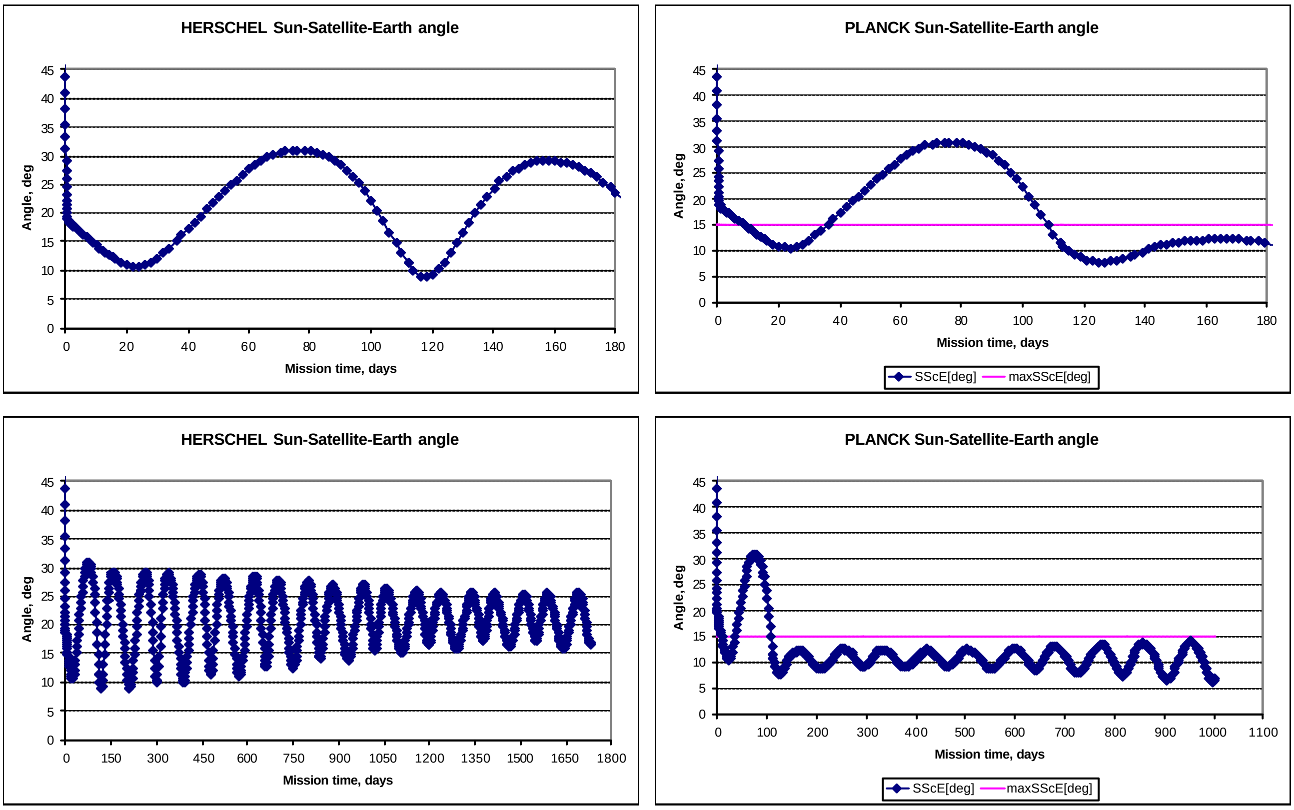
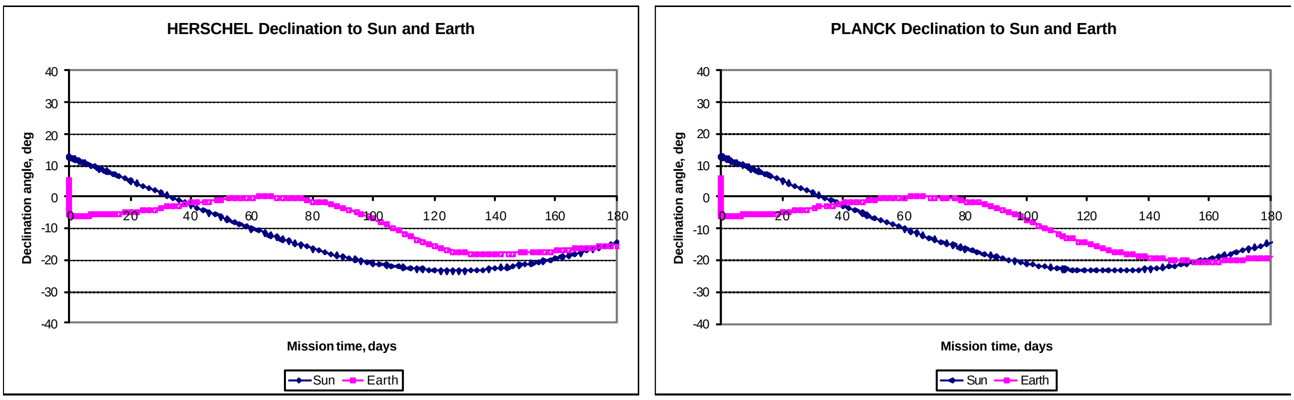


FIGURE 4.4-5 HERSCHEL AND PLANCK SUN-SATELLITE-EARTH ANGLE DURING TRANSFER AND ON-ORBIT

4.4.2.3 Declination to Sun and Earth

Figure 4.4-6 presents the declination to the Earth, which will drive the telecommunications and the radiation and thermal environment, and also the declination to the Moon.

HERSCHEL PLANCK



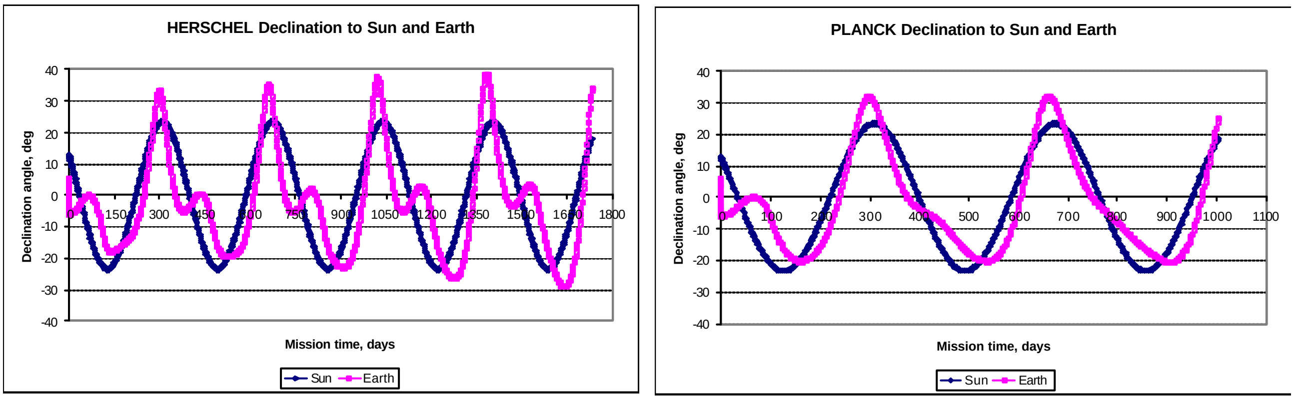


FIGURE 4.4-6 HERSCHEL AND PLANCK DECLINATION TO THE SUN AND EARTH DURING TRANSFER AND ON-ORBIT

4.4.2.4 Synthesis of the environment conditions

Table 4.4-3 summarises the minimum-maximum ranges of values reached by HERSCHEL and PLANCK during the transfer phase (about 6 months of mission) and the on-orbit phase.

SATELLITE		**HERSCHEL**		**PLANCK**	
		Transfer	On-orbit	Transfer	On-orbit
Distance to Earth, km	Maximum	1.69 M	1.73 M	1.59 M	1.63 M
Distance to Moon, km	Minimum	0.37 M	0.88 M	0.37 M	1.02 M
	Maximum	2.05 M	2.11 M	1.98 M	2.00 M
Sun-Satellite-Earth angle, deg	Minimum	8.8	8.7	7.8	6.2
	Maximum	156.0	29.3	156.0	14.1
Declination to Sun, deg	Minimum	-23.4	-23.4	-23.4	-23.4
	Maximum	12.6	23.5	12.6	23.5
Declination to Earth, deg	Minimum	-18.1	-29.0	-20.2	-20.4
	Maximum	5.7	38.7	5.7	32.2

TABLE 4.4-3 SYNTHESIS OF THE ENVIRONMENT CONDITIONS DURING TRANSFER AND ON-ORBIT

4.4.3 Ground coverage analyses

4.4.3.1 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, PERTH and VILLAFRANCA. These stations belong to the ESA network and their locations is illustrated in Table 4.4-4 and Figure 4.4-7. The minimum elevation mask is taken equal to 5 deg for each station.

GROUND STATION	KOUROU	PERTH	VILLAFRANCA
Longitude, deg	-52.63	115.88	-3.95
Latitude, deg	5.10	-30.20	40.45
Min. elevation, deg	5	5	5

TABLE 4.4-4 GROUND STATIONS NETWORK LOCATION

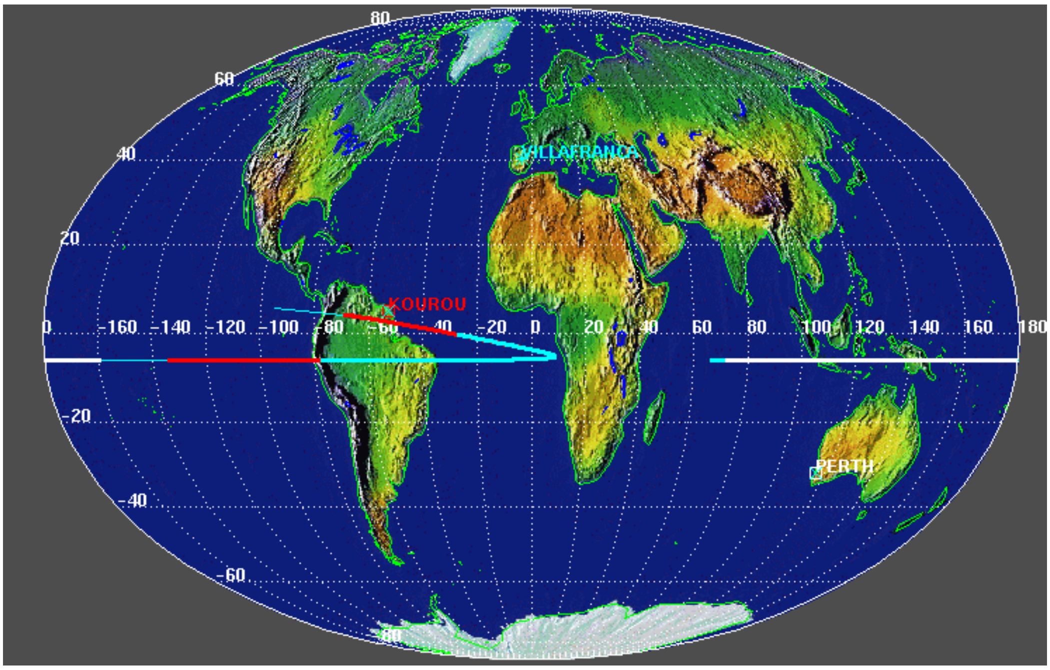


FIGURE 4.4-7 GROUND STATIONS COVERAGE DURING TRANSFER

<u>Satellite motion in the Local Tangent Coordinate System</u>

A natural coordinate system for describing the motion of satellite with respect to a ground station is the *topocentric or local tangent* coordinate system. For a given point on Earth, it is aligned with the local horizontal plane, i.e. with the plane that is tangential to the surface of the Earth at that point. Commonly, three orthogonal units vectors LE, LN and LZ pointing to the local East, North and Zenith directions, are employed to define the reference axes of the local tangent coordinate system for a given station. As illustrated in Figure 4.4-8, the vectors LN and LE are aligned with the meridian and the parallel of latitude passing through the station, while LZ is perpendicular in the direction away from the centre of Earth.

FIGURE 4.4-8 SATELLITE MOTION IN THE LOCAL TANGENT COORDINATE SYSTEM

For the description of antenna pointing directions, the Cartesian coordinates are commonly supplemented by the azimuth and elevation angles. The azimuth gives the angle between the projection of the station-satellite vector on the horizontal plane and the North direction. It is counted positively from the North to the East. The elevation, on the other hand, describes the angle between the topocentric satellite vector and the horizontal plane.

Longitude interval visible by a station (simplified model of geometric visibilities)

The satellite is visible by a station only if its elevation is greater than the minimum elevation. Let express the longitude difference $\Delta\lambda$ such that this condition of visibility is satisfied:

$$El > El_{min}$$

$$| \lambda_{sat} - \lambda_{station} | < \Delta\lambda$$

The longitude visibility half-range is given by:

$$\cos \Delta\lambda = [(r_{Earth}/r_{sat}) \cos^2 El_{min} [1 - (r_{Earth}/r_{sat})^2 \cos^2 El]^{1/2}$$

$$- \sin \varphi_{station} \sin \varphi_{sat}]/(\cos \varphi_{station} \cos \varphi_{sat})$$

Where:

- $(\lambda_{sat}, \varphi_{sat})$: longitude and latitude of the sub-satellite point
- $(\lambda_{station}, \varphi_{station})$: longitude and latitude of the ground station
- r_{sat}: distance from Earth center to the satellite point (satellite radius)
- r_{Earth}: Earth radius at Equator (6378.14 km)
- El: elevation angle of the satellite point
- El_{min}: minimum elevation angle for visibility (typical value in the 5 to 10 deg range).

4.4.3.2 HERSCHEL and PLANCK visibility by KOUROU

Figure 4.4-9 plots the motion of HERSCHEL and PLANCK during the first week of mission in the KOUROU local tangent coordinate system, including the components and modulus of the position, velocity and acceleration vectors. The plots are the same for Herschel and Planck as the initial trajectories are identical.

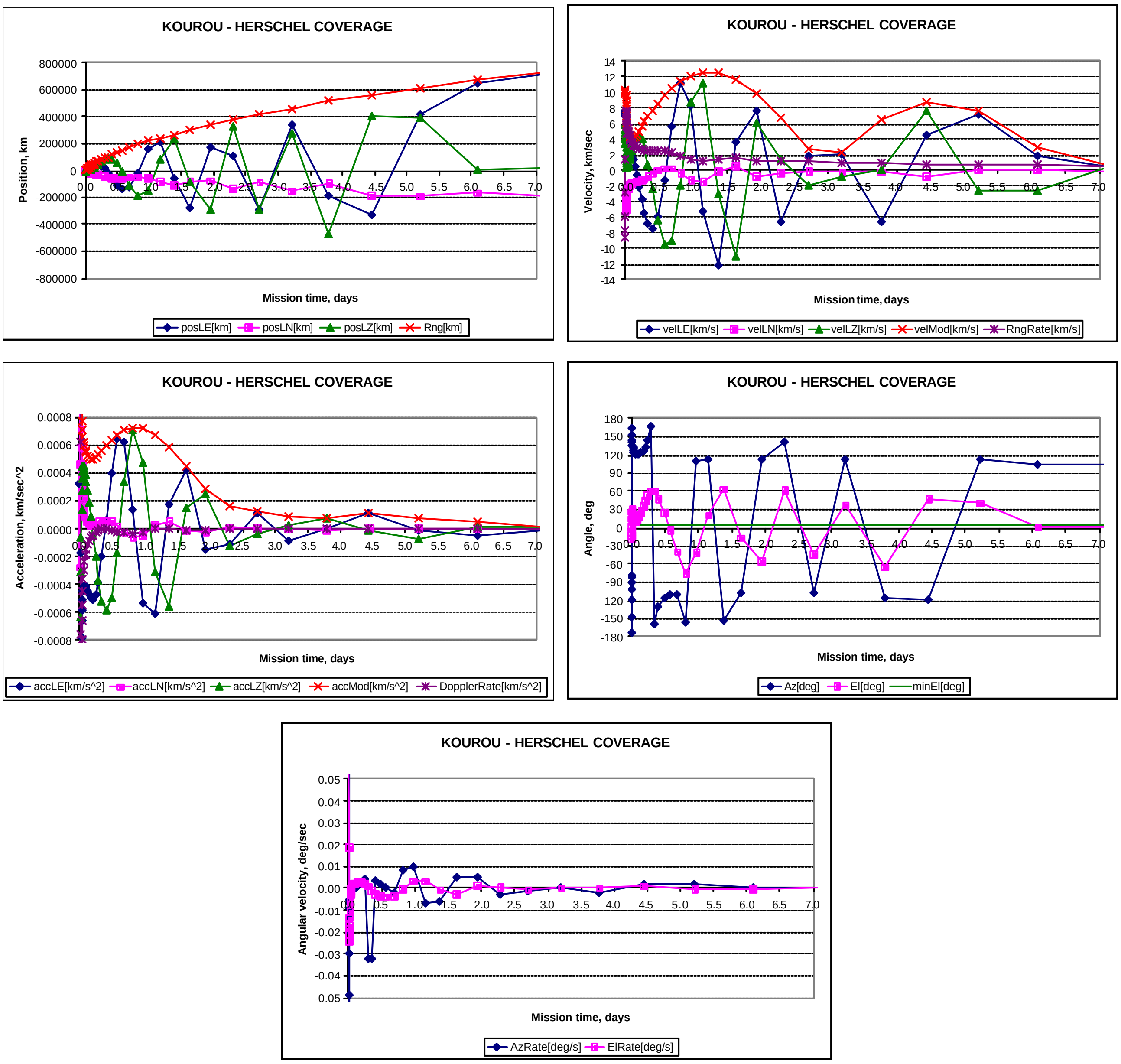


FIGURE 4.4-9 SATELLITE MOTION IN THE KOUROU LOCAL TANGENT FRAME DURING FIRST WEEK OF TRANSFER

Figure 4.4-10 show the duration of the visibility intervals on-orbit of HERSCHEL and PLANCK by the KOUROU station.

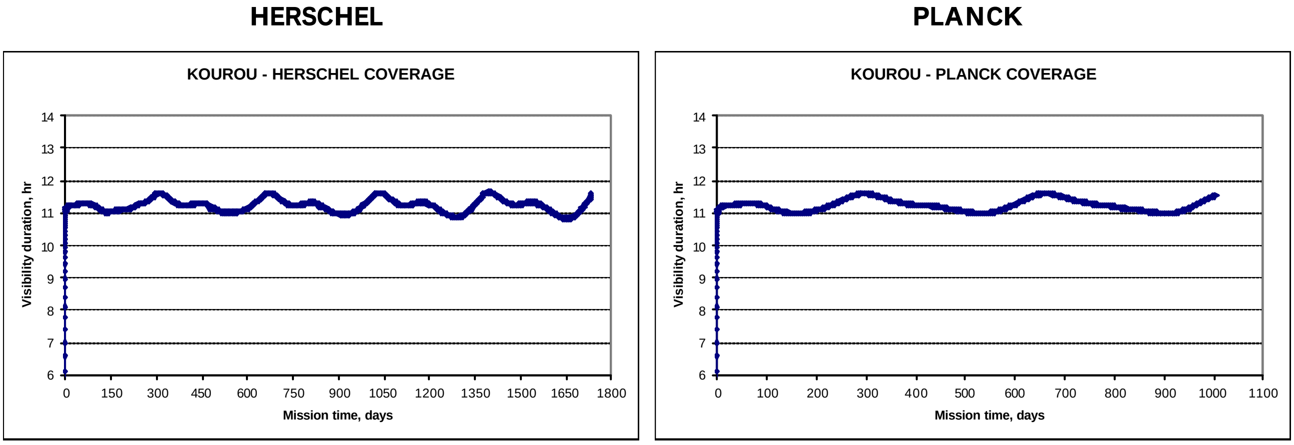
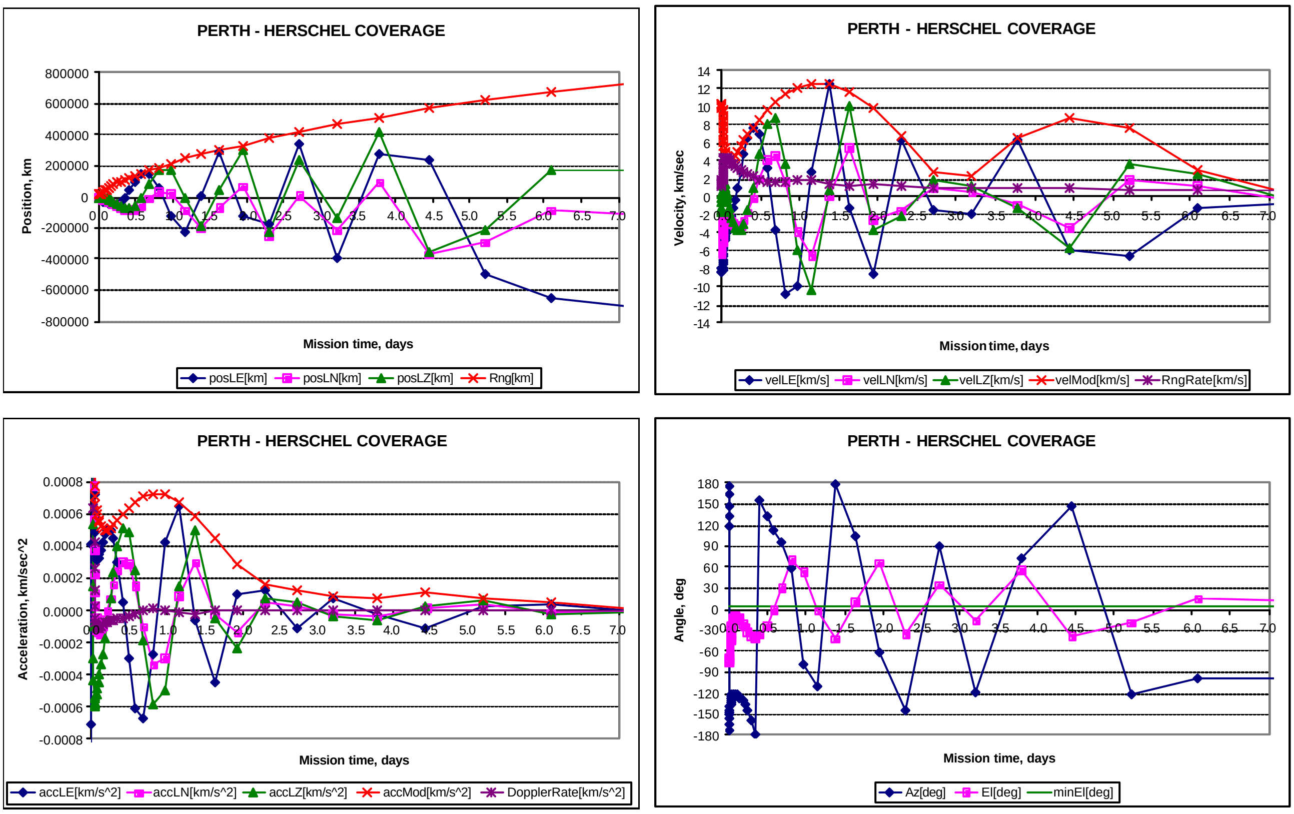


FIGURE 4.4-10 COVERAGE BY KOUROU ON-ORBIT

4.4.3.3 HERSCHEL and PLANCK visibility by PERTH

Figure 4.4-11 plots the motion of HERSCHEL and PLANCK during the first week of mission in the PERTH local tangent coordinate system, including the components and modulus of the position, velocity and acceleration vectors. The plots are the same for Herschel and Planck as the initial trajectories are identical.



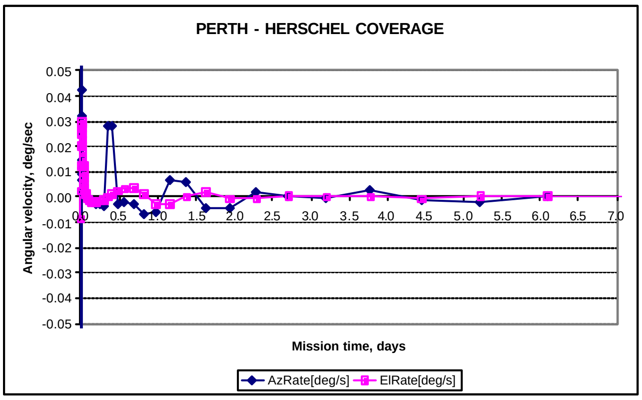
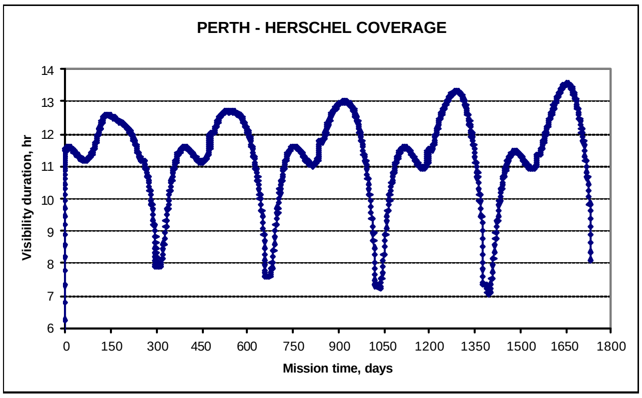


FIGURE 4.4-11 SATELLITE MOTION IN THE PERTH LOCAL TANGENT FRAME DURING FIRST WEEK OF TRANSFER

Figure 4.4-12 show the duration of the visibility intervals on-orbit of HERSCHEL and PLANCK by the PERTH station.

HERSCHEL **PLANCK**



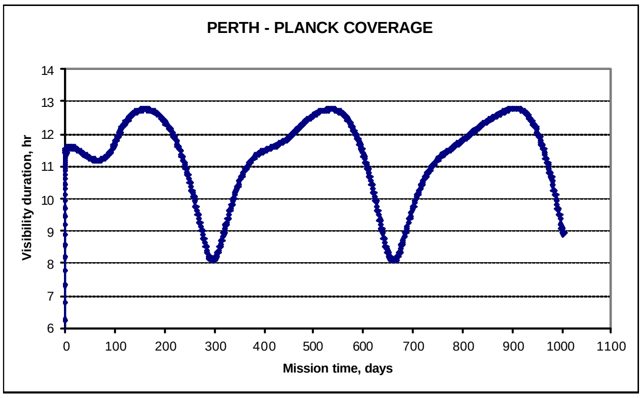
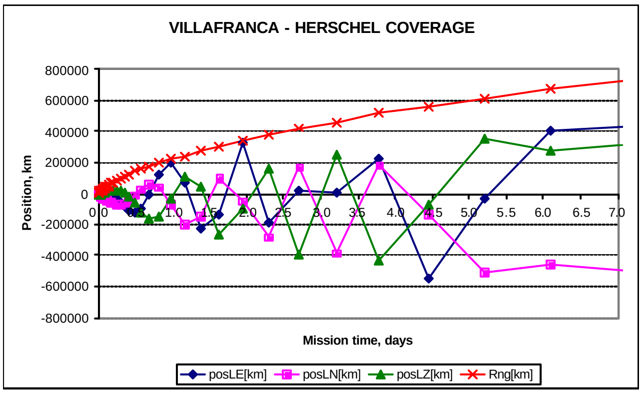
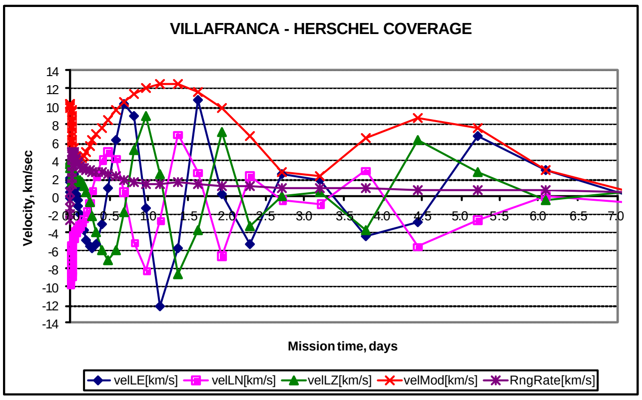


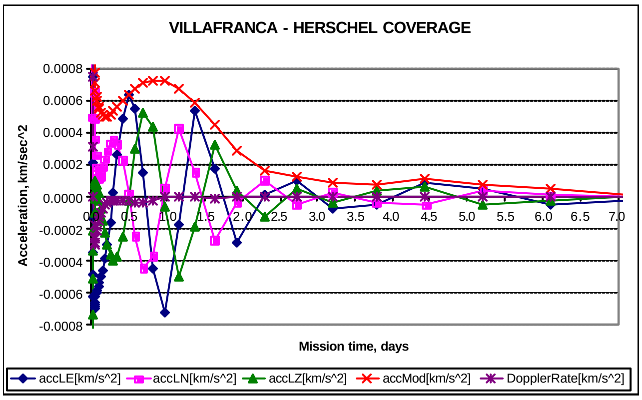
FIGURE 4.4-12 COVERAGE BY PERTH ON-ORBIT

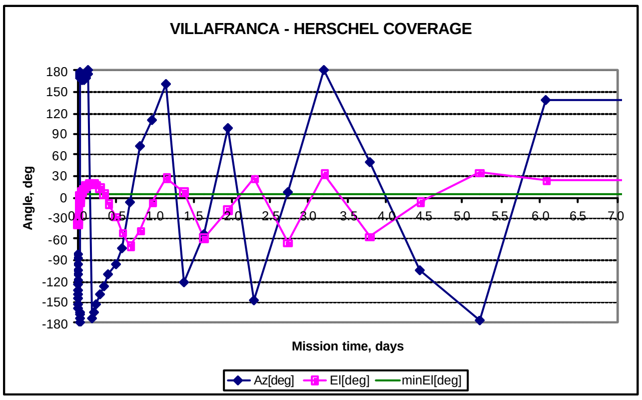
4.4.3.4 HERSCHEL and PLANCK visibility by VILLAFRANCA

Figure 4.4-13 plots the motion of HERSCHEL and PLANCK during the first week of mission in the VILLAFRANCA local tangent coordinate system, including the components and modulus of the position, velocity and acceleration vectors. The plots are the same for Herschel and Planck as the initial trajectories are identical.









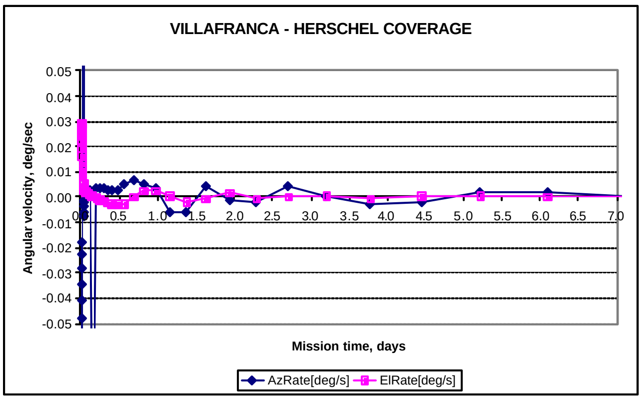


FIGURE 4.4-13 SATELLITE MOTION IN THE VILLAFRANCA LOCAL TANGENT FRAME DURING FIRST WEEK OF TRANSFER

Figure 4.4-14 show the duration of the visibility intervals of HERSCHEL and PLANCK on-orbit by the VILLAFRANCA station.

HERSCHEL **PLANCK**

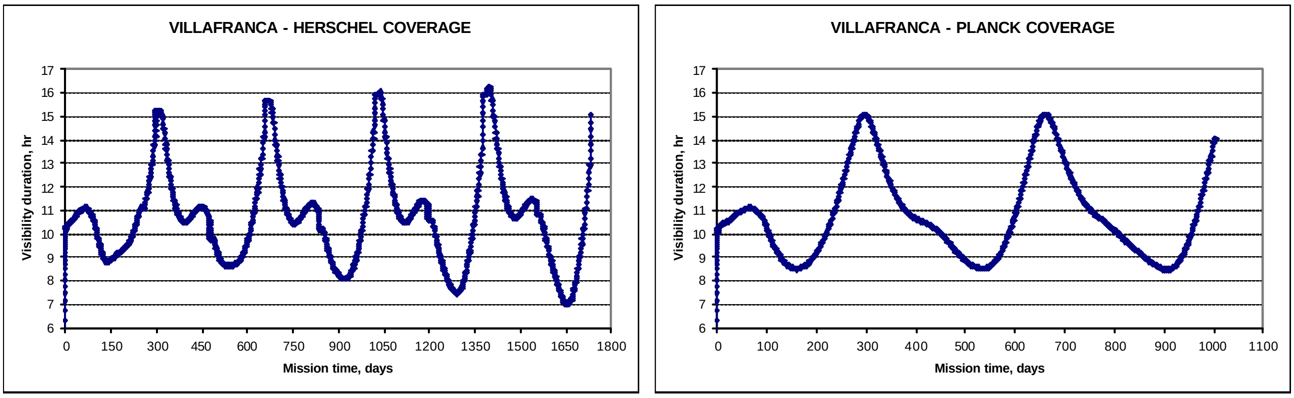


FIGURE 4.4-14 COVERAGE BY VILLAFRANCA ON-ORBIT

4.4.3.5 Synthesis of the visibility analysis

Table 4.4-5 summarises the minimum-maximum ranges of values reached by HERSCHEL and PLANCK during the beginning of the transfer phase (first week) for range, Doppler and Doppler rate. Notice that these ranges of values are reaching extreme values at beginning of mission.

GROUND STATION		KOUROU	PERTH	VILLAFRANCA
Distance from station, km	Minimum	1906	12471	7875
	Maximum	0.73 M	0.73 M	0.73 M
Range rate, km/sec	Minimum	-8.56	0.67	-2.55
	Maximum	7.69	4.38	5.11
Doppler rate, km/sec ^ 2	Minimum	-0.0015	-0.0001	-0.0003
	Maximum	0.0394	0.0018	0.0088

TABLE 4.4-5 SYNTHESIS OF RANGE AND RANGE RATE DURING FIRST WEEK OF TRANSFER

The left part of Figure 4.4-15 show the ground stations coverage intervals for the three ground stations during the first week of transfer. On first day of mission, the coverage is globally ensured by the ground network, with the exception of a visibility gap starting 13 hours after launcher separation, and lasting 1 h 40 mn later. Due to a daily repeat cycle, this situation is repeated the following days.

During all the transfer phase, the coverage is ensured successively by one of the three ESA ground stations for a duration of about 10 to 12 hours, which will allow the monitoring of the satellite, the commanding of the attitude and orbit correction manoeuvres, as illustrated in the right part of Figure 4.4-15.

The ground station visibility during the on-orbit phase is ensured by PERTH. On Lissajous orbit, the coverage is available around 7 to 13.5 hours per day during the Mission. Figure 4.4-16 shows the coverage period from PERTH ground station for HERSCHEL and PLANCK. The minimum elevation is taken equal to 5 deg for this computation, if this value is changed to 10 deg, the visibility duration is reduced to about little more than one hour.

Note that the minimum communication time requirement during the on-station phase (at least 2 x 3 hours of visibility per day for HERSCHEL and PLANCK) is satisfied with the PERTH ground station, even at worst time of mission (around day 300 and day 650 after separation) where the minimum visibility duration is reached (about 7.5 hours).

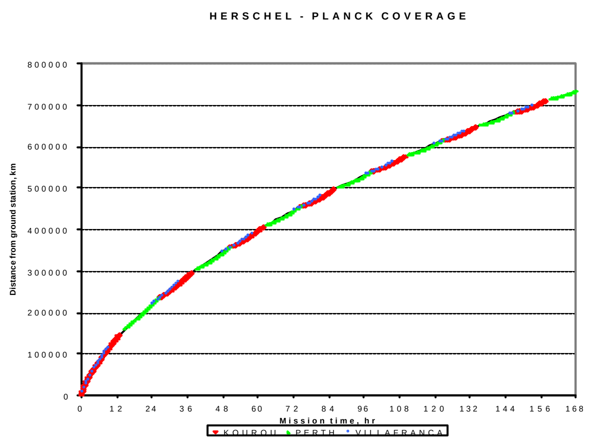


FIGURE 4.4-15 GROUND STATIONS VISIBILITY DURING FIRST WEEK OF TRANSFER

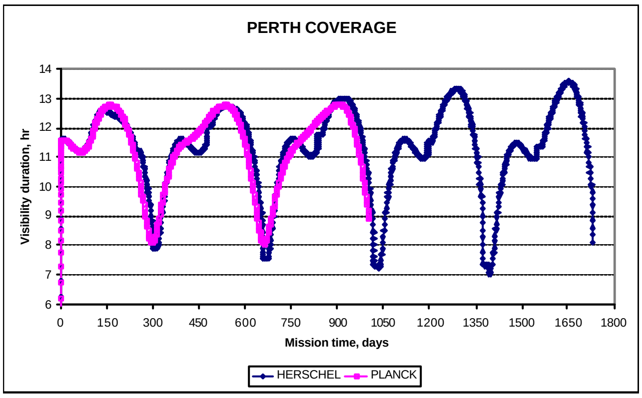


FIGURE 4.4-16 PERTH COVERAGE DURING THE MISSION

4.4.4 Orbit acquisition and maintenance

4.4.4.1 Baseline with A5-ESV

4.4.4.1.1 Orbit correction manoeuvres

The orbit correction manoeuvres have been computed with the assumptions described hereafter. Few manoeuvres have been scheduled as presented in Table 4.4-6.

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. The main hypothesis of the computation are:

- Launcher performances as given in previous section (including a 20% margin)
- Orbit Determination accuracy (typical data)
- Manoeuvre execution error less than 1% in size and 1 deg in pointing at 1 sigma
- Solar radiation bias error of 10%.

All the orbit manoeuvres are considered inertial for HERSCHEL and PLANCK.

DATE	DELTA-V (M/SEC)	PURPOSE	SOLAR ASPECT ANGLE
T_0 + 2 hours	5	Launcher interface	[0-180] deg
T_0 + 2 days	52	Remove launcher dispersions	[0-180] deg
T_0 + 12 days	4	Remove first manoeuvre execution error	[0-180] deg
$T_{injection}$ – 20 days	3	Remove accumulated error during cruise and fine targeting	[0-180] deg
$T_{injection}$ (PLANCK only)	187.5	Lissajous orbit manoeuvre (specification for 6 months launch window)	125 deg
$T_{injection}$ + 2 days (PLANCK only)	5	Remove injection manoeuvre execution error	28.4 or 208.4 deg

TABLE 4.4-6 HERSCHEL AND PLANCK ORBIT CORRECTION MANOEUVRES (T0: LIFT-OFF) (A5-ESV, 15 DEG ORBIT)

4.4.4.1.2 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 4.4-17).

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.

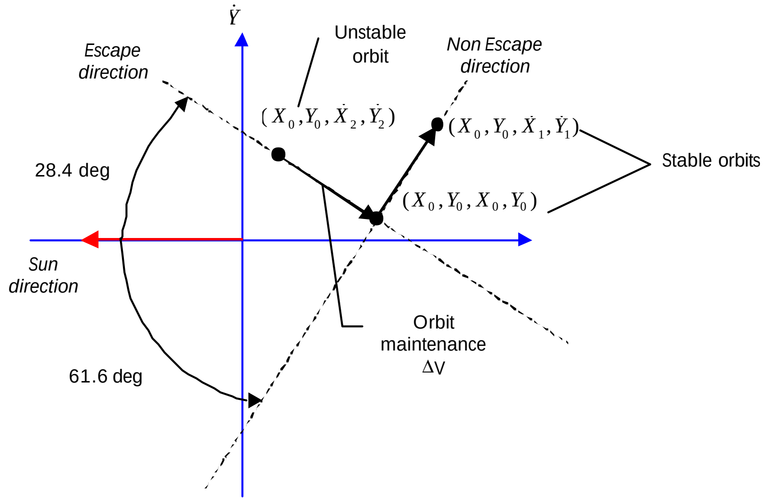


FIGURE 4.4-17 ESCAPE AND NON-ESCAPE DIRECTIONS IN THE XYZ EARTH ROTATING FRAME

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 values of 6 m/sec for HERSCHEL, and 2.5 m/sec for PLANCK have been selected for all their mission duration.

4.4.4.1.3 Mission Delta-V budget

This paragraph synthesises the Delta-V results for both spacecraft and both strategies 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 described in Section 4.4.5.1.1, and also the orbit maintenance contribution explained in Section 4.4.5.1.2.

Table 4.4-8 present the Delta-V budgets for HERSCHEL and PLANCK for the direct injection scenario with the A5-ESV 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 + 2 hr	5	5	[0-180] deg
Removal LV dispersions Day 2	52	52	[0-180] deg
Manoeuvre 2 Day 12	4	4	[0-180] deg
Mid course corrections $T_{injection}$ – 20 days	3	3	[0-180] deg
Orbit injection ECL avoidance 85 to 125 days	0	187.5	125 deg
Correction for injection $T_{injection}$+ 2 days	0	5	28.4 or 208.4 deg
Orbit maintenance for specified lifetime	6	6	28.4 or 208.4 deg
Total	**70**	**262.5**	

TABLE 4.4-8 DELTA-V BUDGET FOR HERSCHEL AND PLANCK (A5-ESV, 15 DEG ORBIT)

4.4.4.2 Backup with A5-ECA

4.4.4.2.1 Orbit correction manoeuvres

The orbit correction manoeuvres have been computed with the assumptions described hereafter. Few manoeuvres have been scheduled as presented in Table 4.4-9.

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. The main hypothesis of the computation are:

- Launcher performances as given in previous section (including a 20 % margin)
- Orbit Determination accuracy (typical data)
- Manoeuvre execution error less than 1 % in size and 1 deg in pointing at 1 sigma
- Solar radiation bias error of 10 %.

All the orbit manoeuvres are considered inertial for HERSCHEL and PLANCK.

DATE	DELTA-V (M/SEC)	PURPOSE	SOLAR ASPECT ANGLE
T_0 + 2 hours	5	Launcher interface	[0-180] deg
T_0 + 2 days	40	Remove launcher dispersions	[0-180] deg
T_0 + 12 days	4	Remove first manoeuvre execution error	[0-180] deg
$T_{injection}$ – 20 days	3	Remove accumulated error during cruise and fine targeting	[0-180] deg
$T_{injection}$ (PLANCK only)	312.5	Lissajous orbit manoeuvre (specification for 6 months launch window)	125 deg
$T_{injection}$ + 2 days (PLANCK only)	5	Remove injection manoeuvre execution error	28.4 or 208.4 deg

TABLE 4.4-9 HERSCHEL AND PLANCK ORBIT CORRECTION MANOEUVRES (T0: LIFT-OFF) (A5-ECA, 15 DEG ORBIT)

4.4.4.2.2 Orbit maintenance strategy

The orbit maintenance strategy applied is the same than for the Baseline option with A5-ESV. Refer to Section 4.4.5.1.2.

4.4.4.2.3 Mission Delta-V budget

This paragraph synthesises the Delta-V results for both spacecraft and both strategies 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 described in Section 4.4.5.2.1, and also the orbit maintenance contribution explained in Section 4.4.5.2.2.

Table 4.4-10 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 + 2 hr	5	5	[0-180] deg
Removal LV dispersions Day 2	40	40	[0-180] deg
Manoeuvre 2 Day 12	4	4	[0-180] deg
Mid course corrections $T_{injection}$ – 20 days	3	3	[0-180] deg
Orbit injection ECL avoidance 85 to 125 days	0	312.5	125 deg
Correction for injection $T_{injection}$+ 2 days	0	5	28.4 or 208.4 deg
Orbit maintenance for specified lifetime	6	2.5	28.4 or 208.4 deg
Total	**58**	**372**	

TABLE 4.4-10 DELTA-V BUDGET FOR HERSCHEL AND PLANCK (A5-ECA, 15 DEG ORBIT)

4.4.5 Communication aspects

This sections derives the requirements on the antennas from the environment conditions of Section 4.4.2.

4.4.5.1 Observation phase

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 nominally oriented along the spacecraft Z axis.

The maximum angle between antenna axis and the Earth direction can be derived from the maximum SSCE of 40 deg combined with the spacecraft ability to have its Z axis at ± 30 deg for the Sun direction. The Figure 4.4.5-1 shows that the Earth can be at up to 10 deg from antenna axis.

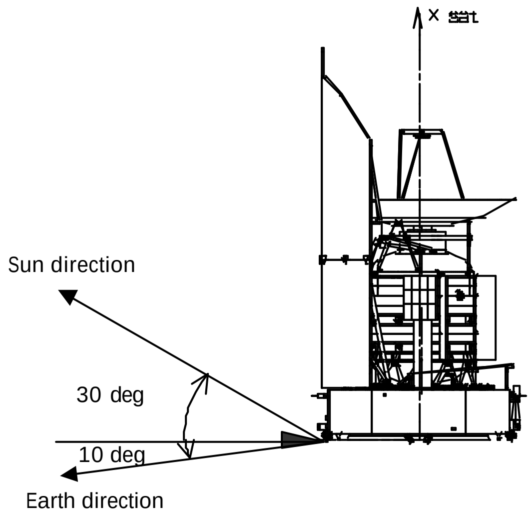


FIGURE 4.4.5-1 HERSCHEL COMMUNICATION WITH EARTH

The baseline MGA has a half cone aperture of 15 deg. This means that if the SCCE is above 30 deg, the 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 4.4.5-2.

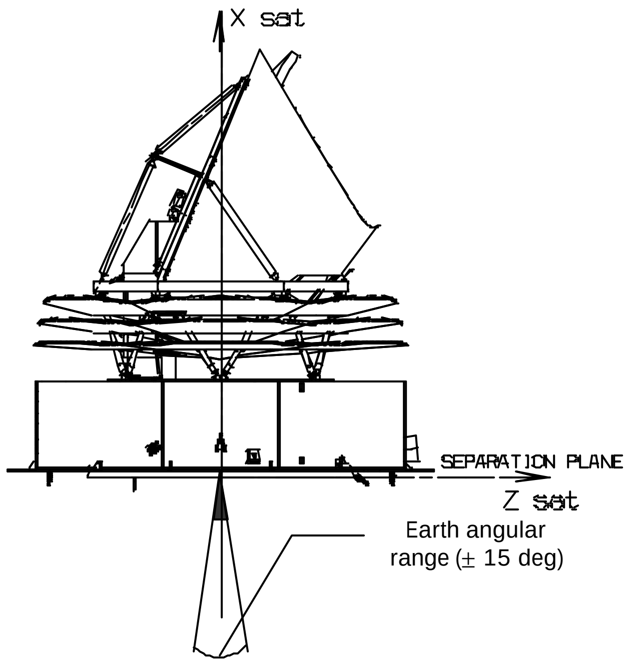


FIGURE 4.4.5-2 PLANCK COMMUNICATION WITH EARTH

4.4.5.2 Transfer phase

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 32 deg. This is not a problem for Herschel but it will limit the data transfer capability with Planck:

- SSCE is above 20 deg from day 44 to day 104, meaning 60 days without the possibility to have contact with Kourou at medium rate
- SSCE is above 25 deg from day 54 to day 97, meaning 43 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). This means that from day 44 to day 54, Performance verification can continue using New Norcia. The same applies for the period from day 97 to day 104. This means that Performance verification phase will be interrupted for 43 days. Taking into account a 2 months duration for this phase it will still finish before the 6 months allocated for transfer phase.

5. PAYLOAD INTERFACE REQUIREMENTS

5.1 General

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 LFI (+ sorption cooler)+ HFI for Planck.

These requirements are described in the PDR version of the IID-B's. These version were reviewed by instruments, ESA and industry, and correspond to a set of agreed interface requirements.

- SPIRE IID-B 2.2 (SCI-PT-IIDB 02124)
- PACS IID-B 2.1 (SCI-PT-IIDB 02126)
- HIFI IID-B 2.2 (SCI-PT-IIDB 02125)
- HFI IID-B 2.1 (SCI-PT-IIDB 04141)
- LFI IID-B 2.1 (SCI-PT-IIDB 04142)
- Sorption cooler ICD 2.1 (PL-LFI-PST-ID-002) annexed to LFI IID-B

The definition of the instruments in these documents corresponds to the IBDR's (Instrument Baseline design reviews) which took place around March-April 2002. Industry reviewed the data-packages, and participated to these reviews.

The first part of this section (§ 5.1) will compare the main satellite allocations compatible with the current design at PDR with the instrument demands.

In the second part is described the status of the interfaces for HERSCHEL (§ 5.2) and Planck (§ 5.3).

5.1.1 Evolution of Instrument and satellite design

5.1.1.1 Interface documentation

The satellite configuration proposed as response to the ITT was compatible with the instruments interfaces definition described in the IID-B 1.0.

At the SRR, ESA published a version 2.0 of the IID's, reflecting the evolution of the instruments between the ITT, and the SRR. However, as the changes of the instruments were significant, industry could not commit to these new interfaces, and the interface documents were not agreed by industry. However, they were used as engineering baseline. After SRR, it was decided to manage IID evolution in full configuration control. However, because of the large number of changes and the relative slowness of the process, this was not very effective. To reach an agreed and consistent set of interface documents for the PDR, the method has been adapted:

For IID-B's, after discussion and agreement (Instrument, industry, ESA), instrument evolution with cost or schedule impact for industry are processed using the change process while the other changes are directly updated as redline copy of the interface document (version 2.1 or 2.2).

For IID-A, as it required a large number of updates to describe the PDR design of Herschel & Planck, a redline version 3.0 is proposed to instrument.

At PDR, the design and the set of interface documents are consistent.

5.1.1.2 Main instrument evolution

Since the SRR, the instrument design has continued in parallel with the spacecraft development, leading to the IBDR (Instruments Baseline Design Reviews) taking place around March-April 2002.

The main instrument evolutions which have influences on the interfaces are:

All Instruments

- Growth of the warm units (all instruments), associated to a reduction of the allocated areas on the SVM (assembly and integration constraints), leading to an accommodation crisis. This was solved by a set of technical meetings with all instruments resulting in a doable accommodation.
- Increase of mass and power (all instruments), see budget section below.
- Increase of the Data-rate requirement.
- Delay of the instrument CQM and FM delivery dates by 6 months (+ 11 months for the CQM sorption cooler).

Planck

- Introduction of a Planck HFI 4K Cooler current regulator to smooth the 40Hz cooler power peaks of the 4K compressor.
- Merging of HFI "fill & vent panel" and "Dilution control electronics DCE" into a single DCCU (Dilution Cooler Control Unit).
- Modification of the Dilution Helium exhaust (from spin axis to T piece directly on DCCU via mouse hole in SVM panel).
- Reduction of Planck LFI from 16 to 12 radiometers, after a not yet concluded funding crisis. Split of the BEU into BEU and DAE power box.
- New LFI Wave-guide support structure.
- Reduction of the Planck sorption cooler power demand from 655W to 570W.
- Modification of the number of LCL to the HFI REU (from 2 to 11 to 6).

Herschel

- Modifications/refinement of the cryoharness definition & electrical requirements.
- Change of the HIFI wave guide responsibility from HIFI to ASTRIUM.
- After several iterations, the HIFI radiator remains finally at HIFI, but interfaces (mechanical & thermal) with the ASTRIUM provided CVV LOU support Frame (and not directly to the LOU, as it should do).
- HIFI: the HRI doesn't exist any more, the 3dB couplers have moved from FPU to ICU then to independent units.
- SPIRE: the DRCU splits to DCU & FCU.
- PACS SPU are to be stacked to allow accommodation.

5.1.2 *Instrument accommodation*

The main activities of the Phase B was to define or refine the instrument accommodation inside the spacecraft (SVM & PLM) taking into account the evolution of the instruments, refinement of the spacecraft definition, while insuring the compatibility of all interfaces.

5.1.2.1 Warm units accommodation

From the outline proposed by ALCATEL at the SRR, ALENIA has refined the instrument warm units accommodation inside the SVM's, together with the instrument warm interconnecting harness routing (warm units interconnections), the SVM harness (Power, data and clock links), the Herschel cryo-harness warm interface (from ASTRIUM), the Planck instruments cryo-harness, and the Planck cooler pipes.

There is a current commonly agreed configuration which is described in the annex 5 of the IID-A 3.0 (ICD's) and more detailed in the ALENIA design report (RD 1.1), 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 SRR configuration are:

- the distribution of the 2 HIFI panels between polarisation rather than between spectrometers
- the stacking of the PACS SPU
- the containment of non yet frozen units into agreed frozen volume and interfaces (PACS DECMEC, HFI 4K current regulator & DCCU).

5.1.2.2 Herschel FPU accommodation and CVV attached items

The Herschel FPU and warm units accommodation are described in the IID-A 3.0 (Section 5.3.1.1, 5.6.1, and annex 6 for ICD's) ASTRIUM design report (RD 1.2), and in the Herschel MTICD (AD 07.4)

The main modification since SRR is the definition of thermal straps interfaces to Level 0, 1 and 2, the modification of the routing of the He loop (Level 2 is now attached to the Optical bench). As the heat loads on the cooling level has significantly increased, one still on going modification is to thermally insulate the SPIRE JFET boxes from the optical bench and connect it to the vent line, to reduce the Optical bench temperature.

The position of the PACS BOLS has also moved from the –Z side to +Z side (beneath the Solar Array) to reduce the length of the cryo-harness, and is directly bolted to the CVV (lower dissipation). We still hope that the BOLA will not be needed by PACS (option)

5.1.2.3 Planck FPU 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 the fact that the LFI RAA (including LFI + HFI cryogenics FPU's at the focal plane, together with the LFI BEU on the SVM upper platform linked together with the LFI wave-guides and harness) is a single deliverable.

The new element is the need of a wave-guide structure which makes this interface highly complex. Second driver is accommodation of all instrument cooler pipes and heat exchangers (20K, 4K and 0.1K).

5.1.3 Instrument budgets and satellites resources

5.1.3.1 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.

5.1.3.2 Instruments budgets & associated Satellite resource allocation

In the following chapter, we propose the resources that we can allocate to the instruments (as updated in the IID-A 3.0) and compare them to the current instrument demand as reflected in the latest IID-B 2.1/2.2.

During Phase B, there was a clear tendency to increase the resources required by instrument from spacecraft. These requests have been contained, and the instruments are compatible with the allocations.

5.1.3.2.1 Mass of instruments and Mass Allocation

As the system mass margins are limited, the mass allocation for the instruments cannot be increased compared to what it was at the ITT and SRR.

The following table gives the distribution of the Payload allocated mass per instruments, compared to the current estimated mass of the instruments.

Instruments Mass budgets at PDR (~ May 2002) | **ref** | **History**

Planck

Instrument	IIDB 2.1 Nominal Mass	IIDA 3.0 Allocation	Delta / Allocation: Delta	Delta / Allocation: delta	evolution since last IID: Delta	evolution since last IID: delta	ref	IID-B 1.0 Nominal	IID A 1.0 Allocation	IID-B 2.0 Nominal	IID A 2.0 Allocation
	kg	kg	kg	%	kg	%	*CR Documents ...*	kg	kg	kg	kg
HFI	*216.5*	**244**	27.5	11.27%	-12.81	-5.59%	HP-HFI-CR-0013 v 2.0	212	244	229.31	244
LFI	*96.3*	**89**	-7.3	**-8.20%**	-9.48	-8.96%	LFI 26/3/02	74	89	105.78	89
Sorption	*121.8*	**112**	-9.8	**-8.75%**	7.3	**6.38%**	SCS 26/3/02	100.2	112	114.5	112
Total Planck	***434.6***	**445**	10.4	2.34%	-14.99	-3.33%		***386.2***	**445**	***449.6***	**445**

Herschel

Instrument	IIDB 2.1 Nominal Mass	IIDA 3.0 Allocation	Delta / Allocation: Delta	Delta / Allocation: delta	evolution since last IID: Delta	evolution since last IID: delta	ref	IID-B 1.0 Nominal	IID A 1.0 Allocation	IID-B 2.0 Nominal	IID A 2.0 Allocation
	kg	kg	kg	%	kg	%	*Convergence meeting*	kg	kg	kg	kg
PACS :	*128.8*	**133**	4.2	3.16%	2.98	**2.37%**	HP-ASPI-MN.1369	110.76	133	125.82	133
SPIRE :	*87.9*	**90**	2.11	2.34%	3.39	**4.01%**	HP-ASPI-MN-1346	78	90	84.5	90
HIFI (1)	*194.4*						HP-ASPI-MN.1367				
HIFI (2)	*5.7*						HP-ASPI-MN-1439				
HIFI Total	*200.1*	**192**	-8.1	**-4.22%**	20	**11.10%**		201.1	192	180.1	192
Total Herschel	***416.8***	**415**	-1.8	**-0.43%**	26.4	**6.75%**		***389.9***	**415**	***390.42***	**415**

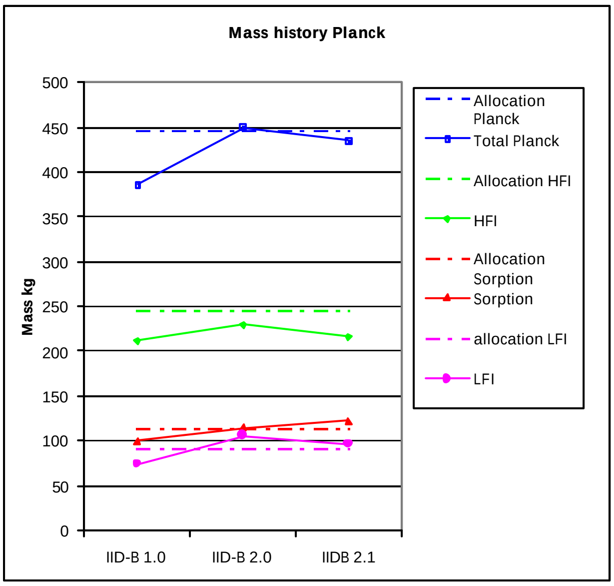
(1) : Total of HIFI components supplied by HIFI, including LOU Radiator

(2) : Total of HIFI components supplied by Astrium : LOU Waveguides.

Herschel + Planck

Instrument	IIDB 2.1 Nominal Mass	IIDA 3.0 Allocation	Delta / Allocation: Delta	Delta / Allocation: delta	evolution since last IID: Delta	evolution since last IID: delta	IID-B 1.0 Nominal	IID A 1.0 Allocation	IID-B 2.0 Nominal	IID A 2.0 Allocation
	kg	kg	kg	%	kg	%	kg	kg	kg	kg
Total	***851.4***	**860**	8.61	1.00%	11.38	**1.35%**	***776.1***	**860**	***840.0***	**860**

TABLE 5.1-1 MASS BUDGET AND ALLOCATIONS OF HERSCHEL & PLANCK INSTRUMENTS



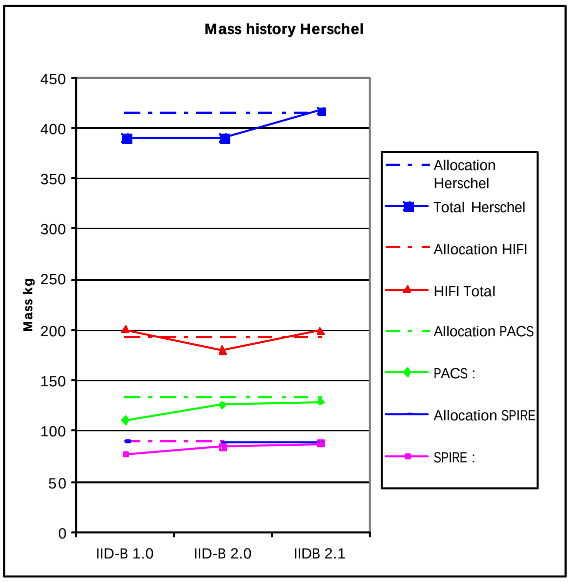


FIGURE 5.1-1 MASS BUDGET HISTORY OF HERSCHEL AND PLANCK INSTRUMENTS

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 very (too) small (2.34% for Planck, thanks to HFI), -0.34% for Herschel, 1% total).

We believe that the instrument design maturity is now such that no significant mass evolution is expected in the future.

5.1.3.2.2 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 gives the current situation for Power allocation and power demand for the instruments, together with the evolution since the ITT.

We propose to increase the HERSCHEL Power allocation in the IID-A (including Instrument margins) from 500 W (at SRR) to 550W (giving up all hidden margins compared to Herschel instruments originally specified power allocation from SRS SINT020). (was 454 W at ITT)

For Planck, the situation is more delicate as there is no possibility for increasing the power allocation of 1kW. The tendency of instruments during phase B was to increase the power demand. However, the limitation of the power resources has been understood by instrument teams, and agreement was reached during the LFI design status review to share the 1kW allocation between HFI, LFI and sorption cooler. The operating point of the sorption cooler has been reduced from 655W to 570W (470W TMU + 100W SCE).

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).

This is true for most of the instruments, except for HIFI, where there is a difference of 50W between maximum average and dissipation (ref HP-HIFI-CR-034). This means large power fluctuation at time scale between 5mn and 1h, probably incompatible with the high temperature stability required.

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 PDR (~ May 2002)							ref	History			
Planck											
	IID-B 2.1/2.2	IID-A 3.0	Delta / Allocation		evolution / Last IID			IID-B 1.0	IID-A 1.0	IID-B 2.0	IID A 2.0
Instrument	Nominal	Allocation	Delta	delta	Delta	delta		Nominal	Allocation	Nominal	Allocation
	W	W	W	%	W	%	*CR Documents …*	W	W	W	W
HFI	*284.8*	310	25.2	8.13%	29.8	11.69%	HP-HFI-CR-0014	254.15	255	255	255
LFI	*120.2*	120	-0.2	-0.17%	4.15	3.58%	HP-LFI-CR-0010	73	74	116.05	74
Sorption	*526*	570	44	7.72%	-4	-0.75%		655	655	530	655
Total	*931*	1000	69	6.90%	29.95	3.32%		*982.15*	984	*901.05*	984

Herschel											
	IID-B 2.1/2.2	IID-A 3.0	Delta / Allocation		evolution / Last IID			IID-B 1.0	IID-A 1.0	IID-B 2.0	IID A 2.0
Instrument	Nominal	Allocation	Delta	delta	Delta	delta		Nominal	Allocation	Nominal	Allocation
	W	W	W	%	W	%	*Convergence meeting*	W	W	W	W
PACS :	*125.9*	125	-0.9	-0.72%	-10.1	-7.43%	HP-ASPI-MN.1369	85.3	86	136	100
SPIRE :	*95.3*	110	14.7	13.36%	0	0.00%	HP-ASPI-MN-1346	86	86	95.3	100
HIFI :	*315.6*	315	-0.6	-0.19%	26.5	9.17%	HP-ASPI-MN.1367	268	281	289.1	300
Total	*536.8*	550	13.2	2.40%	16.4	3.15%		*439.3*	453	*520.4*	500

PACS power includes margin

TABLE 5.1-2 POWER BUDGET AND ALLOCATIONS OF HERSCHEL & PLANCK INSTRUMENTS

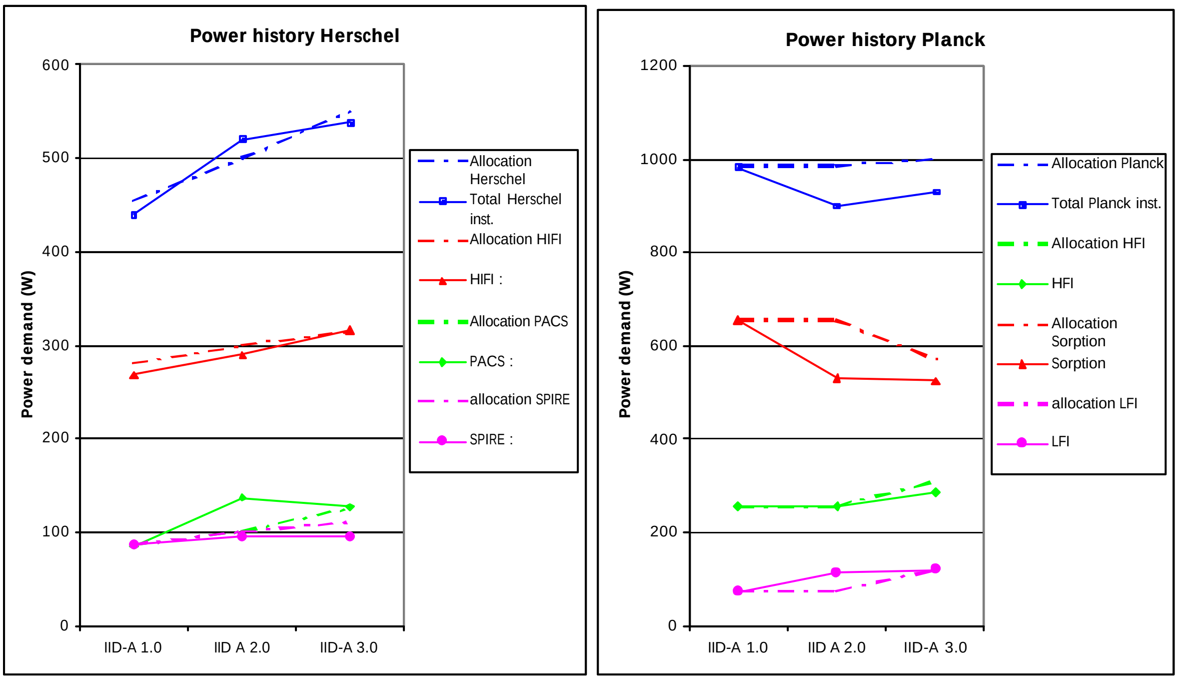


FIGURE 5.1-2 POWER BUDGET EVOLUTION OF HERSCHEL & PLANCK INSTRUMENTS

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

Herschel Allocation	To	Type	Protected	Class
HIFI HRH	FHHRH	LCL	NO	II
HIFI HRV	FHHRV	LCL	NO	II
HIFI ICU Nom	FHICU	LCL	NO	II
HIFI ICU Red	FHICU	LCL	NO	II
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 Nom	PLBEU	LCL	YES	I I I
LFI DAE Red	PLBEU	LCL	YES	I I I
LFI REBA Nom	PLREN	LCL	YES	I I
LFI REBA Red	PLRER	LCL	YES	I I
HFI DCE	DCE	LCL	NO	I
HFI DPU Nom (PHBA-N)	PHBAN	LCL	YES	I I
HFI DPU Red (PHBA-R)	PHBAR	LCL	YES	I I
HFI REU belts group 0&1	PHBAR	LCL	NO	I I
HFI REU belts group 2&3	PHBAR	LCL	NO	I I
HFI REU belts group 4&5	PHBAR	LCL	NO	I I
HFI REU belts group 6&7	PHBAN	LCL	NO	I I
HFI REU belts group 8&9	PHBAN	LCL	NO	I I
HFI REU belts group 10&11	PHBAN	LCL	NO	I I
HFI REU Proc Nom	PHCBC	LCL	YES	I
HFI REU Proc Red	PHCBC	LCL	YES	I
HFI 4KC Drive bus Nom	PHDC	15A-LCL	YES	15A
HFI 4KC Drive bus Nom	PHDC	15A-LCL	YES	15A
HFI 4KCDE Nom (PHDC)	PHDC	LCL	NO	I I
HFI 4KCDE Red (PHDC)	PHDC	LCL	NO	I I
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	I I I
Sorption Cooler Electronics Red	PSR4	LCL	YES	I I I

TABLE 5.1-3 HERSCHEL & PLANCK INSTRUMENTS LCL ALLOCATION

5.1.3.2.3 Temperature ranges for SVM warm units

See Herschel & Planck sections.

5.1.3.2.4 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.

5.1.3.2.4.1 HERSCHEL:

On HERSCHEL, the thermal interfaces between the instruments and the spacecraft are on 3 identified levels.

Level 0 (< 2 K) on the Helium tank, Level 1 (< 5 K) and Level 2 (< 15 K) on the helium vent line.

The following table summarises the temperature and instruments heat loads allocations on these 3 levels.

Instruments Temperature & Heat lift requirements on FPU

Herschel	IID-A Allocation				Instrument needs (IID-B)							
	Temperatures			Heat Lift	Temperatures							
	HIFI	PACS	SPIRE	All	HIFI	PACS				SPIRE		
										goal	max	
	K	K	K	mW	K	K	K	K	K	K	K	K
Level 0						red detect	blue detect	cooler pump	cooler evap	all	all	cooler pump
	2	1.75	2	**10**	2	1.75	2	2.2-10	2	1.7	2	2.2-10
Level 1	6	5	6	**25**	6	5				4	6	
Level 2	15		15	**50**	20					10	15	

		Temp. error	Steady state Analysis (PDR)							
Level 0		0.025	1.83	1.71	1.79	1.95		1.76		1.73
Level 1		0.35	6.29	4.25				5.15		
Level 2		0.5	14							
			HIFI	PACS				SPIRE		

TABLE 5.1-4 TEMPERATURE AND HEAT LIFT ALLOCATION ON HERSCHEL FPU, COMPARED TO INSTRUMENT REQUESTS

Comments

There is a new request from SPIRE (ECR09) to reduce the temperature at Levels 0, 1, and 2 (shown as goals on the above table), to guarantee the operation time of the Sorption cooler, which is being analysed.

It is to be noted that the heat lift allocation is global, for all 3 instruments Only one instrument operates at a given time the other are in Standby mode. (except for parallel mode with PACS and SPIRE that is not expected to need more than 3 months of the mission)

This means that for each instrument, the allocation has to be estimated taking into account the instrument modes and performing a realistic averaging (in a first approach this can be done by giving a preliminary allocation of 1/3 of this budget, and a duty cycle of 1/3 for dissipative elements (including the sorption cooler), and of 1 for conduction/radiation).

The following table gives our estimation of the duty cycles of the instruments into all modes.

Instrument usage

	SPIRE					PACS					HIFI							
status	ON			Stdby	Total	ON			Stdby	Total	ON						Stdby	Total
duty cycle	1/3			2/3	#	1/3			2/3	1	1/3							
Mode	PHOT	SPEC	PARALLEL	OFF	Total	PHOT	SPEC	PARALLEL	OFF	Total	Chan 1	Chan 2	Chan 3	Chan 4	Chan 5	Chan 6	OFF	Total
duty cycle	7/48	7/48	1/24	2/3	#	7/48	7/48	1/24	2/3	1	1/21	1/21	1/21	1/21	1/21	2/21	2/3	1
Astrium Modes	3	4	6			2	1	6			5	5	5	5	5	5		

Assumption:

Even distribution for the 3 instruments (1/3 each)

Even distribution between instruments modes (Spetrometer / Photometer mode for PACS & SPIRE, Chanels 1..6 for HIFI)

3 months allocated to parallel mode (PACS + SPIRE, ie 1/12 of the mission, as part of PACS & SPIRE time (ie 1/24 taken from each of their allocation)

HIFI Channel 6 is composed of 2 sub-channels, so there are effectively 7 channels

TABLE 5.1-5 HERSCHEL INSTRUMENT USAGE (PER INSTRUMENT AND PER MODE, ASSUMING EVEN DISTRIBUTION)

For the sorption cooler of SPIRE and PACS, each recycling is equivalent to 48 h of usage, whatever the real duration of use. As a baseline it is agreed to use a duty cycle of 1/3 for each sorption cooler. (this will require optimisation of the mission timeline, fixing minimum usage duration (48h..66h) for an instrument with sorption cooler, or defining a procedure to do a partial recycling of cooler).

The estimation of the available heat lift allocation is different for Level 0, where it translates directly into lifetime (10 mW allocated for instruments, for a total heat load on the tank about 50 mW), and on the Vent line, where it depends of the mass flow rate ($Q = m_{dot}.Cp.(T_{i+1}-T_i)$). The total available heat lift (Instruments + Optical bench support, radiation + thermal straps support + harness) versus the mass flow rate, and temperatures of level 1 and 2 can be extracted from the following Figures 5.1.3.1: On level 1, 2 mg/s gives 24.5 mW available on level 1 at 4 K if the tank is at 1.7 K, 35 mW at 5 K. For a level 2, 2 mg/s at 10 K, 63 mW is available (2.5 mg/s, 4 K on level 1), 115 mW would be available at 15 K. These values include thermal loads form the cryostat and are <u>not</u> to be considered for the instrument budgets. This will be confirmed by the detailed simulation to be performed by ASTRIUM.

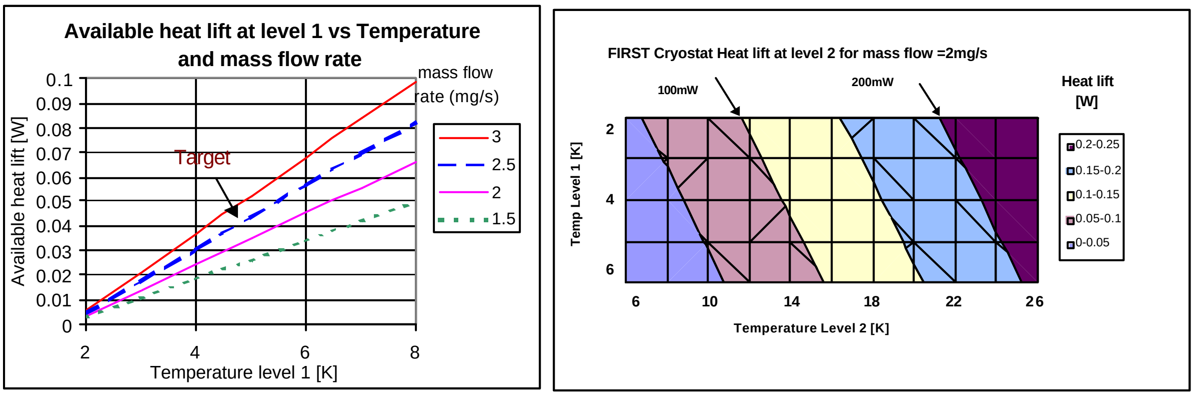


FIGURE 5.1-3 HEAT LIFT ON LEVELS 1 & 2 VS MASS FLOW RATE AND TEMPERATURES

The following table gives the heat flow on each levels, from each instruments, according to the Steady state ASTRIUM thermal analysis (H-EPLM Thermal model & Analysis HP-2-ASED-RP-0011 issue 2, part of the HPLM data package), using a constant mass flow rate of 2.2mg/s., and the 6 instruments modes.

The various dissipation are averaged and summed taking into account the duty cycle

We see that the instrument average heat load is now significantly larger (30%) than the allocation for Level 0 & 1, making difficult to guarantee the required temperatures.

Herschel		model results (mW)																								total		Allocation
		mode 1 pacs spectro				mode 2 pacs photo				mode 3 spire photo				mode 4 spire spectro				mode 5 HIFI				mode 6 parallel				mW		heat lift mW
		PACS	SPIRE	HIFI	total	PACS	SPIRE	HIFI	total	PACS	SPIRE	HIFI	total	PACS	SPIRE	HIFI	total	PACS	SPIRE	HIFI	total	PACS	SPIRE	HIFI	total			
	Level 0	4.2	5.3	5.1	14.6	8.2	3.6	4.1	15.9	2.1	5.4	5.5	13	2.1	5.8	5.4	13.3	2.4	6.3	8.6	17.3	8.5	6.5	6.6	21.6			
	Level 1	23.4	8	5.2	36.6	11	7.8	4.9	23.7	9.8	16	7	33	9.4	18.2	6.4	34	14	18.7	12	44.3	15.1	17.9	8.1	41.1			
	Level 2	-9.3	-10.7	-9.8	-29.8	-7.6	-8.1	-8.5	-24	-8.1	23.5	-12	3.3	-7.8	2.1	-11	-17	-12.3	-23	26	-10	-11.8	20.2	-14	-5.92			
	duty cycle	7/48				7/48				7/48				7/48				1/3				1/12				1		
PACS	Level 0	0.61				1.20				0.31				0.31				0.80				0.71				3.93	PACS	
PACS	Level 1	3.41				1.60				1.43				1.37				4.67				1.26				13.74	PACS	
PACS	Level 2	-1.36				-1.11				-1.18				-1.14				-4.10				-0.98				-9.87	PACS	
SPIRE	Level 0		0.77				0.53				0.79				0.85				2.1				0.54			5.57	SPIRE	
SPIRE	Level 1		1.17				1.14				2.33				2.65				6.23				1.49			15.02	SPIRE	
SPIRE	Level 2		-1.56				-1.2				3.42				0.31				-7.7				1.68			-5.06	SPIRE	
HIFI	Level 0			0.74				0.6				0.8				0.8				2.9				0.6		6.35	HIFI	
HIFI	Level 1			0.76				0.71				1				0.9				3.9				0.7		7.97	HIFI	
HIFI	Level 2			-1.4				-1.2				-1.8				-1.7				8.5				-1.2		1.21	HIFI	
ALL	Level 0				2.13				2.32				1.90				1.94				5.77				1.80	**15.85**	ALL	**10**
ALL	Level 1				5.34				3.46				4.78				4.96				14.77				3.43	**36.73**	ALL	**25**
ALL	Level 2				-4.35				-3.52				0.47				-2.49				-3.33				-0.49	**-13.71**	ALL	**50**

TABLE 5.1-6 HERSCHEL FPU HEAT LOADS, FROM HPLM STEADY STATE THERMAL ANALYSIS

5.1.3.2.4.2 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).

Planck FPU	ITT				SRR		
Radiator & V-Groove	**Temperature**		**heat lift**		**Temperature**		**heat lift**
Heat Lift allocation (Instruments + PPLM)	Goal	Max			Goal	Max	
	K	K	mW		K	K	mW
V-Groove 3 (Cold)	< 50	< 60			< 50	< 60	**2930**
V-Groove 2 (Medium)						100	**1320**
V-groove 1 (Warm)						160	**7150**

TABLE 5.1-7 PLANCK HEAT LOADS ALLOCATION AT ITT AND SRR

Guaranted temperatures range on shield for SCS / Operating

SCS	*3rd V-Groove*	*2nd V-Groove*	*1st V-groove*
Min	45	100	150
Max	60	120	170

Temperature to be used for instrument heat load estimation (boundary)

Design temperatures:	*3rd V-Groove*	*2nd V-Groove*	*1st V-groove*
LFI	52	106	166
HFI	50	110	165
SCS	52	108	158

Heat Load Allocation on 3rd V-Groove estimated for above temperatures

Heat Loads	*3rd V-Groove*	*2nd V-Groove*	*1st V-groove*	*Design margin (**)*
HFI	620	20	50	20%
LFI	710	560	5370	20%
Sorption	1175	453	581	10%

(**) Margin used by Alcatel on instrument heat loads to estimate prediction er

TABLE 5.1-8 UPDATE OF PLANCK HEAT LOADS ALLOCATION ON V-GROOVE THERMAL SHIELDS AT PDR (IIDA 3.0)

These heat lift capabilities of the passive cooling system can be distributed among the known contributions as follows:

Instruments Power dissipation on FPU

Dissipations and Heat losses on Planck PLM	Allocation from Spacecraft				Nominal Instrument estimated heat load (*****) (No margin)			Maximum Instrument estimated heat load (with margin)		
Planck PPLM	V-Groove 3 (Cold)	V-Groove 2 (Medium)	V-Groove 1 (Warm)	SVM	V-Groove 3 (Cold)	V-Groove 2 (Medium)	V-Groove 1 (Warm)	V-Groove 3 (Cold)	V-Groove 2 (Medium)	V-Groove 1 (Warm)
Total Planck PPLM heat lift allocation	2505mW	1033mW	6001mW		2562mW	1701mW	3663mW	2776mW	1941mW	4222mW
HFI Nominal Temperature (****)	50K	110K	165K	295K						
Total heat load HFI	620mW	20mW	50mW		517mW	3mW	37mW	598mW	4mW	43mW
Total heat loads LFI	710mW	560mW	5370mW		665mW	1198mW	2766mW	798mW	1438mW	3319mW
Total heat load Sorption cooler	1175mW	453mW	581mW		1380mW	500mW	860mW	1380mW	500mW	860mW

TABLE 5.1-9 PLANCK INSTRUMENT STATUS OF DISSIPATION ON V-GROOVES (TO BE UPDATED)

5.1.3.2.5 Data rates Allocation

The data-rate allocation has been increased for both satellite to 130kbps (average over 24h) corresponding to 25subframe/s, taking into account the real capabilities of the hardware installed.

There has been some work performed to estimate the actual capability of the proposed data bus, by analysing the traffic on the bus (See discussion in § 6.1.4). A technical note has been issued (RD03.11), giving a maximum average data-rate capability of 130kbps, and a burst capability of 300 kbps, including Science data, housekeeping and overheads.

This is a starting point for a discussion with ESA and the instruments, as the interpretation of the PS-ICD is not the same for all parties. Conclusion of this debate might allow increased data-rate allocation for both HERSCHEL and Planck.

Data rate IID-A Allocation		ITT	SRS	PDR	
Herschel	**Science + housekeeping**	**100**	**100**	**130**	**kb/s Average 24h**
				25	**subframe/s**
	Storage MMU	48	48		h
	Burst mode	300	300	300	kbps
Planck	**Science + housekeeping**	**60**	**100**	**130**	**kb/s Average 24h**
				25	**subframe/s**
	Storage MMU	48	48		h
	Burst mode	240	300		kb/s

TABLE 5.1-10 DATA RATE ALLOCATION FOR INSTRUMENTS

5.1.3.2.6 Data-Rate demand

The requirement for data rate was marginally compatible with the allocation at the ITT has now evolved.

The following tables summarises the situation in the current proposed IID-B's.

Herschel

from IID-B	SPIRE						PACS					HIFI		
	Herschel Instruments data rates in kb/s													
modes	Prime		parallel	Serendipity	Burst	standby	Prime		parallel	burst	standby	prime	burst	standby
	Spectrometer	Photometer					spectrometer (GeGa)	Photometer (bolometer)	photometer					
Science uncompressed	97.4	93.6	10	87			3600	1600				98	300	
Science compressed	97.4	93.6	10	87	200	0	122	122	50	292		98	300	
Housekeeping	4.2	4.2	2.1	4.2	4.2	4.2	4	4	2	2	2	2	2	2
command verif							2	2						
Event handling							2	2						
duration of burst mode					short					30mn			short	
Total	**101.6**	**97.8**	**12.1**	**91.2**	**204.2**	**4.2**	**130**	**130**	**52**	**294**	**2**	**100**	**302**	**2**

System requirement specifications

MODE	Herschel MODES: SPIRE	PACS	HIFI	Data Rate (kb/s): SPIRE	PACS	HIFI	total	
#1	Standby	Standby	Prime	4.2	2	100	**106.2**	
#2 P	Standby	Prime P	Standby	4.2	130	2	**136.2**	<-- Driver
#2 S	Standby	Prime S	Standby	4.2	130	2	**136.2**	option with PACS Spectrometer
#3 P	Prime P	Standby	Standby	101.6	2	2	**105.6**	
#3 S	Prime S	Standby	Standby	97.8	2	2	**101.8**	
#4	Parallel	Parallel	Standby	12.1	52	2	**66.1**	

IID-A Allocation		
total (science + HK)	**130 kb/s**	**24h**
Storage MMU	48 h	
Burst mode	300 kbps	

TABLE 5.1-11 DATA RATE USAGE FOR HERSCHEL INSTRUMENTS

The comparison between current allocation shows some discrepancy between demand and allocation, especially on HERSCHEL when PACS is prime. This should be solved at the end of the current on-going discussion about data-rates.

Planck

from IID-B	Planck instruments demand for Data rate (Kbps): LFI	HFI	SCS	Total	Allocation: kpbs	Subframe/s
Science compressed	51.3	70		**121.3**		
Housekeeping	2.2	4	1.5	**7.7**		
Total	**53.5**	**74**	**1.5**	**129**	**130**	**25**

TABLE 5.1-12 DATA RATE USAGE FOR PLANCK INSTRUMENTS

5.1.3.2.7 EMC

The most significant updates to the EMC chapters of the IID-A are the following:

- notch in the RE mask protecting the spacecraft receive band.

The notch depth has been increased to 0 dBµV/m (deduced from the spacecrafts TC signal power level, cf. H/P EMC analyses, H-P-A-ASPI-AN-0202, § 4.1.1). The width of it may be reduced in the future when ALCATEL Espacio provide consolidated X-Band receiver susceptibility characteristics taking into account:

- LNA saturation

– Bit Error Rate
– Loss of Lock

It must be noted that this notch in the RE specification is applicable to all Instruments including HIFI, even if it is not supposed to be on during telecommunication periods: one may need to send commands to the spacecrafts whatever units are on or off, and whatever their mode is.

The Instruments signals liable to produce radiated spurious harmonics in X-Band are in particular:

– HIFI comb generator (100 MHz, 23 dBm), used during calibration phases: HIFI team is aware of the problem, and ready either to be compliant with the RE specification or to change the frequency so that the harmonics are out of the X-Band
– Instruments high frequency clocks (at a few tens of MHz): from our experience, we expect them to be compliant with the RE specification (unless the digital units internal grounding is very bad):
  • ESD (§ 5.14.3.13).

The specified energy level has been changed from 5.6 mJ to 15 mJ in order to be consistent with the SRS. The rise time as been specified as it critically affects the coupling to circuits.

5.2 HERSCHEL

The HERSCHEL satellite accommodates 3 instruments PACS, SPIRE and HIFI, the most relevant updates and open points of which are described in the following paragraphs. The implementation of the FPUs of these instrumuments onto the Herschel Optical Bench is illustrated in the following figure.

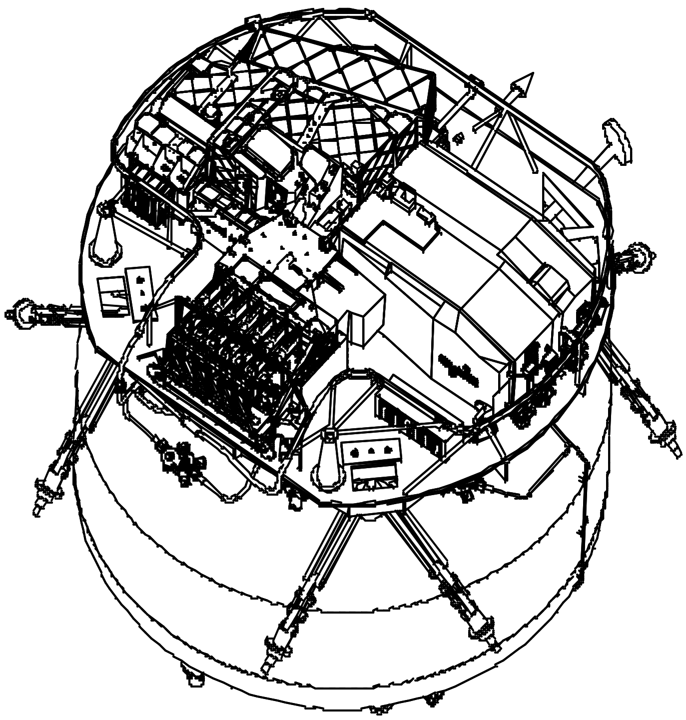


FIGURE 5.2-1 3D IMAGE OF THE HERSCHEL FPUS ON THE OPTICAL BENCH/DRAFT VIEW SUPPLIED BY ASTRIUM. IN THIS VIEW, PACS IS LOCATED AT THE UPPER LEFT, SPIRE AT THE LOWER RIGHT, AND HIFI AT THE LOWER LEFT

5.2.1 PACS

The following references are used to describe the documents from which design descriptions, requirements, specifications, etc. are drawn for PACS:

AD04.1 Herschel/Planck **IID Part A**
SCI-PT-IIDA-04624, Issue 3.0 (June 2002)

AD04.4 IID Part B: **PACS**
SCI-PT-IIDB/PACS-02126, Issue 2.1 (June-2002)

AD04.4 describes the PACS design, based on agreed changes (proposed by means of formal change requests) and updates, minuted during an "IIDB Convergence Meeting" held on 26-04-02. At the time of writing of the present document, the new issue of the IIDB is pending comments and possible minor corrections.

The previous issue of this document (PACS IID-B 2.0, dated 31-July-2001) corresponds to the previous design, and which has been used as a reference since the time of the SRR.

The following provides a description of the current status of the PACS instrument design. It also reflects the *changes* or *evolutions* described in the IIDB. Whenever spacecraft/instrument interfaces are found by ALCATEL to be unacceptable, the acceptable design criteria / specifications are provided, and the corresponding discrepancies are highlighted.

To facilitate comparisons of the present document with the above references, the IID-B chapter references are identified in the following.

5.2.1.1 PACS Mechanical/thermal interfaces

Instrument Units (IIDB - § 5.1 and § 5.5)

Previously, the "Detector + Mechanism" (nominal & redundant) control units (FPDMC1 & FPDMC2) were split into 4 units, namely FPDEC1, FPDEC2, FPMEC1, and FPMEC2. These have now been recombined into one single large unit, designated "FPDECMEC". The proposed *length* of this unit was some 582 mm, which could not be accommodated on the PACS SVM panel. The agreed maximum dimensions for this unit are now: 560 x 320 x 300 mm. The corresponding interface drawings for the FPDECMEC have not yet been provided by PACS.

The above-described changes in the DECMEC configuration (in particular, its considerably increased *volume*) have led to accommodation problems on the PACS SVM panel. For this reason, it was agreed with PACS (AD04.4) to stack the nominal and redundant SPU units (FPSPU_nom and FPSPU_red), one on top of the other. The corresponding interface drawings have not yet been provided.

Location and Alignment (IIDB - § 5.3.1.2)

The harness between the BOLA pre-amplifier unit and the PACS FPU was requested by PACS to be **not more than 2 m** in length, in order to minimise SNR degradation in this harness. With respect to its original design, ASED has been able to re-position the BOLA on the CVV (from its previous location on the +Y side, to the –Y+Z side) in order to satisfy this requirement.

PACS also filed a Change Request, with the aim of maintaining the BOLA at a minimum temperature of 120 K. This request, which would have considerably complicated the mechanical interfaces between the BOLA and the CVV, has not been accepted. As a result, the current design foresees direct fixation of the BOLA to the CVV, such that its temperature would settle close to 70 K.

Instrument Alignment (IIDB - § 5.3.2)

PACS has filed a formal Change Request (CR-005), with the objective of achieving the following alignment performances (at system level):

– Focus: ± 3 mm

– Pupil misalignment: ± 3 mm.

The above values are considerably more demanding (by more than a factor of ~ 2) than foreseen in the industrial proposal alignment budget, and depend on factors which remain outside the control of the Prime contractor (telescope alignment performance). The CR has therefore not been accepted, although the performance requested by PACS has been noted as a design *goal*.

Size and mass properties (IIDB - § 5.5)

As discussed under "Instrument Units", the *dimensions* and *number* of the warm electronic boxes has evolved, and has been accepted by industry under certain conditions.

As far as mass is concerned, the updated table in § 5.5 of AD04.4 proposes a total nominal mass of of 128.8 kg for PACS. Although this leaves a very small margin (~ 3%) wrt the mass allocation (133 kg), PACS now has a strong degree of confidence in *most* of the provided unit masses. It should nevertheless be noted that in the case of the DECMEC, an uncertainty of ± 5 kg was mentioned during the IBDR presentations!

Thermal Mathematical Model of the FPFPU (IIDB - § 5.9.1)

The reduced thermal model of PACS has been included in a new Annex-2 to the IIDB. The thermal data relevant to the FPU (IIDB - § 5.9.1.2) is no longer valid, but has been left in the document, pending updated input from PACS.

Power outside cryostat – on CVV (IIDB - § 5.9.2)

The expected dissipation of the BOLA has been maintained at approximately 0.2 W. The lifetime impact of this dissipation has been evaluated by ASTRIUM to be of the order of a few days only.

As a consequence of the decision not to provide a temperature of 120 K to the BOLA, PACS has recently (20-06-02) proposed a change to its cryoharness definition. This change presumably (although not yet stated) corresponds to their intention to accommodate additional heaters in the BOLA, to achieve its desired temperature level of ~ 120 K. Further implications, in terms of additional heat-load to the CVV, and power requirements on the SVM, have not yet been clarified by PACS.

Thermal dissipation on the SVM (IIDB - § 5.9.3)

The previous table of SVM power dissipations (IIDB 2.0) has been replaced with a more detailed one, in which the expected maximum-average (worst-case) "Spectroscopy Mode" and "Photometry Mode" (or "Parallel Mode") dissipations are given. These result in maximum average (worst-case) totals of respectively 125.9 W and 124.5 W.

5.2.1.2 PACS Electrical interfaces

Electrical interfaces with the S/C – Block Diagram

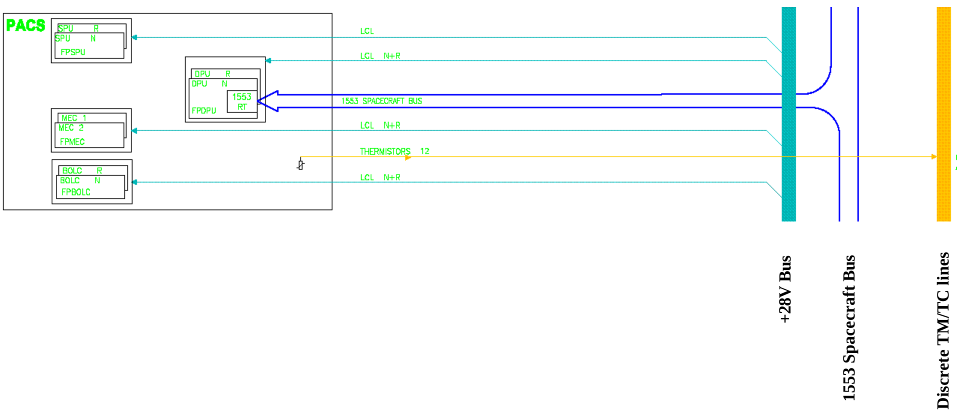


FIGURE 5.2-2 ELECTRICAL INTERFACES BETWEEN PACS AND THE HERSCHEL SATELLITE

Load on the 28 V. main bus (IIDB - § 5.9.5.1)

The previous table (IIDB 2.0) has been replaced with a more detailed one, in which the expected " Spectroscopy Mode", "Photometry Mode", Short-Peak and Long-Peak loads are given. These result in total loads of respectively 125.9 W, 124.5 W, "N/A" and "N/A", as opposed to an increased allocation (IIDA v.3.0) of 125 W. The "N/A" totals result from the fact that short and long peaks are not expected to occur simultaneously on all units.

Of potential concern are the peak power demands, some of which remain TBD. The following table indicates, for reasons of LCL rating, the maximum values which can be accepted.

PROJECT CODE	LCL CURRENT RATING (IIDA)	REQUESTED SHORT/ LONG PEAK DEMANDS (W)	ACCEPTABLE SHORT/ LONG PEAK DEMAND (W)
FPDECM	Class II	TBD W/78 W	78 W
FPBOLC	Class II	TBD W/51 W	78 W
FPDPU	Class II	43.2 W/28.8 W	78 W
FPSPU	Class II	TBD W/35 W	78 W

TABLE 5.2-1 PACS LCL RATINGS AND ACCEPTABLE PEAK POWER VALUES

The above value are based on LCL current-limiting (which can occur at the LCL rating + 20%), for the foreseen Class II LCLs (2.5 A).

Interface circuits, between PACS and the spacecraft (IIDB - § 5.9.5.1.2)

The circuit diagram provided still does not contain enough detail. The equivalent impedance elements of each warm unit I/F circuit have been requested.

Cryo Harness (IIDB - § 5.10.2.3)

The cryoharness data relevant to PACS has been updated, following a harness convergence meeting held with ASTRIUM on 16-04-02. During the PACS IIDB convergence meeting (26-04-02), it was agreed that the PACS cryoharness requirements would be included in a separate Applicable Document (within the PACS IIDB: AD-17, Doc. ref. "PACS-MA-SP-001"), referred to in Annex 3 of the IIDB. This data is therefore no longer included in the many body of the document.

Telemetry rate (IIDB - § 5.11.1.1)

A CR was filed by PACS wrt the maximum average data rate it could transfer over the I553 Bus. It has now been agreed the following:

PACS in PRIME mode:

- 130 kbit/s total (average over 24 hours), comprising …
    - 4 kbit/s (average) are used for housekeeping,
    - 2 kbit/s (average) are used for Command Verification,
    - 2 kbit/s (average) are used for Event Handling,
    - up to 300 kbit/s burst mode for up to 30 min.

Frequency Plan (IIDB - § 5.14.3)

A new Frequency Plan has been introduced into the IIDB. This plan is in principle acceptable, although caveats have been placed on certain WU frequencies. In particular, PACS is to assess its compliance with the RE requirements, in the vicinity of the 0 dBμV/m notch in the TC band (7.208 G), in relation to the following clock harmonics:

- 200th harmonic of the SPU SPU main oscillator, and of the MEC DSP clock (36 MHz x 200 = 7.2 GHz)

- 450th harmonic of the DPU 1553 quartz (16 MHz x 450 = 7.2 GHz)
- 360th harmonic of the BOLC main oscillator (360 X 20 MHz = 7.2 GHz).

5.2.2 SPIRE

The following references are used to describe the relevant documents from which design descriptions, requirements, specifications, etc. are drawn for SPIRE:

AD04.1 Herschel/Planck **IID Part A**

SCI-PT-IIDA-04624, Issue 3.0 (June 2002)

AD04.2 IID Part B: **SPIRE**

SCI-PT-IIDB/SPIRE-02124, Issue 2.2 (June-2002)

5.2.2.1 SPIRE Mechanical/Thermal interfaces

Identification and labeling (IIDB - § 5.1)

SVM Warm Units: The number of warm electronic boxes has increased since the previous issue of the SPIRE IIDB (v. 2.0, July 2001):

The previously labelled “DRCU” is now split into two separate warm units, as follows:

- HSDCU – SPIRE Detector Control Unit
- HSFCU – SPIRE FPU Control Unit.

Principal moments for the warm units have not yet been provided, and updated ICDs are needed for the FCU and DCU. The currently available configuration drawings are now placed in Annex 1 at the end of the IIDB.

Cryogenic units: The JFET amplifiers previously housed in a single unit (FSFTB) are now split into 2 separate units: HSJFS and HSJFP. This evolution has been suitably accommodated on the OB (see also Fig. 5.3-1 of the IIDB).

Size and mass properties (IIDB - § 5.5)

The previous issue of the IIDB proposed nominal mass of the SPIRE units was 96 kg, i.e. 6 kg in excess of the total mass allocation of 90 kg. The total mass of SPIRE has now settled to a value of 87.9 kg. However, this figure is “without margins”, and a clear evaluation of the design maturity and mass margin assumptions is needed.

Micro-vibrations (IIDB - § 5.6.1.1)

SPIRE has re-iterated its sensitivity to microvibrations, in the frequency domain between 0.03 Hz and 300 Hz. In particular, the SMEC and BSM mechanisms, together with the bolometer detectors, can be sensitive to very small perturbations.

Reaction wheel imbalances can lead to micro-vibrations (resonance peaks at OB level) above 10 mg (i.e. 2 to 3 orders of magnitude above the level requested by SPIRE). In the IIDB, it has been agreed that ALCATEL will, following detailed analysis, make the expected micro-vibration levels available to SPIRE – for the frequency range between 30 Hz and 300 Hz.

Thermal straps (IIDB - § 5.6.1.2)

Following an initial Change Request (SPIRE ECR-005), requesting industry to provide thermally conductive, but Ohmically isolating thermal straps to the HSFPU, it has been agreed that SPIRE will provide, close to its detectors, the appropriate (thermally conductive, Ohmically isolating) interface to its thermal straps. This has been clarified in the IIDB.

Thermal interfaces inside the cryostat (IIDB - § 5.7.1)

These interfaces have not been completely settled, as ASTRIUM has clearly demonstrated that the interface temperatures (in particular that of Level 1) requested by SPIRE (formal Change Request: ECR-009) cannot be met without considerable design changes.

The previously requested interface temperatures agreed by industry, are reproduced in the IIDB, whereas the reasoning and justification for SPIRE's new requirements are provided in Chapters 5.7.1.1 and 5.7.1.2 of the same document.

An explanatory paragraph has been added to the beginning of § 5.7.1, stating that SPIRE's updated requirements cannot currently be accepted, and that the outcome of on-going design work, thermal analysis, and technical meetings will determine the ultimate trade-off concepts and interface temperatures which can be provided.

Temperature channels (IIDB - § 5.7.5)

The previously unspecified accuracy and resolution requirements of the temperature sensors have been updated. In the case of the "satellite" temperature sensors (§ 5.7.5.3), an accuracy of 50 mK has been agreed with SPIRE for the temperature sensors provided for the Level 0 and Level 1 straps.

Optical interfaces (IIDB - § 5.8)

A detailed description of SPIRE's "free beam space" requirements was presented at the recent IIDB Convergence meeting (April 2002). These were however too complex to be evaluated, for inclusion into the IIDB. The evaluation of these requirements is considered to be "normal work", and should be submitted to project in the form of a formal change request.

5.2.2.2 SPIRE Electrical interfaces

Electrical interfaces with the S/C – Block Diagram

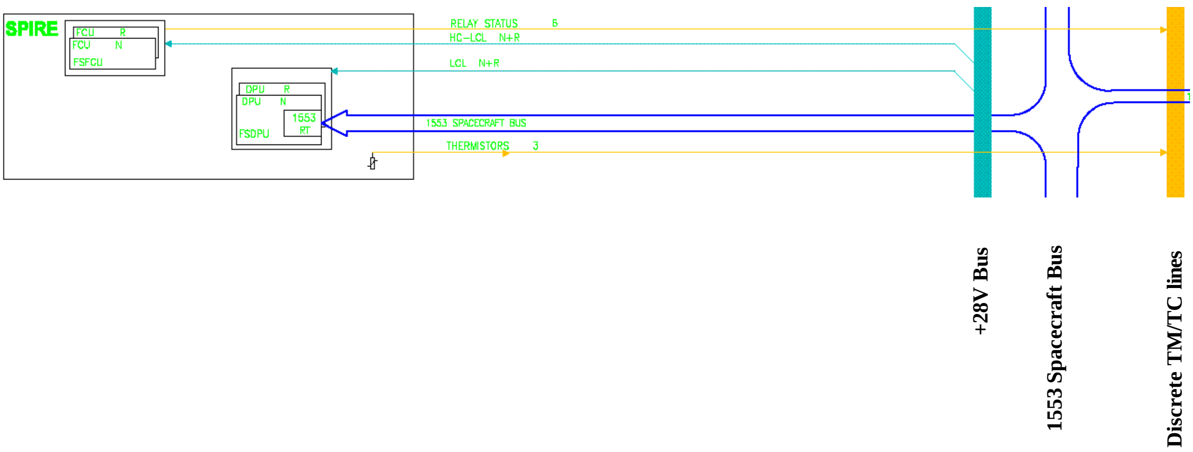


FIGURE 5.2-3 ELECTRICAL INTERFACES BETWEEN SPIRE AND THE HERSCHEL SATELLITE

Power load on the main bus (IIDB - § 5.9.6.1)

The power requirements of SPIRE have been updated to 95.3 W in observing mode, and remain – in principle – within the 100 W allocation. However, the underlying assumptions made by SPIRE remain to be clarified, in particular: a) the margins which may (or may not) be built into this value, b) whether the power requirement corresponds to "worst-case" conditions.

Harness and connectors (IIDB - § 5.10.1)

A dedicated harness meeting was held between SPIRE and ASTRIUM, on from 18-19 April 2002. The agreed harness requirements have been introduced into the IIDB, in the form of a series of tables, providing connector types, numbers of conductors and shields, maximum impedance requirements, and average & maximum conductor currents. This data is taken into account in the design and specification of the SPIRE cryoharness components.

Timing & synchronisation (IIDB - § 5.11.3)

The requested accuracy for a "start of scan" flag is 5 milliseconds, however the accuracy with which this signal can be provided remains TBC.

Attitude and orbit control (IIDB - § 5.12.1)

Raster mode: The requested step size is 1.7 to 30 arcsec, whereas the S/C system requirement is for a step resolution not smaller than 2.0 arcsec.

Frequency Plan (IIDB - § 5.14.3)

This was not previously available. A recently supplied, but incomplete frequency plan has been introduced into the SPIRE IIDB.

The data provided appears acceptable, although the 180th harmonic of the Master clock (40 MHz) lies very close to the TC frequency (~ 7.2 GHz). It remains to be clarified whether this harmonic is suitably suppressed, i.e. does not radiate more then 0 dBµV/m.

Frequency plan data from the DPU is still missing.

On-board hardware (IIDB - § 5.13.1)

The following clarification has been made wrt the use of 1553 addresses: There is a single on-board computer in each of the prime and redundant SPIRE HSDPUs, and each of the latter shall have a different 1553 address.

Transport and Handling Provisions (IIDB - § 5.15)

For reasons of possible damage caused by vibration during transport, environmental testing and launch, SPIRE has requested that mechanisms shall be transported in their launch-latched state. This however represents a potentially major change, which cannot be accepted without a more detailed description from SPIRE providing the appropriate operational and verification procedures.

5.2.3 HIFI

The following references are used to describe the relevant documents from which design descriptions, requirements, specifications, etc. are drawn for HIFI:

AD04.1 Herschel/Planck **IID Part A**
SCI-PT-IIDA-04624, Issue 3.0 (June 2002).

AD04.3 IID Part B: **HIFI**
SCI-PT-IIDB/HIFI-02125, Issue 2.2 (June 2002).

5.2.3.1 HIFI Mechanical/Thermal interfaces

Instrument Units (IIDB - § 5.1)

The number of HIFI units has evolved since the date of the ITT: the WBS (Wide Band Spectrometer) warm units previously named: “FHWBI”, “FHWBO” and “FHWBE” have now been re-arranged into:

- FHWEH: HIFI WBS Electronics – Horizontal Polarisation
- FHWEV: HIFI WBS Electronics – Vertical Polarisation

- FHWOH: HIFI WBS Optics – Horizontal Polarisation
- FHWOV: HIFI WBS Optics – Vertical Polarisation.

In addition, the electronic boards and components previously comprising both polarisations of the HRI unit have been integrated respectively into the HRH and HRV units. FHHRI therefore no longer exists.

It has also been agreed, for reasons of ease of accommodation and harness routing, to remove the 3 dB couplers from the FCU, thereby creating 2 very small, additional "units" to be placed elsewhere on the SVM (see also Fig. 5.4-3 of the IIDB).

Location and alignment (IIDB - § 5.3)

External configuration drawings have been provided for the FPU, although COG and moment of inertia data is missing.

Mechanical interfaces - General (IIDB - § 5.4)

External configuration drawings have been provided for all of the HIFI warm units, except for the 3 dB coupler units (FH3DH, FH3DV) which have now been separated from the FCU.

Implementation of the HIFI warm units on the SVM is described in AD04.01 – Annex 5. The present design places the spectrometer units of each polarisation on respectively diferent panels (-Y-Z and –Y), with semi-rigid coax cables routed between the panels via the upper panel of the SVM, with connector brackets for assembly and maintenance.

Mechanical interfaces – Waveguides (IIDB - § 5.3.1.2, § 5.6.2)

Responsibility for the provision of the HIFI waveguides now lies with ASTRIUM. However, the LSU/Waveguide/LOU interfaces remain to be clearly established. As an example, the waveguide flange interfaces on the LOU and LSU shall be "mirror images" of one another, in order to ensure that no tangling of the waveguides is needed. Drawing 5.4-7 of the IIDB shows irregular waveguide spacings, which – if maintained - would induce unnecessary difficulties to the waveguide routing and interface requirements. These points have been discussed with HIFI, and are pending confirmation in the near future.

Mechanical interfaces - LOU (IIDB - § 5.6.2)

Since the time of the previous issue of the HIFI IIDB (January 2002), the responsibilities for the supply of the LOU radiator and support structure have been clarified.

HIFI is responsible for the design and supply of the LOU radiator, and LOU "Mounting baseplate".

ASTRIUM/ALCATEL are responsible for the design and supply of the LOU mounting structure, including mounting struts, and a so-called "CVV Baseplate", which interfaces with the LOU "Mounting baseplate" described above.

Exact dimensions and design of the interface between the mounting structure (industry) and the LOU baseplate (HIFI) are still TBD, and remain to be clarified between HIFI and industry.

The estimated mass of the LOU radiator has now decreased from 25 kg to ~ 6 kg. pending discussions and negotiations between industry and HIFI.

Size and mass properties (IIDB - § 5.5)

The dimensions and mass values given in § 5.5 have been completely revised, leading to an overall instrument mass of 188.9 kg (AD04.1 allocation = 189 kg). As the former figure is established excluding margins, HIFI has no mass margin whatsoever, such that its total mass may ultimately tend towards a value well in excess of allocation. Improved visibility and closer control of mass margins is thus needed throughout all remaining design phases.

The overall dimensions of many of the units has increased, and some have increased dramatically in volume (the LSU for example). The subject of overall volume of the HIFI warm units, and the resulting difficulty of their accommodation on the SVM, led to two recent "SVM accommodation" meetings in Cannes. An acceptable layout has now been proposed by ALENIA, as described in AD04.01. This solution involves slightly more complex routing of the HIFI semi-rigid IF cables, and separation of the 3 dB couplers from the FCU, as described above. It also leads to a longer than desireable harness between the HRH and HRV units (now on separate panels).

Thermal Interface/outside CVV (IIDB - § 5.7.2)

As discussed above, the design of the LOU radiator remains under the responsibility of HIFI, although the final design is to be agreed with Industry and ESA.

HIFI has responsibility for the thermal design and behaviour of the LOU/Radiator environment, together with its manufacture, and are thus responsible for the resulting operating temperature of the LOU. The *stabilisation* of the LOU temperature also remains under HIFI's responsibility, such that – if necessary – appropriate heaters are to be supplied and controlled by HIFI. The heaters could be used to maintain the LOU at a suitable temperature when it is *not* operating, although the power allocation of the LOU (7W) will not allow them to be run together with the LOU.

Thermal Interface/SVM (IIDB - § 5.7.3)

The requested max. operating temperature of FHWOH & FHWOV is 10° C. Preliminary analysis confirms that this operating temperature is acceptable in orbit, although it may not be acceptable for ground tests.

Difficulties have arisen from HIFI's stated requirement (HIFI CR-006) of 30mK / 100s for its High and Low resolution spectrometer units. Until such time as detailed analysis (ALENIA) confirms this degree of stability can be achieved, ESA and industry accepts these values as a *goal* only, but not as a requirement. The thermal analysis carried out by industry makes certain "worst-case" assumptions about (for example) switching of nearby reaction wheels, and/or pointing slews of the spacecraft. However, it has recently been revealed by HIFI that its own thermal dissipation may vary with time, according to which channels of the instrument are operated. This is likely to add more complexity to the analysis, and may result in poorer thermal stability than otherwise expected.

5.2.3.2 HIFI Electrical interfaces

Electrical interfaces with the S/C – Block Diagram

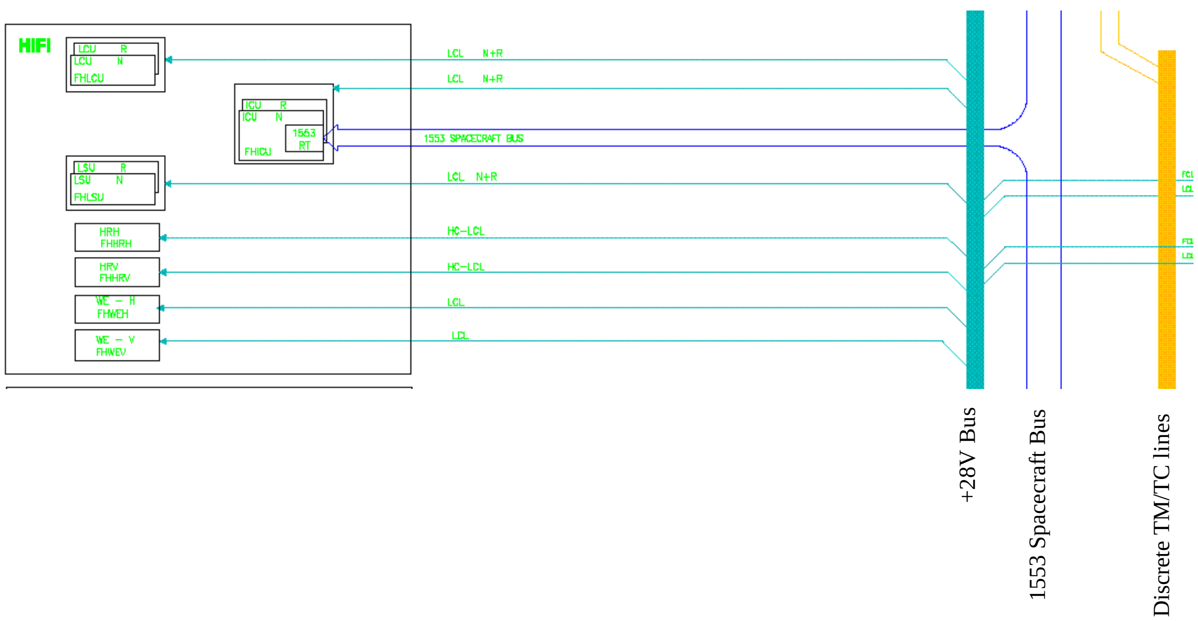


FIGURE 5.2-4 ELECTRICAL INTERFACES BETWEEN HIFI AND THE HERSCHEL SATELLITE

Average power load (IIDB - § 5.9.3)

It has been agreed with HIFI that the average dissipations of its warm units be used to determine the main bus power demand. The data provided in the IIDB - § 5.9.5 is used for dimensioning of the LCLs.

HIFI's power requirements have evolved since the previous issue of its IIDB (v. 2.1, Jan. 2002), from 288 W to 316 W. As agreed with ESA, the IIDB foresees an additional allocation of 15 W for HIFI, such that their updated allocation is 315 W. Nevertheless, even with this additional allocation, HIFI already has a slightly negative margin on its power budget. This situation needs to be closely monitored in the future.

Load on main bus (IIDB - § 5.9.5)

The table provided in this chapter provides the "maximum-average", short and long peak power requirements. HIFI's power is suppled over a total of 6 LCL lines (see figure above). The short-peak power demands are the drivers for LCL selection: 3 Class II LCLs, and 3 Class III LCLs are required.

Interface circuits (IIDB - § 5.9.5.2)

The interface circuit of the FHICU has been provided in the IIDB, as shown below. HIFI has stated that the other interface circuits, although not yet available, will adhere to the requirements given in the IIDB.

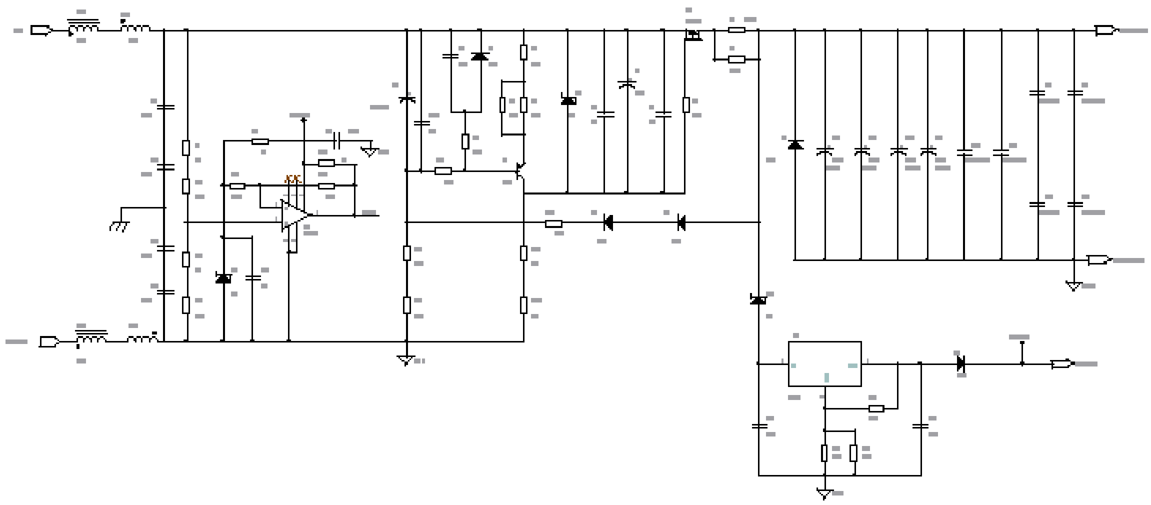


FIGURE 5.2-5 ELECTRICAL INTERFACES BETWEEN HIFI ICU AND THE HERSCHEL SATELLITE

EMC Requirements (IIDB - § 5.14.3)

HIFI generates microwave signals at certain frequencies, with the potential of interfering with other systems on the satellite. The frequency plan has been checked, and appears acceptable. The only frequencies of concern are those generated by the "comb oscillator", which has strong harmonics in the X-Band. This oscillator is however stated to be used for calibrations only, and to be switched off at all other times.

The RFW "SRON-U/HIFI/RW/2001-001 (20-06-02), related to radiated susceptibility, has recently been re-submitted by HIFI. Industry has several reservations concerning this RFW, which will need to be resolved in the near future.

TM/TC & Synchronisation Signals

The nominal and redundant MIL-1553 busses will be provided to HIFI, connections to be made according to the 1553 standard using the “long stub” with an isolating and coupling transformers.

No other discrete TM/TC line are requested by HIFI.

5.3 Planck

The Planck Satellite accommodates 2 instruments: LFI developed by a Consortium led by N. Mandolesi (TESRE-Bologna-I) and HFI, developed by a Consortium led by J.L. Puget (IAS-Orsay-F).

Common to the 2 instrument 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 systematics (ie all perturbations (thermal, EMC, straylight, vibrations) which might affect the signal)

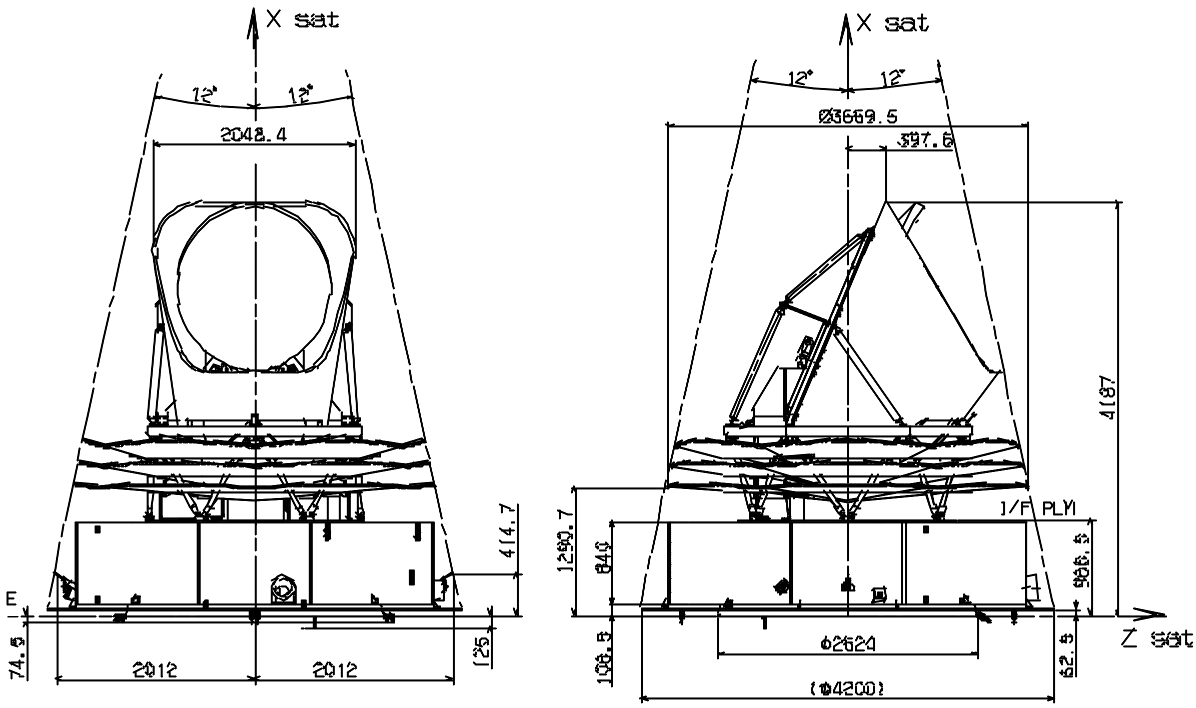


FIGURE 5.3-1 PLANCK SATELLITE

5.3.1 HFI

HFI (High frequency instrument) is based on very sensitive bolometers cooled at 0.1 K, and will map the CMB temperature fluctuations with 48 spider web bolometers split in 6 channels from 83 GHz to 1 THz.

5.3.1.1 HFI Mechanical & Thermal interfaces

FPU mechanical architecture

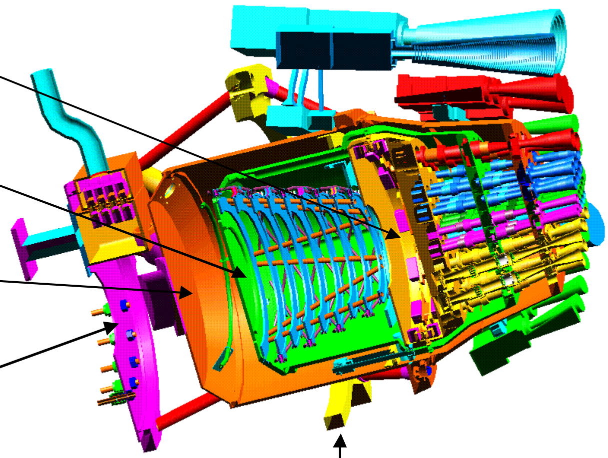


FIGURE 5.3-1 HFI FPU

Size & mass properties

The main changes are:

- 0.1 K Dilution cooler control unit (DCCU) and Filling and Venting Panel in one single box (with mass reduction)
- 4K Current Regulator as a new box
- Add of the exhaust pipe
- Slightly different dimension of the box, mainly to take into count the feet or the connectors
- Better description of the harness and the pipes.

Interfaces of the FPU with LFI and envelopes volumes have been clarified during technical meetings.

Pipes, harness and bellow routing have been achieved between 20K, 50K stage and SVM.

The following table compares the Mechanical interfaces of the HFI instrument between IIDB 2.0 and 2.1. The current mass budget of HFI Instrument shows a decrease of 6% wrt IID-B 2.0, and a 13% margin wrt the allocation of 244 kg

			IID-B 2.1		IID-B 2.0	
PROJECT CODE	**INSTRUMENT UNIT**	**# of**	**DIMENSIONS (mm)**	**NOMINAL MASS (kg)**	**DIMENSIONS (mm)**	**NOMINAL MASS (kg)**
PHA	HFI (alone) Focal Plane Unit	1	Not interfacing PPLM	17,4	Not interfacing PPLM	16.5
PHBA-N	Data Processing Unit (DPU) Nominal	1	316x280x90	6.9	280x280x100	6.5
PHBA-R	Data Processing Unit (DPU) Redundant	1	316x280x90	6.9	280x280x100	6.5
PHCA	J-FET Box	1	250x180x160	2.2	220x160x120	2.0
PHCBA	Pre-Amplifier Unit (PAU)	1	444x243x215	10.0	422x250x232	9.0
PHCBC	Readout Electronics (REU)	1	435x411x321	33.5	413x413x324	32
PHDA	4 K Cooler Compressor Unit	1	460 x 250 x 200	14.2	460 x 250 x 200	16
PHDB	4 K Cooler Ancillary Unit	1	350 x350 x130	7	350 x350 x100	5.1
PHDC	4 K Cooler Electronics Unit	1	220 x 220 x 200	6.5	220 x 220 x 200	7.0
PHDJ	4K Cooler Pre Regulator	1	150x150x150	2.2	N/A	N/A
PHEAA	0.1 K Dilution Cooler ^{3}He Tank	1	Diameter 480	13.4	Diameter 480	16
PHEAB-1 to 3	0.1 K Dilution Cooler ^{4}He Tanks	3	Diameter 480	3 x 14.15	Diameter 480	3 x 16
PHEC	0.1 K Dilution Cooler Control Unit	1	800X660X260	25	660X350X260	25
PHAD	FPU to J-FET Box Harness	1	OD = 27 L = 500	2	OD = 35 L = 500	2
PHBBA-N	DPU to REU signal harness Nominal	1	L =1000 OD = 2	0.3	L =1000 OD = 2	0.3
PHBBA-R	DPU to REU signal harness Redundant	1	L = 1000 OD = 2	0.3	L = 1000 OD = 2	0.3
PHBBB-N	DPU to REU power harness Nominal	5	L = 1000 OD = 4.5	1.1	L = 1000 OD = 4.5	1.1
PHBBB-R	DPU to REU power harness Redundant	5	L = 1000 OD = 4.5 TBC	1.1	L = 1000 OD = 4.5 TBC	1.1
PHBBC-N	DPU to 0.1K signal harness Nominal	1	L = 3500 OD = 2	0.3	L = 3500 OD = 2	0.3
PHBBC-R	DPU to 0.1K signal harness Redundant	1	L = 3500 OD = 2	0.3	L = 3500 OD = 2	0.3
PHBBG 1&2	DPU Nominal to Redundant harness	2	TBD	TBD	N/A	N/A
PHBBE-N	DPU to 4KCDE signal harness Nominal	1	L = 4500 OD = 2	0.5	L = 4500 OD = 2	0.5
PHBBE-R	DPU to 4KCDE signal harness Redundant	1	L = 4500 OD = 2	0.5	L = 45 OD = 2	0.5
PHCBB	PAU to J-FET box cryo harness	1	L = 2500 OD = 33	5.6	L = 2500 OD = 52	5.6
PHCBD	REU to PAU harness	12	L = 2500 OD = 70 TBC	10	L = 2500 OD = 70 TBC	10
PHDD	4 K Cooler Cold End (CCE) pipes and cryo-harness from the SVM bracket to FPU	1	L = 2600 OD harn = 5 OD pip = see	1.1	TBD	1.1

			IID-B 2.1		IID-B 2.0	
PROJECT CODE	INSTRUMENT UNIT	# of	DIMENSIONS (mm)	NOMINAL MASS (kg)	DIMENSIONS (mm)	NOMINAL MASS (kg)
PHDE	4 K Connecting warm pipework and harness from the CAU to the SVM bracket	1	L = 3000 (2) OD harn = 5 OD pip = see	1.5	TBD	1.5
PHDFA-A&B	4KCDE to Compressor PPO A & B signal harness	2	L = 1000	0.2	L = 1000	0.2
PHDFB	4KCDE to Compressor force harness	1	L = 1000	0.1	L = 1000	0.8
PHDFC-A&B	4KCDE to Compressor drives A&B harness	2	L = 1000	0.2	L = 1000	0.35
PHDFD	4KCDE to Ancillary Unit harness	1	L = 1000	0.4	L = 1000	0.2
PHDFE	4KCDE/CCU Temperature Harness	1	TBD	TBD	TBD	TBD
PHDK	4K CDE to Regulator harness	1	L = 1000 OD = TBD	0.4	N/A	N/A
PHEEA	0.1K ^{3}He Tank to Control Unit Piping and harness	1	L = 1000 OD harn: 3 OD pipe: 6.35	0.2	L = 1000 OD harn: 3 OD pipe: 6.35	0.1
PHEEB	0.1K ^{4}He Tank 1 to Control Unit Piping and harness	1	L =3000 OD harn: 3 OD pipe: 6.35	0.3	L =3000 OD harn: 3 OD pipe: 6.35	0.3
PHEEC	0.1K ^{4}He Tank 2 to Control Unit Piping and harness	1	L = 5000 OD harn: 3 OD pipe: 6.35	0.3	L = 5000 OD harn: 3 OD pipe: 6.35	0.4
PHEED	0.1K ^{4}He Tank 3 to Control Unit Piping and harness	1	L = 7000 OD harn: 3 OD pipe: 6.35	0.6	L = 7000 OD harn: 3 OD pipe: 6.35	0.6
PHEFG	0.1K Dilution Cooler piping & harness from DCCU to SVM bracket (including bracket)	1	L= TBD OD harn =6	TBD	L= 7000 (DCCU->DCCE)	0.7
PHEFH	0.1K Dilution Cooler piping & harness from SVM bracket to 50K stage	1	L=1500 OD harn =6	TBD	N/A	N/A
PHEEJ	0.1K Dilution Cooler piping & harness from 50K stage to 18K stage	1	L=1400 OD harn =6	TBD	N/A	N/A
PHEEF	0.1K Control Unit to exhaust	1	L = 1000 OD = 20	0.5	N/A	N/A
TOTAL	**Excluding LFI FPU**		**NA**	**215.4**	**NA**	**229.3**

TABLE 5.3-1 HFI ITEMS CODES, SIZE & MASS

Access to the 0.1K DCCU and 4K electronic have been implemented:

- 2 connectors J of the 4K CEU for the test of the CEU and for locking the compressor during transportation
- 3 electrical connectors of the DCCU
- 6 fill and drain hand valves of the DCCU
- 2 VCR for the pre-cooling loop of the DCCU
- 1 exhaust pipe for the 0.1K cooler (with a T piece dismountable) of the DCCU.

Some major uncertainties remains on the DCCU and 4K Current regulator since those units are not designed yet.

We don't have any configured drawings for the 4K Ancillary Unit and the 4 K compressor.

Mechanical Interfaces

Concerning the mechanical interfaces, there are still indication of micro-vibrations susceptibility (0.1 to 1 mg), which will have to be refined.

Thermal interfaces

The following table summarises the HFI thermal requirements, which are very similar to the IIDB 2.0

The main difference is the temperature stability requirement on the PAU (1.1K/h instead of 0.1 K/h in IID-B 2.0). This figure will be easier to achieve, but is still not guaranteed by TCS (3 K/h).

			Temperature required by Instrument								Guaranteed by TCS		
			Operating		Stability	Start-up	Switch-off	Non-operating			Operating		T Stability
			Min	Max	DT/dt			Min	Max		Min	Max	DT/dt
			°C	°C	K/h	°C	°C	°C	°C		°C	°C	K/h
HFI	PHBA-N/R	DPU N / R (Data processing Unit)	-10	40		-20		-20	50		-10	40	
	PHCBC	REU (Read Out Electronics)	-10	40		-20		-20	50		-20	40	
	PHCBA	PAU (Power Amplifier Unit)	-10	30	1,1	-20		-20	50		-20	35	3
	PHDA	4KCU (4K Compressor Unit)	-10	40		-20		-20	40		-10	40	
	PHDB	4KAU (4K Ancillary Unit)	-10	40		-20		-20	50		-10	40	
	PHDC	4KCDE (Cooler Drive Electronics)	-10	40		-20		-20	50		-10	40	
	PHDJ	4K current regulator	-10	40		-20		-20	50		-10	40	
	PHEAA	He3 Tank (1 unit)	-10	40		N/A		-20	50		-10	40	
	PHEAB1 to 3	He4 Tanks (3 units)	-10	40		N/A		-20	50		-10	40	
	PHEC	DCCU (Dilution Cooler Control Unit)	-10	40		-20		-20	50		-10	40	
		Cables and Pipes	-10	40		N/A		-20	50		-10	40	

TABLE 5.3-2 TEMPERATURE REQUIREMENTS AND PROPOSED FOR HFI WARM UNITS

Concerning the need of temperature sensors, there will be only one type provided and powered by the spacecraft (ie no distinction between SPT & SHT), located on the spacecraft, at the instrument interface point (not on the instrument). The information will be part of the spacecraft housekeeping.

Optical Interfaces

There is a good understanding in optical interfaces, and information has been exchanged to perform the PPLM optical and straylight design.

5.3.1.2 HFI Electrical interfaces

Figure 5.3.1.2.1 shows the electrical interfaces between HFI and the satellite.

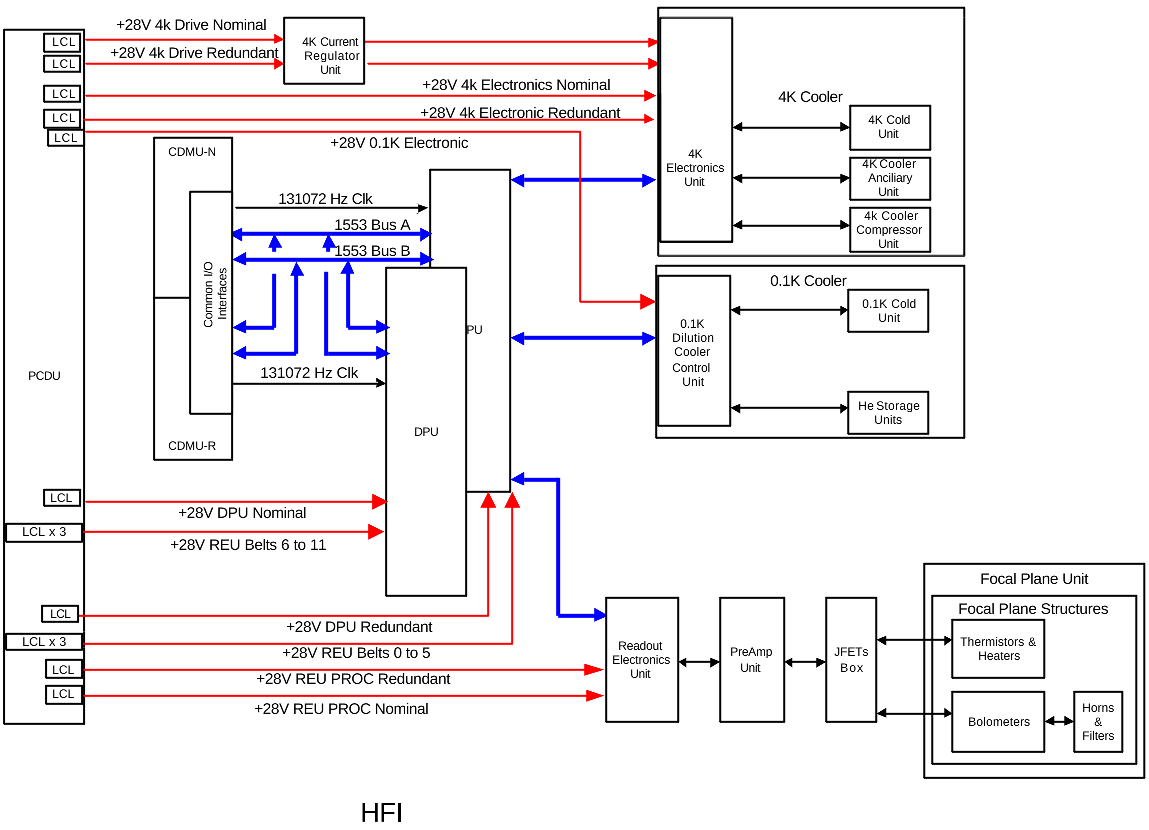


FIGURE 5.3-2 HFI ELECTRICAL INTERFACES BLOCK DIAGRAM

Power Interfaces

The total budget shows a margin of 7% wrt the allocation.

N°	Power Line Name	Status	Average Power	Long Peak	Short Peak	Average Power wm	Long Peak wm	Short Peak wm
1	DPU (Nom)	On	32 W		34 W	32 W		34 W
2	REU Proc (Nom)	On	24 W			24 W		
3	4KCDE Proc (Nom)	On	12 W			15 W		
4	4KC Regulator (Nom)	On	124 W		TBD W	149W		TBD W
5	DPU (Red)	Off						
6	REU Proc (Red)	Off						
7	4KCDE Proc (Red)	Off						
8	4KC Regulator (Red)	Off						
9	DCE	On	16 W	21.6 W	31W	17.5 W	23.5W	33.5 W
10	REU belts 0 & 1	On	13,8 W			15 W		
11	REU belts 2 & 3	On	13,8 W			15 W		
12	REU belts 4 & 5	On	13,8 W			15 W		
13	REU belts 6 & 7	On	13,8 W			15 W		
14	REU belts 8 & 9	On	13,8 W			15 W		
15	REU belts 10 & 11	On	13,8 W			15 W		
	Total power		**290.8 W**					

TABLE 5.3-3 HFI POWER DEMAND

The complete list of LCL is given in Paragraph 5.1.3.2. LCL to the DPU (N+R) and REU Proc (N+R) are required to be secured.

TM/TC & Synchronisation Signals

The nominal and redundant MIL-1553 busses will be provided to HFI, connections to be made according to the 1553 standard using the “long stub” with an isolating and coupling transformers.

1 Nominal + 1 Redundant 131072 Hz clock signal will be distributed to the HFI using SBDL (Standard Balanced Digital Link) interfaces for HFI timing purposes.

Pointing

Our applicable requirement is in the SRS 3.0. IID-A 3.0 is compliant with these requirements.

5.3.2 LFI

LFI (Low Frequency Instrument) is complementary to HFI. It will map the CMB with 27 coherent receivers split in 4 channels from 30 to 100 GHz.

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 23 = 92 wave-guides.

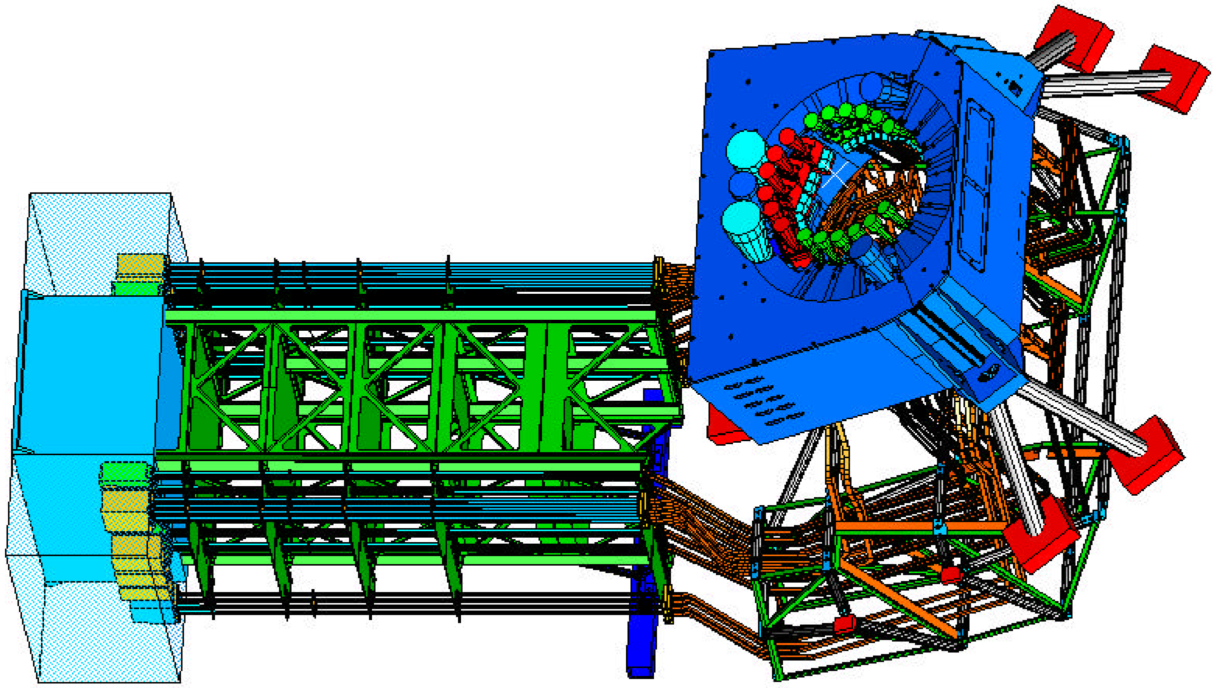


FIGURE 5.3-3 LFI RAA (FEU, WAGE-GUIDES AND BEU)

One of the Key issue for the LFI detectors is to maintain them at 20K despite of a large dissipation (>580 mW), and the large number of wave-guides connected the BEU to room temperature.

5.3.2.1 LFI Mechanical/Thermal interfaces

Location and Alignment requirements

The requirements on alignment and location are well understood, and should not be a major problem. The main concern is the integration of the Radiometer Array Assembly (RAA), composed of the FEU, BEU and wave-guide which has to interface all cooling stages. The only remaining open point is the relative displacement between BEU and FPU during launch which could be very high.

Mass & Size properties

The following table compares the Mechanical interfaces of the LFI instrument between IIDB 2.0 and 2.1. The current mass budget of LFI Instrument shows a decrease of 9% wrt IID-B 2.0, and a 8% negative margin wrt the allocation of 89 kg

			IID-B 2.1		IID-B 2.0	
PROJECT CODE	INSTRUMENT UNIT	# of	DIMENSIONS (lxdxh mm)(3)	NOMINAL MASS (kg)	DIMENSIONS (lxdxh mm)(3)	NOMINAL MASS (kg)
PLFEU	Front End Unit including 4K load, cryo-harness, heat switchand FEU internal harness (LFI part of common LFI/HFI FPU)	1	299x480x553 (without fixation struts) note that FEU is not a rectangular box	25.7	400x426x600 (without fixation struts) note that FEU is not a rectangular box	26.8
PLWG	Wave-guides(2 bundles) and support structur	1 set	See figure 5.4-1 on IIDB	15.5	See figure 5.4-1 on IIDB	10.8
PLBEU	Back End Unit (BEU)	1	570x432x210	30.6	570x400x200	33.5
	BEU internal harness	1set	length = 0.5 m	3.2	length = 0.5 m	2.6
	Power box to BEU and BEM harness	1set	length = 4 m	4.1	length = 4 m	N/A
	DAE Power Box	1	216x119x255	6.3	250x500x200	20.9
PLREN	REBA nominal	1	270 x 215 x 110	4.0	270 x 215 x 110	4.0
PLRER	REBA redundant	1	270 x 215 x 110	4.0	270 x 215 x 110	4.0
PLIH	REBA to BEU harness	1 set	Length = 4 m OD = 30	2.9	Length = 4 m OD = 30	3.0
TOTAL				96.3		105.6

TABLE 5.3-4 LFI ITEMS, CODES, SIZE & MASS

The main changes are:

- the removal of 4 radiometers 100 Ghz, and the associated electronic and wave-guides
- the DAE control box is now the DAE power box which contains the DC/DC converters for the DAE. His mass has dramatically decreased.
- the addition of a support structure for the wave-guides.

Mechanical Interfaces

The FPU, bipod, wave-guide and wave-guide support structure interface are almost frozen with LFI. The remaining open point is the thermal shield between the grooves.

Thermal interfaces

Heat loads

We provided a new allocation of heat load for LFI. We believe that LFI will be compliant with the design of “thick” wave-guides, which is less risky than the “thin” wave-guides. The remaining open point is the heat load on groove 2 which exceeds the allocation.

Temperature range

Main difference with IIDB 2.0 is the temperature stability of BEU which was TBD and is now 0.2 K/h. The guaranteed figure by TCS is still 3K/h. Another major concern is the max temperature of the BEU, which is now assessed at 45° C for a maximum requirement of 40° C.

			Temperature required by Instrument							Guaranteed by TCS		
			Operating		Stability	Start-up	Switch-off	Non-operating		Operating		T Stability
			Min	Max	DT/dt			Min	Max	Min	Max	DT/dt
			°C	°C	K/h	°C	°C	°C	°C	°C	°C	K/h
LFI	PLREN	REBA Nominal	-20	50		-30	TBC	-30	50	-20	50	
	PLRER	REBA Redundant	-20	50		-30	TBC	-30	50	-20	50	
	PLAEF	DAE Power box (Data acquisition Electronics	-20	50		-30		-30	50	-20	**45**	**3**
	PLBEU	BEU (Back end Unit)	-10	40	0,2	-30		-30	50	**-20**	40	**3**

TABLE 5.3-5 TEMPERATURE REQUIREMENTS AND PROPOSED FOR LFI WARM UNITS

5.3.2.2 LFI Electrical interfaces

Figure 5.3.2-1 shows the electrical interfaces between HFI and the satellite.

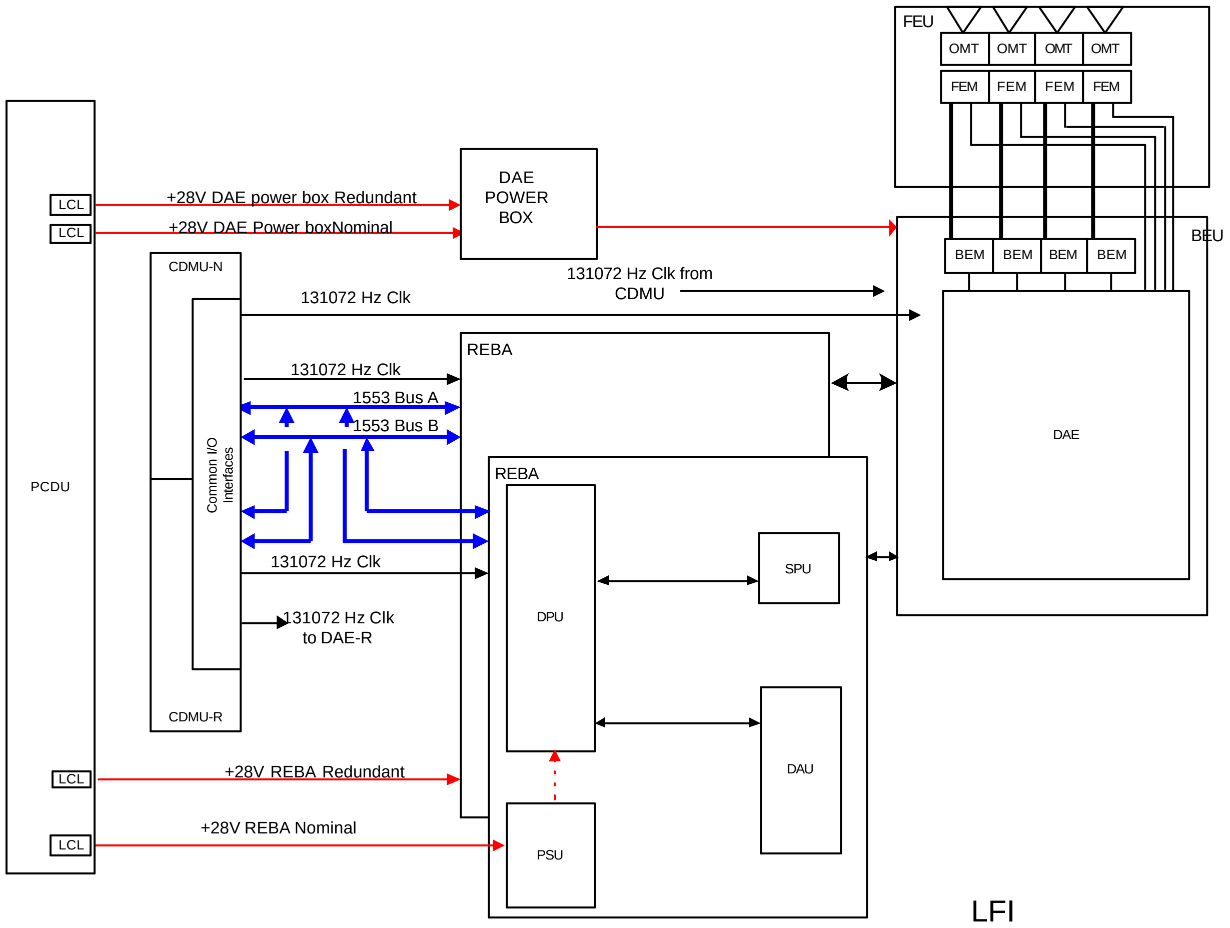


FIGURE 5.3-4 LFI ELECTRICAL INTERFACES BLOCK DIAGRAM

Power Interfaces

The total budget shows no margin wrt the 120 W allocation.

OPERATING MODE	POWER LINE	AVERAGE BOL (W)	AVERAGE EOL (W)	PEAK (W)
Standby	***Total***	***41.5***	***41.5***	***41.5***
	REBA	41.5	41.5	41.5
	RAA	0	0	0
DAE Set-up	***Total***	***50.7***	***50.7***	***50.7***
	REBA	41.5	41.5	41.5
	RAA	9.2	9.2	9.2
Normal Science	***Total***	***120.2***	***120.2***	***120.2***
	REBA	41.5	41.5	41.5
	RAA	78.7	78.7	78.7
Extended Science	***Total***	***120.2***	***120.2***	***120.2***
	REBA	41.5	41.5	41.5
	RAA	78.7	78.7	78.7

TABLE 5.3-6 LFI POWER DEMAND

The complete list of LCL is given in Paragraph 5.1.3.2. LCL to the REBA (N+R) and RRA(DAE) (N+R) are required to be secured.

TM/TC & Synchronisation Signals

The nominal and redundant MIL-1553 busses will be provided to LFI REBA, connections to be made according to the 1553 standard using the “long stub” with an isolating and coupling transformers.

The following 131072 Hz clock signals will be distributed to the LFI using SBDL (Standard Balanced Digital Link) interfaces for LFI timing purposes:

- one to the nominal REBA
- one to the redundant REBA
- one to the nominal DAE
- one to the redundant DAE.

5.3.3 Sorption cooler

The sorption cooler is a subsystem of LFI. It is also used as precooler for HFI, which in return provides the sorption cooler electronics. Because of its impact on the mission reliability, is is composed of 2 units, one in cold redundancy. It is designed to provide 1100 mW of cooling power at 20 K for LFI (including 135 mW at 18 K for HFI). It is based on a H2 closed cycle Joule Thomson cooler, with a sorption compressor based on thermal cycling of metal hydrides (LaNi4.78Sn0.22).

As it requires substantial resources from the satellite (112 kg for 2 coolers, 570 W, 3/8 SVM panels), and because it is common to both instruments, it is described in an independent document: The sorption cooler ICD, annex to LFI IID-B, and having the same structure than any IIDB document.

5.3.3.1 Sorption cooler Mechanical & Thermal interfaces

Size and mass properties

The mass has increased by 6 % since the IID-B 2.0, and shows a negative margin of 8% wrt the allocation of 112 kg. Besides, the real mass estimated by JPL is even 8 kg higher than the current IID-B 2.1 below.

			IID-B 2.1		IID-B 2.0	
PROJECT CODE	**SCS UNIT**	**# of**	**DIMENSIONS (mm) L x W x D (including feet)**	**NOMINAL MASS (kg)**	**DIMENSIONS (mm) L x W x D (including feet)**	**NOMINAL MASS (kg)**
PSM1	Sorption Cooler Cold End (SCCE)	1	Located within PLFEU and HFI FPU	2.6	Located within PLFEU and HFI FPU	1.5
PSM2	Sorption Cooler Pipes (SCP)	1 set	Length: ≈ 9500 Diameter: 6.35	5	Length: ≈ 9500 Diameter: 6.35	4.4
PSM3	Sorption Cooler Compressor (SCC)	1	967x720x250	41.8	1000x750x250	39.8
PSM4	Sorption Cooler Electronics (SCE)	1	300x300x137	8.5	300x300x150	8.5
PSM5A PSM5B	Harness SCE – SCC	1 set	Length = 1500 OD=15 (5A) OD=40 (5B)	2.0	Length = 1500 OD=15 (5A) OD=40 (5B)	2.0
PSM5C	Harness SCE –SCCE	1 set	Length = 5000 OD=10	1.0	Length = 5000 OD=10	1.0
TOTAL	Mass Nominal	1		60.9		57.2
PSR1	Sorption Cooler Cold End (SCCE)	1	Located within PLFEU and HFI FPU	2.6	Located within PLFEU and HFI FPU	1.5
PSR2	Sorption Cooler Pipes (SCP)	1 set	Length: ≈ 9500 Diameter: 6.35	5	Length: ≈ 9500 Diameter: 6.35	4.4
PSR3	Sorption Cooler Compressor (SCC)	1	967x720x250	41.8	967x720x250	39.8
PSR4	Sorption Cooler Electronics (SCE)	1	300x300x137	8.5	300x300x137	8.5
PSR5A PSR5B	Harness SCE – SCC	1 set	Length = 1500 OD=15 (5A) OD=40 (5B)	2.0	Length = 1500 OD=15 (5A) OD=40 (5B)	2.0
PSR5C	Harness SCE –SCCE	1 set	Length = 5000 OD=10	1.0	Length = 5000 OD=10	1.0
TOTAL	Mass Redundant	1		60.9		57.2
TOTAL	(Sum nominal plus Redundant SCS)	2		121.8		114.4

TABLE 5.3-7 SCS ITEMS CODES, SIZE & MASS

Sorption cooler Thermal interfaces

The main change is the agreement found in Bologna for the power consumption of the 3 Instrument which now fit the spacecraft resources. The maximum allowed power for the SCC is now 470 W (instead of 520 W), and a total of 570 W with the SCE. Nevertheless, the design and operating point of the SCS remains the same (cycle time = 667 sec), but the uncertainties are now reduced. JPL will change the operating point if they happen to need more than the allocated power, hence reducing the heatlift.

The SVM radiator has been sized for 520 W though, allowing an increase of power consumption for the Compressor if LFI or LFI power budget happens to be under their allocation.

5.3.3.2 Sorption Cooler Electrical interfaces

Figure 5.3.3.3-2 shows the electrical interfaces between Sorption Cooler and the satellite.

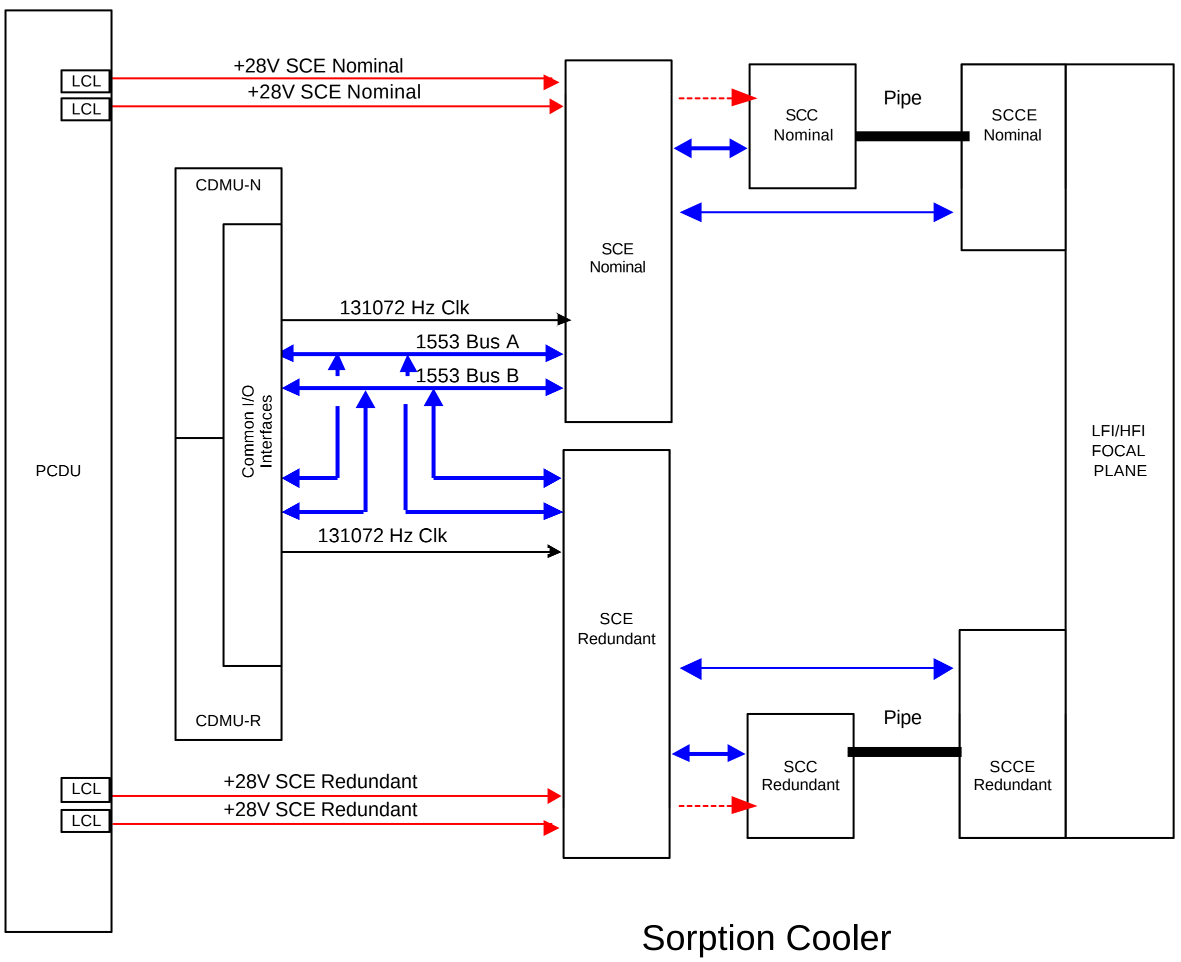


FIGURE 5.3-5 SCS ELECTRICAL INTERFACES BLOCK DIAGRAM

Power Interfaces

The following power lines have been identified for Sorption Cooler:

- Sorption Cooler Electronics Nominal (for SCE N electronic itself)
- Sorption Cooler Electronics Nominal (for SCC R power supply)
- Sorption Cooler Electronics Redundant (for SCE R electronic itself)
- Sorption Cooler Electronics Redundant (for SCC R power supply).

The complete list of LCL is given in paragraph 5.1.3.2. Neither LCL needs to be secured.

TM/TC & Synchronisation Signals

The nominal and redundant MIL-1553 busses will be provided to the Sorption Cooler, connections to be made according to the 1553 standard using the “long stub” with an isolating and coupling transformers.

The following 131072 Hz clock signals will be distributed to the Sorption Cooler using SBDL (Standard Balanced Digital Link) interfaces for LFI timing purposes:

- one to the nominal SCE
- one to the redundant SCE.

5.4 Open points

This paragraph is to summarise the open points concerning the technical interfaces with the instruments that will have to be resolved during the period between the SRR and the PDR.

Mass budget (HERSCHEL, Planck)

Although the overall mass of the instruments are still within the allocation, some effort should be undertaken to increase the margin.

The main efforts should be focused on LFI +SCC (-9% margin), HIFI (-4%).

Power budget (Herschel)

Similarly, the power margin is too small (2.4%), despite the increase by 50W (10%) of the allocation. HIFI and PACS which have increased a lot during phase B should try to reduce their demands to reach adequate margin.

Mechanical load on instruments

The Random mechanical vibration levels proposed in the IID-A have been updated and are considered too high by some instruments. The problem will have to be solved by allowing instrument subsystems to be notched during subsystem tests.

Temperature stability (HERSCHEL/Planck)

Both satellites have units which are very sensitive to temperature fluctuation. The most stringent requirements are on the SVM:

- HIFI Wide Band Spectrometer (0.03 K/100 s) on HERSCHEL,
- HFI PAU (1.1 K/h),
- LFI BEU (0.2 K/h),
- Sorption cooler compressor (3, 1, 0.5K on a cycle period).

In addition, the Planck payload although highly damped by the thermal insulation, is very sensitive to temperature fluctuation (in the microK range) at spin frequency. Both satellites have sources of fluctuations: response of the Satellite tilting wrt Sun for HERSCHEL, instrument warm unit power fluctuations, sorption cooler heat peaks for Planck.

Software controlled heaters (adjustable duty cycle) is the baseline on both satellites for the thermal control, but detailed analysis of the performances will be performed.

Cryogenic Heat loads

Both for Herschel and for Planck, the heat loads on cryogenic interfaces are exceeding allocation. Compromise will have to be found between temperature requirement and heat load allocation.

LFI Instrument maturity

Due to the lack of maturity of some parts of LFI Instrument, we had to anticipate the interfaces and therefore we have to be very careful with the design evolution of such parts.

Wave guide interfaces

If a concept exist for the LFI wave guide mechanical and thermal interfaces, with support frame and themal straps, the detailed interfaces are not yet in a satisfactory status (closure of the V-grooves, position of the thermal and mechanical interfaces). Closer design activities (ALCATEL/LABEN) has to be initiated to close this issue.

BEU mechanical interface

The BEU is a very large box at the bottom of the waveguides. The definition of the box is not yet completely frozen, since LABEN lately proposed to add some internal harness on the –Z and +Z sides of the box. The problem is that –Z side is a radiative face towards space, and in +Z the face is very close to the first V-groove. Work is in progress to find the best solution.

BEU temperature

Some sensitive components of the BEU don't support high temperature. The max temperature of 28° C is exceeded in EoI. Further analysis with detailed thermal model of the box are in progress.

Displacement between FPU and BEU

The current displacement requirement concerns only the cool down. We think that the sizing case is the vibrations due to launch, and therefore agreement has to be reach covering all the cause of displacement.

Heatswitch

The implementation of heatswitch has been decided by LFI, but for now there is no design

HFI Instrument maturity

0.1K DCCU design

The design of the DCCU is just beginning and we had to take some assumptions wrt the interfaces (in agreement with the Instrument): size, consumption/dissipation, access to the valves and connectors, location of the pipes and connectors interfaces, design of the exhaust pipe. We have to be very careful with the design evolution of this equipement.

4K Cooler Current Regulator design

The design of the 4K CCR doesn't exist for now and we had to take some assumptions wrt the interfaces (in agreement with the Instrument): size, consumption/dissipation and connectors interfaces. We have to be very careful with the design evolution of this equipment.

0.1K exhaust valves opening

Due to potential contamination problem, HFI need to open the Helium exhaust valve of the DCCU before the 3rd V-groove reaches 100K, which means about 8 hours maximum after launch. This requirement has arrived too late to be addressed for the PDR

Delivery dates

Instruments QM and FM delivery dates have been shifted by 6 month between SRR and PDR. If Hershel delivery dates for the QM seems to be consolidated, LFI delivery dates are not secured as the funding is not secured.

6. SYSTEM DESIGN

6.1 Summary of main trade-offs

6.1.1 SVM/H-EPLM interface

A trade-off to optimise the number of struts at the Herschel SVM/PLM interface has already been initiated before SRR. It was finalised after SRR and confirmed the new baseline with 24 struts, replacing the previous configuration with 16 struts. The main issues are:

- Mechanical performance (stiffness)
- Mass
- Commonality
- Lifetime

Mechanical performance

The basic configuration for the 16 struts case is to have struts with 50 mm outside diameter and 4 mm wall thickness. The predicted longitudinal frequency in this configuration is 37 Hz, leaving an acceptable margin w.r.t. the 35 Hz requirements.

The 24 struts case providing the same stiffness can be predicted analytically. This is shown in the following table which computes for the longitudinal stiffness for 16 and 24 struts configurations.

The hypothesis taken is that the same basic cone is used for the SVM. ALENIA has studied the influence of having 16 or 24 struts on the cone stiffness performance. A factor of 1.2 between the 2 configurations was found by ALENIA. A value of 6 10^8 N/m is taken for the 24 struts configuration while 5 10^8 N/m is taken for the 16 struts configuration.

# Struts	Wall thickness (mm)	A/l (mm)	α (deg)	Kax (struts) N/m	Kax (SVM) N/m	Kax (susp. Mass) N/m	Kax (total) N/m
16	4	13.54	37.1	4.307E+08	5.00E+08	8.83E+07	6.391E+07
24	1.6	9.49	27.6	3.728E+08	6.00E+08	8.83E+07	6.380E+07
Kax (struts) = E A/l $\cos(\alpha)^2$ E (GFRP) = 50 000 N/mm^2							

It can be seen that, to obtain the same longitudinal stiffness, a wall thickness of 4 mm is required for a 16 struts configuration while, with 24 struts, a 1,6 mm wall thickness is required.

Lateral stiffness was also investigated and was found not to be a design driver.

Mass

The mass impact at PLM level is shown in the following table.

Number of struts	16	24
Outside diameter (mm)	50	50
Wall thickness (mm)	4	1.6
Length of tubes (mm)	491	423.1
GFRP tube mass	10.32	6.96
CVV attachment	16	18
Top bracket (CVV)	3.5	5.25
Bottom bracket (SVM)	2.4	3.6
End fittings	4.64	5.62
Total	**36.86**	**39.43**

The mass impact on the SVM is estimated to be 5 kg maximum, corresponding to additional structural inserts to interface with the PLM (12 inserts instead of 8) and to local tube reinforcement.

The total mass impact at system level is thus 7.5 kg more for 24 struts compared to 16 struts.

Commonality

The 24 struts configuration on Herschel allows a better commonality with Planck at the level of the SVM structure central cone. As the Planck PLM has 12 struts, the Herschel configuration with 24 struts allows to use Herschel interface points for the Planck PLM. This was not possible with the 16 struts configuration.

Lifetime

The main goal of going to 24 struts was to improve the lifetime with the same stiffness performance. This is normally expected as, in the 24 struts configuration, the overall A/l is smaller than in the 16 struts configuration. Taking into account the actual length of the glass fiber tubes, the following A/l relevant to conductive heat transfer are found:

– 16 struts with 4 mm wall thickness: 20.06 mm

– 24 struts with 1.6 mm wall thickness: 14.86 mm

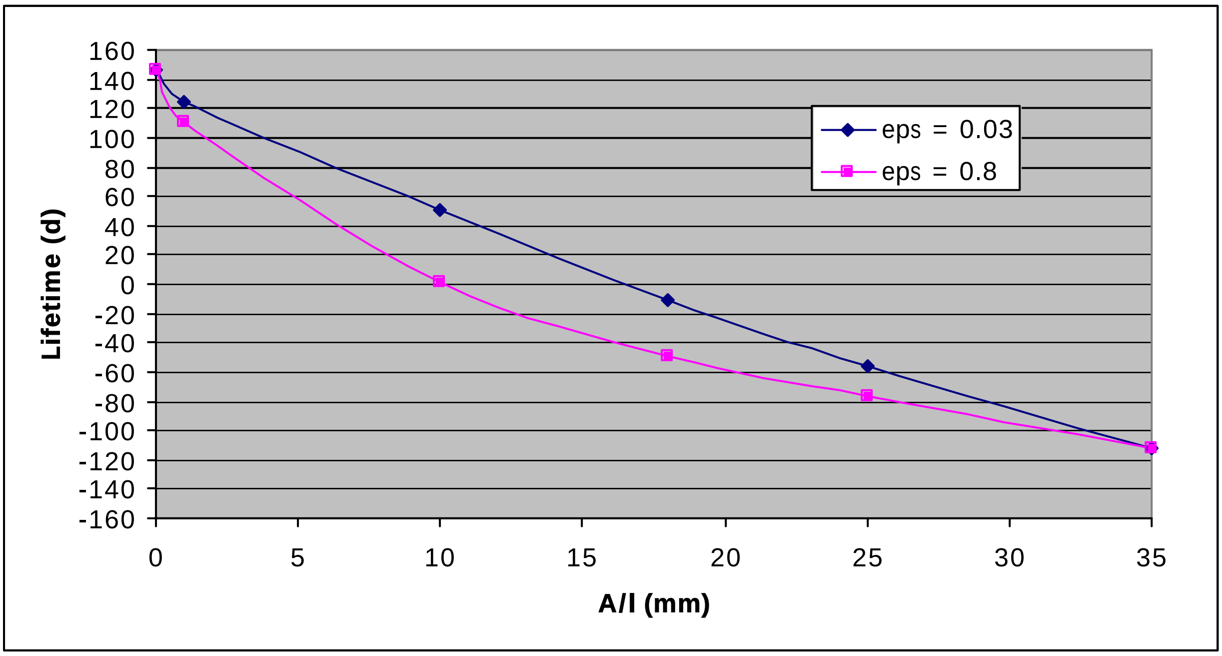
thus showing a clear reduction of the conductive heat transfer with 24 struts.

In order to properly assess the impact on lifetime, Astrium has included the effect of struts radiation to space. In order to properly assess the effect of struts radiation, the struts were modelled with 10 thermal nodes. Two cases are investigated:

– struts with high emissivity ($\varepsilon = 0.8$): struts radiatively coupled to space

– struts with low emissivity ($\varepsilon = 0.03$): struts radiatively decoupled from space.

The results are shown in the following plot:



It can be seen that the lifetime performance is better when the struts are radiatively decoupled. From the other cases studied by Astrium, the following conclusions can also be drawn:

- the performance is driven by the cross section to length ratio and is nearly independent from the struts configuration (16 or 24 struts)
- the 24 struts configuration leads to longer lifetime: 40 days more lifetime are found w.r.t. the 16 struts configuration.

Further struts optimisation

It appears in the frame of phase B that a further struts optimisation could take place, with use of the high rigidity of the SVM cone. This allows to reduce the section of PLM supporting struts (CVV struts) with benefit to lifetime, while maintaining the satellite mechanical performances (overall stiffness and main frequencies).

Preliminary analysis at SVM structure level evidenced that the SVM cone stiffness would be greater than expected, because of the cone construction with a 4 plies lay-up (27.5,-27.5,-27.5,27.5) th=0.54 mm with high fibre module G969/M18 derived from previous and proven experience with space program at EADS CASA. The cone global stiffness was calculated in the order of 14.5 E8 Vs 4.5 E8 N/m specified.

The implementation of this higher cone stiffness in FEM modelling led to higher Satellite fundamental frequencies for Herschel and Planck. For Herschel in particular, it is resulting from the overall stiffness of satellite mechanical backbone, i.e. cone with CVV struts and CVV itself.

This new status did not create additional problem on Planck, as Planck modes were already high in frequency. On the other hand for Herschel, it produced a compression and re-combination of second lateral modes, with a modal coupling between SSH modes and He Tank lateral modes. This situation conducted to QSL increase for these items.

Then, it was decided to play in 2 directions to recover a safe situation for Herschel, when the situation was indifferent for Planck. First axis was to reduce the cone stiffness to a lower level, when the second was to reduce the CVV struts stiffness, with the objective to come back to a satellite global stiffness and fundamental frequency as before.

These actions converged to the current baseline design with:

Cone design

- a SVM cone configuration with 4 layers (35,-35,-35,35) th=0.54 mm with fibre 914/M40
- a cone stiffness (Kx): achieved 5.13E+8 N/m with required < 6.5 E+8 N/m by ASPI, the specification being relaxed to reach a suitable solution
- a cone skins presenting global positive MoS, but with local reinforcement

Struts design

- reduction of CVV struts by 30 %, for lifetime benefit
- struts section still presenting low but sufficient margin wrt buckling, which makes think that the design is close to optimum
- lifetime benefit of 20 days with 30 % reduction.

Conclusion

During Phase B, various optimisation of the SVM to PLM interface of Herschel has been conducted. The first evolution was to chose the 24 struts configuration as it was providing a clear lifetime advantage and was favouring commonality. The mass penalty was considered acceptable.

Further optimisation was found possible when it appears that the SVM central cone was stiffer than initially thought.

It made possible on additional strut reduction which are now close to the optimum.

6.1.2 Sunshield/Sunshade configuration and supporting

Evolutions of Herschel Sunshield/Sunshade design are described in Section 6.2.3.

6.1.3 Power conditioning

One of the characteristics of a solar array employing triple junction cells is the high electrical capacitance of the array sections. This additional capacitance will lead to additional noise on the mainbus since during the shunt switching this capacitance will have to be charged and discharged. There are several possible solutions for this problem: 1) change the switching concept from shunt switching to series switching, 2) increase the bus capacitor, 3) or to arrange the regulation as to not to directly shunt the array but to provide a constant load.

The option 1) was rejected for further investigation because it would lead to major concept and design changes for existing PCDU of the same power class. Option 2) and 3) were retained for further investigation.

Option 2 Increase of Bus capacitor:

Since the precise electrical capacitance of the array cannot be determined at present (there are not enough test results available for triple junction cells) assessments were made using experience from previous triple junction cell array, notably from the ESA SMART1 program. This led to an estimated section capacitance of around 4 µF so applying margin this gave 5 µF which has been specified in the PCDU requirement specification. A typical bus capacitor for a system like the Herschel Planck application would be around 1.5 mF to 2 mF, various assessments of the increase in bus capacitor yielded a total of 3 mF to 5 mF. It was assumed that each mF of capacitance would incur a mass penalty of 1 kg.

Option 3 Provide a constant load (Heater mats)

A classic S3R regulation system shunts (shorts circuits) solar array sections, this option provides a method whereby the solar array section "sees" a constant load; either providing power to the mainbus or providing power to a dump resistor, in this way the solar array section capacitance is never short circuited. This leaves the problem of where to dump the power in the dump resistor, in worst case configuration with the maximum solar array power available and the minimum load, this power could exceed 1 kW. A solar array section which is shunted has a higher temperature to one which is not shunted, so if the dump resistor is sized to correspond to dump the power for one section the heat taken out of the section will correspond to the power dumped in the resistor. Hence if the dump resistor could be physically sized and located on the backside of the array the over all heat budget would be the same as a traditional S3R shunt system if the section were providing power to the bus or being shunted. The principle advantage of this arrangement is that a standard PCDU regulation system can be utilised without any change to the bus capacitance, and since the solar array section is not being short circuited, the capacitance whether high or low is irrelevant. The price to pay for this is a more complex design of the solar array, how to bond the heater mats to the appropriate section, increase of harness, failure modes of the resistor mats…..

The following table provides a summary of the two options:

OPTION	PRO	CON
Increase of Bus capacitor	Known technology, just an increase of an existing parameter	Expected mass penalty of up to 5 kg
	Only one unit with the power subsystem affected.	
Use Heater Mats	PCDU design is independent of Solar Array capacitance	Expected mass penalty of around 8 kg
		Modifications required to the Solar Array to implement the heater mats
		Thermal analysis is more complex for the Solar Array
		Interfaces between the Solar Array and PCDU more complex due to additional harness
		Increased testing complexity, the PCDU test equipment would require shunt resistors.

After review of the proposed PCDU options and the proposed Solar Array implementation from the bidders, it has been decided to eliminate the Heater mat option. Apart from the additional mass penalty, the application of the heater mats to the solar array posed technological problems due to the high temperatures and the number of interfaces to manage between the PCDU and Solar Array became rather complex. This only leaves the option of increasing the bus capacitor, fortunately, since the preparation of the original PCDU specification, ESA have performed some tests and measurements on triple junction cells which indicate that the original hypothesis for the electrical capacitance was rather pessimistic and that the requirements may be revised leading to a smaller bus capacitor. The present design implements a larger bus capacitor than would be used if triple junction cells were not employed, the objective being to reduce this capacitor and save mass during the next design phase after additional tests on representative coupons.

6.1.4 Instrument data rate

The initial requirements for the instrument data rate was expressed only in terms of bits/s and the overall instrument data rate for Hershel was different from Planck. It became apparent that it is necessary not only to define an average data rate in number of bits/s but also to consider the constraints of implementing the 1553 bus protocol defined in the ESA PSICD and to establish the number of subframes per second allocated to each user.

After several iterations with the instruments, the data rate allocation has been defined as given in the following table. It should be stressed that the subframe allocation **and** an average (over 24 hours) data rate no greater than 140 kb/s.

Four subframes per second are reserved for instrument related Telecommands. These four TC may be distributed between the instruments as required, it is not intended that each instrument has 4 TC/sec (the maximum rate per instrument is 2 TC per sec). For each TC a TC Acknowledge subframe is allocated, however since the TC acknowledge may be delayed for up to 1 second there could be a maximum of 6 TC acknowledments per second.

One TM subframe per second per instrument (for instrument HK TM) have been allocated. For Planck, the Sorption cooler is allocated 1 subframe per second for HK TM. Therefore each satellite has 3 subframes per second allocated for instrument periodic and non-periodic HK TM.

Several instruments identified the need for a "burst mode", this is a specific situation where the instrument is generating larger than normal amounts of data for a short duration (typically less than 30 minutes). To handle this condition a separate 1553 bus mode has been envisaged where the instrument has access to a higher number of subframes. During this mode no TC and TC acknowledge subframes are allocated and only one instrument can be in burst mode at a time. To be within the mass memory allocation, even with burst mode, the average (over 24 hours) total instrument data rate cannot be greater than 140kb/s.

PLANCK Subframe Budget Allocation			
	Subframe/s	Max equivalent kb/s	Actual equivalent kb/s
TC reserved	4		
TC Acknowledge	6		
HFI Science TM Packet	11	90.112	90.112
LFI Science TM Packet	11	90.112	90.112
HFI Other TM	1	8.192	2
LFI Other TM	1	8.192	2
Sorption Cooler Other TM	1	8.192	0.5
Total Payload Science+Other TM	**25**	**204.8**	**184.724**

PLANCK Burst Mode Subframe Budget Allocation			
	Subframe/s	Max equivalent kb/s	Actual equivalent kb/s
TC reserved	0		
TC Acknowledge	0		
HFI Science TM Packet	11	90.112	90.112
LFI Science TM Packet	25	204.8	204.8
HFI Other TM	1	8.192	2
LFI Other TM	1	8.192	2
Sorption Cooler Other TM	1	8.192	0.5
Total Payload Science+Other TM	**39**	**319.488**	**299.412**

Note that for Planck the precise allocation of subframes between the instrument can be decided by the instruments. "Other" TM includes all housekeeping TM, both periodic and non-periodic, only the TC acknowledge are excluded since they are budgeted apart.

HERSCHEL Subframe Budget Allocation			
	Subframe/s	Max equivalent kb/s	Actual equivalent kb/s
TC reserved	4		
TC Acknowledge/ Event	6		
HIFI Science TM Packet	0	0	0
PACS Science TM Packet *	22	180.224	180.224
SPIRE Science TM Packet	0	0	0
HIFI Other TM	1	8.192	2
PACS Other TM	1	8.192	4
SPIRE Other TM	1	8.192	2
Total Payload Science+Other TM	**25**	**204.8**	**188.224**
* Prime Instrument shown, same datarate applies to any Prime Instrument			

HERSCHEL Subframe Budget for PACS Burst mode			
	Subframe/s	Max equivalent kb/s	Actual equivalent kb/s
TC reserved	0		
TC Acknowledge	0		
HIFI Science	0	0	0
PACS Science	37	303.104	303.104
SPIRE Science	0	0	0
HIFI Other TM	1	8.192	2
PACS Other TM	1	8.192	4
SPIRE Other TM	1	8.192	2
Total Payload Science+Other TM	**40**	**327.68**	**311.104**

6.1.5 Mass optimisation

The mass reduction plan is detailed in [RD03.1]. The present section give the synthesis of the mass optimisation.

6.1.5.1 System level

Herschel Planck are launched on an ARIANE 5 ESV. No mass reduction can be expected from the launcher adapters. Herschel and Planck wet masses are therefore limited to 4491 kg.

If the mission scenario and the specified fuel margins remain identical, it can be envisaged to reduce the fuel and pressurant mass:

- redesign of thruster configuration
- use of helium instead of nitrogen as pressurant.

The following table summarises shows the relative proportions of the current launch mass, showing that some investigations may also be made for the customer furnished equipment.

RESPONSIBILITY	ITEMS	LAUNCH MASS [kg]	LAUNCH %
ESA – ARIANESPACE – PIS	Instruments, Adapters, CFEs, ESA reserve	2158.2	38.8 %
ALCATEL	P-PLM, VMCs, balancing masses	296.1	5.3 %
ASTRIUM-D	H-PLM	1861.3	33.4 %
ALENIA	SVMs	1252.5	22.5 %
	TOTAL	**5568.1**	**100 %**

6.1.5.2 Module level

All the sub-level contractors have not been kicked-off, and the budgets are under consolidation. About ¾ of the hardware is under contract for both service modules and Herschel PLM, while Planck PLM is almost complete.

For every module, some mass reduction exercises have been carried out:

- The main contributor to the SVM mass excess is the structure, for both Herschel and Planck. A reduction of 33 kg has already been presented by CASA, and included in the budgets.
- A 51 kg reduction has been achieved by the H-PLM.
- A 33 kg reduction has been achieved by the P-PLM.

Further investigations are planned at the beginning of Phase C/D.

6.1.5.3 Conclusion

The system maximum mass budget at PDR exceeds the launch mass requirement of **258 kg**.

However, by comparison with XMM, the launch mass of which was 1.5 % above the PDR nominal mass, Herschel-Planck has the following characteristics:

- PDR nominal mass = **4458.2 kg** (Herschel and Planck only)
- Launcher capacity = 5310 – 671 kg (adapters) = **4639 kg**.

This resulting margin is then **4 %**. Although this margin is regarded as low compared to standards, the experience of XMM tends to show that it is manageable to achieve a launch mass compliant with the specified launcher performance.

Nevertheless, in order to further explore the possibilities to recover a more comfortable margin, a mass "Tiger Team" has been initiated and nominated. The team will include ALCATEL, ASTRIUM and ALENIA representatives and is given the following mandate:

The Tiger Team shall analyse:

- the mass sizing requirements and their flow down from ESA requirement specification down to subsystem/ equipment requirements
- the mass margin philosophy required or adopted by each party and their coherence
- the baseline design presented at the PDR and its justification
- the justification of the mass margin with respect to development maturity
- the completeness of the mass budgets and of the mechanical analyses (with the objective to assess the credibility of the proposed design).

The Tiger Team shall then define:

- The mass drivers pertinence and completeness
- Potential mass saving areas by optimisation of the proposed PDR design (with associated order of magnitude)
- Potential requirement changes leading to a mass reduction, with associated risk identification when relevant,

In the elaboration of these recommendations, the Tiger Team shall consider the specificity of the Payload Modules, and in particular the thermal performance aspects as both Herschel and Planck instruments require a cryogenic environment.

The Tiger Team will issue a preliminary report including major outcomes/mass reduction potential latest on 16/09/02 for the co-location period of the PDR.

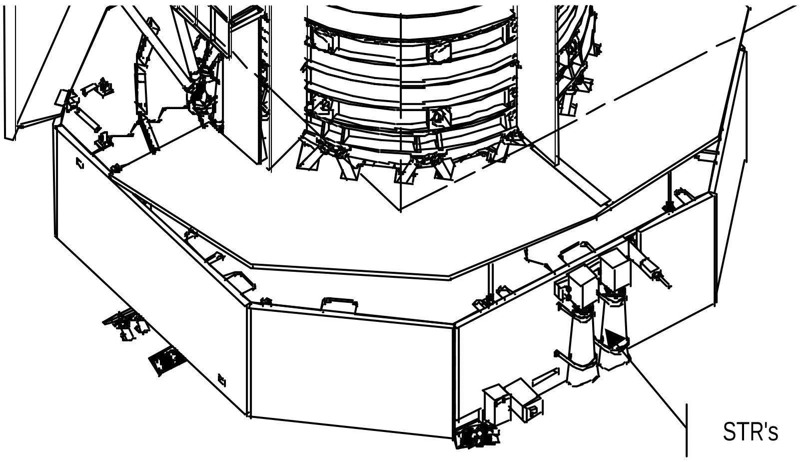
The Tiger Team will issue a final report before the ESA PDR board meeting scheduled on 04/10/02.

6.1.6 STR accomodation on Herschel

During the pre-phase B studies before the Herschel/Planck proposal, various star tracker implementation were traded-off. The main drivers were:

- ensure STR line of sight stability w.r.t. instrument LoS. The main issue is thermo-elastic stability driven by the Sun aspect angle variation between -30 deg and + 30 deg
- limit impact on the Herschel cryogenic lifetime.

The selected configuration from the proposal phase was to have 2 STR, parallel to the instrument LoS but pointing in the opposite direction. These 2 STR are implemented on the -Z side of the SVM.



When the thermo-elastic analyses from the SVM were available during Phase B, it appeared that the STR implementation from the proposal phase was leading to out of specification thermo-elastic motions. The trade-off has thus been re-opened.

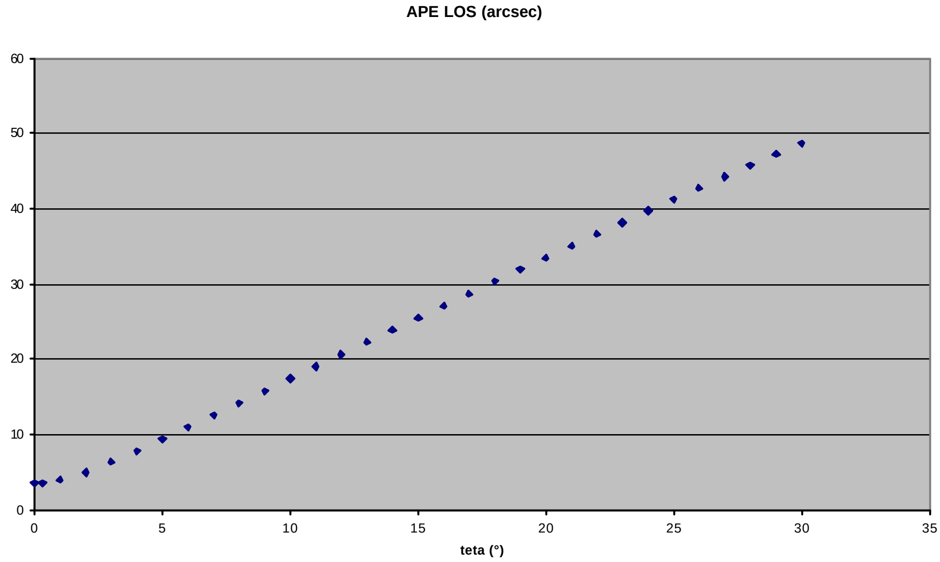
ALENIA has investigated alternative STR implementation on the SVM. The most promising solution is to have the STR's implemented inside the SVM cone, linked to the top of the cone, close to the H-EPLM interface struts, by an isostatic truss or beam. This concept is described in the SVM Design Report (RD01.1) and in a specific Tehnical Note "Star Tracker Positioning Trade-Off" (H-P-TN-AI-0030).

In order to cover all possible solutions, ASPI has investigated the possibility to implement the Star Tracker on the H-EPLM as it might lead to a better positional stability w.r.t. the instrument LoS.

6.1.6.1 Design drivers

The Herschel pointing requirement are very stringent and performance of the STR is crucial in meeting these requirements. The requirement are more severe for LoS (around Y and Z axis) than around LoS (X axis). The STR performance is such that maximum accuracy is obtained along the axes perpendicular to the STR LoS, while the performance around the LoS is much worse, by a factor of at least 10.

If the STR is not aligned with the instrument LoS, then the pointing of the instrument LoS will use a combination of LoS and around LoS STR measurement. The following figure shows that, taking into account a ratio of 10 between LoS and around LoS STR performance, the APE performance is degraded and out of spec when the STR is depointed from instrument LoS. It can be seen that a depointing of only a few degrees (< 2 deg) would be tolerable.



In the configuration with 2 STR in cold redundancy it is thus mandatory to have the STR's aligned with the telescope LoS: this is the "on-axis" configuration.

If the STR's cannot be implemented parallel to the instrument LoS, then a configuration with 3 STR's have to be implemented (off-axis configuration). The nominal configuration uses 2 STR at a time. In a configuration in which the 3 STR's are at 90 deg each, the accuracy around all axes is the same.

The other important design driver is the thermal impact on the cryostat. Two aspects have to be considered:

- Conductive load: in order to reduce the conductive load, the STR have to be connected to the H-EPLM via a GFRP truss.
- Radiative load: the presence of the STR's on the H-EPLM limits the view factor to space of the cryostat radiator. The STR implementation has to be optimised such as to limit this impact.

6.1.6.2 On-axis configuration

In the on-axis configuration, the STR implementation on H-PLM has to take into account the size of the SVM and telescope. A relatively large field of view is considered for the STR (25 deg cone) which leads to 2 possible solutions:

1- in the cryostat lower part, pointing towards -X

2- in the cryostat upper part, pointing towards +X

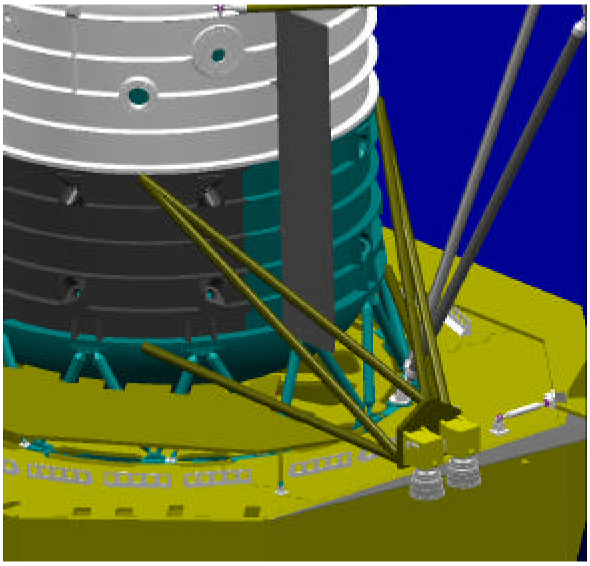
Solution 2 is the one which has been investigated for the following reasons:

- the SVM being smaller than the telescope, the supporting truss of the STR's will be smaller
- the STR's are located closer to the SVM, allowing easier routing of the electrical harness,
- implementation of the STR close to the telescope poses problems of interferences of the STR truss with the HSS truss.

The proposed implementation is shown in the following figure. The main features are:

- STR's are on the +Y side to limit the view factor with the H-PLM radiator. It also allows to balance the LOU.
- the STR's are located below the SVM shield level to further limit the view factor to the H-PLM radiator.

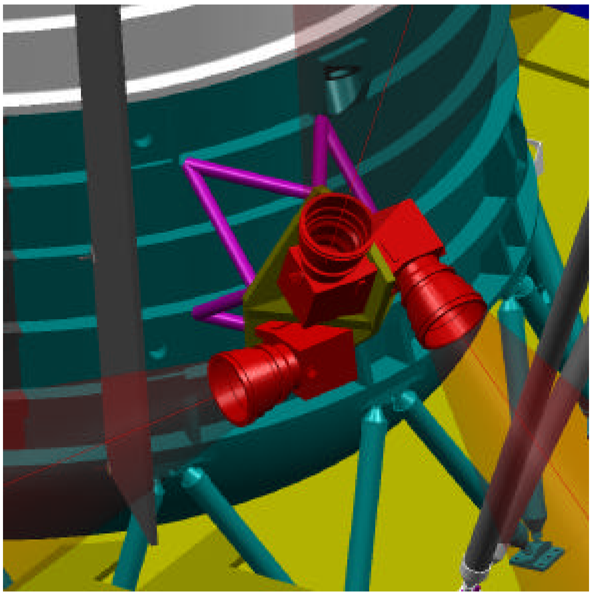
As it can be seen in the figure, the on-axis implementation on the H-PLM calls for a very large truss (struts length of 1.7 m) which is viable neither from a mechanical point of view nor from a thermal point of view (see section 7.3).



6.1.6.3 Off-axis configuration

If an off axis solution is retained, then 3 STR's are needed. The following figure shows a proposed implementation. The main features are:

- the three STR's have their boresight at 90 deg on from each other to maximise the attitude determination accuracy.
- the STR's are implemented on the +Y side to limit view factor with the H-PLM radiator,
- the implementation has taken into account the constraints from the STR's field of views and avoids interference with the telescope for the up-looking STR, with the lateral PLM ear for the side-looking STR, with the HSS for the down-looking STR.
- the STR's are linked to the H-PLM with a compact truss made of 4 bipods, similar in concept to the one used for the LOU.



A preliminary assessment of the thermal impact of this configuration shows a reduction of lifetime of around 1 month.

6.1.6.4 Conclusion

As already identified in the trade-offs conducted during pre-phase B studies, the STR implementations fall into two main categories:

- on-axis for which a configuration with 2 STR's can be used
- off-axis for which 3 STR's with a 2 out of 3 redundancy concept has to be used to maintain the attitude determination performances

For an implementation on the H-PLM, the on-axis implementation leads to a very large supporting truss which is not viable mechanically. An alternative off-axis implementation was found to be feasible and needs further investigation. The drawbacks of this solution are obviously:

- cost impact due to the additional star tracker
- lifetime: the proposed implementation has been optimised concerning the radiative impact to the H-PLM. This is a step forward w.r.t. the implementation envisaged during pre-phase B studies in which the STR was implemented on the -Z side, blocking the cryostat radiator. However, the conductive impact cannot be avoided and a value of 1 month lifetime impact has been estimated.
- interface management between SVM and PLM. The STR's belongs functionnally to the SVM and their implementation on H-PLM will require to manage complex mechanical, thermal and harness interfaces with the H-PLM.
- mass impact from the additional STR and supporting structure

Due to these drawbacks, the STR implementation on the H-PLM is only considered as a backup. The baseline remains to have the STR on the SVM and the solution with the STR inside the SVM tube, attached close to the H-PLM/SVM interface looks promising and have to be consolidated by ALENIA. However, the off-axis solution will be further analysed by ASPI before the PDR colocation to better assess its performance.

6.2 Mechanical and thermal design

6.2.1 Herschel overall configuration

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 SRR, but keeps the same general configuration as explained hereafter. These evolutions reflect the phase B 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 PayLoad Module) which includes:

a large Cryostat Vacuum Vessel (CVV) in which is suspended the He Tank, Optical bench with focal plane units. The CVV carries instruments external as LOU Assy with radiator (part of HIFI) and the BOLA (part of PACS)

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 Assy with forming a large screen surrounding the H-PLM on sun side, ensuring a shadowing function for 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:

the SVM houses the equipment of the Avionics and Servicing S/S's, the payload "warm" boxes for HIFI, PACS and SPIRE Instruments; Herschel 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

the SVM supports the H-EPLM with the H-PLM Cryostat support truss; it supports also the SVM Shield on its top, used for radiative de-coupling with the cryostat

the SVM ensures the mechanical link with the Launcher adaptor, and therefore ensures the main load path during launch.

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

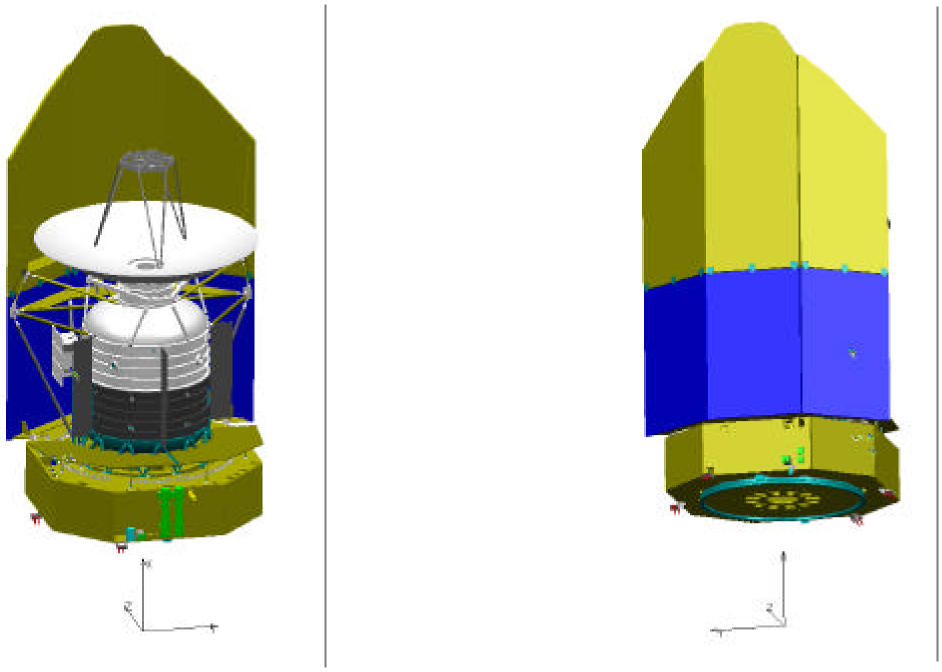


FIGURE 6.2.1-1 HERSCHEL SPACECRAFT OVERALL CONFIGURATION

6.2.1.2 Main design evolution since SRR

Main updates relatively to SRR configuration refer to changes in System configuration, H-PLM configuration and to the SVM configuration, but also in refinement and improvement of modules and S/S's design that have been implemented in course of Phase B. These changes and evolutions are developed with more details under § 6.3.2.2.

Update of Satellite configuration

Herschel satellite overall configuration remains very close from the SRR configuration.

However, a certain number of System level orientations are to be mentioned here for a better understanding of changes and evolutions explained under SVM and H-PLM sections:

- refinement of H-PLM and SVM mechanical interfaces covering PLM main supporting (CVV struts), HSS supporting, SVM shield and LOU WG supporting
- definition of Cryogenic harness routing at the frontier between PLM and SVM, and repercussion on Interfaces definition and AIT accessibility
- use of the high rigidity of the SVM cone to reduce the section of PLM supporting struts (CVV struts) for lifetime optimisation, with maintain of the satellite mechanical performances (overall stiffness and main frequencies)
- re-opening of Star Trackers accommodation trade-off, as last PDR analysis evidenced that STR configuration presented at SRR did not provide expected performances in term of thermo-elastic stability. Current investigations are presented with more details under § 6.1, and include alternative accommodation on SVM and possible accommodation on H-PLM.

Update of H-PLM configuration

The H-PLM overall configuration presents the following changes or evolutions wrt SRR design:

- optimisation of Telescope mounting on H-PLM, providing a high rigidity at Launch but with a high filtering of CVV thermo-elastic distortions in orbital conditions

- optimisation of Sunshield/Sunshade configuration and supporting, in order to improve assembly and integration operations on satellite
- update of LOU configuration: LOU radiator is now made independent from the LOU, and directly supported by the LOU baseplate. The LOU supporting remains however of the same concept as before with 4 bipodes with GFRP struts for thermal de-coupling
- confirmation of 24 GFRP struts configuration for CVV supporting. Trade-off conclusions shown best mechanical and thermal performance versus a 16 struts configuration
- shift of CVV in order to recover H-PLM CoG in a convenient range wrt satellite balancing. The requested CVV shift is about 60 mm in -Z direction, when the HSS is moved by 15 mm only. This conducts to re-define the CVV struts with a variable angle but without impact on SVM Interfaces
- increase of the number of radiators on the CVV (now one nose and two ears)
- consolidation of Cryo. harness design and routing, and Interfaces with SVM
- reduction of the section of the PLM supporting struts (CVV struts) for lifetime optimization
- cut of SVM shield for mass saving, with maintain of shielding function at a sufficient level
- maintain of Instruments up-to-date on OB and CVV, with modification from Instruments team.

The result of 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 wrt SRR design:

- update of Instruments layout in SVM:

in course of Phase B, successive and numerous modifications from Instruments were announced after edition of IID-B Issue 2. These numerous modifications created each time a new situation with agreed Instruments layout in SVM challenged by new changes. The resolution of these problems necessitates intensive discussions with Instruments and settlement of periodic Convergence meetings between Instruments and Industry. The objective was to achieve or to maintain continuously a good equivalence between Instruments design (overall dimensions, connector configuration, and harness) with the SVM capability accommodation.

- Update of equipment layout in SVM:

consolidation of SVM harness design and routing, and Interfaces with SVM

consolidation of Antenna layout

consolidation of RCT's layout

study of alternative STR layout to improve thermo-elastic behaviour of STR supporting, and therefore to recover acceptable STR de-pointing in-orbit due to SVM contribution.

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

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 a few evolutions with Planck configuration at SRR, but keeps the same general configuration as explained hereafter. These evolutions reflect the Phase B development and module evolutions (i.e. SVM and PLM), regarding their general configuration, equipment layout and S/S design.

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

– the **PLM** (PayLoad 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 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 the Planck-PLM with the PLM support truss

ensures the mechanical link with the Launcher adaptor, and therefore ensures the main load path during launch.

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

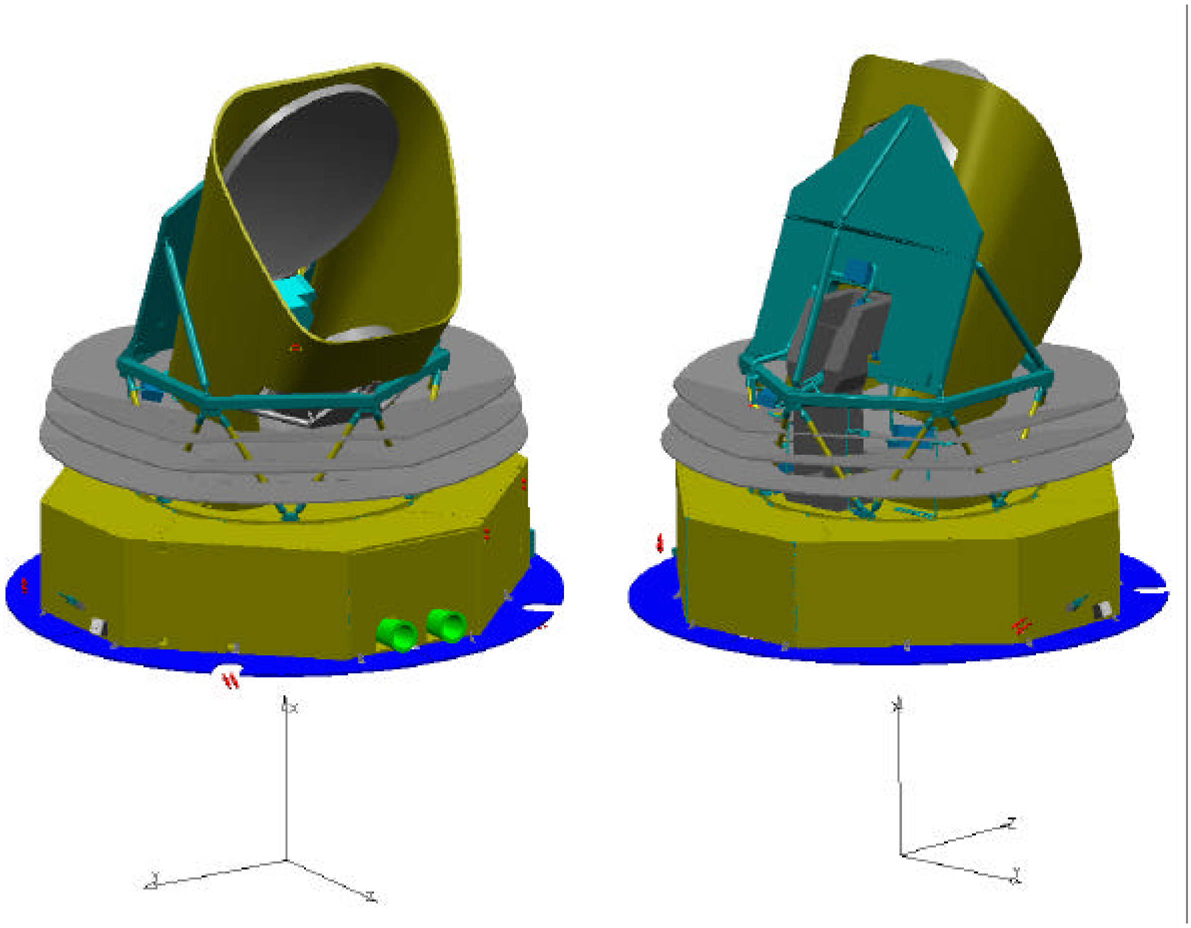


FIGURE 6.2.2-1 PLANCK SPACECRAFT OVERALL CONFIGURATION

6.2.2.2 Main design evolution since SRR

This chapter describes briefly the main updates relatively to SRR configuration refer to changes in System configuration, H-PLM configuration and to the SVM configuration. It reflects also refinement and improvement of modules and S/S's design that have been implemented in course of Phase B. These changes and evolutions are developed with more details under § 6.2.5.2.

Update of System configuration

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

At System level main intervention rests in:

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

Update of P-PLM configuration

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

- maintain of Instruments up-to-date on FPU, with modification from Instruments team
- 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 SRR design:

- update of Instruments layout in SVM.

  As on Herschel, updates of the instrument interfaces following edition of IID-B Issue 2, necessitated updates of instrument layout. In particular, increase of dissipation of equipment installed on the payload sub-platform led to allocation of boxes to different panels.
- Replacement of the Star mapper installed in the SVM by 2 Star Trackers (STR). The PDR baseline is to have the 2 STR's installed at the same location as the former STM, i.e. accommodated at the bottom of the lower platform, pointing through the +Z panel with field of view axis parallel to Telescope line of sight.
- Update of equipment layout in SVM.
- Consolidation of SVM harness design and routing, and Interfaces with SVM.
- Consolidation of Antenna layout.
- Consolidation of RCT's layout.

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

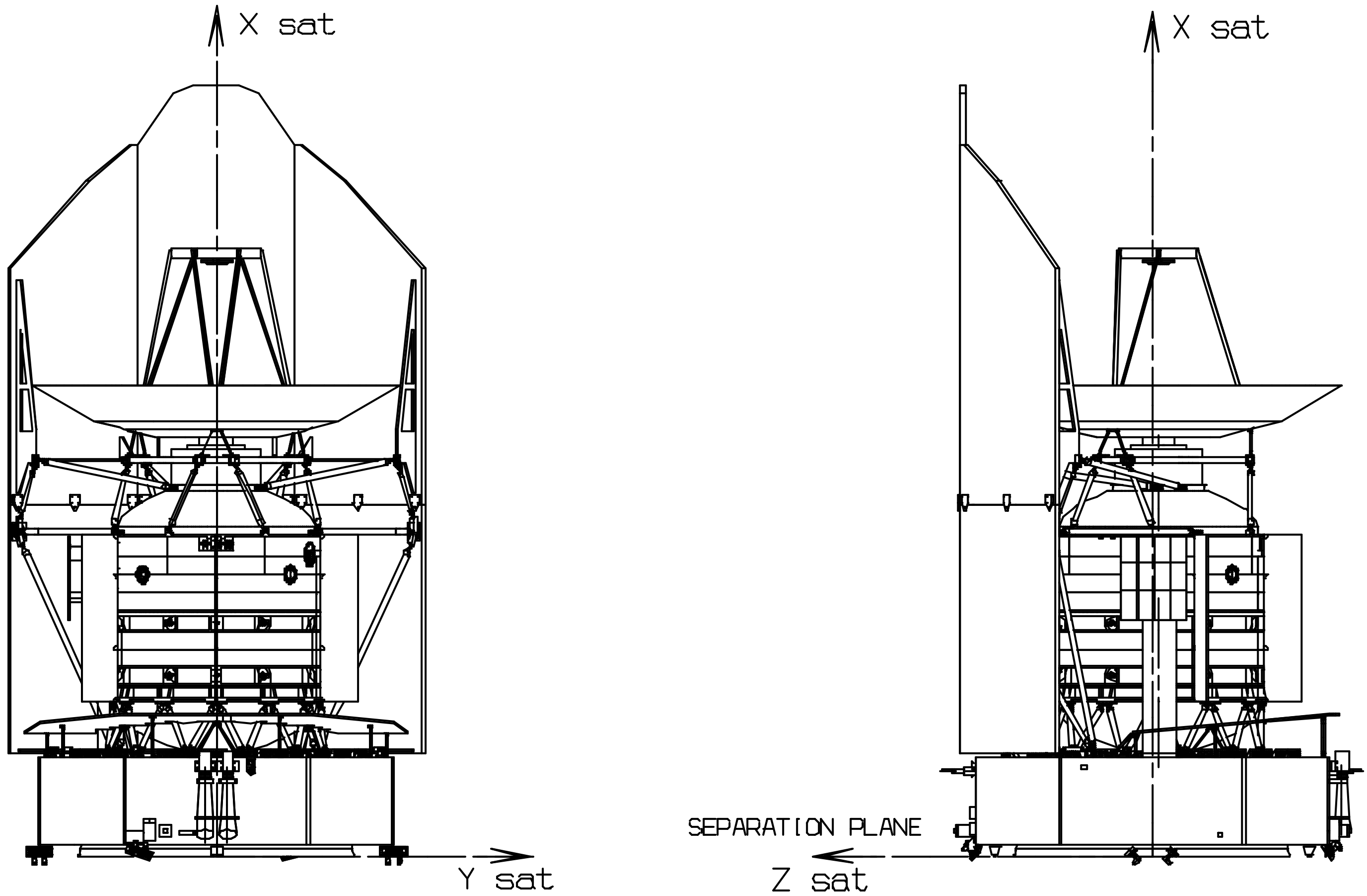
6.2.3 Herschel mechanical design

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 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 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

As explained above, Herschel configuration at PDR presents a certain number of evolution since SRR. These configuration updates, constituting the current baseline are presented hereafter with some details.

General update of S/C configuration

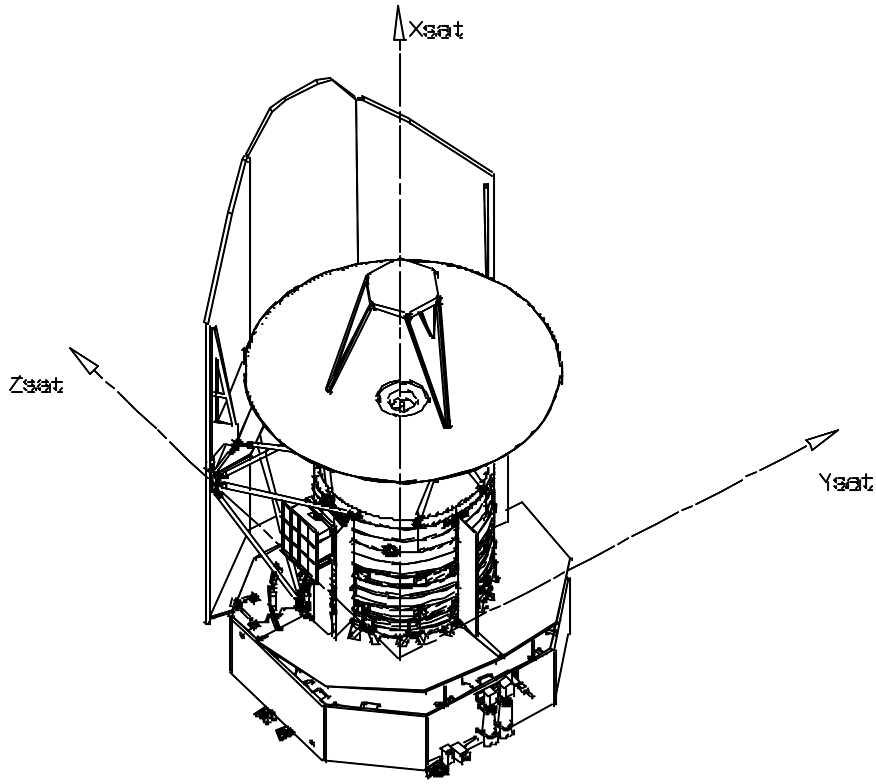
Herschel overall configuration is apparently rather to SRR original configuration. The most visible change stays in:

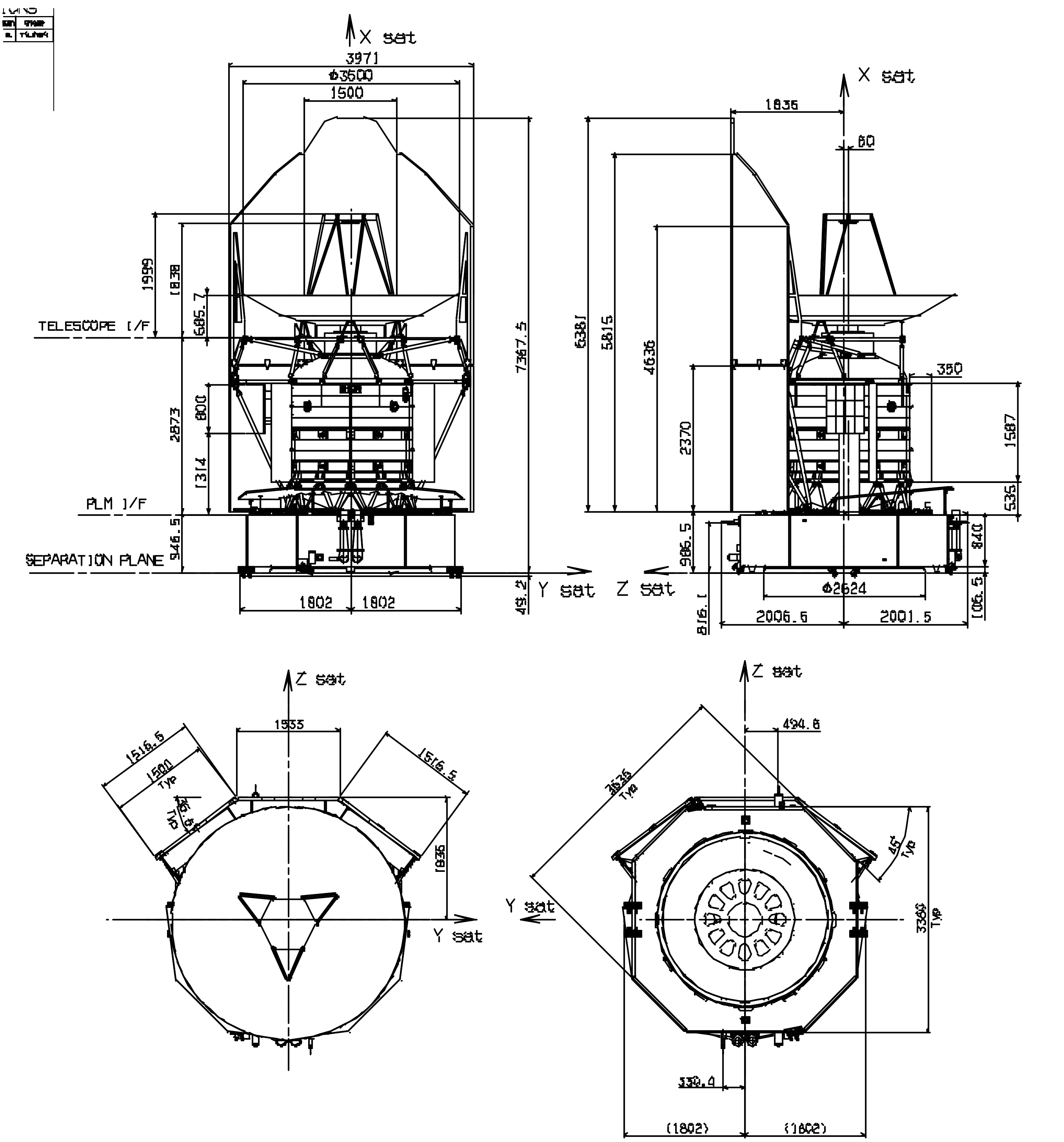
- the H-PLM supporting with 24 GFRP struts configuration, implementing the CVV shift of 60 mm in -Z direction
- the SSH/SSD configuration with SSH/SSD showing additional stiffeners and a reduced number of supporting struts in counter-part
- the accommodation of a SiC Telescope with hexapod support for secondary mirror, implementation of new Telescope supporting on top of CVV
- cut of SVM shield for mass saving, with maintain of shielding function at a sufficient level

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

NOTE: STR layout is to be updated according to the conclusion of the System trade-off in progress.

At the end, Herschel satellite presents overall dimensions quite un-changed wrt previous dimensions.





Status of H-PLM to SVM interfaces definition

At the present time, it is considered that Modules interfaces are rather defined and mature. This results from common technical discussions between all involved parties (ASPI, ALS and ASED) to consolidate this Interface definition.

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

- the PLM supporting IF on central cone
- the SSH/SSD IF on central cone and platform

– the SVM shield IF on central cone and platform

– LOU WG IF on upper platform

– Cryo. harness and brackets IF.

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

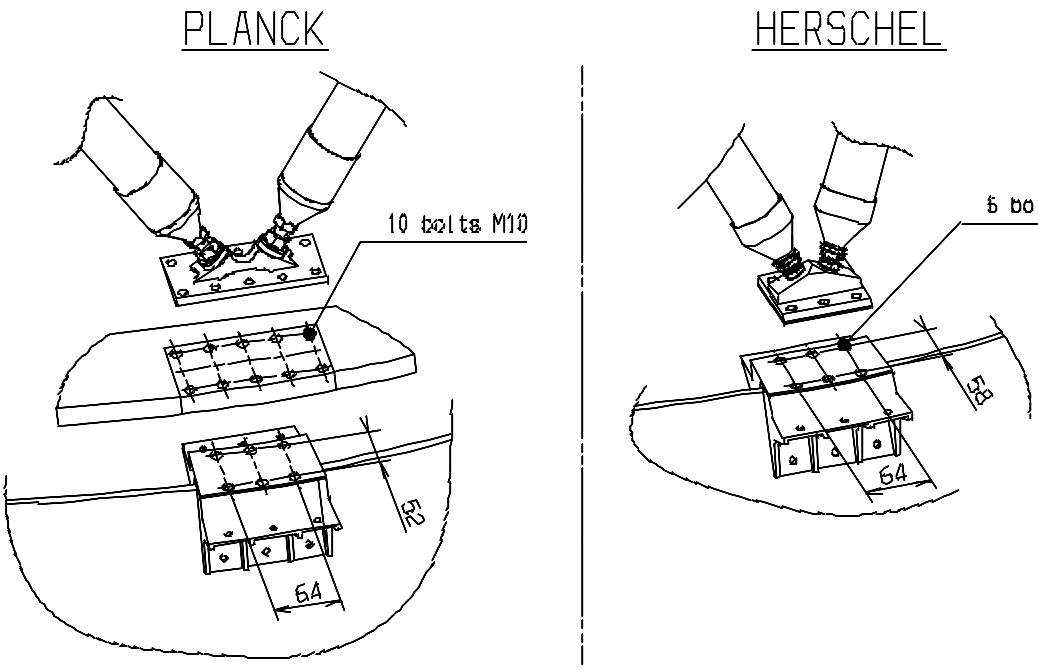
PLM supporting IF on central cone: see drawings in RD05.3

– Optimisation of SVM design, with Central IF now compatible with:

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

PLM struts geometry optimised for “pure” loads path

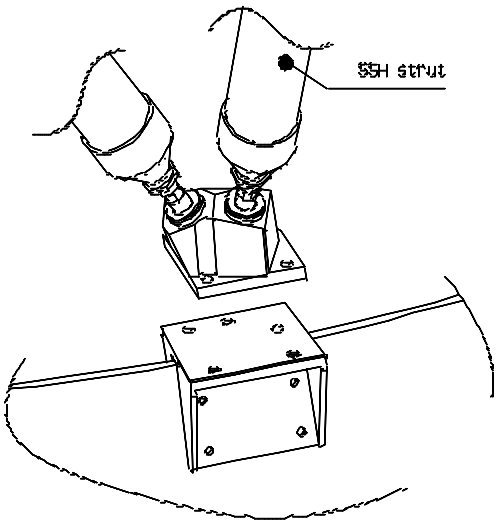
foot prints definition and location harmonised between H-PLM and P-PLM (communality is preserved on central tube), with implementation of bolts M10 Vs bolts M8 for both Herschel and Planck.



SSH/SSD IF on central cone and platform: see drawings in RD05.3

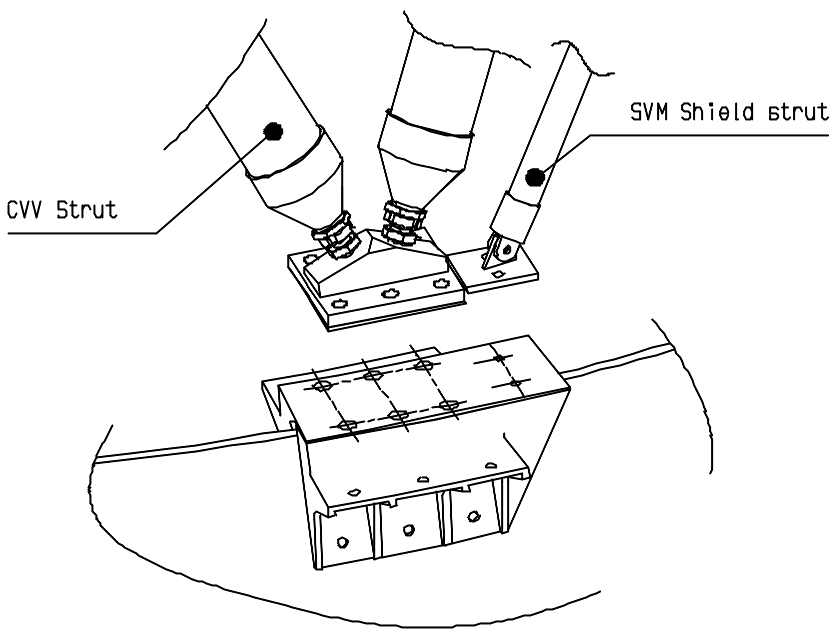
– SSH IF on central cone for 2 vertical struts have been combined with PLM IF with SVM brackets fixed on top of the central cone. See Figure below.

– SSH IF on upper platform for lower beams have defined in the prolongation of the SVM shear walls to take advantage of high local stiffness.



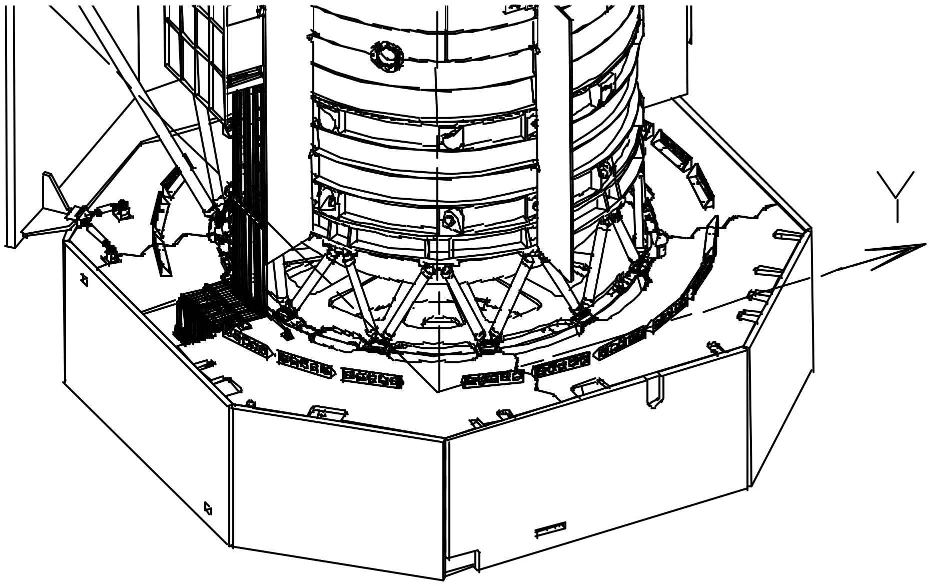
SVM shield IF on central cone and platform: see drawings in RD05.3

- SVM shield IF on central cone for vertical struts have been 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-podes and mono-podes have been defined closed to the platform edges to take advantage of high local stiffness.



LOU WG IF on upper platform: see drawings in RD05.3

- WG supporting IF defined on upper platform, for fixation of 3 supporting beams at the bottom.
- Cut-out in upper platform implemented to allow connection with FHLSU on SVM panel (+Y panels with HIFI WU).



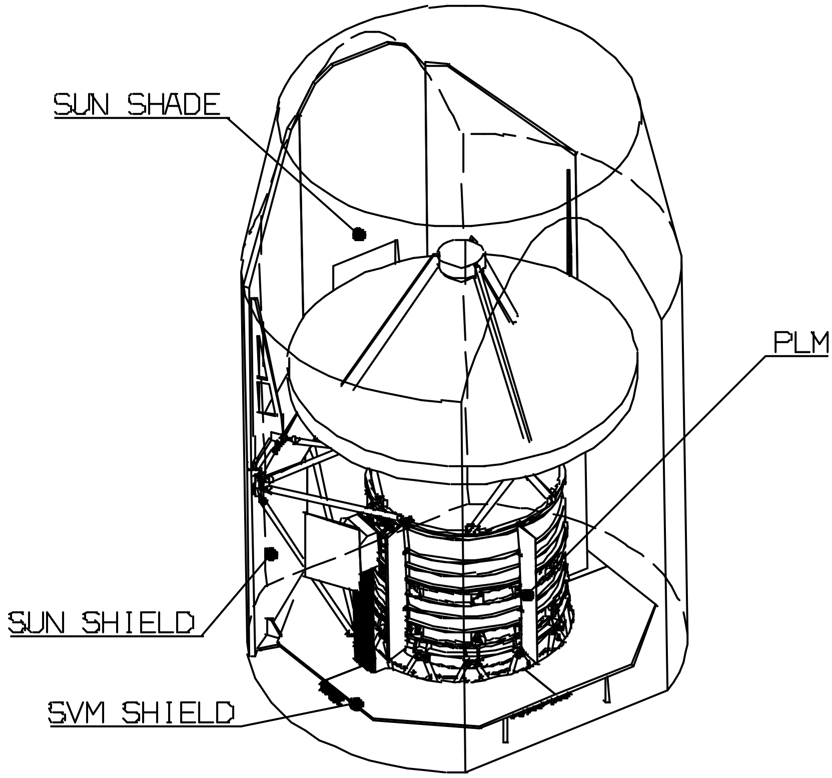
Cryo. harness and brackets IF on upper platform: see drawings in RD05.3

- Cryo. harness routing on SVM bounded from PLM struts to cryo. harness brackets, and then relieved by SVM harness to WU.
- Numerous cryo. brackets arranged on upper platform all around the CVV basis to feed all WU in SVM.
- Cut-out in upper platform implemented to allow connection with the WU on SVM panels.
- See Figure above under LOU WG IF

Allocated volumes for SVM and H-PLM

The SVM allocated volume remains the same as defined for SRR. Refer to RD05.3.

The definition of the H-PLM allocated volume has been reviewed mainly at the top. The new volume definition allows the PLM to exploit the full space provided at the top of the Fairing without restriction.



Other Interfaces specification

In addition of the PLM to SVM 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

  VOLUME FOR FAIRING FILLING RATIO

  I/F RING DEFINITION

  ANTENNA CONFIGURATION

- Other SVM IF:

  THRUSTER ACCOMMODATION

  BALANCING MASSES

- Other PLM IF:

  ACCESS DOORS DEFINITION

Mechanical requirements

Stiffness requirements

Stiffness requirements have been defined considering CVV supporting struts combined with H-PLM. 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).

Interface loads

The basic interface loads at SVM to H-PLM interface (CVV struts roots) are to be simply calculated by application of QSL loads at CVV CoG, considering same H-PLM characteristics as for SVM frequency requirement:

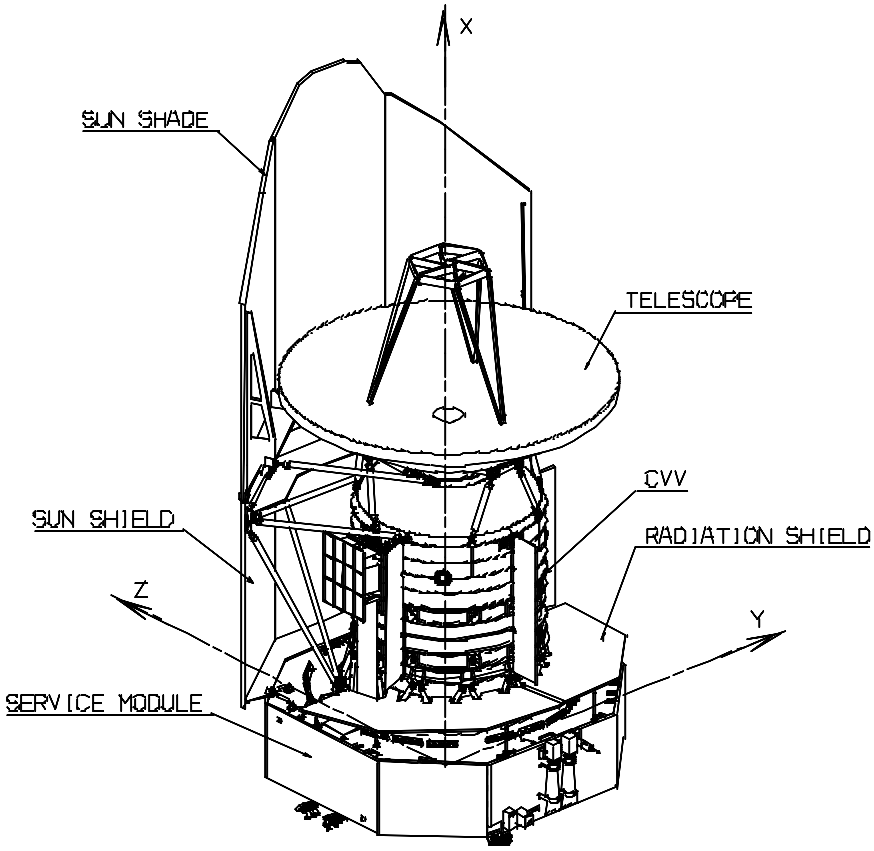
LOAD CASES	X AXIS	Y/Z AXIS
1	12.5g	1.56g
2	2.2g	4g
3	/	/

TABLE 6.2.3-1 H-PLM TO SVM INTERFACE LOADS (DESIGN LOADS)

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 at PDR presents a certain number of evolution since SRR. These configuration updates, constituting the current baseline are presented hereafter with some details.

LOU radiator and WG supporting

- Accommodation of HIFI LSU unit and LOU/LSU wave-guides routing according to CVV shift and available accommodation area on HIFI SVM panel.

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, and to ease PLM integration. This optimisation was conducted according to the following steps:

- consolidation of cryo. harness routing with Instruments layout in SVM
- implementation of Cryo. IF brackets implemented for clear separation and dismounatbility between cryo. harness and SVM harness
- The cryo. IF brackets have been implemented on upper platform to make a clear and physical separation between cryo. harness (stainless steel or brass wire) with SVM harness (copper wires). The electrical dismountability provided by the cryo. bracket is necessary for opening 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 design of the SSH/SSD has been improved at H-PLM module level wrt base-line design at SRR.

Design drivers

From a technical point of view, the key points driving the SSH/SSD concept and design can be identified as follows:

- mechanical stiffness Vs thermal de-coupling between SSH and SSD to be managed
- mechanical stiffness of SSD to be maintained at a certain level to prevent internal frequency coupling in H-PLM
- lifetime requirement to be achieved
- power supply
- impact of the SSH/SSD concept and mechanical stiffness on QSL applicable to FPU's on Herschel OB, on Telescope QSL.

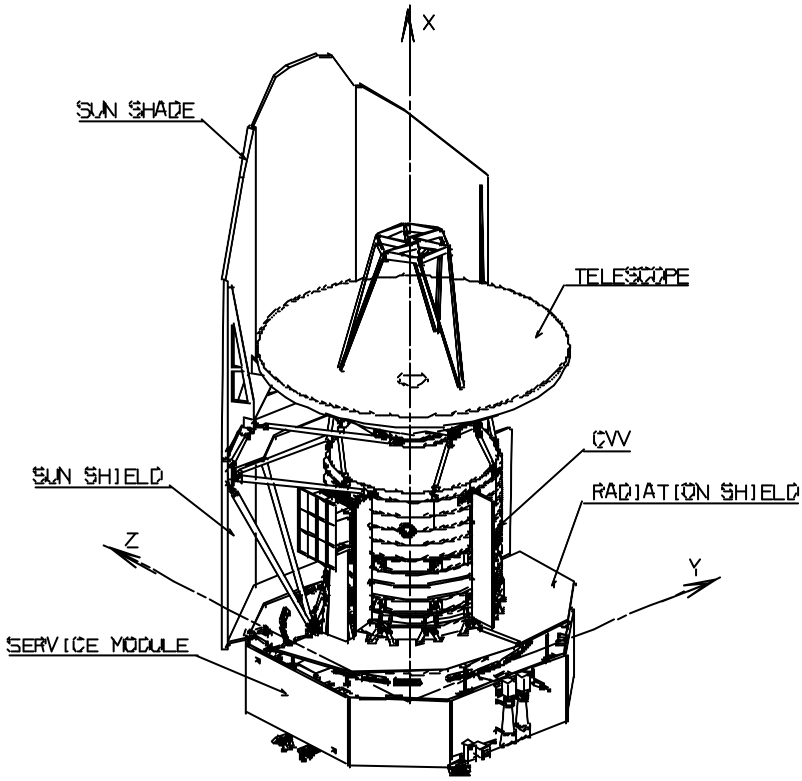
Mechanical design optimisation

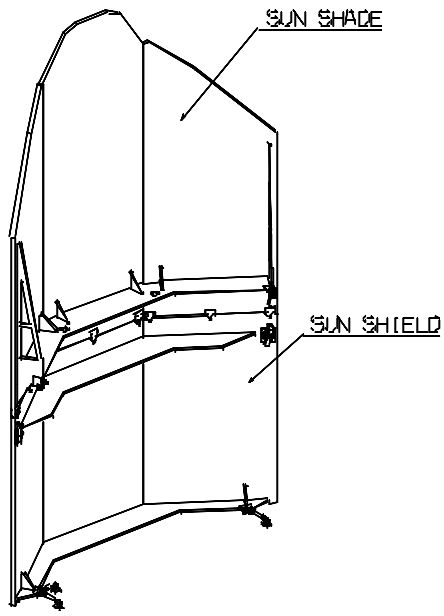
From a structural point of view, the following modifications have been implemented:

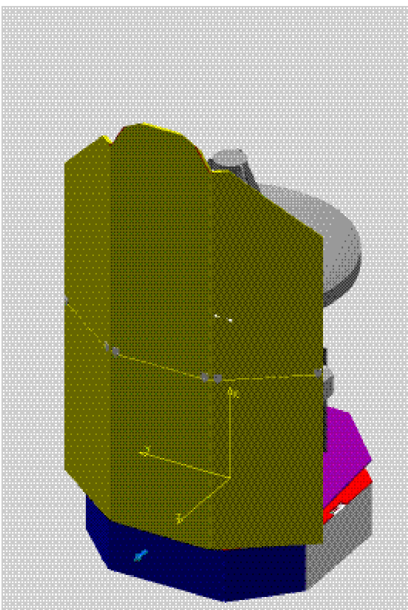
- modified strut supports and panel stiffening ribs, with consequence of higher HSS lateral frequency above 26 Hz
- reduction of unfavourable coupling with optical bench and He II tank
- stiff panels (stiffening ribs) mounted on SVM/ CVV via 12 struts + 2 attachment brackets.

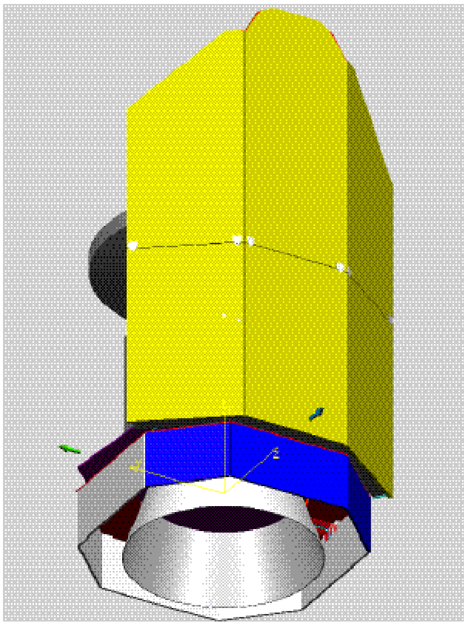
Additionally, the height of the separation between Sunshield and Sunshade have been optimised according to the following criteria:

- the area allocated to Sunshield is 3 x 2370 x 1500 mm^2 which is compliant with the power requirement of 1350 W EOL. Growth potential to 1400 W EOL is also available
- the decrease of the sunshield size implies an increase of SSD height to maintain the global shadowing capability of the SSH/SSD









Thermal design and impact on HSS temperatures:

- thermal isolation of hot SSH (409K)/cold CVV (70K) through GFRP struts
- thermal isolation of hot SSH (409K)/colder SSD (277K) through GFRP blades
- minimisation of HSS temperature
- maximum SSH temperature: 140° C (on centre panel shunt mode).

Optimisation of Telescope supporting:

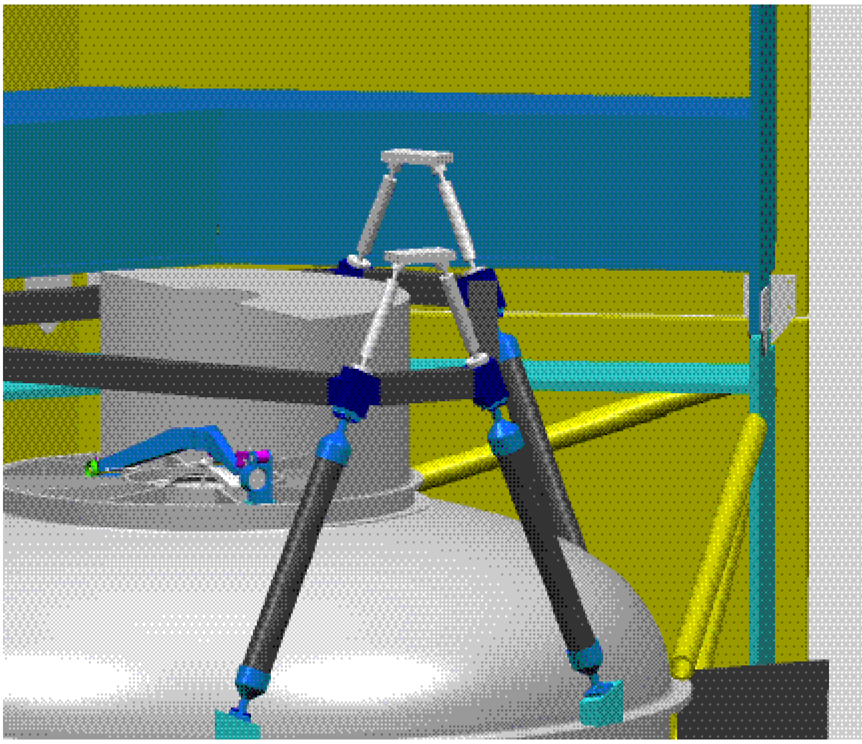
The design and concept of the Telescope supporting have been refined in the direction of proposal made by ASPI at SRR. The optimisation was conducted according to the following steps:

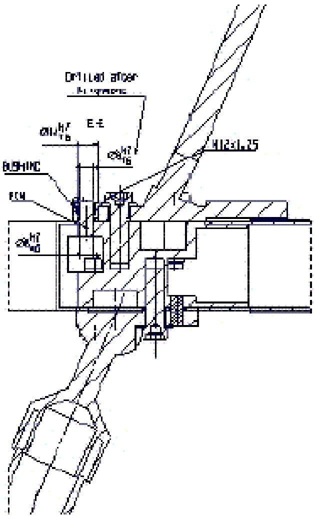
- clarification of mechanical function of Triangle IF, with re-location on PLM side
- Telescope supporting constituted now by 3 bipodes of Telescope struts on top of CVV, IF frame on top of Telescope struts and 3 pairs of lateral struts to connect to the IF frame to the CVV cavity
- mechanical concept of Telescope supporting provides a stiff mounting for Telescope (around 36 Hz on Satellite), and filtering of large CVV retraction in-orbit

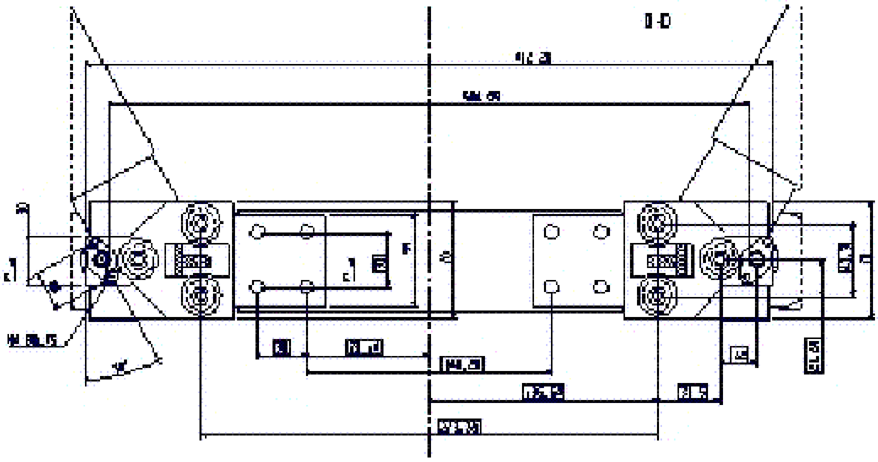
  The mechanical stiffness of the Telescope supporting is mainly ensured by the GFRP struts, which need however the IF frame to maintain the mechanical link between them. In addition, the lateral struts bring additional rigidity in lateral motion. The assembly is viewed as a stiff and closed structure from the Telescope side.

  The function of mechanical filtering wrt to CVV retraction is ensured by the IF triangle which restrains distortion at Telescope to a low level as limited to IF triangle distortion only (made in CFRP)
- struts of Telescope supporting are now made with CFRP instead of GFRP, as it still provides a sufficient thermal isolation between CVV and Telescope, with a better mechanical rigidity

The current Telescope supporting design is shown hereafter.







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.

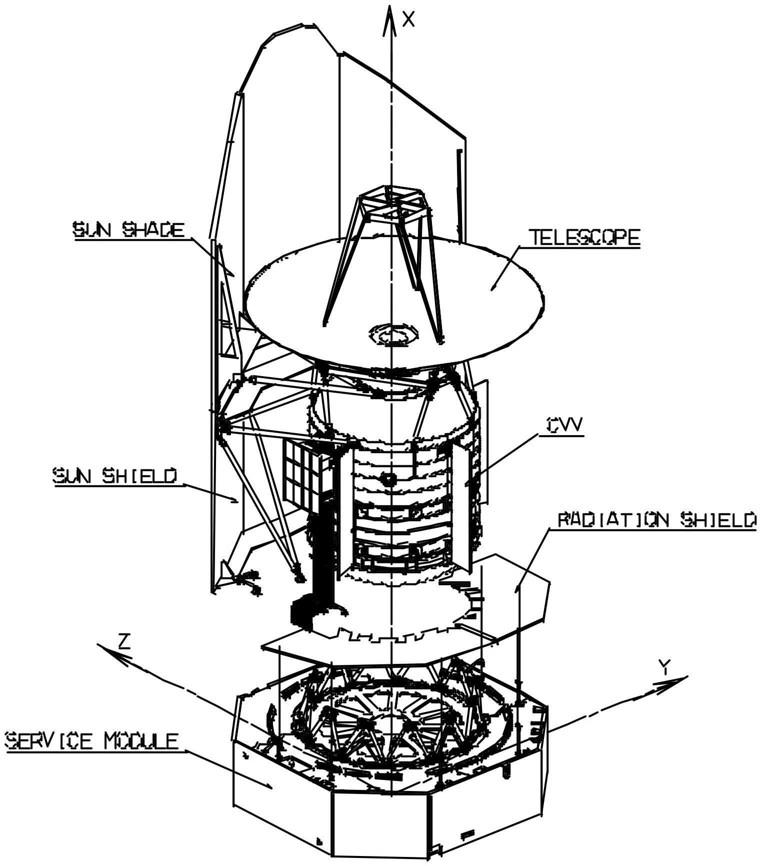
The SVM Shield is split into two parts for easier integration and de-integration once the H-EPLM is mounted on

The SVM. Cut-outs are made in the shield in order not to collide with the PLM/SVM interface struts during integration.

Last optimisation in frame of phase B introduce the following improvement:

- removal of SVM Shield half part on +Z side, for mass reduction, easiness of SVM Shield integration, and improvement of SVM accessibility on +Z side
- replacement of aluminium skin of thermal shield by CFRP skin, for mass reduction, and with implementation of a surface coating to provide equivalent properties as former aluminium skin.

At the total the mass reduction on SVM Shield is about 15 Kg, wrt to SRR budget.



CVV shift for Satellite balancing

The cryostat has been shifted by 60 mm in -z direction and the HSS by 15 mm in -z direction. This shift was needed to find the best compromise between the overall requirement for the position of the CoG, the clearance of the HSS to the fairing and the clearance of the HSS to the telescope.

In fact, the evolution of the H-PLM design in course of phase induces a shift of the PLM centring characteristics:

- **H-PLM CoG characteristics in course of Phase B**
- DZ 107 mm Vs 70 mm required
- decision about CVV shift by 60 mm in -z direction and the HSS by 15 mm in -z direction
- **New CoG after CVV shift**

	CURRENT VALUE	REQUIREMENT
X	2610 mm	
Y	- 41 mm	± 35 mm
Z	58 mm	< 70 mm

CURRENT VALUES AND REQUIREMENTS FOR E-PLM ALONE

DIRECTION	CURRENT VALUE	REQUIREMENT
X	2005 mm	
Y	-17 mm	< radius 30 mm
Z	-5 mm	

CURRENT VALUES AND REQUIREMENTS FOR HERSCHEL SATELLITE

Latest value for H-PLM and Satellite are given in respective H-PLM and Satellite budgets section and show compliance with launcher requirements.

6.2.3.4 Update of SVM configuration

Equipment layout and updates

Power (PCDU and battery), data (CDMU) and attitude control (ACC) units are still 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.

Communication and Reaction Wheels panels are proposed to be swapped by Alenia. According to MCI data provided by Alenia, this change does not impact Herschel SVM centring which remains within balancing specification.

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 the same as Planck one.

Four Reaction Wheels (RWL) are accommodated on the +Y+Z Lateral Panel, together with the relevant electronics unit (RWE).

Herschel ACMS configuration also includes a Gyroscope (GYR), mounted on the +Z Shear Panel.

SREM and VMC accommodation

These two CFE units are accommodated on the space-looking face of –Y lateral panel.

STR accommodation and stability

See discussion under §6.1 of the present Design report.

Instruments layout and updates

General

The new PDR baseline shows a lot of differences with SRR baseline, as a lot of changes of Instruments units configuration lead to reconsider completely SVM instruments accommodation.

Indeed Instruments proceeded in course of phase B to numerous and various changes: most of Instrument presented significant changes with box growth in terms of mass and dimensions, modifications of units connectors and mounting feet inducing new constraints in Instruments accommodation.

For all these reasons and aiming to set up quickly viable Instruments accommodation, Convergence Meetings with Instruments teams and Industry. Goal was to set a commonly agreed baseline for the preparation of the PDR. It lead to following results:

- units envelope setting including everything, e.g. mounting feet, internal connectors …
- harness routing constraints taking into account last block-diagrams
- recall of allocated mass
- setting of mounting feet number and type
- setting of usable instruments accommodation area for each panel.

Recall of SVM accommodation constraints

This paragraph explains 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 995.5*748.8 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 1135*748.8 mm for the central part, and 158.1*748.8 mm for the lateral sides.

Panel tilting

SVM configuration must ensure that accessibility to the warm unit is possible after integration in case of necessity (replacing of a unit, connector, cable …).

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 dismountables.

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

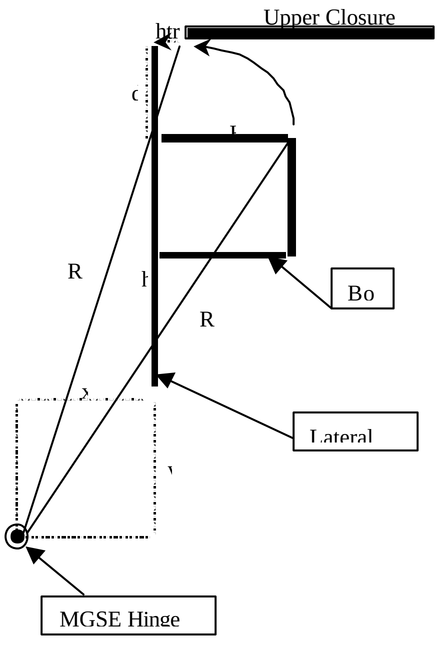


FIGURE 6.2.3-1 PANEL TILTING MGSE CONCEPT

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).

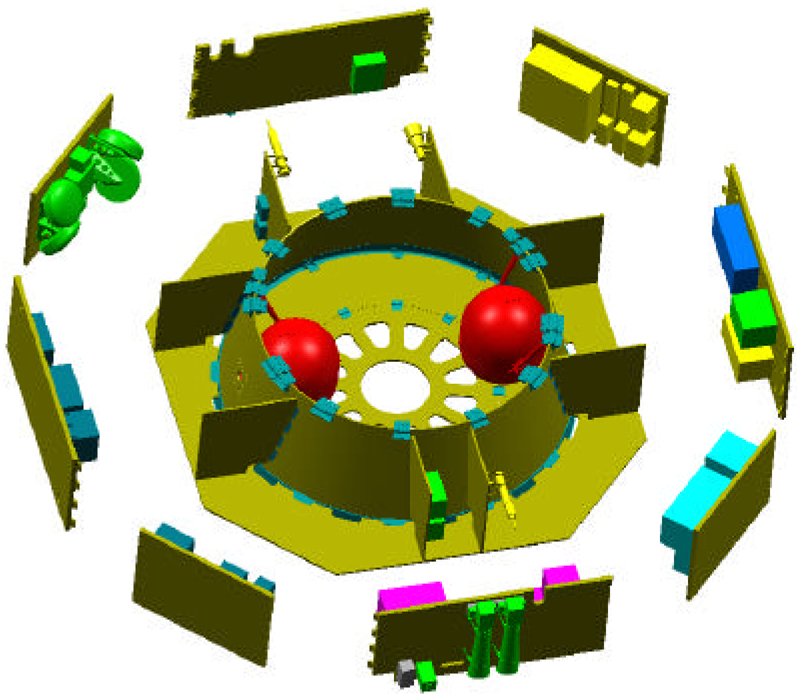


FIGURE 6.2.3-2a HERSCHEL SVM GENERAL LAYOUT

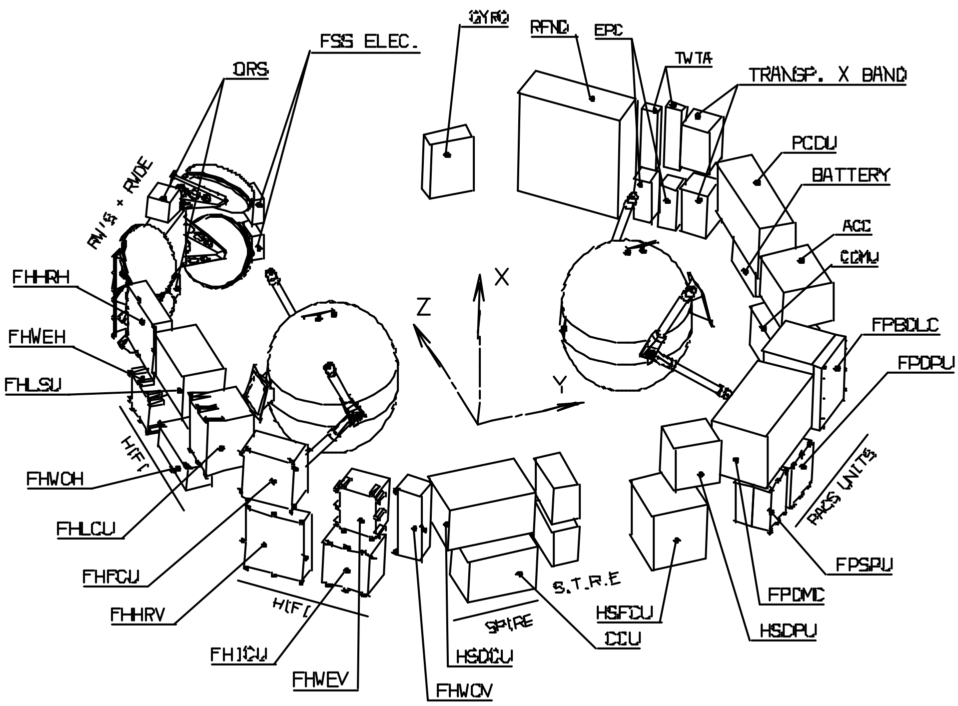


FIGURE 6.2.3-2b HERSCHEL SVM GENERAL LAYOUT

HIFI panels

The following changes occurred from IID-B 2.0:

- LSU grown up severely in dimensions
- FHHRI has been deleted but FHHRH and FHHRV increased in dimensions
- FHICU, FHLCU, FHFCU increased their dimensions
- Adding of a 3dB coupler previously inside LOU. This device imposes hard routing constraints (semi-rigid cable)
- Re-arrangement of WBO, WBE and HRS in a Vertical Chain assembly and a Horizontal Chain assembly, because of semi-rigid cable constraints.

Panel –Y

Instrument accommodation and preliminary harness routing are presented hereafter.

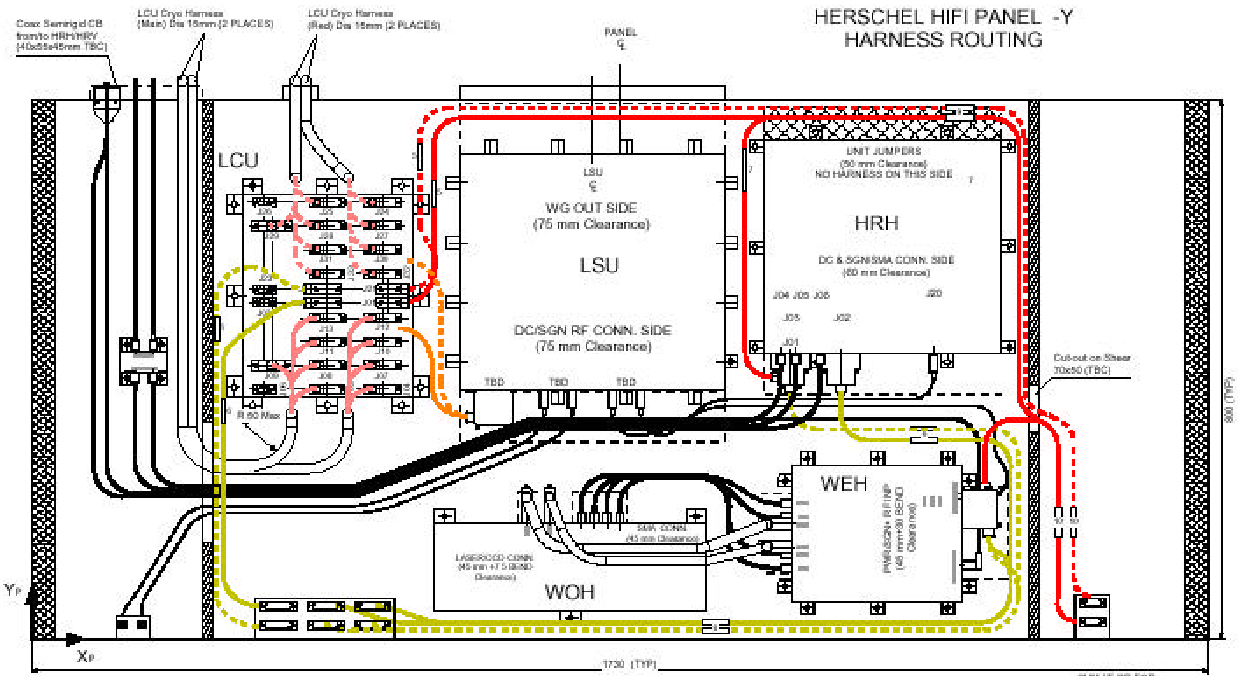


FIGURE 6.2.3-3a HIFI -Y PANEL LAYOUT

Horizontal Chain assembly has been set on this panel (WOH, WEH, HRH), with LCU and LSU units. The 3dB coupler 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 to allow panel dismountability.

The FHLSU location remains at the centre of the panel. However, FHLSU could not be ideally set in the axis of the LOU Wave-guides, which necessitate bending the LOU Wave-guides to meet the FHLSU.

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 and preliminary harness routing are presented hereafter.

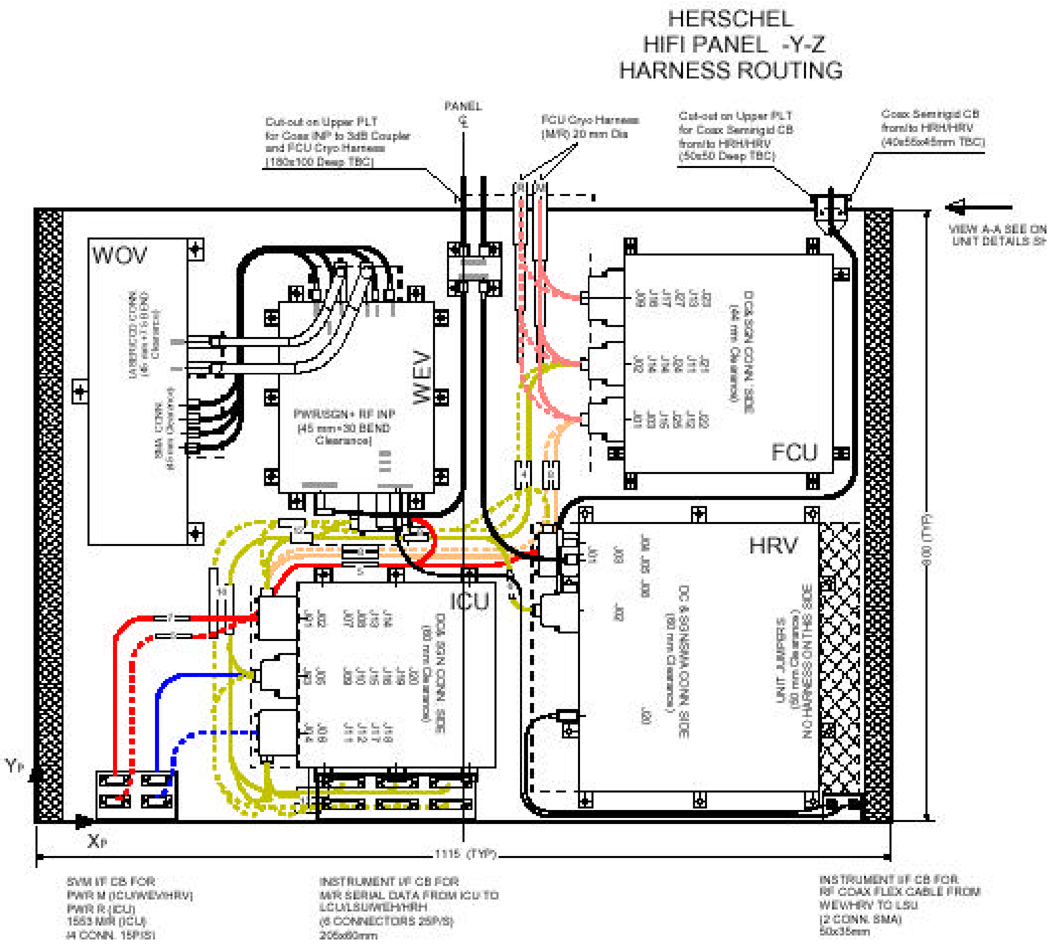


FIGURE 6.2.3-3b HIFI -Y-Z PANEL LAYOUT

Vertical Chain assembly has been set on this panel (WOV, WEV, HRV), with FCU and ICU units. The 3dB coupler set on centred 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 occurred w.r.t. IID-B 2.0:

- increased dimensions of BOLC, additional internal connectors resulting in excrescences
- DECMEC becoming a single huge unit instead of 4 small boxes stacked 2 by 2. It has to be noticed that the volume taken by the single box is about 2 to 3 times the volume taken by the previous units
- SPU growth in dimensions.

The consideration of SVM accommodation constraints together with new design of warm units made a very difficult situation. The agreed solution during Convergence Meeting implied to stack the 2 SPU units to make it viable. This option has still to be confirmed by PACS Consortium, but remain the major condition to freeze PACS panel accommodation.

Instrument accommodation and preliminary harness routing are presented hereafter.

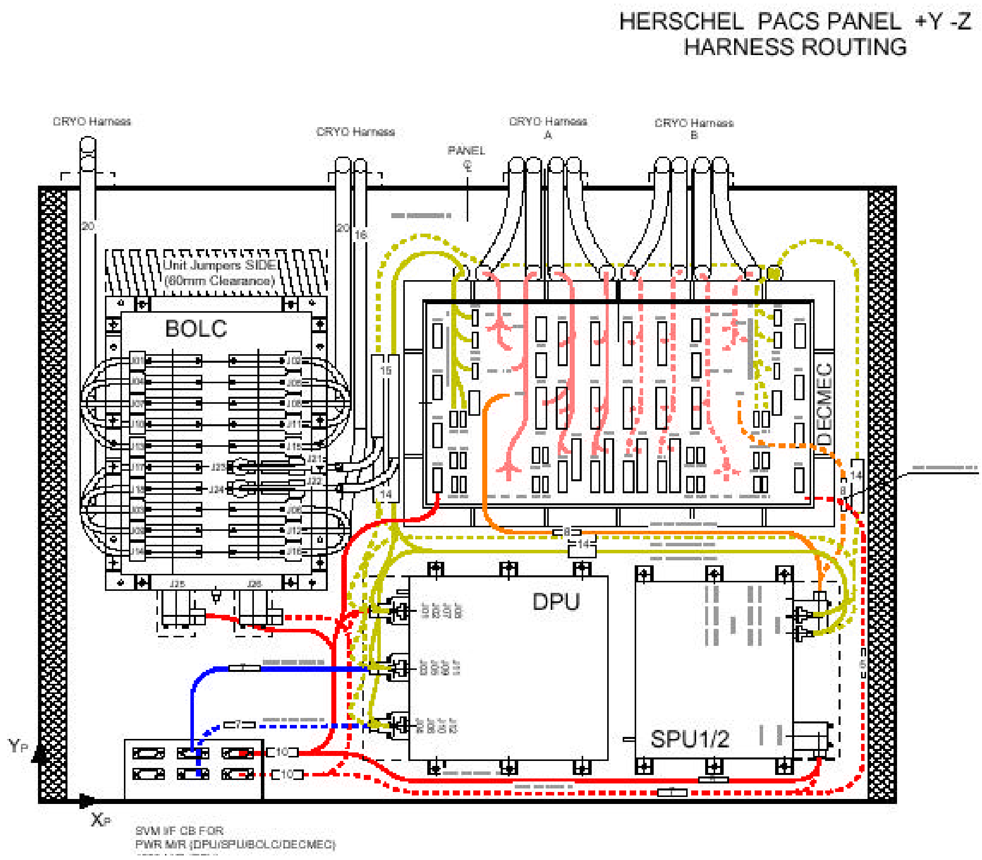


FIGURE 6.2.3-4 PACS +Y-Z PANEL LAYOUT

In order to ease units' connectors mounting and harness routing, using of connectors with 45° bent back-shells is envisaged (DECMEC, BOLC).

SVM connector bracket has been set at left bottom of the panel.

SPIRE panel

Compared to IID-B 2.0 baseline, main changes are increasing in dimensions of DCU and FCU units. However, units remain settable within available accommodation area.

Instrument accommodation and preliminary harness routing are presented hereafter.

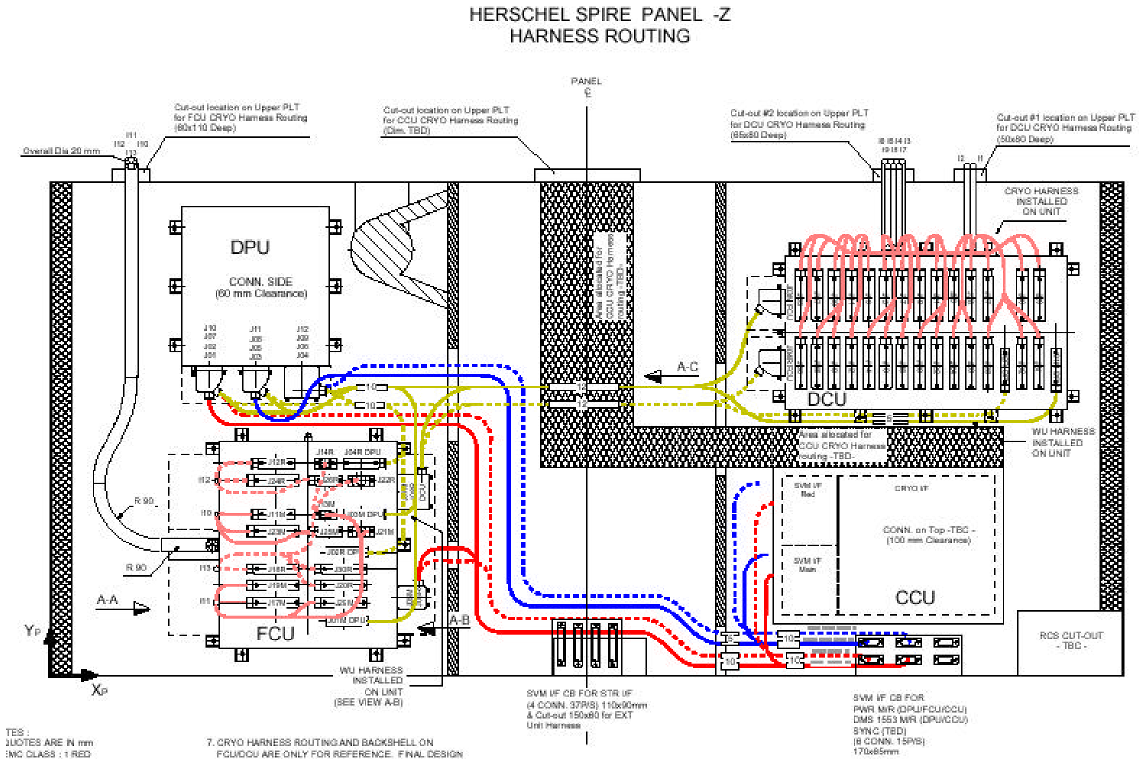


FIGURE 6.2.3-5 SPIRE -Z PANEL LAYOUT

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.

There are 2 SVM connector brackets, one for the warm units (at the right bottom of the panel), the other for the Star Trackers (center bottom of the panel - TBC).

LGA is now 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.

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 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 (at a mid-diameter of the platforms). I/F CB relative to an Instrument is set on upper platform 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.

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.

The last definition of cut-outs layout proposed by the SVM module is base-lined for PDR:

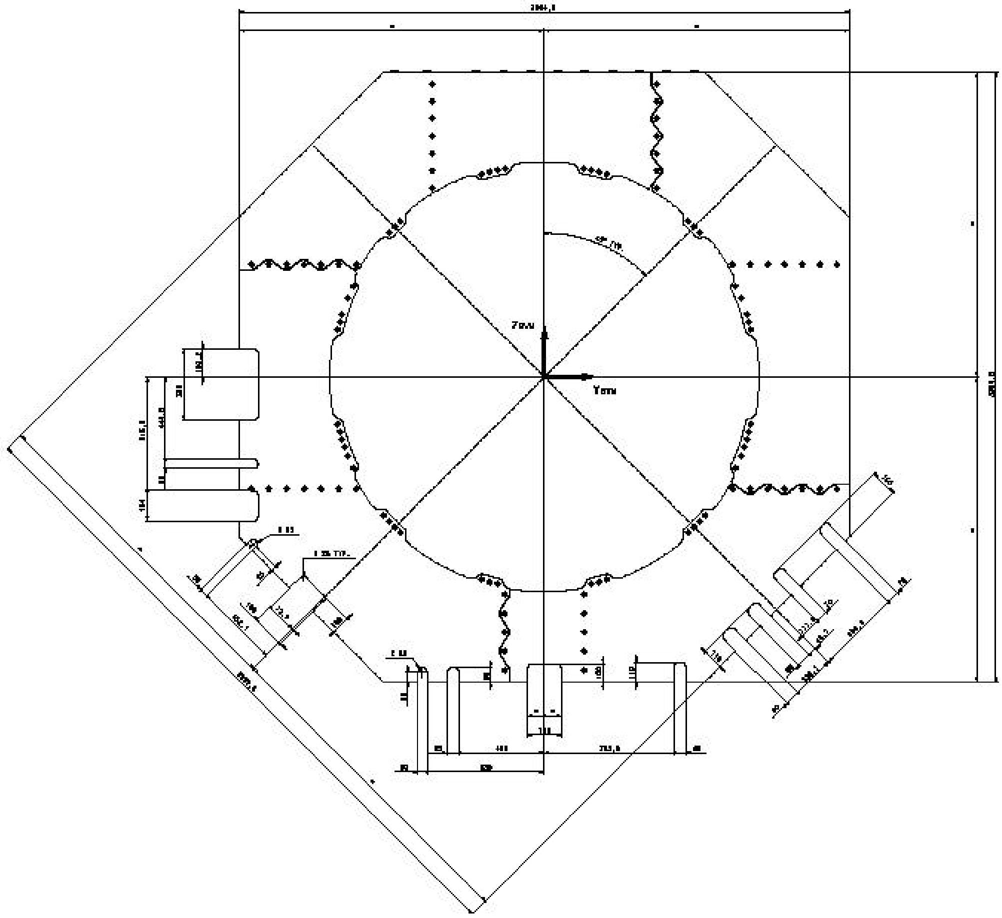


FIGURE 6.2.3-6 HERSCHEL UPPER PLATFORM CUT-OUTS LAYOUT

A final check would have to be performed between SVM and PLM modules, to verify that this cut-out proposal matches in all areas with Instruments harness requirements and cryo. brackets under PLM responsibility.

The last cryo. bracket accommodation base-lined for PDR is described as follows.

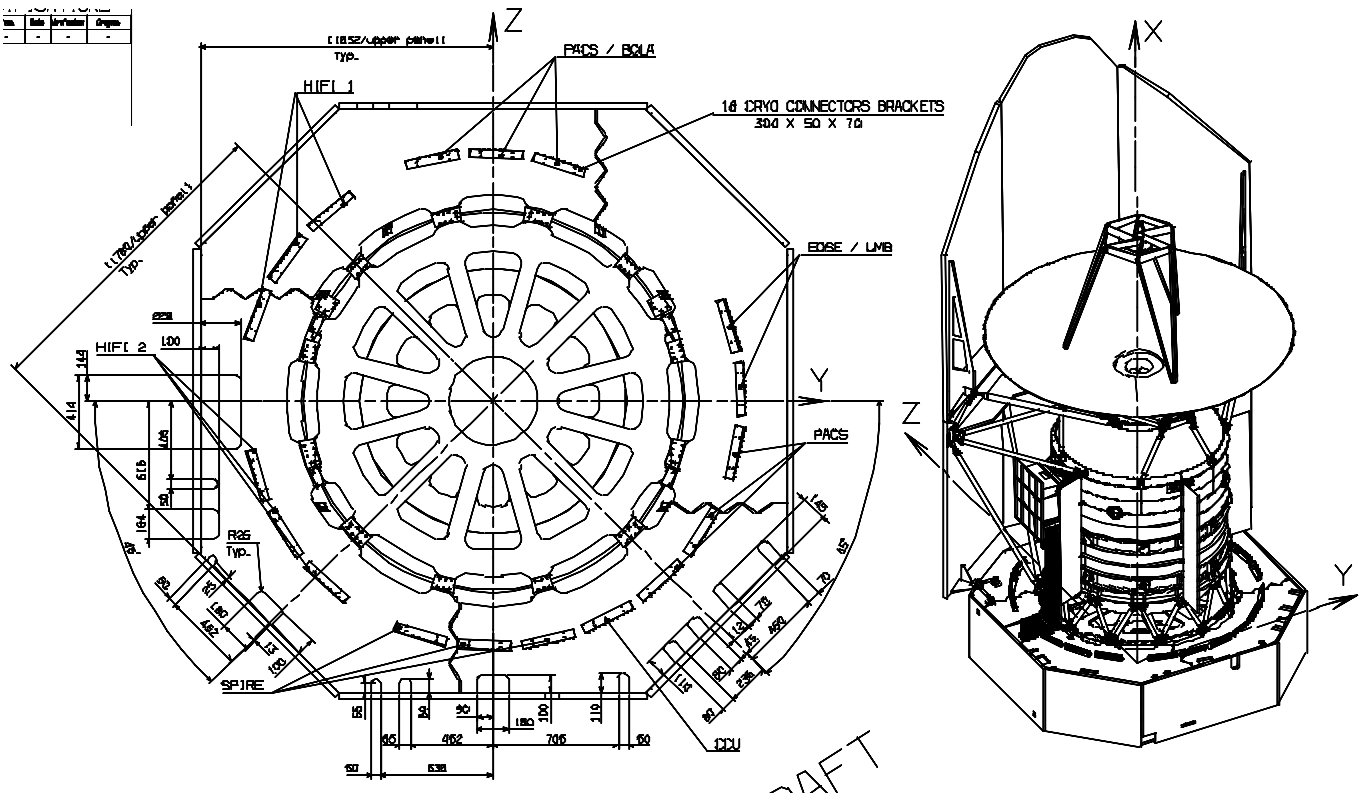


FIGURE 6.2.3-7 HERSCHEL CRYO BRACKETS INTERFACE LAYOUT

Sensors accommodation

Herschel and Planck ACMS configurations share the below listed common features:

- the Quartz Rate Sensors (QRS) 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 are mounted to the external of the SVM structure in accordance with the relevant field of view requirements.
- the ACMS Power Distribution Unit (PDU), if confirmed in the design, is mounted on a dedicated Shear Panel.

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
- 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

- a main distribution loop is routed along the external 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.

Refer to 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 (ORS), 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). For clarity, we have reported in Figure 6.2.4-1 the Herschel axis definition.

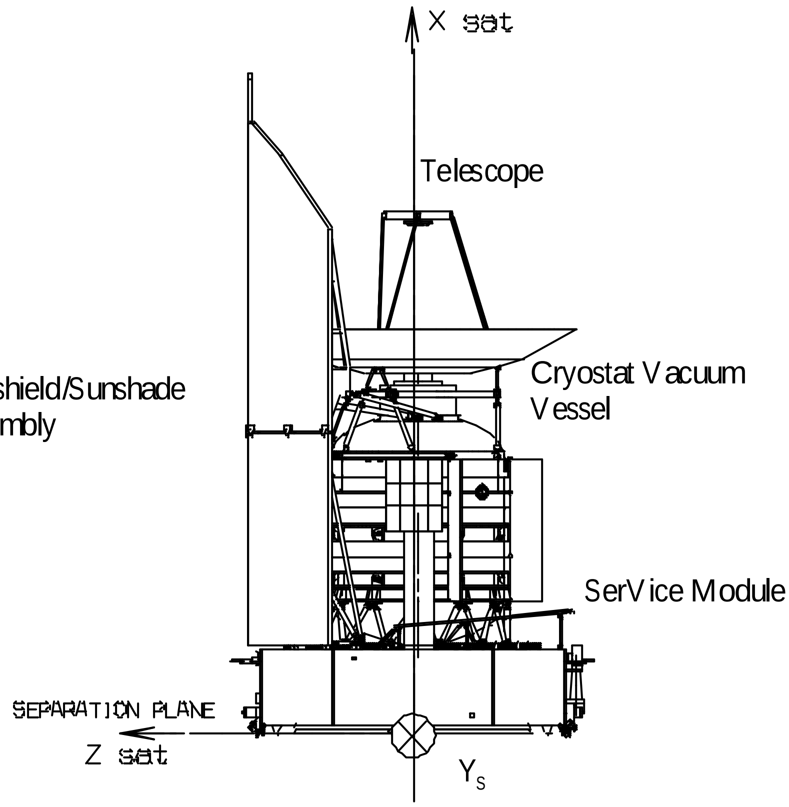


FIGURE 6.2.4-1 HERSCHEL AXIS DEFINITION

Launch phase

- Aerothermal fluxes: 1135 W/m² maximum occurring at fairing jettisoning, on a plane normal to the trajectory (ENVM-160).

This requirement is critical especially for the telescope, which design shall take into account this constraint

- Solar flux: from fairing jettison to launcher separation Herschel shall be compatible with a Sun direction between – 23° and +23° from the (X_s , Z_s) plane, and between + 60° and + 140 ° from the X_s axis (ENVM-170)

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. 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.

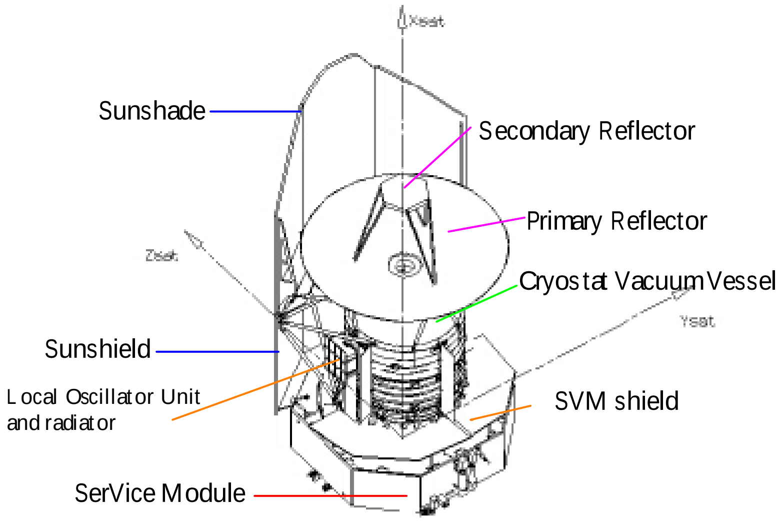


FIGURE 6.2.4-2 HERSCHEL OVERALL CONFIGURATION

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 AsGa 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 (AD01.1, SPER-005 H)
- 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 6.2.4.2-1).

	Maximum I/F Temperatures			Maximum Dissipation
	HIFI	PACS	SPIRE	
Level 0	2 K	1,75 K	2 K	10 mW
Level 1	6 K	5 K	6 K	25 mW
Level 2	15 K	N.A.	15 K	50 mW

TABLE 6.2.4.2-1 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.

Besides the main constraints recalled above, the H-PLM thermal design must also ensures the suitable thermal environment to operate the two warm units mounted on the CVV. The thermal requirements of these units are recalled hereafter:

- Local Oscillator Unit (LOU from HIFI instrument): operating range = [90 K - 150 K] for 7 W thermal dissipation
- Bolometer Buffer Amplifier Unit (BOLA from PACS instrument): operating range = [70 K - 90 K] for 0.2 W thermal dissipation.

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 0°C and 10°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 two of the units (FHFCU and FHICU) is 0.14 K over 100 seconds. The target temperature stability on all the remaining warm units is 0.03 K over 100 seconds.

The above specifications have a deep impact on the TCS. Indeed, an active thermal control is required in order to meet the requirements on FHFCU and FHICU, all the more to achieve the goal of 0.03 K over 100 seconds on the other units. Classical "ON-OFF" regulation is even not fine enough, and a heater loop controlled by the CDMU/PCDU shall be implemented.

SPIRE instrument needs also temperature stability level (AD04.2) for correct operation. The stability required, < 3 K/hour, is not considered as a major driver for the TCS. Indeed, SPIRE units are mounted onto –Z panel, which benefits from an extremely stable thermal environment.

6.2.4.3 Spacecraft thermal design description

The overall Herschel thermal design is depicted in Figure 6.2.4-3.

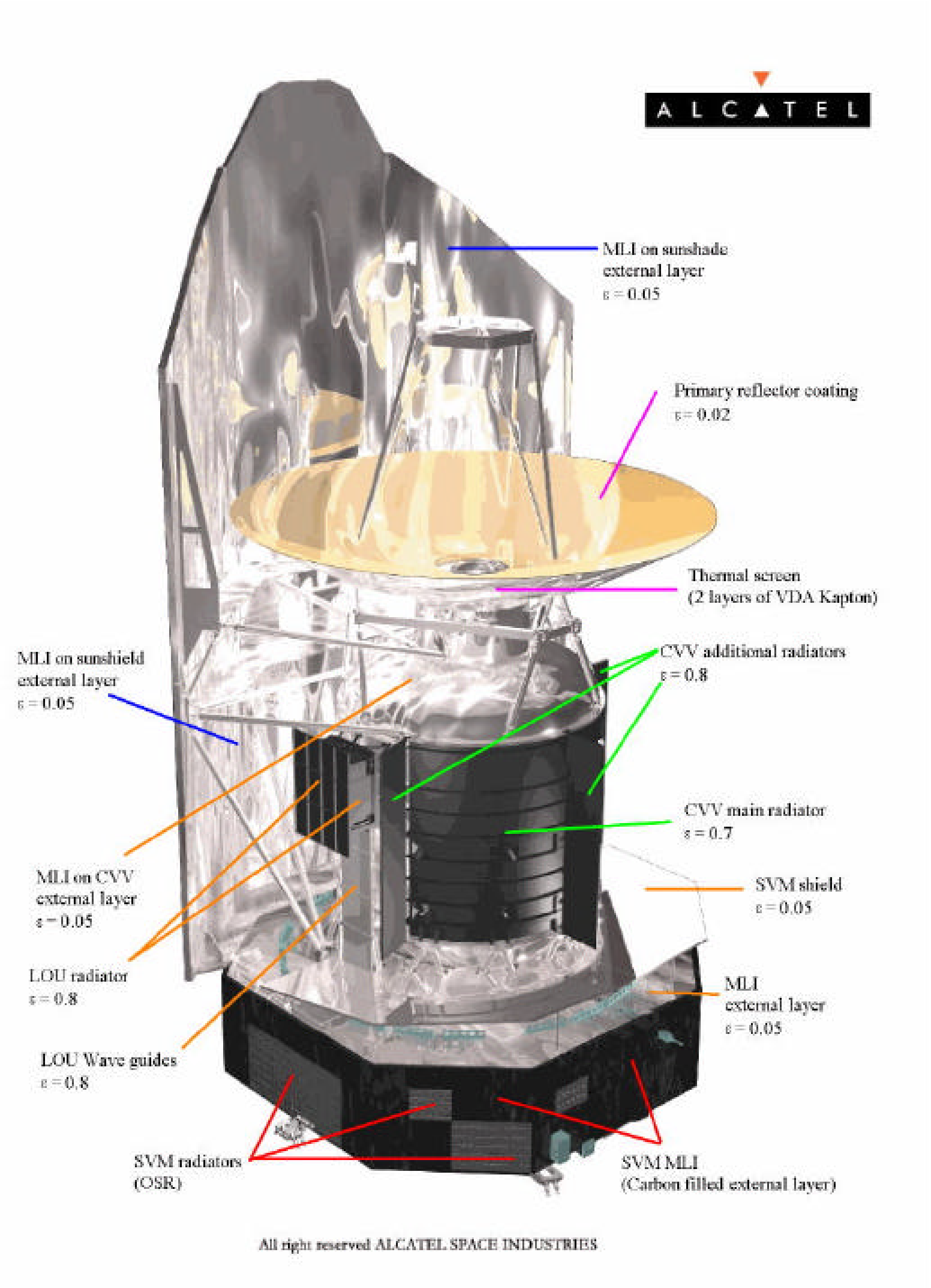


FIGURE 6.2.4-3 HERSCHEL THERMAL DESIGN

From a thermal point of view, Herschel is clearly divided into two modules, which have to be maintained in very different temperature ranges:

- 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)

electronics boxes mounted onto the CVV (LOU and BOLA) from respectively HIFI and PACS instruments

Telescope (maximum temperature at 90 K).

Specific heat exchange constraints between the two modules are required in order to fulfil the 3.5 lifetime specification. Basically, cold part of the HPLM must be thermally insulated from the H-SVM. This is achieved on one side using Glass Fibber Re-inforced Plastic (GFRP) struts for conductive de-coupling. As far as possible, mechanical fixations between SVM and warm part of the H-PLM have been preferred to fixations onto cold part of H-PLM.

On the other side, MLI blankets as well as thermal shield allows to reduce the radiative heat loads between the modules as much as possible. For this purpose, high efficiency MLI blankets (~ 20 layers with low "singularities" density) are installed on top of the SVM (H-PLM sub-platform as well as upper closure panels). Furthermore, the emissivity of the external layer shall be as low as possible ($\varepsilon < 0.05$). The baseline is to use aluminium coating on the MLI blankets external layer.

To insulate more strongly the SVM from the PLM, a thermal shield is implemented between the SVM and the radiative parts of the CVV. A dedicated low conductive truss mounted onto the SVM supports this shield. At beginning of phase B, this shield was extended towards the +Z side of the spacecraft. It had been shown that reduction of its size had no impact on CVV lifetime and a very low one on the telescope temperature (+ 0.5 K). Given the mass saving, it had been decided to keep only the useful part of this shield, i.e. the one blocking the view factor between the SVM and the CVV radiative parts. The baseline proposed by ASED, is to cover the +X side of this shield with a MLI blanket. Quick computations at system level demonstrates that using low emissive and highly reflective Aluminium coating on the shield would not have a significant impact on the lifetime (a few days). This option shall be investigated in the next future in the frame of overall mass reduction exercise.

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 mandatory). 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 a coating on the Sun illuminated side with a $\frac{\varepsilon}{\alpha_{solar}}$ ratio as high as possible (ε infrared emissivity and α_{solar} Solar absorptance). The baseline is therefore to use Optical Solar Reflector.

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 external layer) where submitted to a warmer thermal environment than its average temperature (~ 70 K). As far as possible, the CVV is free from MLI insulation and coated or treated in order to provide a high emissive surface. This is the case for "cold Space oriented" surfaces. Additional radiators (three) are implemented in order to enhance the heat rejection capability of the CVV. 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 is 0.7, data correlated against Alcatel in-house values at the relevant CVV temperature. This emissivity is increased to 0.8 thanks to the geometrical effect created by the ribs implemented on the additional radiators. Selection of a high emissive coating at low temperature can take advantage from activities undergoing at Planck-PLM level. Some black paints have been selected for deeper analyses (see RD01.3), which are believed to provide an emissivity higher than 0.7 at 50 K, therefore 0.9 when applied in an open honeycomb structure. The operating CVV radiator temperature being greater than Planck radiator one, it is considered possible to achieve higher emissivity data than the ones used for the present PDR thermal performances. According to ASED sensibility analyses, a month gain in lifetime is possible.

The telescope performance temperature achievement is considered also as challenging, since the help of a cryogenic radiator is not possible. Indeed, the power allowable (600 W maximum) for decontamination at least at 313 K dictates the need to insulate the telescope from cold Space. Backside of the primary reflector is also radiatively insulated from the CVV, in order to minimise the impact on the lifetime of the decontamination phase (3 weeks). Performance temperature can therefore be met only by reducing as far as possible all the spacecraft heat loads towards the telescope. The thermal design solutions brought for the minimisation of the CVV temperature are therefore applicable as well for the telescope.

6.2.4.4 Launch phase design impact

Herschel Payload Module thermal design is severely constrained by lifetime as well telescope and instruments focal plane temperature requirements. 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. Indeed, H-PLM thermal design takes benefit from the orbit type to provide a heat rejection capacity as high as possible. This means optimisation of the radiative surface area for high coupling with cold Space. The drawback of this design is that H-PLM is very sensitive to Solar and Earth input heat fluxes, which may occur during the launch phase. Thermal aspects become important drivers for the system optimisation of the launch sequence.

6.2.4.4.1 "Barbecue Mode"

One of the two standard strategy defined for an ARIANE 5E/SV launcher with delayed EPS ignition, is a 2°/s spin during the ballistic phase. The ballistic phase is defined between end of EPC thrust phase (H2 point on Figure 6.2.4-4) and EPS ignition (K2.1).

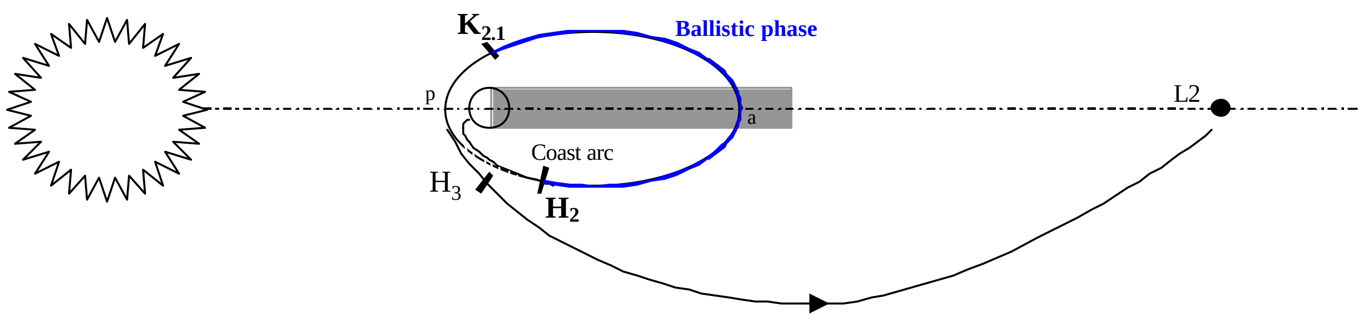


FIGURE 6.2.4-4 STANDARD INJECTION TO L2 WITH ARIANE 5E/SV (SCHEMATIC VIEW, NOT TO SCALE)

A technical note had been edited (RD03.19) in order to estimate the thermal impact of this strategy on Herschel Pay-Load Module, especially on MLI and telescope temperatures, as well as on CVV lifetime. For this purpose, we have used the HERSCHEL PLM Thermal and Mathematical Model Issue 00 provided by ASTRIUM in December 2001. This TMM has been slightly updated in order to match the solar absorptance data included in the model with the actual materials (previously not the case since the delivered TMM aimed not to compute solar fluxes inside H-PLM). The orbital parameters of the coast arc have been taken into account for computation of the external heat fluxes. Three pitch angles (angle between Sun direction and X_s satellite) have been considered (see Figure 6.2.4-5).

- Pitch angle = 90° (fig. 1.4).
- Pitch angle = 60° ("Xs side" Sun illuminated).
- Pitch angle = 120° ("-Xs side" Sun illuminated).

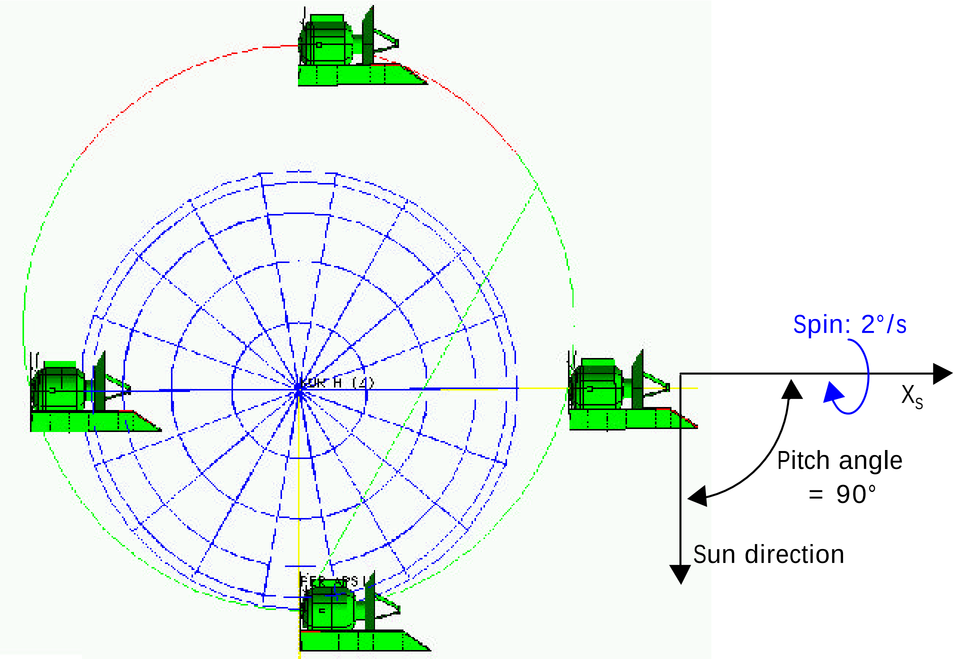


FIGURE 6.2.4-5 SPACECRAFT ATTITUDE DURING COAST PHASE THERMAL COMPUTATIONS

Once set at a value as reported above, the pitch angle is considered constant during the ballistic phase thermal computation.

Main results and conclusions are reported in document RD03.19

For the three studied spacecraft attitudes, temperatures are periodically closed to the usual MLI maximum design temperature (620 K typical value). Hot spots are obtained due to multi-reflections of the Solar rays between the H-PLM components.

The computed temperatures (up to 570 K) are calculated ones, i.e. without uncertainties and margin. It is also to be noted that the thermal modelling is a macroscopic one, indicating the average temperature of large surfaces. "Microscopic" effects such as solar-trapping are not taken into account. This means that additional temperature gradient around the previous calculated temperature may occur. As a conclusion, the usual maximum MLI design temperature is likely to be exceeded. The risk is a degradation of the concerned MLI efficiency, which in turn impacts the CVV lifetime.

Investigations have been carried out in order to assess the sensitivity of the H-PLM performances (lifetime and telescope temperature) on the MLI type external layer. Computations have been performed using Kapton foil external layer, and white painted MLI (ISO concept). In both cases, an important reduction of the H-PLM lifetime has been observed (~100 days), and this alternative has been discarded.

From a thermal point of view, the "Barbecue Mode" during coast arc has been rejected.

6.2.4.4.2 Three axis Mode

The second option proposed by ARIANESPACE is a 3-axis control during the coast arc. SAA possible excursion leads to illumination of the H-PLM "Space side". Critical elements identified are the telescope, which design must takes into account this constraint, as well as MLI blankets. These elements present two drawbacks w.r.t. Sun-illumination, which are their low thermal inertia and their "warm" external layer coatings (α/ε ratio>1). Adding effects due to multi-reflection of the solar flux (solar trapping), the impact could be a drastic increase of the temperatures beyond the usual design range. Design solutions to be set are to locally use diffusive surface such as Kapton or white painted MLI external layers. The optimisation to achieve is to reduce as much as possible the involved surfaces, while reducing the risk to damage the thermal insulation.

6.2.4.5 Modules Interfaces specification

This chapter deals with the establishment of the interface requirements between the H-SVM and H-PLM modules, as reported in their respective documentation (AD07.1 and AD07.2). Most of the requirements are linked to the need of important thermal insulation (both radiative and conductive) between the SerVice Module at warm temperature and the cryogenic PayLoad Module. At SVM level, the specifications are split into environmental specifications and interfaces requirements. The first ones deal with the H-PLM thermal input to be taken into account for SVM thermal analyses. The second ones establish the thermal performances required to the SVM in order to achieve the thermal performances at H-PLM level. The requirement figures are in turn environmental specifications for the H-PLM thermal analyses. To close the loop, H-PLM thermal performances are input for SVM environmental specifications.

The elements on which are applied the requirements are depicted on Figure 6.2.4-6.

REMARK: we have reported only the SVM thermal interface requirements. No critical features are associated to the SVM thermal environment (input data for SVM thermal analyses).

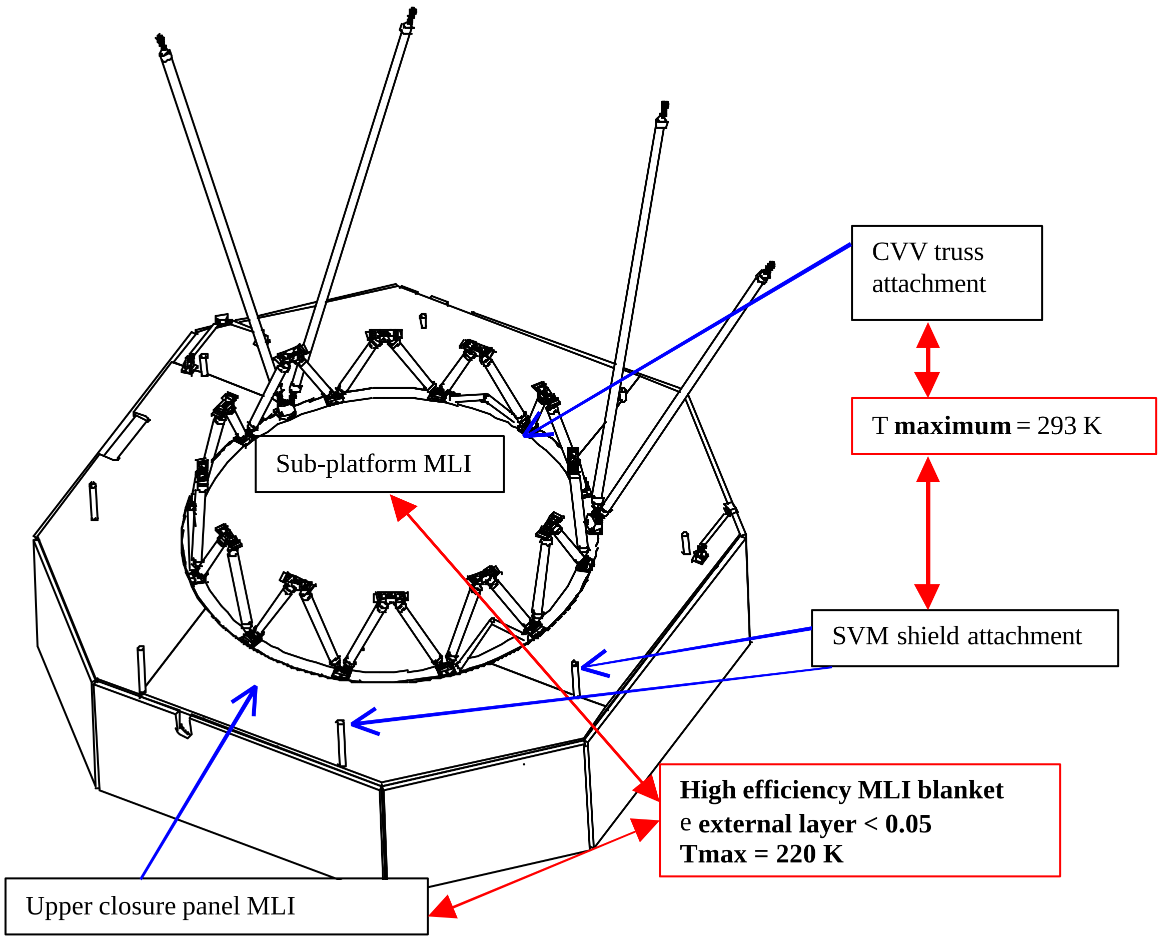


FIGURE 6.2.4-6 SVM THERMAL INTERFACES REQUIREMENT

Results obtained by Alenia with the SVM TMM are gathered in Table 6.2.4.5-1

	Requirement	Alenia results (7°C margin included)
SVM/PLM truss interface	< 20 °C	up to 40 °C in SVM hot case
MLI SVM on Upper closure panels	< -73 °C	some nodes out of specifications (-39 °C maximum)
MLI SVM on Sub-platform	< -73 °C	some nodes out of specifications (-48 °C maximum)
SVM shield struts interface	< 20°C	up to 38 °C in SVM hot case

TABLE 6.2.4.5-1 SVM THERMAL INTERFACE REQUIREMENT ASSESSMENT

The above results point out non-compliance between the required maximum temperature at CVV and SVM shield interface and Alenia results. We have estimated the impact of the SVM/PLM interface truss at 40° C (with ASED TMM issue 2.0). The lifetime reduction is ~1 week. No impact on lifetime has been observed in the case which SVM shield struts interface temperatures are at 40° C. The computation has been performed setting all the interfaces thermal nodes at 40° C, which is a sizing case w.r.t. Alenia results. The out of specification is therefore considered acceptable, and the requirement will be re-written in term of maximum average temperature.

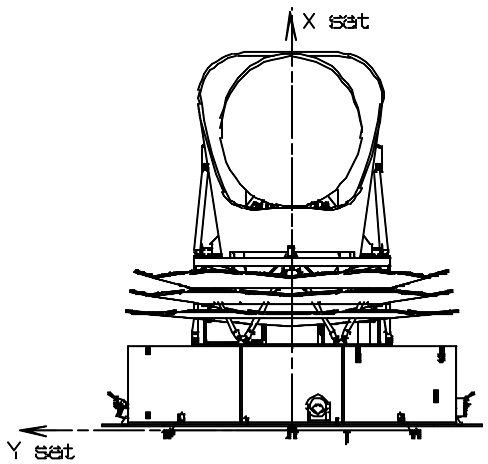
Concerning the temperatures of the MLI blanket, impact on the H-PLM will be assessed. Again, it is considered not critical due to the high level of radiative insulation at H-PLM side. The specification will be nevertheless re-formulated whether in maximum AVERAGE temperature, whether in maximum heat fluxes exchanged with the H-PLM.

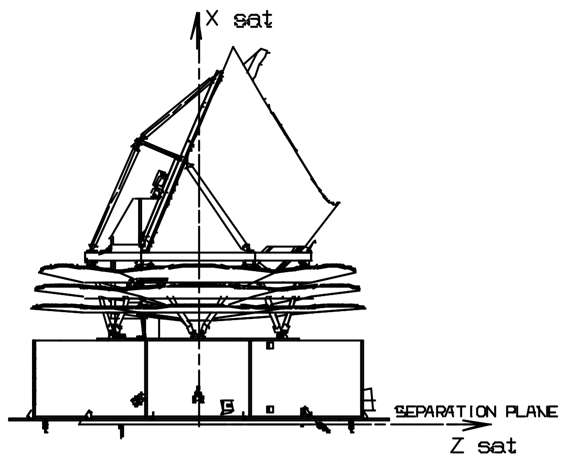
6.2.5 PLANCK mechanical design

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 X_S axis is oriented opposite to the Sun in nominal operation. The X_S axis coincides with the launcher longitudinal axis
- Zs is such that the PLANCK telescope line of sight is in the (X_S, Z_S) plane. The telescope is pointing in the $+Z_S$ half-plane
- Ys completes the right handed orthogonal reference frame.





6.2.5.2 S/C configuration and updates

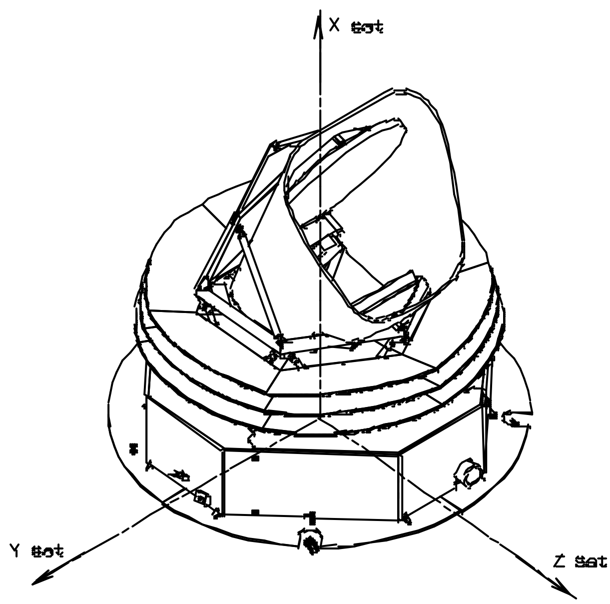
As explained above, HERSCHEL configuration at PDR presents a certain number of evolution and possible further evolutions in study since SRR. These configuration updates, constituting the current baseline or auguring a new baseline are presented hereafter with some details.

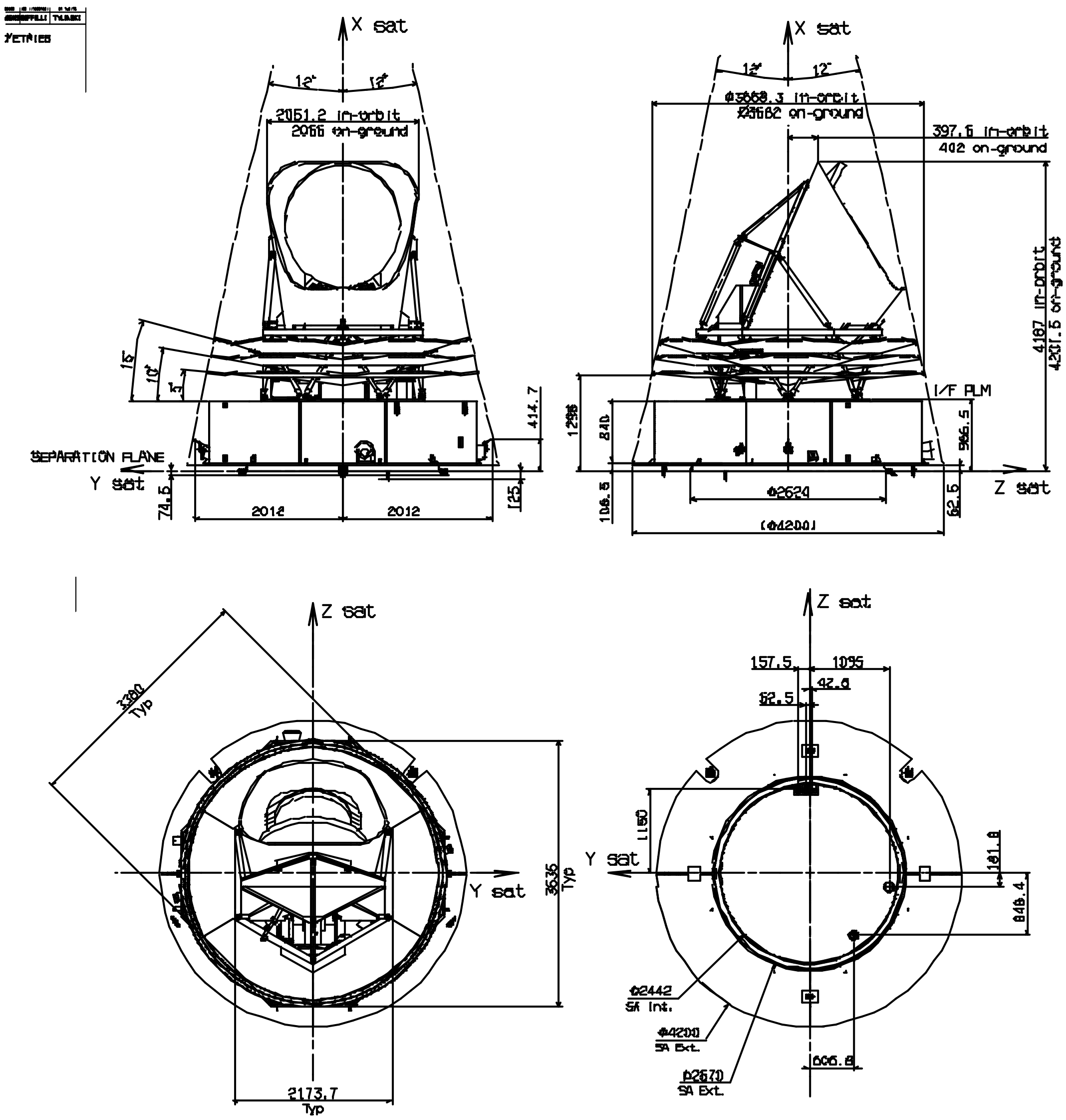
UPDATE OF S/C CONFIGURATION:

PLANCK overall configuration remained rather similar to SRR original configuration. The most visible change stays in:

- the implementation of 2 Star TRackers (STR) in SVM, instead of one STar Mapper (STM) previously installed
- the implementation of a large DAE Power box on top of the P-PLM sub-platform
- the implementation of a large cut-out at the center of the P-PLM sub-platform to prevent excessive acoustic vibration on BEU unit
- design optimisation in P-PLM architecture, detailed definition of Telescope and Cryo. structure items

PLANCK satellite presents overall dimensions quite un-changed wrt previous dimensions.





STATUS OF P-PLM TO SVM INTERFACES DEFINITION:

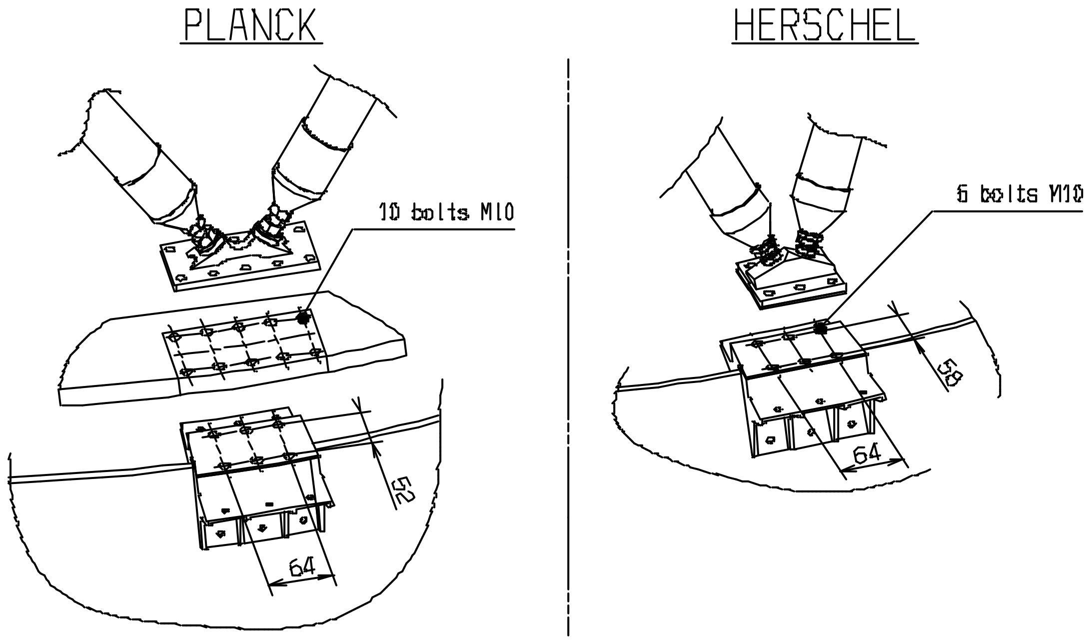
At the present time, it is considered that Modules interfaces are rather defined and mature. This results from common technical discussions between all involved parties (ASPI, ALS) to consolidate this Interface definition with respect and promotion of modules interest.

As a recall, the P-PLM and SVM mechanical Interfaces covers Cryo. Structure IF with Central cone.

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

<u>PLM supporting IF on central cone:</u> see drawings in RD05.3

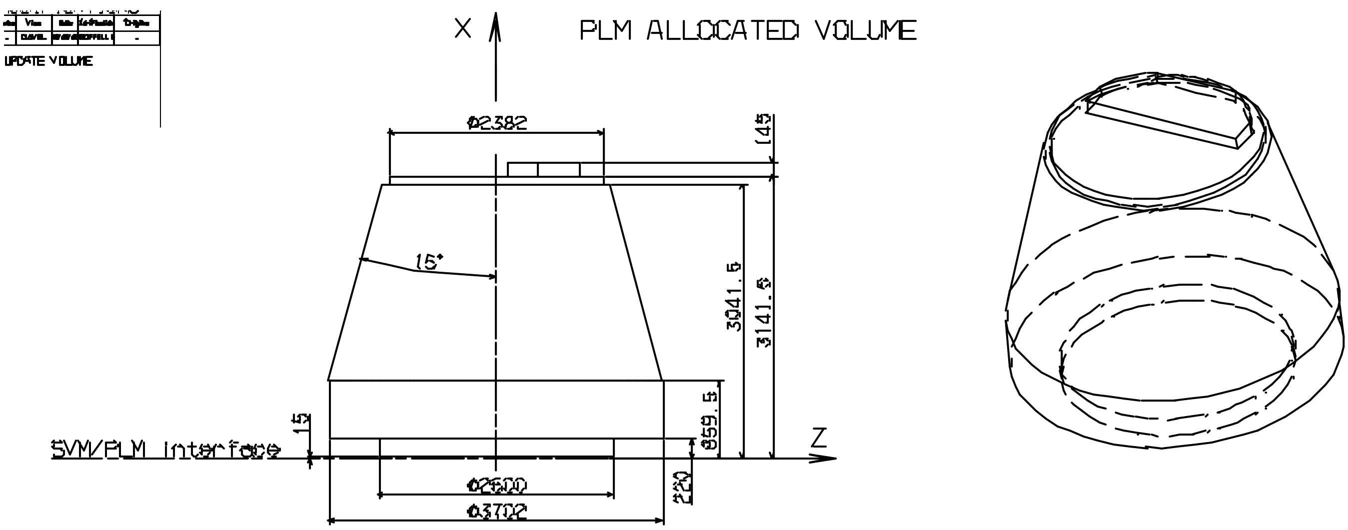
- optimization of SVM design, with Central IF now compatible with:
- interface of PLM struts for Planck on sub-platform. The sub-platform then interfaces with central cone using the same interface as Herschel PLM struts, using only 6 out of the 12 interface points
- PLM struts geometry optimised for "pure" loads path
- foot prints definition and location harmonised between H-PLM and P-PLM (communality is preserved on central tube), with implementation of bolts M10 Vs bolts M8 for both HERSCHEL and PLANCK.



ALLOCATED VOLUMES FOR SVM AND P-PLM

The SVM allocated volume remains the same as defined for SRR. Refer to RD05.3.

The definition of the P-PLM allocated volume has been reviewed to account for a lower station of the P-PLM induced by a reduction of 20-mm of the PLM sub-platform height on which it is accommodated.



OTHER INTERFACES SPECIFICATION

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

- 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

Stiffness requirements have been refined as for HERSCHEL. Stiffness requirements are declined in frequency requirements and rigidity requirements. Frequency requirements qualify the global stiffness behaviour of the modules, in consistency with frequency 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 verify stiffness perfomances at specific interfaces.

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

<u>SVM frequency requirement:</u>

SVM design shall ensure that eigen frequencies of HERSCHEL 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.

<u>P-PLM frequency requirement:</u>

The eigen frequencies of H-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.

<u>Interface loads:</u>

At the present time, interfaces loads are preliminary defined.

The basic interface loads at SVM to P-PLM interface (Cryo structure struts roots) are to be simply calculated by application of QSL loads at PLM CoG, considering same P-PLM characteristics as for SVM frequency requirement:

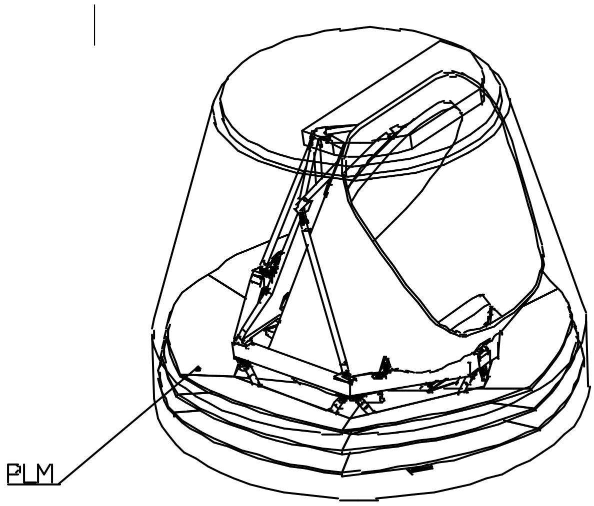
Load Cases	X longitudinal	Y lateral	Z lateral
1	+ 15g	/	+ 5g
2	+ 5g		+ 15g
3		+ 15g	
4	- 10g		+ 15g

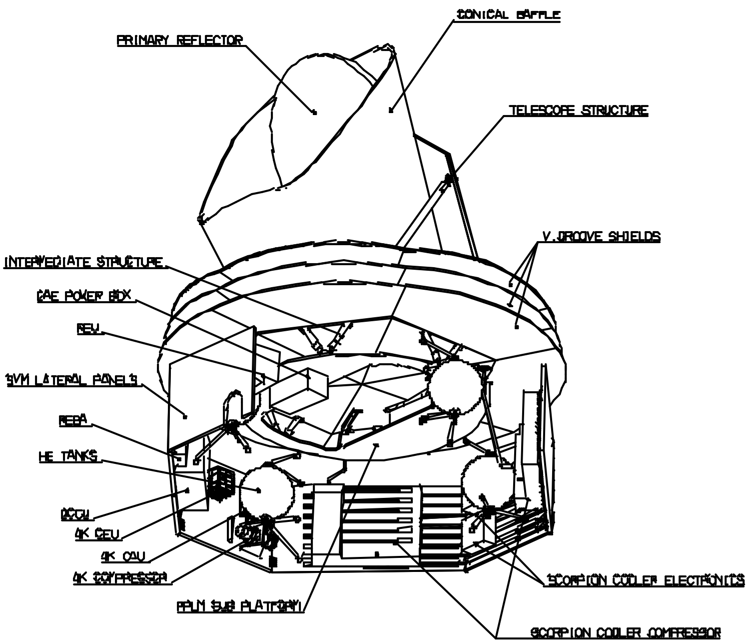
TABLE 6.2.5-1 P-PLM TO SVM INTERFACE LOADS (DESIGN LOADS)

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.





As explained above, Planck PLM configuration at PDR presents a certain number of evolution since SRR. These configuration updates, constituting the current baseline are presented hereafter with some details.

Global slip-down of P-PLM

The reduction of 20 mm of PLM sub-platform height results in a lowering of the P-PLM, as shown in Figure below. The P-PLM slip-down plays positively on:

- the S/C overall volume under SYLDA5. This allows to increase play with the bottom of HERSCHEL, accommodated on top of SYLDA5
- the calculation of Lamba factor representative of the inertia ratio between X longitudinal axis and Y and Z lateral axis,. The slip-down of the P-PLM allows to relatively increase the Ixx value and consequently increase the Lambda factor for a better S/C manoeuvrability according to the selected command law

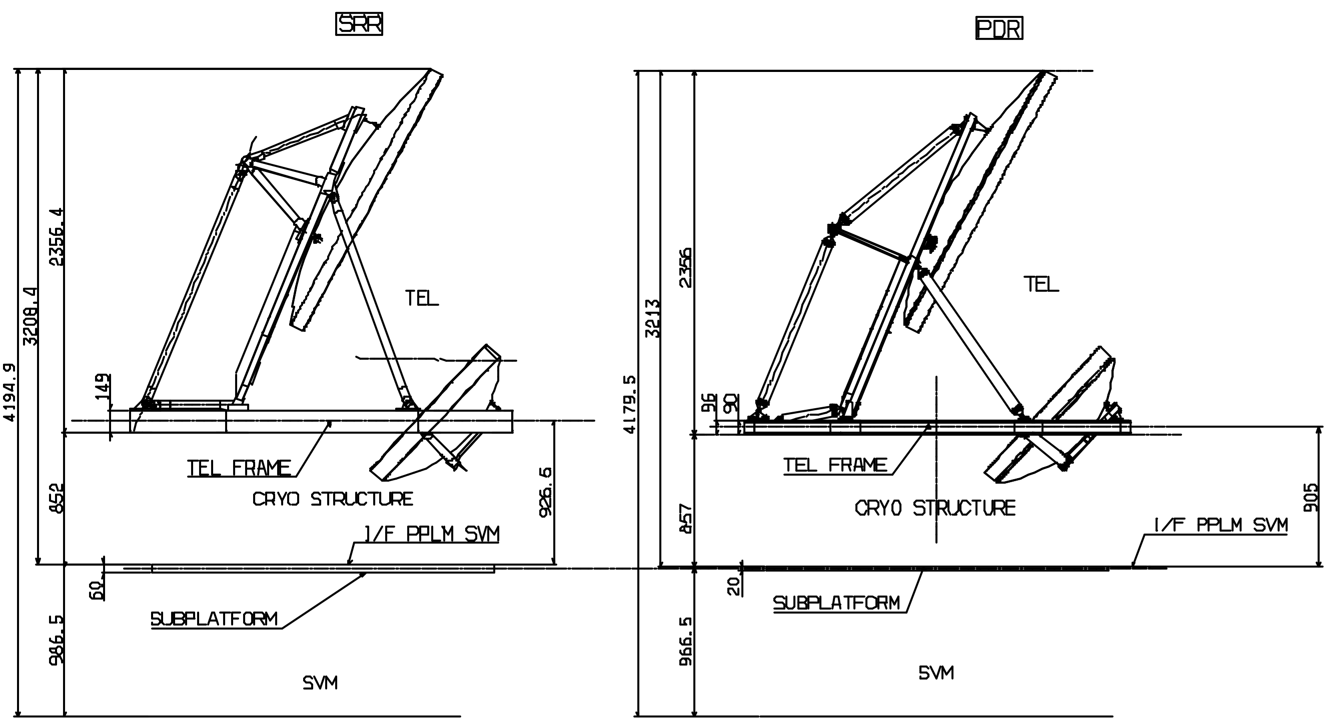
Telescope frame design optimisation

The Telescope frame has been reduced from 149 mm to 96 mm as a result of the Telescope design trade off regarding the best ratio mass/frequency. This new frame section allows keeping a high stiffness performance, out of plane towards cryo structure, in-plane for radial and tangential link between the 6 cryo IF. The out of plane flexure stiffness is sufficient to oppose to local bending moments induced by thermo-elastic distortion of cryo structure.

PR support design optimisation

The rear structure with a truss evolved now to a more simple structure constituted by a horizontal (perpendicular to the main panel) triangle panel and 2 vertical beams as a result of the Telescope design trade off regarding the best ratio mass/frequency.

The 2 top attachment points of the panel have been moved down in order to have an optimized location of the triangle panel this leads to an additional mass saving by removing the useless area. Moreover the new location (lower) of the 2 diagonal beams permits to have a better access for Baffle integration, consequently this one can be made of only 2 parts.



6.2.5.4 Update of SVM configuration

EQUIPEMENT 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 the same as Hershel one.

SREM AND VMC ACCOMMODATION

These two CFE units are accommodated on the space-looking face of –Y lateral panel.

STR ACCOMMODATION AND STABILITY

Two Star Trackers are accommodated in place of the previous Star Mapper. Their line of sight must point toward –Zs with an angle of 5° wrt YZ plane. As Star Trackers have not been selected yet, an envelope volume has been taken into account for Electronics plus Baffle dimensions among the envisaged ones. Several options have been studied:

- accommodation of a Star Tracker outside –Ys panel, the other one outside +Ys panel. Due to their line of sight, field of view aperture and SA shadowing constraints, no realistic solution is viable.
- In order to avoid optical stray light on PPLM telescope, it is not possible to accommodate them on the top of SVM (under PLM).
- Then they must remain inside SVM, at the same place as the Star Mapper on the lower platform, with baffle respecting SA shadowing volume. This implies to move the lower DPU, now replaced by the second Star Tracker.

In fact, 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.

Accommodation of Star Trackers inside SVM leads to have 2 imposing cut-outs in the panel for baffle passing through, a structural analysis will assess the feasibility and dimension possible local reinforcement (because of the presence of the REU unit above which is very heavy).

Regarding the stability, no mechanical analysis has been performed yet, but the requirement is less stringent than on Herschel, and Planck SVM is in a more stable environment on a thermal point of view (no Sun incidence rotation).

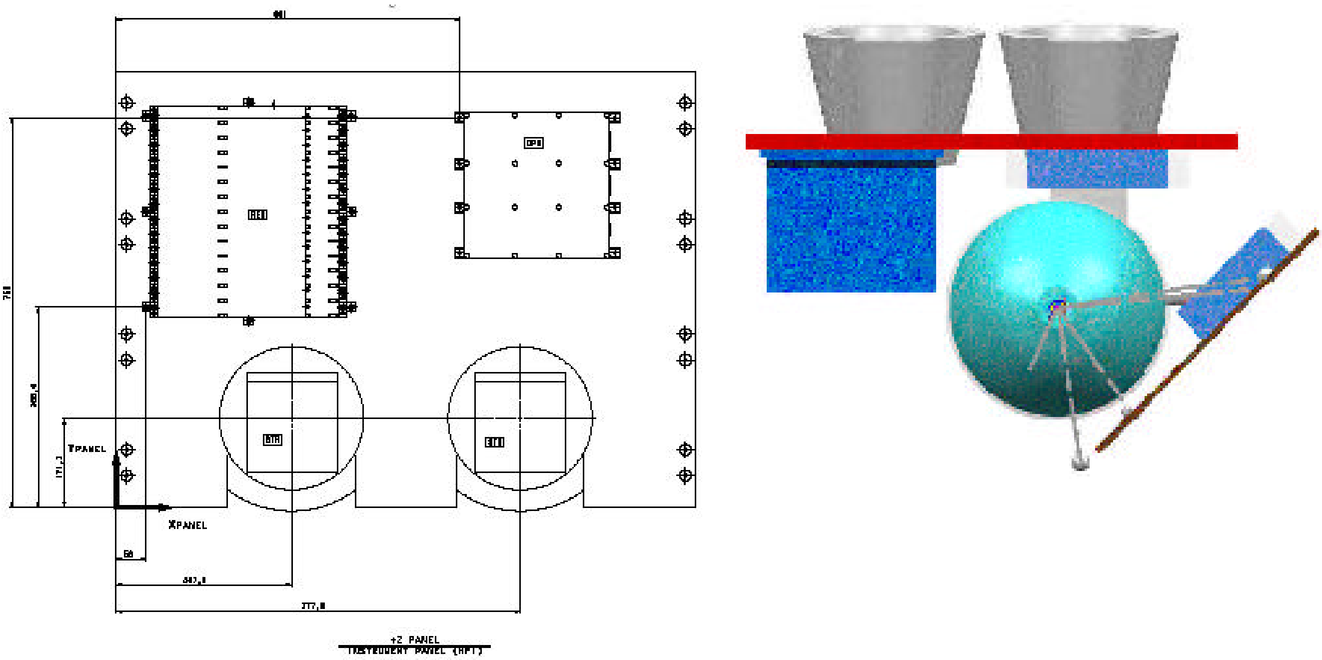


FIGURE 6.2.5-1: Star Trackers accommodation

INSTRUMENTS LAYOUT AND UPDATES

General

The new PDR baseline shows differences with SRR baseline, as changes of Instruments units configuration lead to reconsider the SVM instruments accommodation. As on Herschel, several evolutions of instruments boxes in terms of size and mass, modifications of units connectors and mounting feet occurred since SRR. On Planck, the evolution was however less drastic than on Herschel.

Recall of SVM accommodation constraints

The constraints are the same as on Herschel, see § 6.3.2.4.

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 requires first platform removal 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 the same as on Herschel.

SVM connector bracket

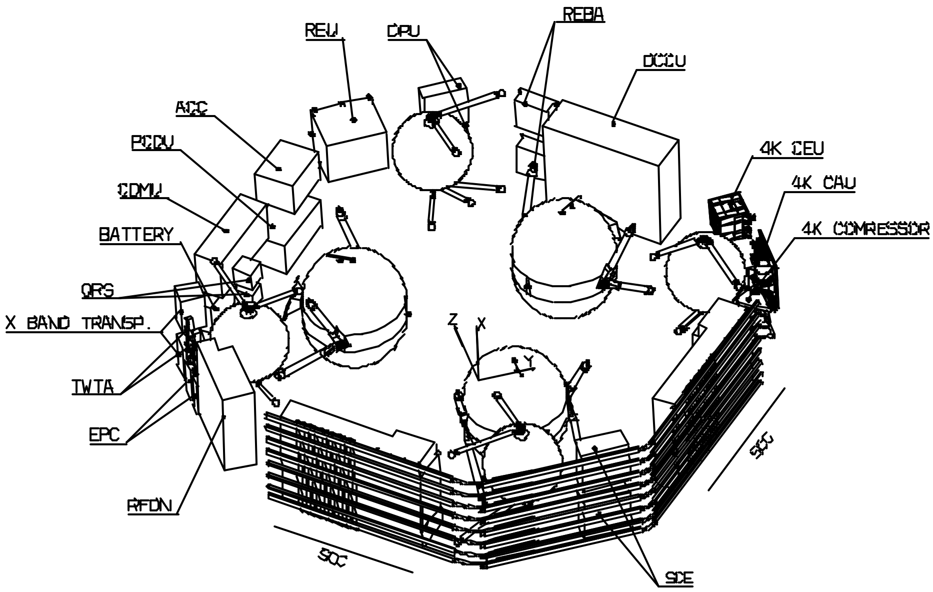
SVM harness (from PCDU, CDMU to warm units) is routed on the lower platform via interfacing connecting bracket set in each equipment/instrument partition in order to allow a disconnection before dismounting a lateral panel.

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 (AD04.5 and AD04.6).



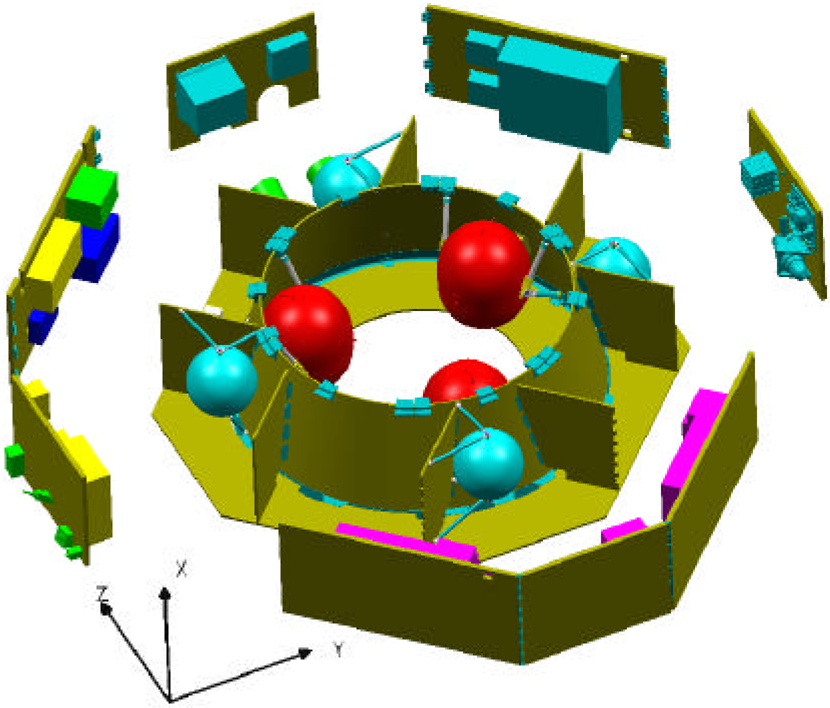


FIGURE 6.2.5-2: PLANCK SVM GENERAL LAYOUT

HFI Change/0.1 K Assembly

Panel accommodation

Previous DCCU and FVP units have been replaced by the single unit DCCU of which dimensions are 800*660*260 mm (mutually agreed by Instruments and Industry). It is set on the same panel in-between shear webs.

Helium tanks supporting design has been changed, Alenia chose to support them vertically. Exact design of supporting is currently under definition.

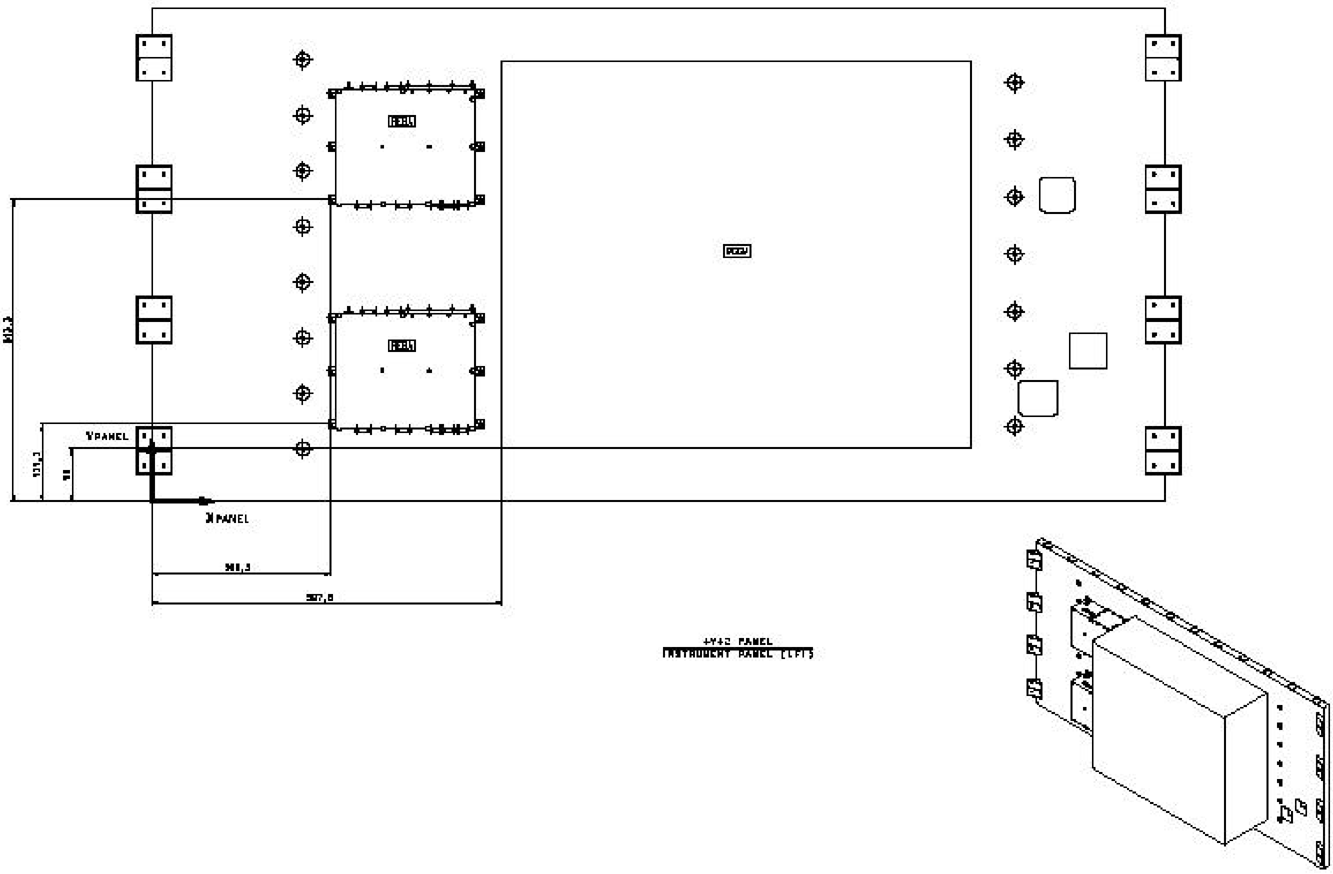


FIGURE 6.2.5-3: 0.1K PANEL LAYOUT

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 which is located on the subplatform 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 subplatform, then route around this one to go and connect to the Interface Connecting Bracket. They are routed together with a harness going to a connector either on the same bracket or on an additional one.

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. Currently it is accommodated at the center of the DCCU panel going out through it with the Helium exit direction horizontal (to avoid blowing toward the Telescope). Refer to Figure 6.2.3.2.3. It has been checked that this excrescence does not disturb SA shadowing.

This T complies with 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 maneuvres to perform the operations, then it shall be avoided to dismount part of SVM (like upper platform). It makes sense to foresee brackets supporting the different elements. These are 6 Fill and Drain Valves, 2 VCR and 3 connectors.

Several options were studied, among one was to place these interfaces on the lateral panel, but it seems hardly feasible because this one already supports high load-levels. It is then recommended to set them on the upper panel but carried by the DCCU unit. They are separated in several parts but functionally grouped in order to fit as much as possible with the current structural inserts layout design. In fact, the 3 connectors are on one bracket located between 2 existing inserts, it is the same for the VCR supporting bracket. Then the FDV are split in 2 brackets of 3 valves each, which leads to remove one insert and to move one another.

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.

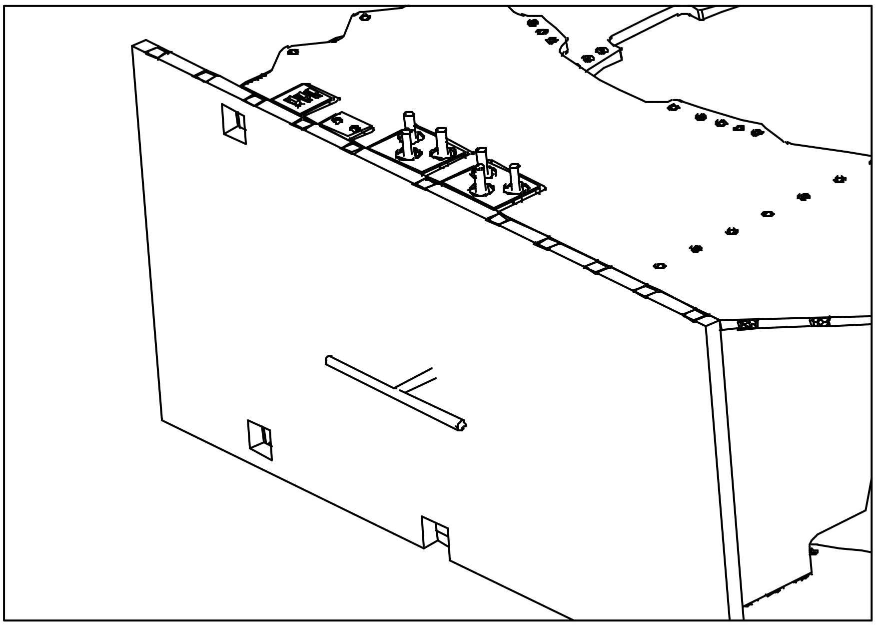


FIGURE 6.2.5-4 0.1 K ACCESSES AND EXHAUST PIPE

HFI change/4 K 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.

Implementation of a Current regulator unit of which design has not begun yet (afforded volume 150*150*150 mm).

4K Instrument team proposed an accommodation suiting to SVM constraints (available area and Helium tank location), wichc has to be consolidated by Alenia with refined studying and harness and pipe routing.

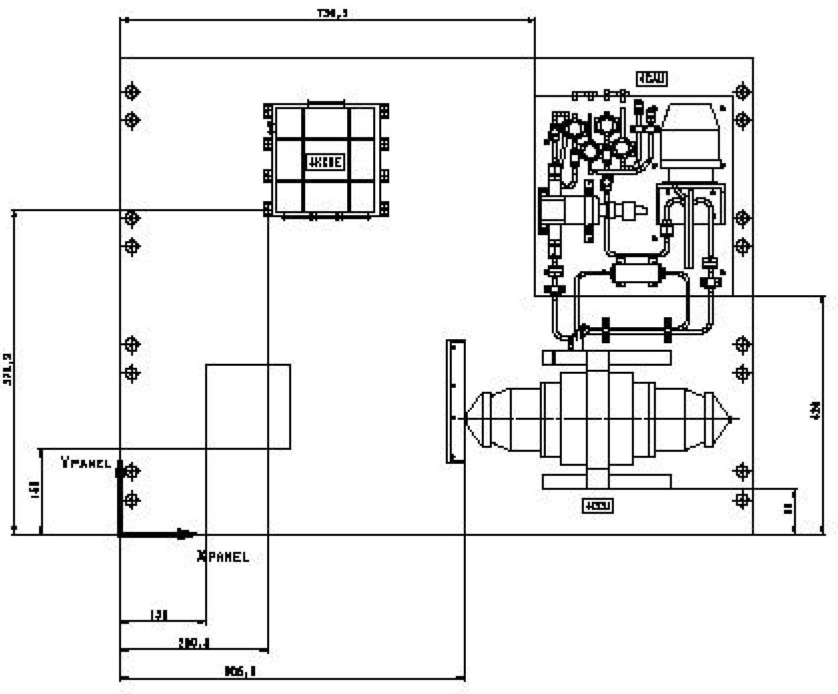


FIGURE 6.2.5-5: 4K PANEL LAYOUT

Pipe routing

Two pipes and a harness start from 4K CAU and go toward PLM. Pipes exit from upper side of CAU and harness from its left side (when considering a person located inside SVM and looking to 4K panel) but is routed together with the pipes. They route from upper right side of CAU going to next shear web, then route along the cone and emerge from SVM through a groove between upper platform and subplatform to join the PLM interface. They interface with PLM through a connecting bracket to be located on the subplatform near BEU in +Y-Z area (in fact opposite 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.

Access to 4K electronic box

Before any transportation of PLANCK Satellite, the Compressor piston need to be fixed by making a short-circuit on the CCU though the CEU (electronic box). For that 2 connectors must be placed on the CEU before transport and remove after. These 2 connectors are located on the same side of the box close to each other.

Aiming to reduce additional hardware and save mass, the 4K CEU is accommodated near the upper platform in such a way that the 2 connectors are being placed between 2 structural inserts. A cut-out is then made in the upper platform to allow the access by hand for connection and disconnection. A small removable piece of MLI will cover the hole to avoid any external flux entry. Finally, connectors savers will be placed on the units connectors to prevent from any mechanical failure when accessing them.

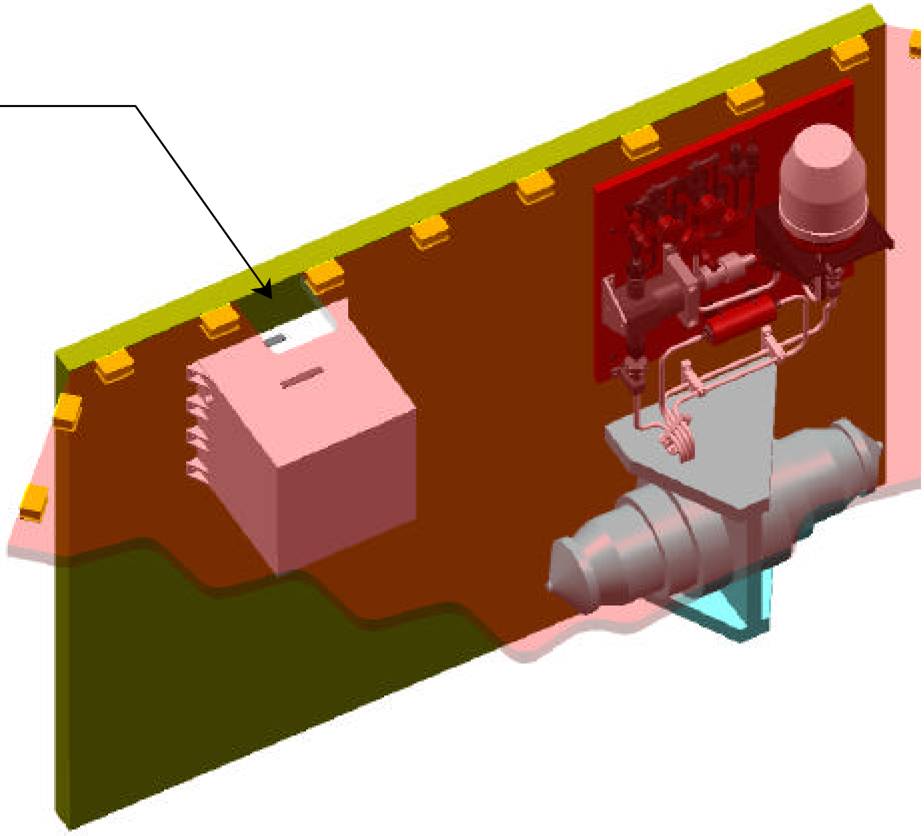


FIGURE 6.2.5-6 4 K ACCESS

HFI change/DPU – REU panel

Considering Instruments evolution, since IID-B 2.0, REU and DPUs have enlarged in length, but did not lead to reconsider a new accommodation of this panel : units still fit where they were previously set.

But last change from accommodation of 1 Star Mapper to accommodation of 2 Star Trackers resulted in reconsidering panel's units layout. The 2 Star Trackers must have the same pointing line and it is preferable to have them accommodated together in the same location, thus leading to have a Star Tracker in place of the lower DPU. This last DPU is then placed on the adjacent shear web and will have a dedicated thermal control (but this DPU should be the redundant one), for harness routing, disconnecting brackets will certainly be used.

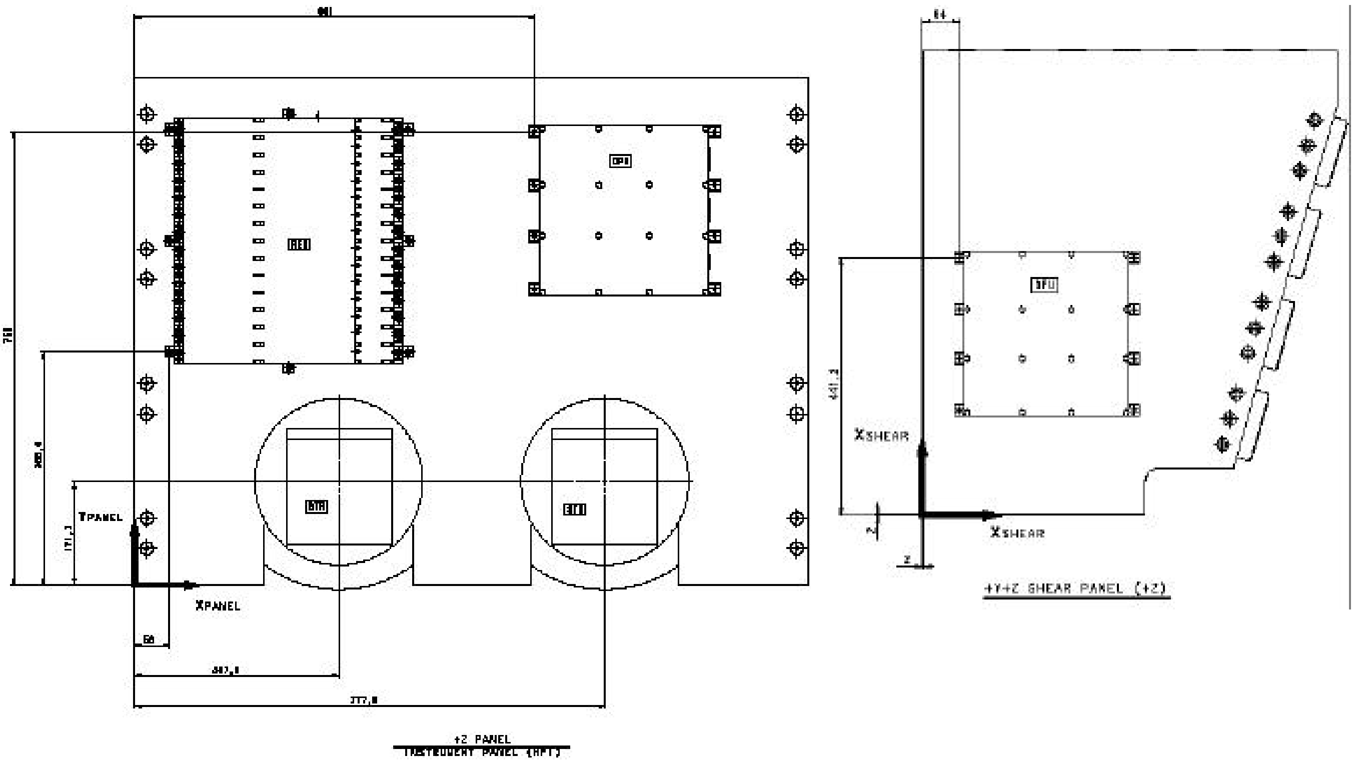


FIGURE 6.2.5-7 STAR TRACKERS, REU AND DPUS LAYOUT

LFI changes/REBA

The 2 REBAs which were previously on the subplatform are now set by DCCU side inside the area between the shear webs.

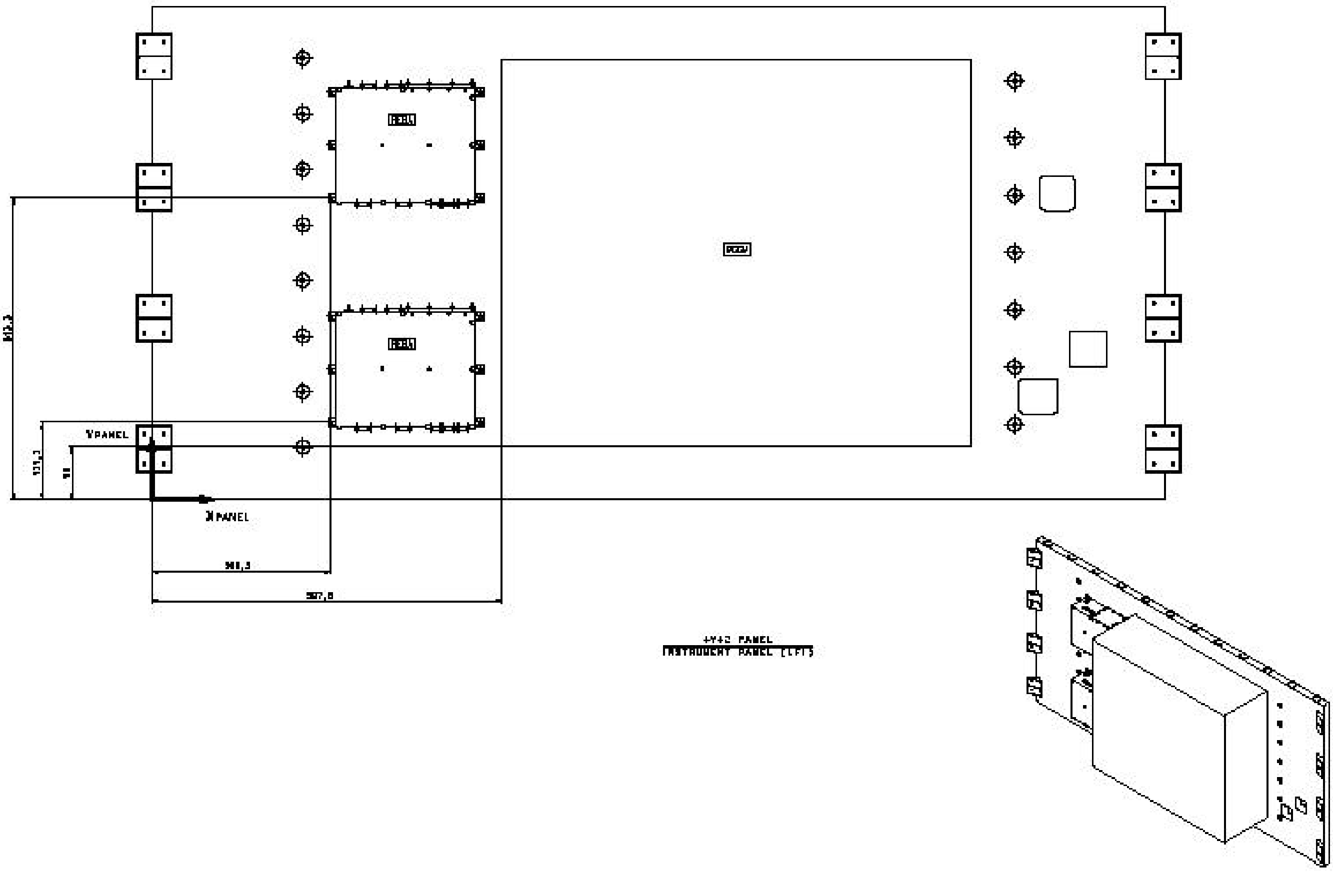


FIGURE 6.2.5-8: REBA ACCOMMODATION

The impact on satellite balancing is not important because the REBAs stay in the same zone than the previous one (on subplatform).

LFI changes/SCC panels

Main changes in SCC design is the reducing of their envelope and moving of the 20K pipe outlet.

The SCCs configuration has changed, from now they are accommodated in-line with the 20K outlet down (compared to previous accommodation where SCCs were in reverse positions).

The heat pipes network has been updated to fit this configuration.

The SCE have been accommodated in a vertical position to provide clearance w.r.t He tank.

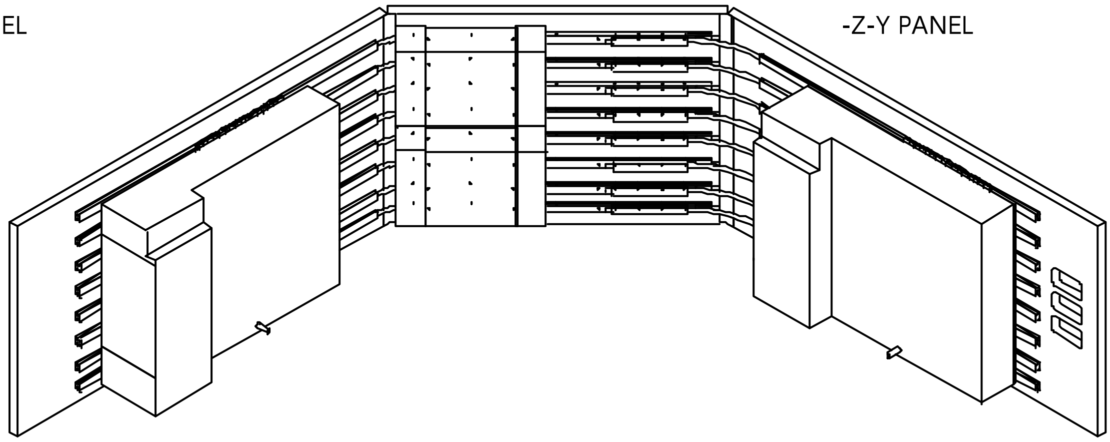


FIGURE 6.2.5-9 SCC ACCOMMODATION

Cryo-harness interface:

The Cryo-harness coming out from FPU is going directly to the BEU on top the PLM sub-platform, and at the contrary of HERSCHEL it is not interfacing with SVM.

WU inter-connecting harness IF and separation

Because of the integration sequence, with a set of WU coming on the PLM sub-platform integrated with the P-PLM, it appears necessary to set electrical dismountability between this set of WU and other WU integrated inside the SVM.

The last accommodation of dismountability brackets. base-lined for PDR is presented hereafter.

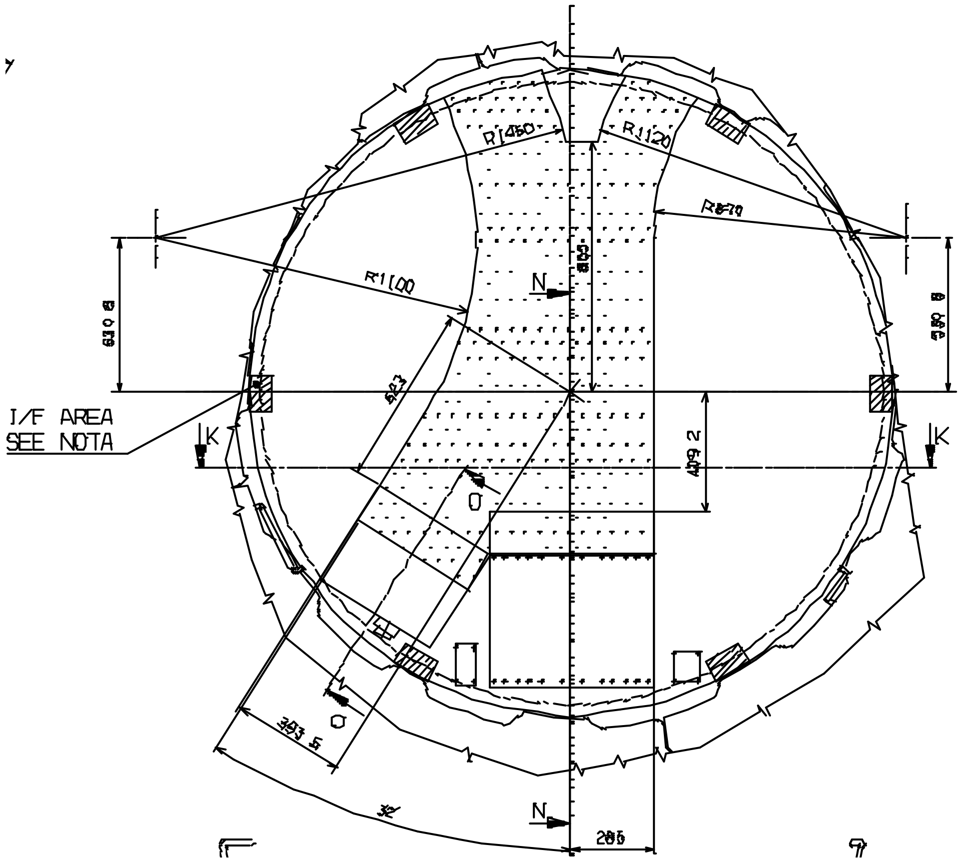


FIGURE 6.2.5-10: allocated volume on subplatform for harness routing

Sensors accommodation

Herschel and Planck ACMS configurations share the below listed common features:

- the Quartz Rate Sensors (QRS) are mounted on the Shear Panels, with their reference axis parallel to the X_S axis
- the San Acquisition Sensors (SAS) and the Attitude Anomaly Detector (AAD) are mounted to the are mounted to the external of the SVM structure in accordance with the relevant field of view requirements.
- the ACMS Power Distribution Unit (PDU), if retained in the design, is mounted on a dedicated Shear Panel.

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 Wave Guides 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
- 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
- a main distribution loop is routed along the external 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

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 (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.

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 (ORS), 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, at RCS Panel level.
- the External Solar Array, which covers remaining area between the Central Cone and the AR5 Launcher allowable envelope (...4200mm), and is segmented in four 90degrees quadrants.

ACMS- and TT&C-specific cut-outs shall be present in the Central Solar Array (for SAS/AAD and MGA/LGA, respectively), while RCS-specific cut-outs shall be present in the external Solar Array (for Flat Thrusters).

Additional cut-outs shall also be present in the External Solar Array for the Umbilical Connectors.

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 less sensitive than Herschel to the thermal environment experienced during the launch phase. Planck is indeed protected by SYLDA 5 until launcher separation. However, Planck shall sustain the net heat flux radiated by Sylda 5 (AD05.2 ENVM-165), during the 133 min aboard the launcher. The 1000 W/m^2 specified by ARIANESPACE corresponds to a 90° C black body. Withstanding a 90° C black body environment during 133 min would lead to probably unacceptable temperature elevation of some of the spacecraft components. This requirement is a very conservative one since the Sylda 5 temperature elevation occurs only during the aero-thermal flux peaks. It should be considerably relaxed after launcher coupled thermal analyses, given existing results about Meteosat Second Generation satellite.

From launcher separation to the end of the mission, Planck attitude is constrained so the Sun direction remains below 10° from X_s 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). A trade-off has been performed in order to converge on this maximum allowable value. Thermal fluctuation aspect was one of the most important parameter in this study. All details of system approach are gathered in Chapter 4.2.4.

Definition of spacecraft axes is shown on Figure 6.2.6-1.

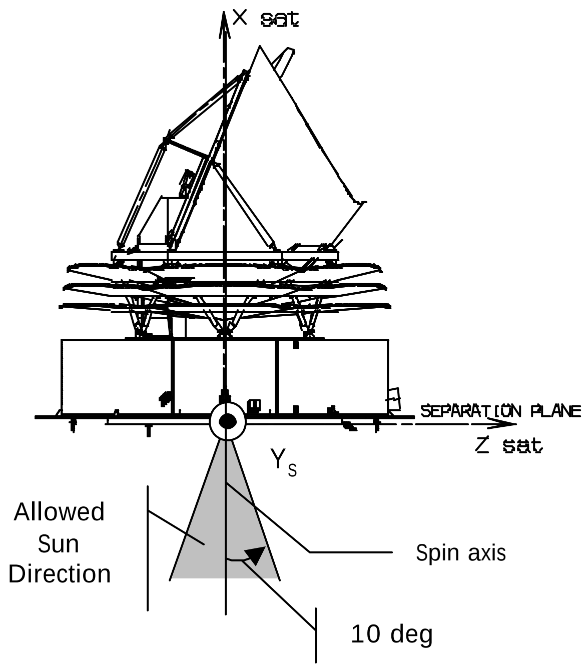


FIGURE 6.2.6-1 PLANCK AXIS DEFINITION

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.

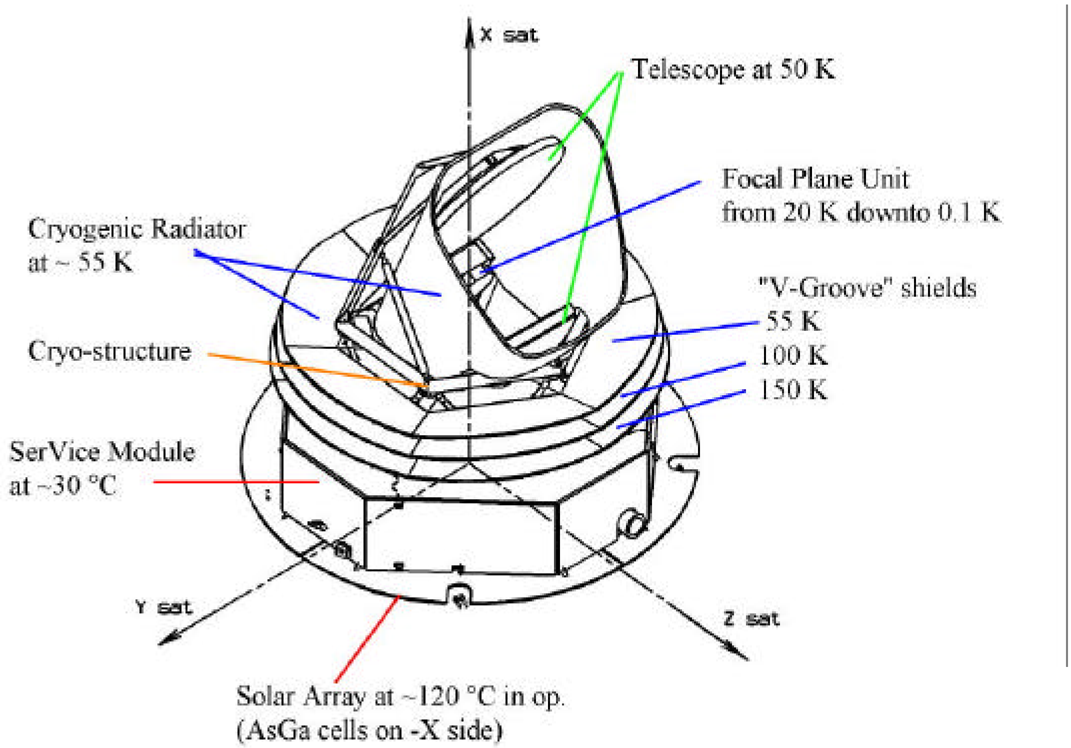


FIGURE 6.2.6-2 PLANCK OVERALL CONFIGURATION

As for Herschel, 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. As far as practical, components, processes and modelling philosophy shall be common for both Herschel and Planck SVM. The P-SVM thermal concept is a "classical" one, which aims to maintain the equipment within conventional design temperature ranges. Passive thermal control is extensively use thanks to adequate coatings, MLI blankets, heat sinks… On the contrary of Herschel, P-SVM supports also the AsGa 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 as for Herschel PLM, 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 serves also as cryogenic radiator at its external side and offering around 3 W cooling power at 60 K
- 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.

The overall configuration of the spacecraft has been optimised keeping in mind the need of thermal insulation between each different level. For this purpose, each "temperature level" receives a radiative 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 with 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, insulating the backside of the Solar Array thanks to MLI blanket.

The overall configuration of the spacecraft is therefore optimised to achieve the low temperatures required by the Payload. The concept is indeed based on a gradual temperature decrease between the hottest part, which is the Solar Generator down to the payload.

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 documentation or P-PLM one.

6.2.6.2.1 Temperature Levels

- SerVice Module.

The SVM shall ensures to the spacecraft warm units as well as to the instruments warm units, the required thermal environment to maintain them within their temperature design range. For the LFI and HFI instruments, unit requirements are described in their respective Instruments Interfaces Documents IID-B 2.1 (AD04.5 and AD04.6).

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 Range**	**Temperature stability**	**Dissipation**
Power Amplifier Unit (PAU from HIFI instrument)	[-10 °C , 30 °C]	goal : 1,1 K/hour	15 W
Back End Unit / Data Acquisition Electronics (BEU/DAE from LFI instrument)	[-10 °C , 28 °C]	goal: ± 0.2 K/hour	58,7 W
Data Acquisition Electronics Power box (DAE power box from LFI instrument)	[-20 °C , 50 °C]	NA	20 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. The thermal interface management is described in Section 6.2.6.5.2.

Besides the temperature levels difficult to achieve given the total heat loads on the P-PLM sub-platform, temperature stability performances are required (as a goal) for two of the three units mounted on.

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:

- 490 W average thermal dissipation at Beginning of Life

– 570 W average thermal dissipation at End of Life
– 1300 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 are demanded by the cooler responsible in order to minimise the temperature oscillations at 20 K stage. The stability required 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 very severe thermal requirements for the proper operation of the instruments. Main specifications are recalled hereafter.

Coldest Interface with Spacecraft	Maximum Design Operating temperature	Heat Load
Front End Unit	65 K	NA
LFI wave-guides	60 K	1 W @ 60 K
Sorption Cooler Pipes	60 K	1 W @ 60 K 1,5 W @ 50K
JFET box	70 K	0,15 W
4 K cooler pipes	NA	0,2 W @ 60 K 0,25 W @ 50 K
0,1 K cooler pipes	NA	0,15 W @ 60 K 0,16 W @ 50 K

TABLE 6.2.6-2 MAIN THERMAL REQUIREMENTS AT COLDEST P-PLM LEVEL

The exhaustive description of the P-PLM requirements can be found in the P-PLM design Report (RD01.3).

6.2.6.2.2 Straylight induced Temperature fluctuations

One of the most challenging characteristics of Planck is linked to the very low level of Stray-light to achieve the scientific mission. Preliminary straylight and thermal analyses had been performed in the frame of the Planck Architect Study in order to consolidate Planck design with regards to straylight performances.

From this study, have been derived temperature fluctuations specifications on the whole spacecraft. The specifications have been subsequently declined at SVM level on one side and PLM level on the other side. Concerning the SVM, the requirements at beginning of phase B were the following (reported in the SVM interface specification document):

– on each SVM lateral panel average temperature:

stability < ± 0.4 K on a 325 sec. time period

stability < ± 0.5 K on a 2 hours time period.

– At the SVM-PLM attachment struts temperatures:

stability < ± 325 K on a 325 sec. time period

stability < ± 0.25 K on a 2 hours time period.

The requirements on the lateral panels express Signal Induced Noise via thermal radiation (Planck's law). The requirements on the I/F truss aims to limit the transmission of the SVM thermal fluctuations towards PLM through thermal conduction.

The Straylight requirements have evolved at the start of the Phase B project. The head specification is given in the System Requirement Specification 2.1 (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 updated maximum acceptable SIN values have been declined again in temperature maximum fluctuation levels on the SVM elements. A major difference lies in the expression of the need, which is now an Amplitude Spectral Density (ASD) in $K/Hz^{1/2}$ to be in line with the new SIN requirements. The figures included in the last issue of the SVM Interface Specification (AD07.1) are the following:

- on each SVM lateral panel average temperature: component at 1/60 Hz < 0.01 $K/Hz^{1/2}$
- at the SVM-PLM attachment struts temperature: component at 1/60 Hz < TBD
- the ASD shall be performed on a 7200 s. time scale, with a acquisition frequency of 20 s. (to observe component at 1/60 Hz).

In parallel with the establishment of the above updated specifications, RF activities have been carried out in order to upgrade the straylight budget and take into account among other things the increase of the Planck orbit size. The new budget, as well as result of thermal computation is gathered in Section 6.2.6.4.2. Especially, the figure at the SVM-PLM interface strut is reported.

6.2.6.3 Overall Thermal design description

The main features of the overall PLANCK spacecraft thermal design lies in high level of thermal insulation required between the two modules making up the spacecraft. On one side, this feature is mandatory to achieve the low temperature requirements on the payload, and on the other side 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.

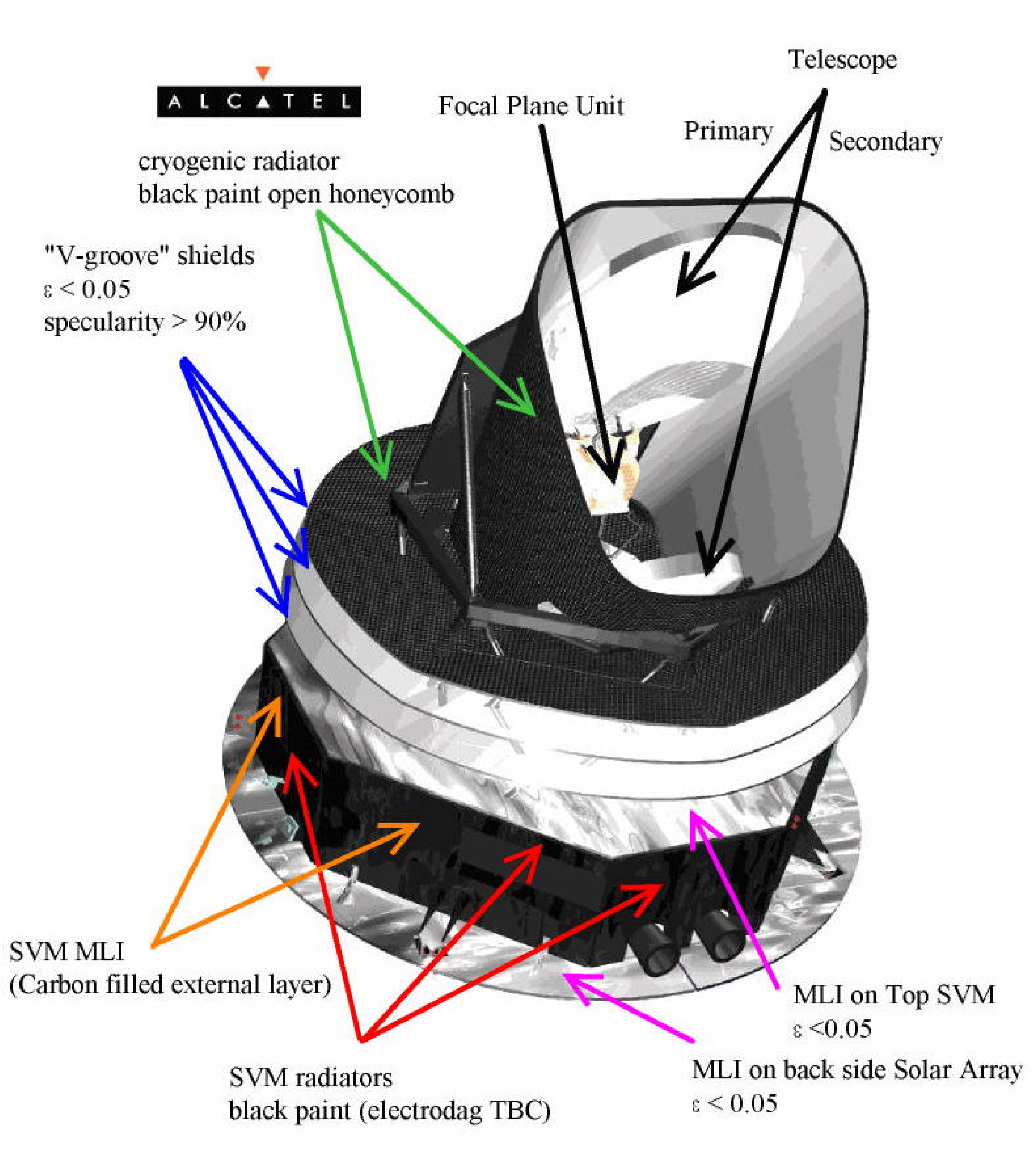


FIGURE 6.2.6-3 PLANCK OVERALL THERMAL DESIGN

Thermal insulation between P-SVM and P-PLM is required at the following levels:

- PLM supporting truss.

This truss is made of 12 GFRP struts for conductive thermal de-coupling. The baseline is to paint the struts with a high emissive coating to radiate towards Space part of the heat flux transmitted from the SVM to the PLM.

- 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 required 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 Justification

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 what concerns the SVM, the requirements deal with radiative constraints to be fulfilled by the Thermal Control Sub-system on one side, and temperature boundary constraints on the other side. The requirements are briefly recalled hereafter and described in Figure 6.2.6-4:

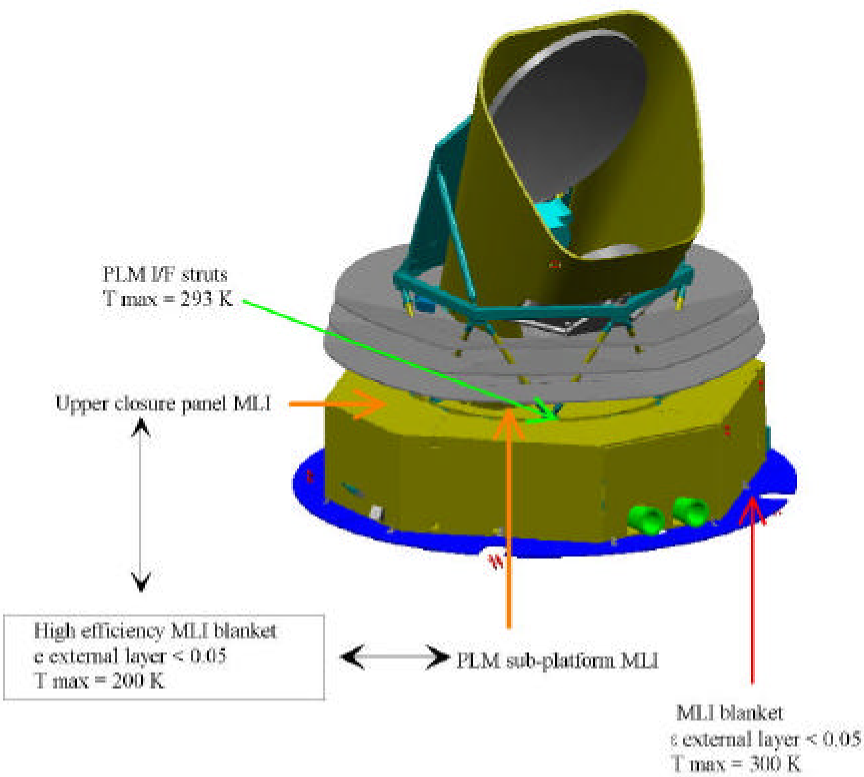


FIGURE 6.2.6-4 SVM THERMAL INTERFACES REQUIREMENTS

A first kind of specifications has been derived in order to limit the radiative heat fluxes from the warm SVM onto the cold P-PLM. They have been turned in 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:

< 200 K for Top of SVM and P-PLM sub-platform warm units

< 300 K for MLI on back side of external Solar Array.

The above requirements are in fact equivalent to a limitation of the radiative heat fluxes onto the P-PLM, and could be expressed in term of maximum allowable radiative fluxes. Anyway, is has been decided to decline the requirements as presented above due to the criticality and sensitivity of the P-PLM thermal performances to the radiative environment.

Concerning the warm units onto the sub-platform, a specific requirement has been edited in order to limit the heat flux from the radiative side of these boxes to the P-PLM. The total flux towards the first "V-groove" shield shall be lower than 2.3 W. This requirement is necessary in order to constrain the heat loads within the allowable data to achieve the P-PLM thermal performances. The figure has been selected in order to meet the P-PLM performances and ensure an acceptable temperature range for the warm units. The 2.3 W heat load has been taken into account for the P-PLM thermal budget.

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 293 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 PDR analyses are presented in the next table:

	Requirement	Alenia results (7°C margin included)
SVM/PLM truss interface	< 20 °C	out of specifications: up to 41 °C
MLI SVM on Upper closure panels	< -73 °C	out of specifications in hot case (~ - 60°C)
MLI on PLM Sub-platform	< -73 °C	out of specifications in hot case (~ - 50°C)
MLI on P-PLM warm units	< -73 °C	in specification: ~- 110 °C
MLI on back side Solar Array	< 27 °C	within the specification: 15 °C max in hot case
BEU/DAE & PAU radiative flux on V-groove 1	< 2,3 W	within the specification: 2,0 W

TABLE 6.2.6-3 SVM/PLM INTERFACE REQUIREMENT ASSESSMENT

As for Herschel, the MLI external layers temperature level is not considered as a critical area. Work will be done anyway to compare the total heat flux from the MLI blanket on the "V-groove-1" to the current data taken into account for P-PLM thermal analyses.

For what concern the temperature level at the interface struts, the impact on the P-PLM critical interface (Sorption Cooler coldest point on "V-groove" 3) is lower than 0.1 K. The SVM interface specification will be updated accordingly in its next issue. Let's note however that the results on the interface point temperatures are pessimistic since they are supposed completly covered with MLI in Alenia TMM. A local refinment of the modelling should show that the temperatures are well within the actual requirements (coupling factor with space).

6.2.6.4.2 Temperature Stability requirements

The methodology to derive the spacecraft temperature fluctuation specifications from the SIN system requirement (see 6.2.6.2.3) is described in the P-PLM design report (RD01.3). We only summarise in this section the main steps of the approach.

First of all, spacecraft components presenting a Radio Frequency (RF) exchange factor with the detectors have been identified. There are reported hereafter:

– SVM level

  back side of external Solar Array

  SVM walls

  Top of SVM.

– PLM level

  baffle

  coldest "V-groove" shield

  telescope (primary and secondary reflector).

Any temperature fluctuations of these surfaces mean a variation of the radiated power (Planck's law), therefore a variation of the power received by the detectors in their respective frequency range. Any signal that cannot be discriminated against the "useful" signal is straylight. The requirement on the maximum power on each detector is declined in maximum temperature fluctuation level in the relevant range, on each spacecraft surface having a coupling factor with the detectors. The coupling factor values depend strongly on the considered element. The highest one is obviously with the telescope. The characteristic of the chosen Planck orbit lead to potential illumination of the primary reflector by the moon (RD03.15). Even very low, the received heat flux induces spin frequency temperature fluctuations, which represent the major part of the Straylight budget. Once the impact of this spin synchronous source identified and sufficient margin applied on, the remaining power allocation is distributed over the elements recalled above. Each maximum power level is finally declined in maximum temperature fluctuation level at spin frequency. The formulation of the requirement is expressed in Amplitude Spectral Density (ASD), in $K/Hz^{1/2}$.

The derived allocations, as well as Alenia computations are gathered on the next table:

	ASD maximum at 1/60 Hz [$K/Hz^{1/2}$]	ASD results at 1/60 Hz [$K/Hz^{1/2}$]
SVM walls SCC	0.01	0.13
SVM walls	0.01	Max: 10^{-5}
Solar Array	NA	$8\ 10^{-6}$
Top of SVM	NA	$3.7\ 10^{-6}$
I/F SVM-PLM	TBD	$1.3\ 10^{-5}$

TABLE 6.2.6-4 ASD REQUIREMENTS AND PERFORMANCES FOR SVM

ASD computation results performed by ALENIA have been used as input data for overall budget. The non compliance on SVM wall is therefore acceptable.

At SVM level, backside of the external solar generator, top of SVM as well as some parts of the walls are covered with MLI blanket for thermal insulation. Each blanket is typically made of a set of 10 to 20 aluminised Kapton layers. The typical thickness of the Aluminium coating is 400 Å. This means that the equivalent thickness of Aluminium which is part of a blanket is in the order of 1 µm. It shall be noted that the RF frequencies considered for stray-light evaluation are not totally blocked by this Aluminium thickness. Skin depth penetration ranges from 0.1 µm for the highest detector frequency (857 GHz) up to 0.5 µm for the lowest detector frequency (30 GHz). In other words, the structure under MLI blankets must be taken into account for stray-light evaluation. As a conservative and easy approach, we consider that the MLI blankets are totally transparent to the RF signal in the detection range. The requirements are therefore applied to the structure.

At PLM level, there are three types of temperature oscillations:

- the ones induced by fluctuations sources located in the P-PLM
- the ones induced by change of the thermal environmental conditions
- the ones induced by temperature fluctuations of the SVM, and transmitted to the P-PLM via conduction and radiation.

Concerning the first type of sources, there are caused by the fluctuations of the heat loads brought by the instruments at each level of their thermal anchoring with P-PLM (all the thermalisations are located on the "V-groove" shields).

The second type of sources is due to the P-PLM Earth and Moon illumination occurring at given relative positions of the Moon/Sun/Spacecraft/Earth, actually met during Planck mission.

The third type of sources are transmitted by conduction through the P-PLM struts, and by radiative thermal coupling between SVM and the warm "V-groove" shield, which induces in turn temperature variation to the remaining P-PLM. All results and budgets are described in PPLM Design Report (RD01.3).

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, as well as still open areas.

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 cooler dedicated to the HFI instrument.

The Sorption Cooler Sub-system (SCS) comprises the main following elements:

- a Sorption Cooler Compressor (SCC), mounted on the SVM
- a Sorption Cooler Electronics (SCE), mounted also on the SVM
- a Sorption Cooler Cold End (SCCE), located inside the instruments Focal Plane Unit
- a 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 expand 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. There are 6 beds for each cooler, which are cycled alternatively in order to provide a continuous gas flow 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. That is achieved thanks to a thermal heat-switch maintained in open position. After all hydrogen is released, the bed must be cool down to 260 K before entering an adsorption phase. The heat-switch is therefore closed, and provides a thermal link between a radiator and the hot bed, which progressively cools down to 260 K. The Sorption cooler Compressor is depicted in Figure 6.2.6-5. We have also reported in Table 6.2.6-5 the main thermal requirements at SVM level.

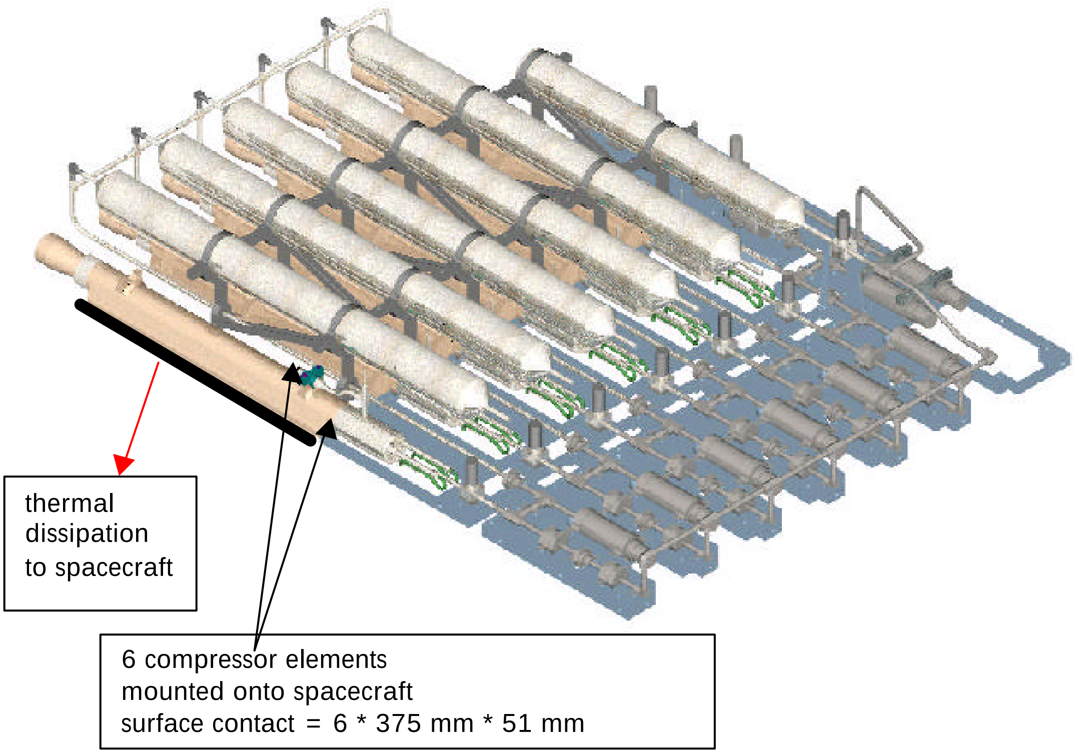


FIGURE 6.2.6-5 COMPRESSOR PHYSICAL ASSEMBLY (JPL DRAWING)

	Thermal Requirements
SCC average thermal dissipation	max : 470 W
SCC peak dissipation	1200 W
single bed peak dissipation	1020 W
adsorbing single bed T design operating range (S/C side)	[260 K, 280 K]
T gradient between S/C and adsorbing bed	< 2 K
Temperature fluctuations level under adsorbing beds	[6K , 2 K, 1 K] peak-peak, depending on the location

TABLE 6.2.6-5 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 at time of the technical proposal is order to provide enough radiative area on a minimum number of adjacent panels in order to evacuate the average SCC and SCE dissipation. A compromise had been found allocating two lateral large panels and one small lateral panel to the SCS. 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 6.2.6-6.

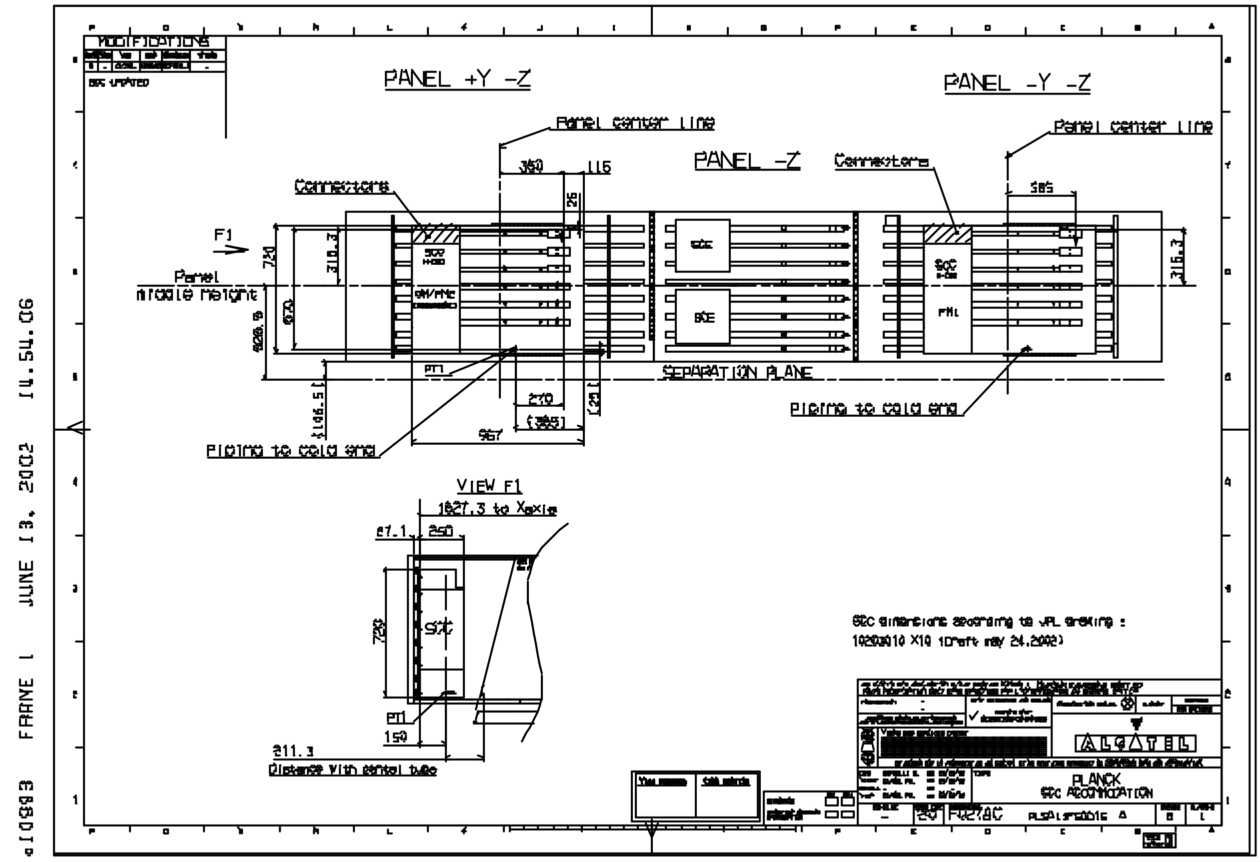


FIGURE 6.2.6-6 SCS ACCOMMODATION IN SVM

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/cm^2, 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 1250 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 additional advantages are mass saving (heat pipe are all the more heavy than they have a larger heat transport capacity), easier manufacturing (heat pipe bending) and integration.

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 implement "start heaters" on relevant location of the longitudinal network. An option to be studied is to rely on the thermal inertia of the whole system to limit the Electronics unit temperature raise when Switched ON. Removing the MLI blanket around the box could improve the situation. It is proposed to evaluate this option, which would simplify greatly the thermal test procedure. Typical SCS dissipation profile has been asked to instruments/JPL for this purpose.

Finally, acceleration levels during orbit maintenance are to be considered and taken into account for the elaboration of the procurement specifications. For information, 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)	263 K w/o margin	[260 K,280 K]
ΔT Spacecraft/outer shell	0.5 K w/o margin	2 K
Temperature stability at Spacecraft interface	[± 2.8 K, ± 2.8 K, ± 2.8 K] (w/o margin)	[± 3K, ± 1K, ± 0.5K]

TABLE 6.2.6-6 SCS THERMAL REQUIREMENTS ASSESSMENT

The above results are obtained with an additional 10 % margin on the EOL thermal dissipation of the Sorption Cooler sub-system. The critical area lies in the temperature fluctuation levels, which are higher than what is required by the instrument. The spacecraft cannot ensure a reduction of the SCS operation induced oscillation level, neither using a heater regulation loop, neither increasing the inertia (mass) of the SCS radiators. A potential reduction of the contact conductance between the SCC and the spacecraft has been even envisaged, without positive conclusions (see Chapter 7.3). At the moment, investigations are undergoing at instrument level in order to assess the real criticality of such fluctuation levels on the cooler performances with regards to Straylight.

6.2.6.5.2 P-PLM warm units equipment

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. The thermal requirements are reported in Section 6.2.6.2.1.

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. At the moment, a maximum heat flux to this shield has been specified to the SVM Thermal Control Sub-System. This heat flux has been in turn used as an input data for the P-PLM thermal budget. The total allowable heat flux is 2.3 W, which represent a radiative surface of about 0.15 m² to be shared between the PAU and the BEU/DAE box. With these conditions, ALENIA computes a temperature of 40° C on the BEU and 38.4° C on the PAU (7° C margin included), for requirements respectively at 28° C and 30° C. This matter is discussed in Chapter 7.3. Finally, the results on the temperature stability level are 0.07 K/hour for the BEU (spec: ± 0.2K/hour) and 0.12 K/hour for the PAU (spec: 1.1 K/hour).

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.

6.3.1 Electrical design overview

Before describing the different functions and their main design features, the major drivers a priori 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 designed 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:

- decentralized, with the Data Handling tasks and the Attitude Control tasks running on 2 distinct computers
- high centralized within each Data Handling and Attitude Control computers, and a Power Conditioning and Distribution Unit
- basically identical for both spacecraft's.

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 selected 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.

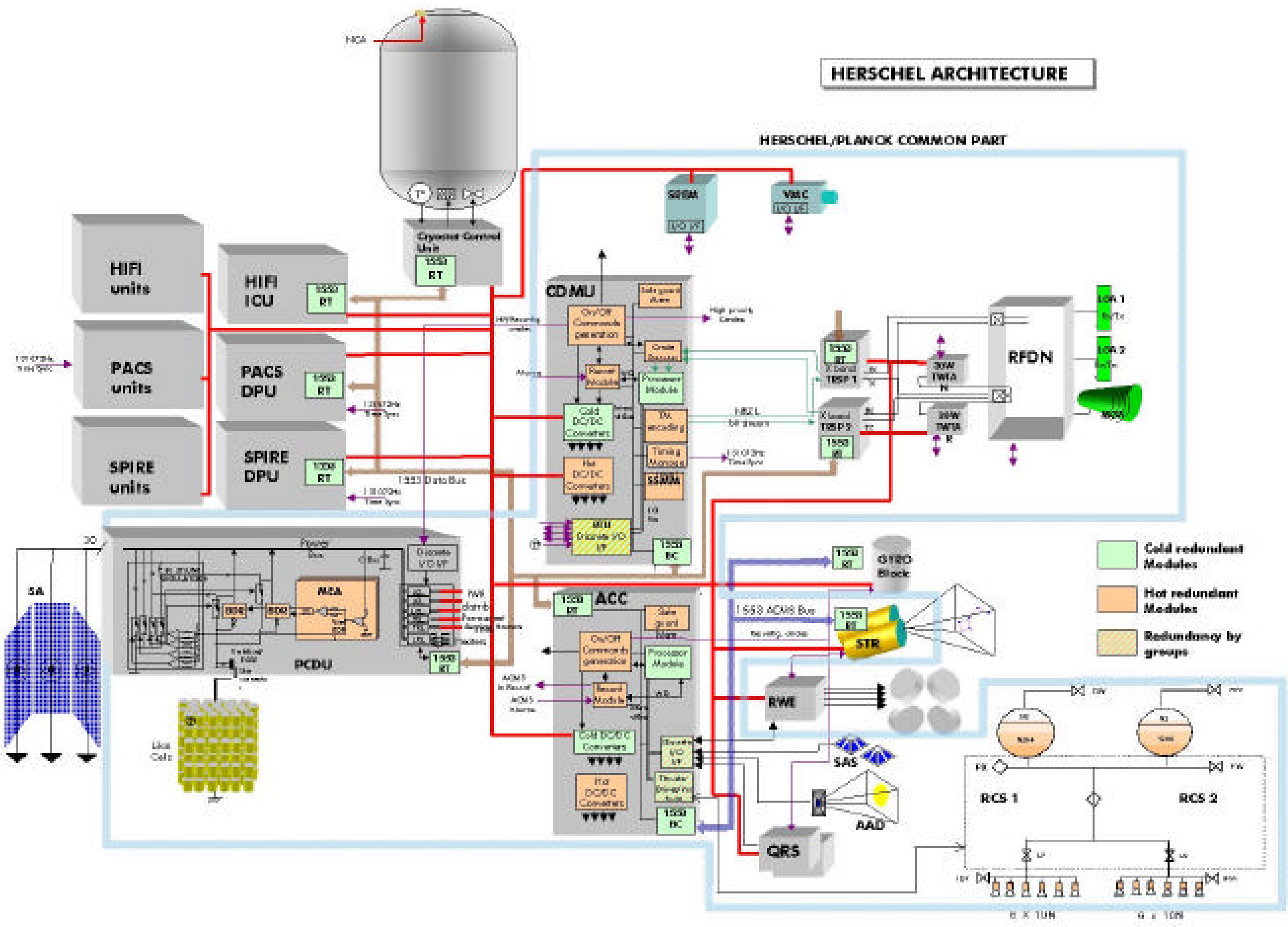


FIGURE 6.3.1-1 HERSCHEL ELECTRICAL ARCHITECTURE

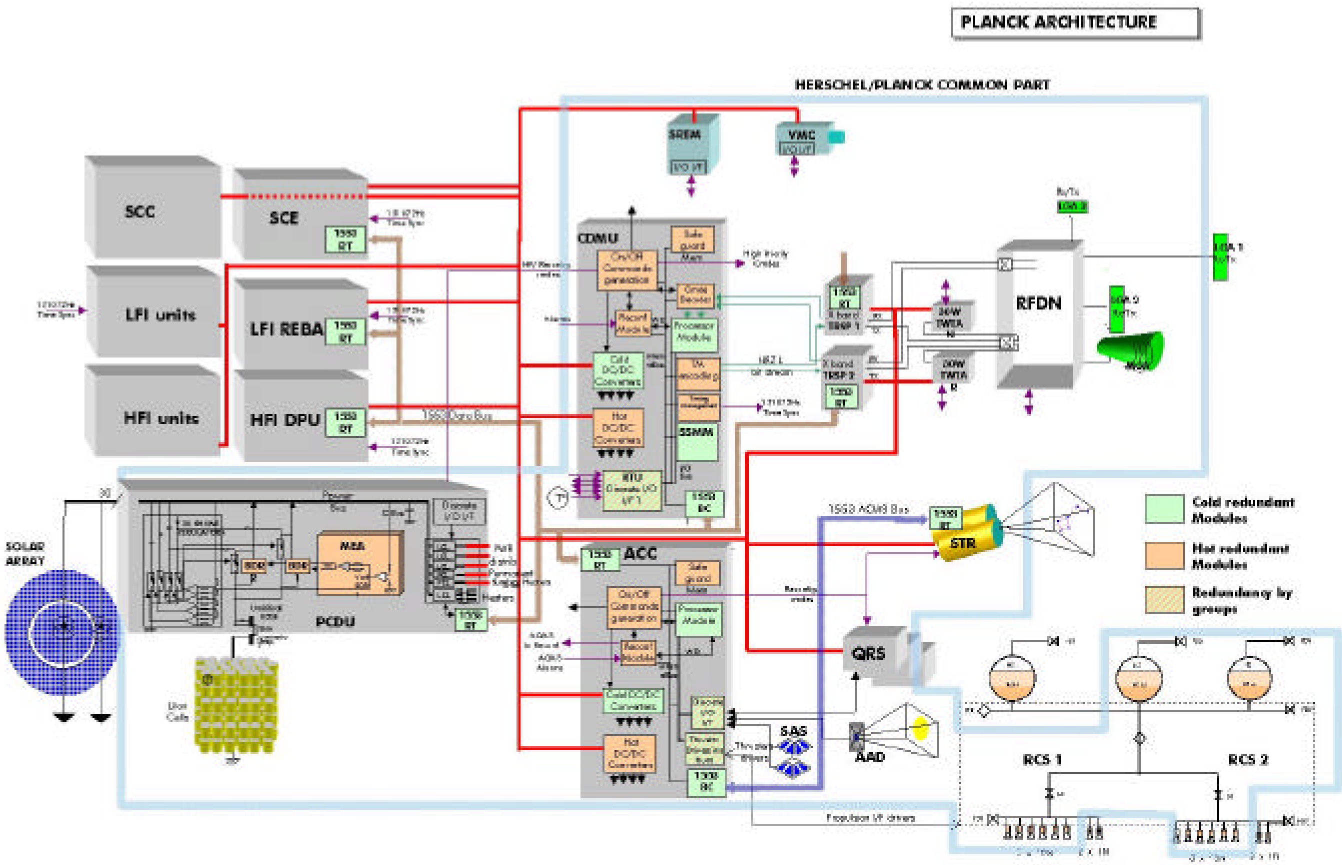


FIGURE 6.3.1-2 PLANCK ELECTRICAL ARCHITECTURE

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: the rear faces of the arrays must be blocked for Herschel and for Planck to minimize 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 characterize both Herschel and Planck missions, a power bus regulated by the S3R technique has been found optimum and baselined.

Another common feature is that both missions are actually eclipse free; however, because of:

- the need to power ON the spacecraft during launch in order to ensure the monitoring of the critical parameters together with a fast and safe post separation recovery
- the need to be robust to a loss of nominal Sun pointing in case of failure, though mission catastrophic.

An additional energy source is implemented consisting in a single, SPF tolerant, LiIon 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 being 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 and Fold Back Current limiters. 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 considered as critical for the mission safety and control, and which shall not be affected by a reconfiguration:

- Telecom receiver
- TC decoder
- Reconfiguration electronics
- On board Time
- critical heating.

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 the CDMU reconfiguration electronics High Level Commands, and by direct ground TC's. This basically implements a DNEL-like function, performed as part of a major recovery action. In order to minimize 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 (eg. Sorption Cooler Compressor).

The heater lines are organized into groups, each group being protected by a LCL while the elementary lines are activated via individual electronic switch devices.

Ground Interface

As far as ground link is concerned, the Herschel and Planck mission are essentially characterised by:

- both use X-Band 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 driven by Planck for which the Earth aspect angle is 15° maximum
- 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.

<u>Downlink:</u>

The data collected by the CDMU are 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. Basically each spacecraft will benefit from 3hours 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 downlink antenna 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, at any spacecraft orientation; these are the nominal downlink antennae at Launcher separation, and major on board failure.

Depending on the ground station in use (New Norcia or Kourou), and on the transmitting antenna, 4 downlink rates can be programmed:

- 500bps with Kourou on LGA's
- 5kbps with New Norcia on LGA's
- 150kbps with Kourou 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 + critical instruments HK
- VC4: real time routine spacecraft HK + routine instruments HK
- VC2: stored spacecraft HK + critical instruments HK + Events TM
- VC1: real time science data
- VC3: stored science data
- VC7: idle frames

where a frame from VCn will be transmitted only if no frame from higher priority Virtual Channels are ready to be transmitted, and the downlink rate permits it.

The instruments data rates and the spacecraft HK rate allocations and current best estimates are:

- spacecraft real time HK = 9 kbps, composed of 4 kbps of essential spacecraft HK and 5 kbps of routine spacecraft HK (eg. data for attitude reconstruction on ground)
- instruments real time HK = 2 kbps/instrument, composed of 300 bps of "quick look" 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 5 kbps downlink rate permits

at Launcher separation to transmit all the VC0 frames plus a few VC2 frames since no critical instrument HK, VC4 and VC1 frames will be present

in case of recovery to transmit all the VC0 frames.

- the 500 bps downlink rate only permits to transmit a subsampling of the VC0 frames
- the 150 kbps downlink rate permits to transmit all the VC0, VC4 and VC1 frames; this rate allows full real time operations of the spacecraft and instruments
- the 1.5 Mbps downlink rate permits to transmit all the VC0, VC4, VC1, VC2 & VC3 frames in a DTCP.

The down link modulation scheme is NRZ-L/BPSK/PM for low rates, consistent with ranging and SP-L/PM and GMSK for medium and high rates.

The down link 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 initialization (typically 5kbps 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 to save power and to avoid to disturb the scientific observations.

The CDMU outputs Reed Solomon and Convolutionaly encoded, pseudo randomized 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 benefit.

Uplink

The signal transmitted from ground is acquired by one of the 2 antennae set:

- nominally the LGA's , oriented towards the +Z direction for Herschel and -X direction for Planck. The other LGA's would be solicited only in case failure leading to an attitude loss. The LGA's ensure an omnidirectional coverage,
- the Medium Gain Antenna as a backup.

Depending on the ground station in use (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 frames are either sent to the Command Priority Distribution Unit for direct commanding of eg. the PCDU limiters, or to the Processor Module in order to be processed by the software.

Since the telecommand chain is basically in hot redundancy, only the receiving antenna is to be selected by software or by the reconfiguration electronics (TBC).

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 organized around a redundant 1553 data bus, to which most of the units are connected. This permits a straightforward on board 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, Transponder)
- or have standard point to point interfaces (TWTA, RFDN, SREM, VMC, thermal control): DS16/ML16, Bilevels, Relay Status, Analog, Temperatures, on/off commands

In these 2 cases, the telemetry packet is built by the CDMU software.

The bus protocol implemented to ensure an efficient and robust transfer of data is based on a cyclic structure synchronized to the On Board Time. The bus time is split into 1s frames comprising 64 subframes. Each of these subframes is itself composed of elementary, well defined, slots where each slot contains the 1553 Bus messages. The content of the subframes, ie the address of the remote terminal(s) to be polled or to command, is defined by a so called Bus Profile. The change of this bus profile shall depend on the spacecraft configuration and on the current instruments operation. It is expected to have a set of fixed Bus Profiles and to switch from one to another based on programmed timings.

Rules have been defined such that:

- One subframe is allocated to one single packet transfer (TM or TC packets). The maximum TM and TC packet size is such that it can be transferred in one subframe only
- An independent 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 Instruments data rates RD03.11). It shall be pointed out that the protocol capabilities, in some specific conditions, corresponds to up to 490kbps, thus well excess of the required performance.

Time Management

An essential parameter in the scientific data processing for both Herschel and Planck missions is the time accuracy, and especially the time synchronization 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 synchronization signals. More precisely, this CTR is

- Used to synchronize 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 100µs between the CTR and a given RT, i.e. a datation accuracy between the Attitude data packets and the science packets of less than 200µs
- Distributed within the Packet Structure ICD service 9 to the packet users
- Used to generated the 131072Hz synchronization 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 time based spacecraft operations can possibly be resumed in any failure conditions, including condition leading to a reset/switch over of the nominal CDMU processor module. The circumstances in which this resume is desirable are discussed in section 6.4.4, FDIR Concept.

The mechanism to synchronize the on board time with the ground Temps Atomique International is provided in compliance with the Packet Telecommand standard, however no need is expressed for such an on board correlation. Contrarily, the instruments, if they look for an accurate on board synchronization of all the events with a Central Reference Time, do not expect any jump in time, consequence of the synchronization with the ground time. Eventually the baseline operation principle is basically to let the on board time "free running", and to achieve on ground the 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.

Active Thermal control

As a result of the drivers announced, the nominal thermal control function is essentially implemented via software, as illustrated in Fig.6.3.1-3, 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. The median value of these 3 measurements is then computed and entered in either a Proportional-Integral regulation loop or a simple min/max algorithm, depending on the interface point to regulate. As a result the corresponding nominal heater line is commanded in the PCDU via 1553 messages.

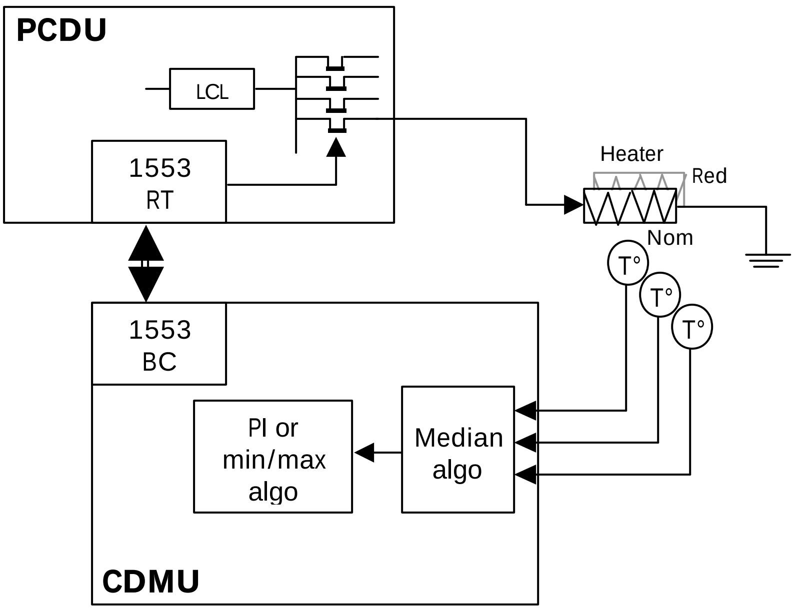


FIGURE 6.3.1-3 NOMINAL ACTIVE THERMAL CONTROL

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 a permanent, FCL protected line 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 failure case. Especially the battery shall be maintained within temperature ranges for which the charge efficiency is kept 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 §6.4.3) and targeting requirements. It is characterized 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 and turned on in the PCDU by the CDMS ; 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.

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 the ACMS unit (especially in a LCL) will simply be seen as a unit failure by the ACMS.

After separation, then, the ACMS <u>automatically</u> enters a Sun pointing mode relying on a limited and reliable set of sensors/actuators. From this status 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 mode, is basically slaved to the CDMS once the sun acquisition is achieved, its commanding is performed via high level " macro-like " commands which are decoded locally and realized autonomously.

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 6.5.4, the survival mode is engaged.

Apart from the design features directly derived from the performance requirements, it shall be pointed out that 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,
- the survival mode is triggered by units which do not participate to the normal mode nor to the survival mode.

The consequences will be presented later in Section 6.3.2.2.

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 optimize 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.

Two FDIR modes are baselined:

- 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 optimize 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 minimize their 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 cold redundant Solid State Mass Memory (SSMM). Its size of 25Gbits EOL allows the storage of all the data generated on board plus the storage of the Mission Timeline for more than 48 hours.

The data in the SSMM is organized in stores which number and size are fixed by command. By design, each store must be allocated to a single virtual channel. Consequently, in order to:

- remain consistent with the virtual channels allocation on the one hand
- be in line with the Herschel and Planck missions characteristics
- ensure a good protection of the stored data.

The baseline approach is:

- to allocate one specific store for the scientific data to each instrument
- to allocate one store for all the instruments routine HK data plus the spacecraft science related HK (eg. attitude reconstruction)
- to allocate one store for the critical (this includes the event TM packets) spacecraft + instruments housekeeping.

It shall be pointed out that the above stores allocation imposes a resizing of the stores, under ground control, each time the instrument configuration (i.e. the prime instrument) changes; this is mainly applicable to Herschel. The 25Gbits Mass Memory is indeed not sufficient to authorize at the same time the three Herschel instruments science stores size to be set to a maximum value consistent with their operation as Prime instrument. The proposed operation principle is to have the mass memory content properly re allocated and uploaded simultaneously with the new MTL planning on which the re-allocation is based, to be valid over the same duration than the new MTL.

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.

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 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.

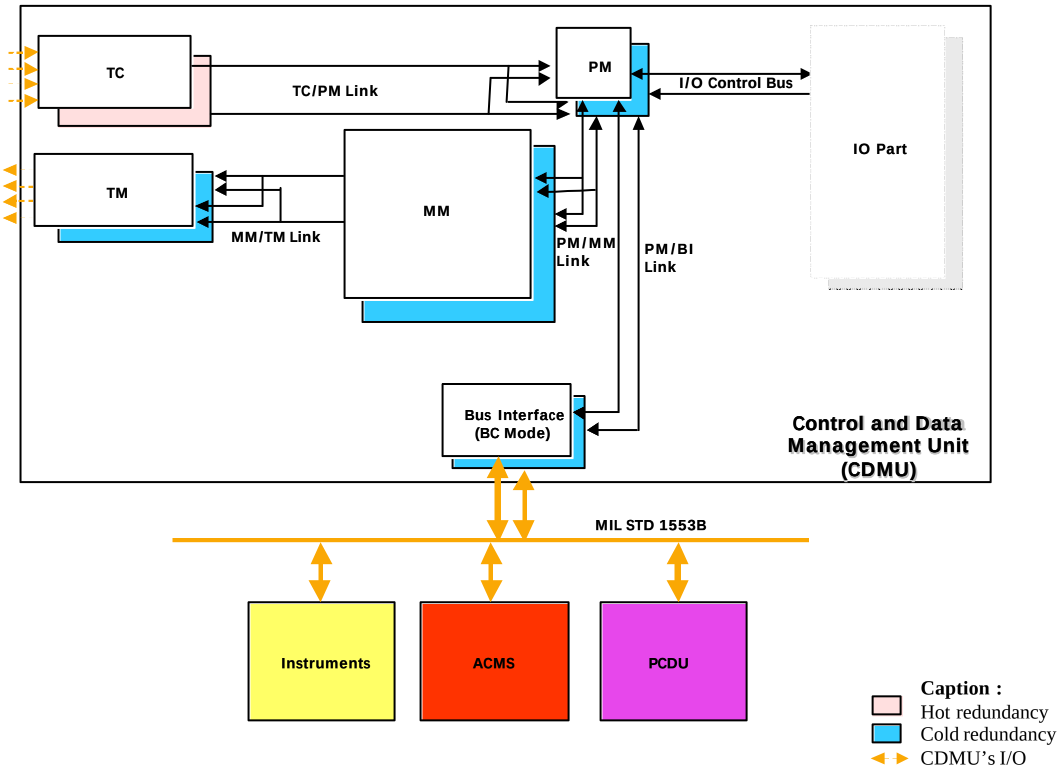


FIGURE 6.3.2.1-1 CDMS DATA FLOW

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.

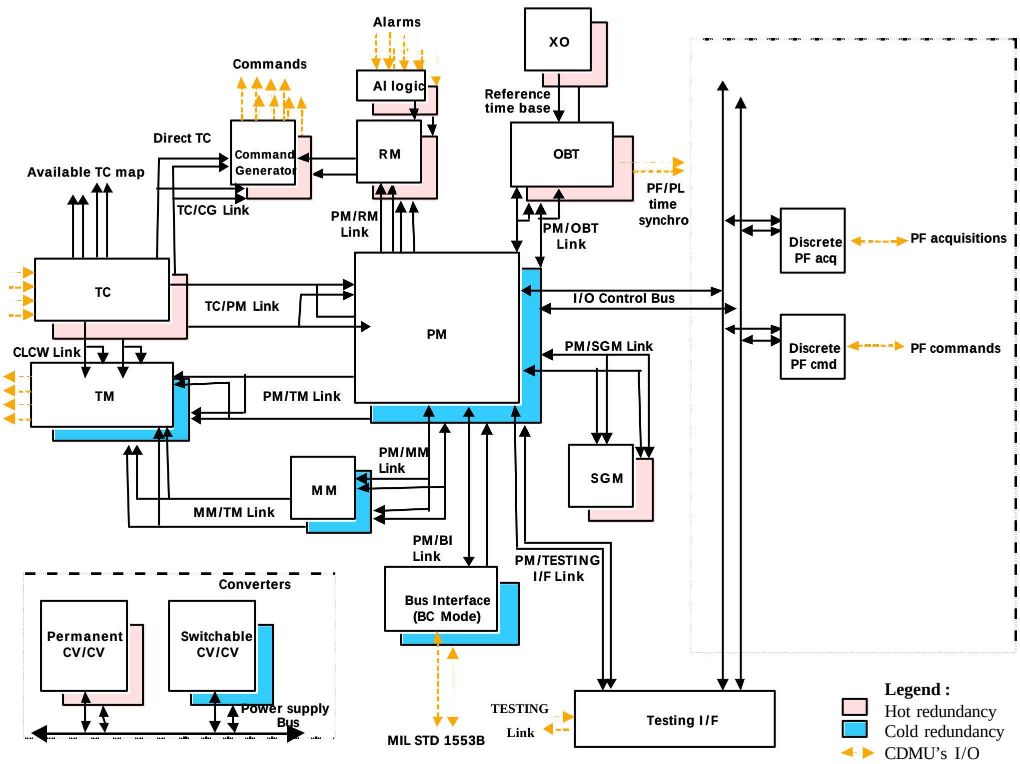
Communication between the CDMU and the others sub-system/modules is done through the communication interfaces. To handle all communication (read/write/execution) within the computer, the communication interfaces has to provide a certain processing capability: the computer must be able to perform real 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
- Mission Time Line service management
- On Board Control Procedures execution
- the 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 6.3.2.1-2 that allows 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.



[1]

FIGURE 6.3.2.1-2 CDMU FUNCTIONAL BREAKDOWN

6.3.2.1.2.1 TC Function

This function provide 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.

The commands processed by the PM are essentially delayed 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.

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 256 bytes. This leads the CDMU, actually the Basic Software (see §6.3.3) to be able to manage per second some 42 TC packets with minimum length and 2 TC packets with maximum length when the maximum bit rate is used (i.e. 4 kbits/s). The related processing load constraints are detailed in the CDMU Basic sofware documentation.

[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).

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),
- 5 kbits/s (with New Norcia) on LGAs
- 150 kbits/s (TBC) on MGA with Kourou or New Norcia.
- 1.5 Mbit/s on MGA with New Norcia.

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 § 6.3.6).

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) 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 1 Mbyte program memory 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 synchronized 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 3 bytes to define the sub-seconds resulting in a resolution of about 60 ns ($1/2^{24}$ 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 module basically consisting in a state machine capable to issue sequences of pre-programmed 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 § 6.5.4).

The Reconfiguration Module also acquires the Launcher separation straps status and initiates the post separation activities.

The RM is able to handle respond to an alarm occurrence by generating the associated reconfiguration sequence, without any OBSW support. A reconfiguration sequence is a series of command requests, 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.

6.3.2.1.2.6 Command Generator Function

Both CDMU and ACC comprise a command generator issuing ON/OFF commands (or reset) individually to equipments.

A command request to the command generator can be originated from either the reconfiguration module or the OBSW (via the PM) or the ground (via the TC decoder).

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 8Gbits each such that the design is tolerant to the loss of a complete bank. Moreover, for safety reasons the mass memory will be redunded.

More precisely, the present mass memory capacity will be sufficient to store during 48 hours the following type of data:

- Spacecraft HK: 1.52 Gbits (9 kbits/s)
- Instrument Data (science + HK): 23.07 Gbits (140 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: TBD but negligible regarding other data flows
- visual monitoring camera: 180 Mbits; the VMC operation being out of the science payload operation phase.

which amounts to slightly less than 25 Gbits.

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 foreseen 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 finally to have a dedicated packet store for science data from each instrument, a packet store for the essential spacecraft housekeeping and critical instrument data, and another one for all the instrument housekeeping plus the non essential spacecraft HK. This is nicely in line with the allocation of virtual channels presented and justified in section 6.3.1 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.

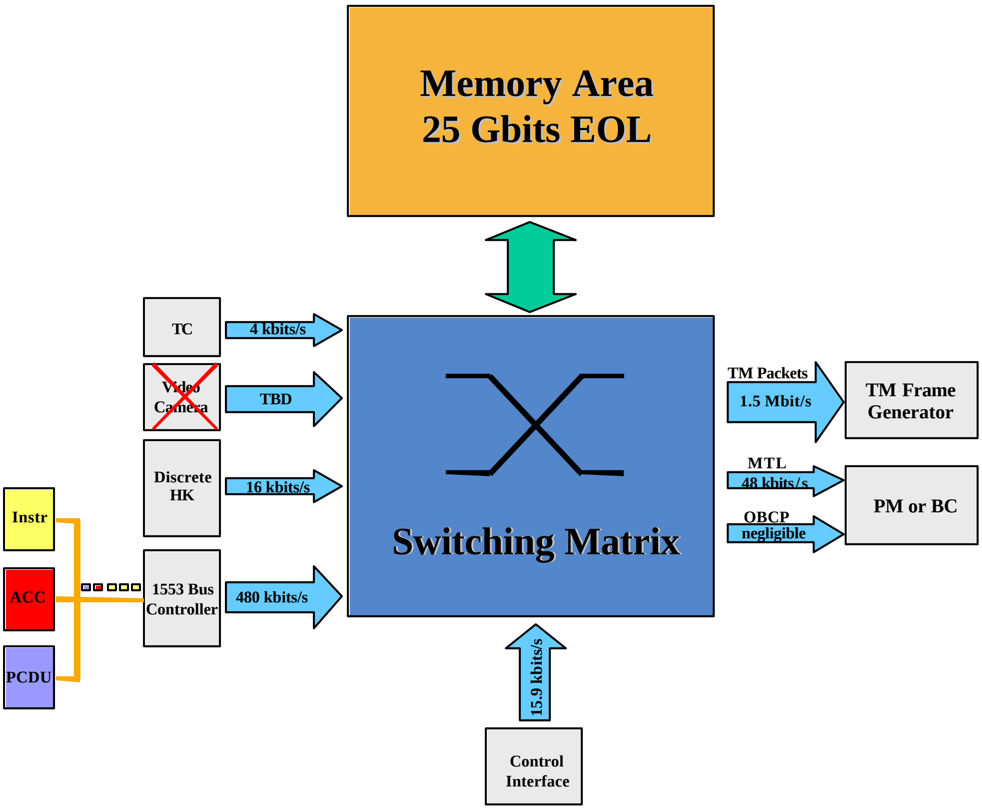


FIGURE 6.3.2.1-3 DATA FLOWS WITHIN THE MASS MEMORY

6.3.2.1.2.8 CDMU Interfaces

The present section addresses the CDMU communcation 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 spacecraft mode 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 others PSICD services
- memory patches.

6.3.2.1.2.8.3 Subsystem and Instruments 1553 Interface

This 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 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 periodicity 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.

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 shall 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 of the CDMS reconfiguration module and is used to acquire external, system level and internal, CDMU level, alarms.

Through this interface the CDMU monitors especially the Power status of the satellite by the mean of a Bus Under Voltage alarm signal and a Depth Of Discharge alarm signal (see §6.5.4).

The alarms are acquired as statuses and are, as part of the reconfiguration function, compared with alarm patterns which trigger the suitable reconfiguration sequence. This sequence issues CPDU TC packets towards the command generator. A series of ON/OFF or reset commands are then sent to configure the spacecraft in a safe status.

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. These signals are synchronized 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 authorize an accurate datation of the science measurement.

6.3.2.1.2.8.8 Video Camera Interface

To support Public Relation activities, each spacecraft integrates a video camera, the VMC, directly connected to the CDMU which is in charge of the acquisition and storage of the image sequences.

For the video camera interface bandwidth a data rate 1 Mbits/s (TBC) during few minutes has been defined. It shall be pointed out that the camera operation is specified not to interfere with science ones.

6.3.2.2 ACMS

This section provides an overview of system ACMS electrical design. Details can be found at SVM level.

The Herschel and Planck ACMS subsystem designs are rather different due to the nature of stabilisation. Herschel is a 3-axis stabilized satellite and Planck a spinning satellite. Still, the two ACMS are designed from a common core which is the ACC hardware identical between 2 satellites. Moreover, communality is optimised by use of maximum common Star tracker in nominal mode and common safe mode equipments.

FDIR and performance are the driving requirement of the ACMS design.

Please note that at the time of the system PDR data package release, the ACMS unit supplier are not chosen. Only main equipment requirement are now defined.

6.3.2.2.1 FDIR

The system FDIR requirements are the major driver for the ACMS architecture design.

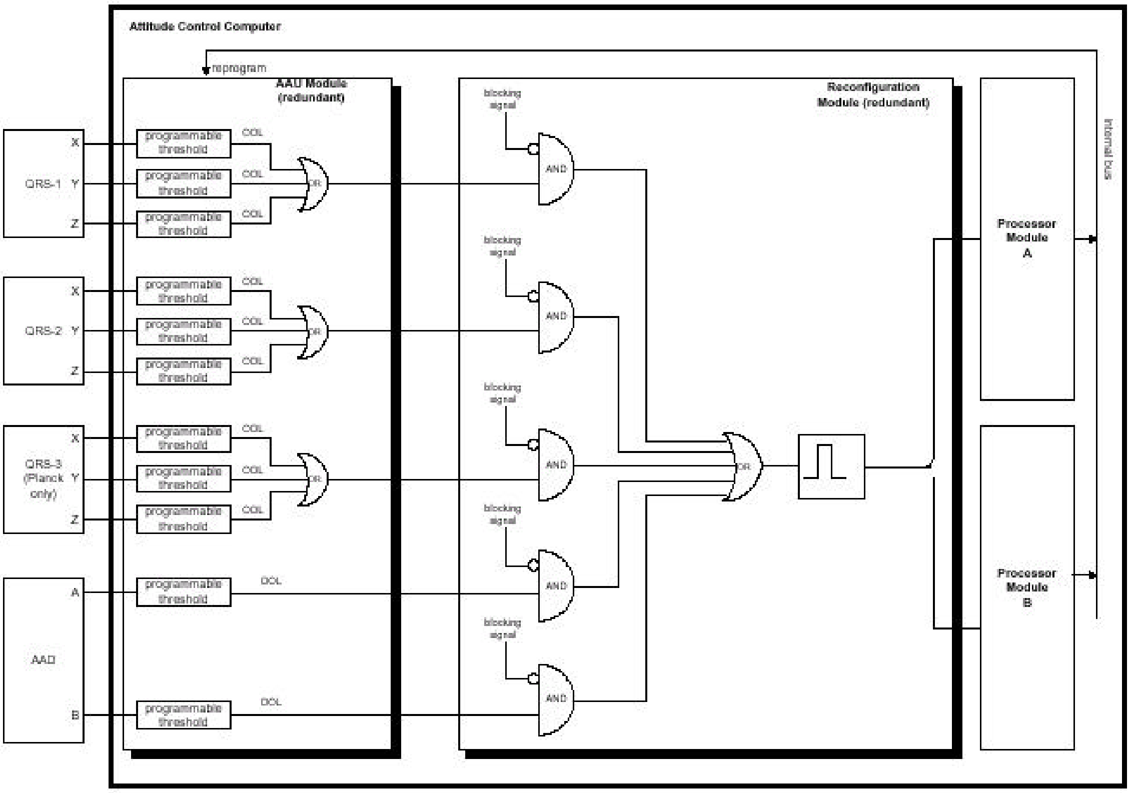
The main system requirements and impacts at design level:

- Safe attitude domain must be guarantied: a full hardware mechanism for attitude and attitude rate detection conditions which lead to allowed domain exceeding, is provided.
- No wheel use in safe mode: the recovery is based on 20 N thrusters.
- Absence of single failure: redundancy of the nominal sensors and actuators is provided. And the units are cross strapped with ACC.
- AFS/AFO modes and 5 failure levels management: all mechanism allowing autonomous failure 0/1/2 detection and recovery are existing. AFS/AFO modes are managed by SW.
- Sensor Independence between level 4 detection, Nominal and Safe: the detection shall also be redunded. The attitude domain is monitored thanks to a redunded Attitude Anomaly detector (AAD) directly connected to RM. Nominal acquisition of its signal by ACC AIU is provided. The rate detection is performed via rough rate measurement units (RMU or QRS). As RMU is also required for Safe mode, a trade (described at SVM level) has been performed to minimize the number of units and best fulfillment of requirement. The following number of units has been selected: 2 RMU for herschel and 3 for Planck. 2 RMUs are cross strapped to both RMs and the 3 RMU for Planck (2 for Herschel) are cross strapped to both ACC AIUs for ground monitoring and use for Safe.

6.3.2.2.1.1 ARAD (Attitude and Rate Anomaly Detector)

The system level 4 ACMS alarms are composed of Attitude and attitude Rate Anomaly Detections (ARAD). The detection is only at hardware level. The sensor used for that detection are Attitude Anomaly Detectors (AAD) and Rate Measurement Units (RMU or QRS). Hardware mechanism which leads to reconfiguration is preferred to be located in ACC. It means that it has to be common between Herschel and Planck. For both Herschel and Planck, the QRS1 and QRS2 3-axis outputs are connected to ACC.

The associated common H & P reconfiguration logic is:



(**NOTE:** AAU could be also located in PDU)

6.3.2.2.1.2 Safe and recovery

The recovery action in case of failure detection depends on AFS or AFO mode. In case of AFS, often a transition to survival mode is made. In AFO, the transition to survival mode is at maximum avoided.

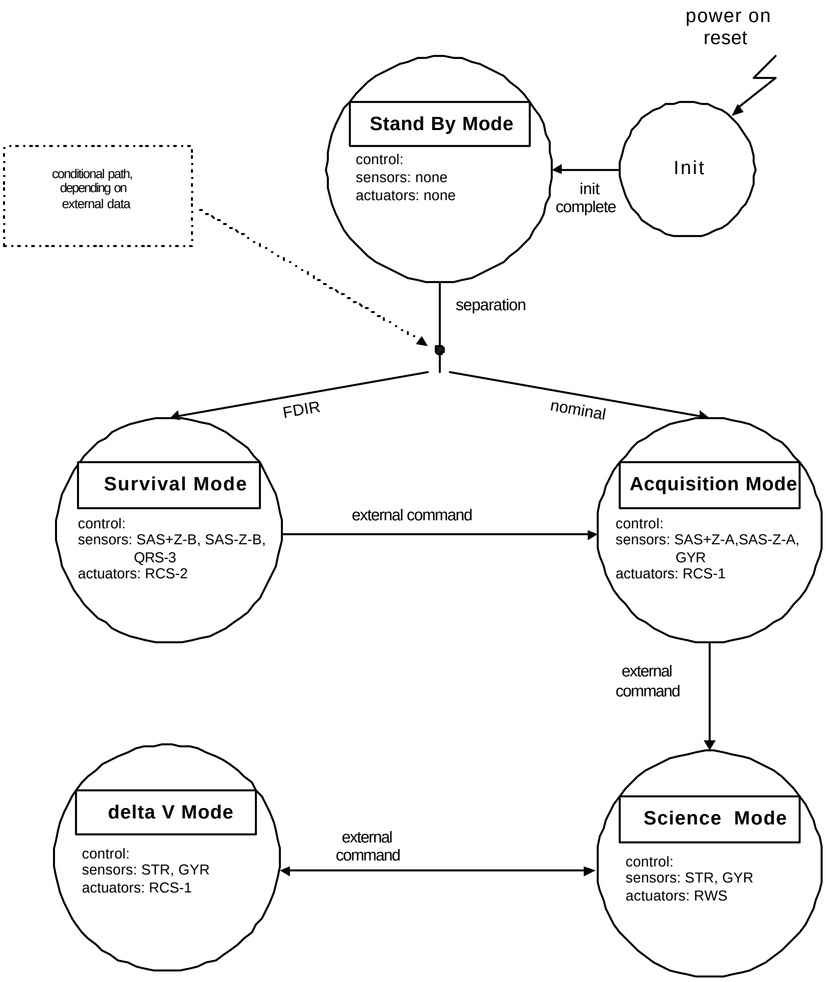
The following table provide the general recovery philosophy:

Check	Action in AFO mode	Action in AFS mode
Power on check	Reconfigure on redundant unit	Reconfigure on redundant unit
Communication check	Reconfigure databus	Reconfigure databus
Housekeeping data	Reconfigure on redundant unit	Reconfigure on redundant unit
Continuity check	Reconfigure on redundant unit	Survival Mode
Others check (GYR sum check…)s	Survival Mode (TBC)	Survival Mode
Command check	Ignore command	Ignore command
ARAD (level 4 alarms)	Survival Mode	Survival Mode

6.3.2.2.2 Herschel ACMS modes

5 Herschel modes are considered:

- STAND BY MODE: is entered in case of PM power ON or reset.
- ACQUISITION MODE: is in charge of sun acquisition and maintenance along satellite Z axis from launcher ejection conditions. Attitude is estimated with GYR and +Z and -Z SAS. Control is based on thrusters RCS A.
- SURVIVAL MODE: plays the same role as sun acquisition mode but is entered in case of system level 4 alarms. It is based on redundant path of sensors except for GYR replaced by QRS2.
- SCIENCE MODE: is entered by command from CDMU from the acquisition mode. It is based on fine RWL control and GYR/STR attitude estimation.
- DELTA V MODE: is also entered from Science Mode; it is performing orbit correction. The performance are reached thanks to thruster on-board book-keeping.



Following table is providing summary of the sensor and actuator configuration per mode. It also provides, per mode, the sensors used for checking the mode health.

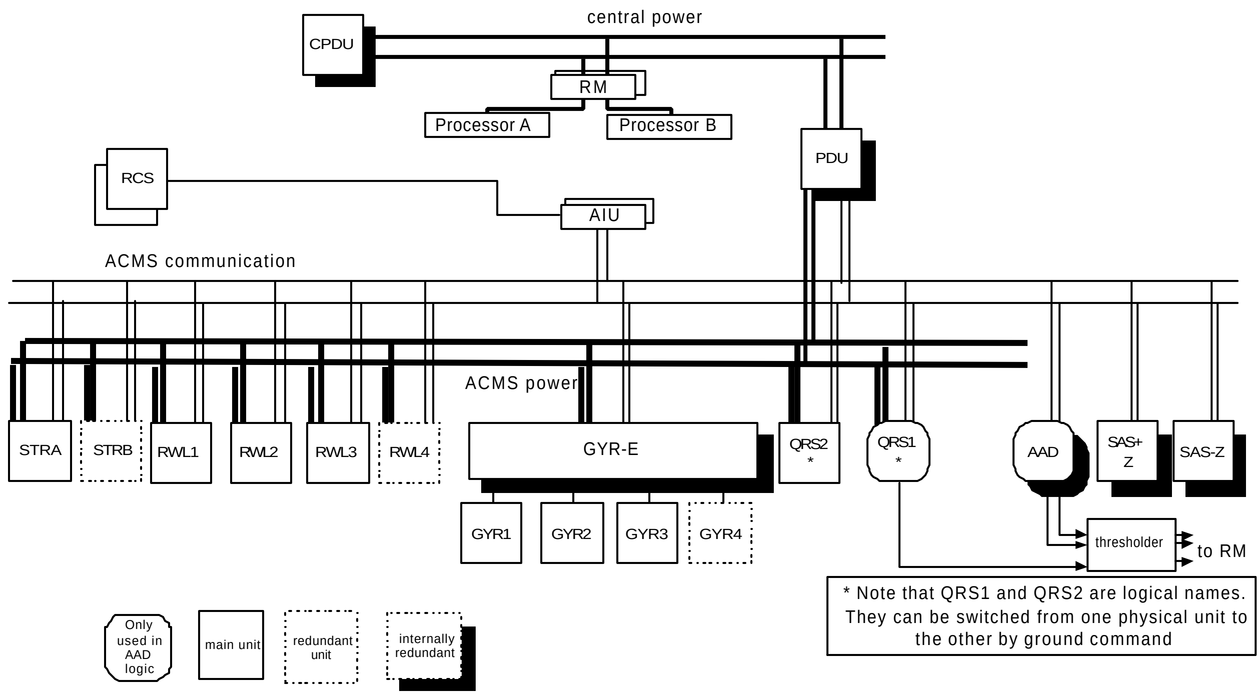
Mode	ACMS units for nominal control		sensors for checking	redundant sensor/ actuator	sensors for ARAD
Stand By	PDU/Main	1553bus/Main		Not appl.	none (blocked)
Survival	SAS+Z/B SAS-Z/B QRS/Red	RCS/2 PDU/Red 1553bus/Red	GYR (TBC)	Not appl.	none (blocked)
Acquisition	SAS+Z/A SAS-Z/A GYR/ABC	RCS/1 PDU/Main 1553bus/1	GYR LV-status CBH temp	SAS+Z/B SAS-Z/B GYR/D RCS/2 PDU/B 1553BUS /2	QRS/Main AAD/A AAD/B
Science	STR/1 GYR/ABC	RWL/123 PDU/Main 1553bus/1	GYR Tacho	STR/2 GYR/D RWL/4 PDU/Red 1553bus/2	QRS/Main AAD/A AAD/B
Delta-V	STR/1 GYR/ABC (SAS+Z/A)	RCS/1 PDU/Main 1553bus/1	GYR LV status CBH temp	STR/2 GYR/D RCS/2 PDU/Red 1553bus/2	QRS/Main AAD/A AAD/B

6.3.2.2.3 HERSCHEL configuration

6.3.2.2.3.1 General architecture

The Herschel ACMS subsystem electrical architecture is the following:

Herschel Configuration



The associated equipment is:

COMPONENT	NUMBER	REDUNDANCY	ELECTRICAL I/F	COMMENT
AAD	2	2/2	• Analog • Cross strapped to ARAD • Cross strapped to AIU	Internally redundant Same component as planck
QRS	2	2/2	• Analog • 2 are cross strapped to ARAD • 2 are cross strapped to AIU	3 axis information for each component Same component as Planck
SAS	4	1/2	• Analog • Cross strapped to AIU	Same component as planck
STR	2	1/2	• MIL 1553B • Cross strapped to AIU	Same component as Planck if (internally redundant)
GYR	4	3/4	• Internal to GYR Assembly	
GYR-E	2	1/2	• MIL 1553B • Cross strapped to AIU	GYR electronic
RWS	4	3/4	• Analog (MIL 1553 B as an option) • Cross strapped to AIU	
PDU	2	1/2	• MIL 1553B • Cross strapped to CPDU	Same component as Planck

HERSCHEL EQUIPMENT LIST AND I/F

Note that a Power Distribution Unit (PDU) is currently baselined. It is in charge of power switching and on/off status monitoring of ACMS units that do not have internal on/off switch and status. It may also contain the ARAD. This unit will be maintained depending of the ACMS unit selection and the trade between ARAD in ACC (preferred) and ARAD in PDU.

6.3.2.2.3.2 HERSCHEL ACMS Sensors

SCIENCE MODE SENSORS

Star TRacker (STR)

Herschel STR is the nominal inertial attitude sensor of the science mode. It is a wide field of view optical star sensor unit performing 3-axis autonomous attitude determination. The STR is the cornerstone of the ACMS since it is used in all science observation modes (target pointing, raster, line scanning, tracking of solar objects) and Delta-V mode.

Main features required half cone Line Of Sight (LOS) accuracy are:

Bias: 0.8 arcsec at 68 % confidence level.

NEA: 1 arcsec at 68 % confidence level.

Bias variation 0.6 arcsec over FOV.

0.2 arcsec over temperature effect.

A fine control of the thermal gradient of the STR baseplate and of the gradient between the mounting feet is foreseen to fulfill this requirement.

2 cold redundant units with parallel lines of sight are accommodated on SVM (TBC) so as to minimize aging, launch and thermal distortion. These lines of sight are nominally aligned with the opposite of the Herschel telescope line of sight. The maximum tolerable misalignment (including ground and orbital effects) between telescope and STRs lines of sight is 0.3° in order to achieve system calibration residual performances.

Each STR is connected to the ACC AIUs via MIL 1553B bus. Attitude frequency delivery is 2 Hz.

GYRoscope (GYR)

Gyroscopes are, with the STR, the primary sensors of the ACMS. The required accuracy of attitude estimation is in the order of the RPE (0.3 arcsec) that's why GYR are necessary to filter STR noise.

So, GYR output is mixed with STR output in an extended Kalman Filter which estimates the inertial attitude of the ACMS frame.

An high performance GYR (Litton) with an on-the-shelf STR has been preferred rather than an European GYR with a high performance STR which will requires modifications or new development.

GYR Assembly is composed of 4 solid state Hemispherical Resonator Gyros and a common redunded electronic. This provides a 3 out of 4 redundancy. Fourth gyro is on but not used for control.

The required performances are:

Gyro rate noise (at 4 Hz)	0.012 arcsec/s
Angle random walk	0.0001 °/√hr
Gyro bias stability	0.0016 °/hr

GYR is also used in Sun acquisition mode after launcher ejection for attitude rate knowledge. In that mode, redundancy is used for checking.

Each electronic is connected to the ACC AIUs via MIL 1553B bus. Attitude rate frequency delivery is 4 Hz.

ACQUISITION AND SAFE MODE SENSORS

Attitude Anomaly Detector (AAD)

AAD is the system attitude level 4 alarm sensor. The unit is internally redundant and 2 outputs are connected to both RMs and to both ACC AIUs for ground expertise. Thresholds are applied on outputs to decide reconfiguration.

Rate Measurement Unit (RMU) or Quartz Rate Sensor (QRS)

2 RMUs are baselined on Herschel. They give 3 axis attitude rate. They are located on SVM panel +Y+Z.

Output is used for:

- 1 RMU is used for system attitude rate level 4 alarms (ARAD input)
- 1 RMU is used for rough but sufficient attitude rate sensor for Survival mode.

Required accuracy is 0.01°/s.

Interface with ACC is analog 0-5V. Both RMUs are connected to both RMs and both ACC AIUs.

Sun Acquistion Sensor (SAS)

The SAS are used to perform the acquisition of the sun and maintain the sun pointing of the spacecraft in sun acquisition mode and safe mode.

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.

Required accuracy is:

- Filed of view: 2π
- Accuracy of the 2 angles: 0.5° (in central 30 x 30° region).

Each SAS is connected to both ACC AIUs via an analog interface.

6.3.2.2.3.3 Herschel ACMS Actuators

Reaction Wheel System (RWS)

4 reaction wheels are accommodated in a skewed configuration allowing commanded torques in all directions. They are located on +Z/+Y SVM panel. The tilt angle is 70° (TBC). 3 wheels are nominally used. Fourth provides redundancy.

The wheel dimensioning will be confirmed during ACMS phase B. Among other things, the dimensioning is taking into account the necessity of perform 2 slews of 90° in 15 min per days and the accumulation of solar perturbing torque over 22 hours. The required performance are currently:

- Torque of 0.2 Nm (TBC)
- Angular momentum of 30 Nms (TBC).

The wheel unloading is provided as a function of the science mode. The wheels are off loaded by the thrusters.

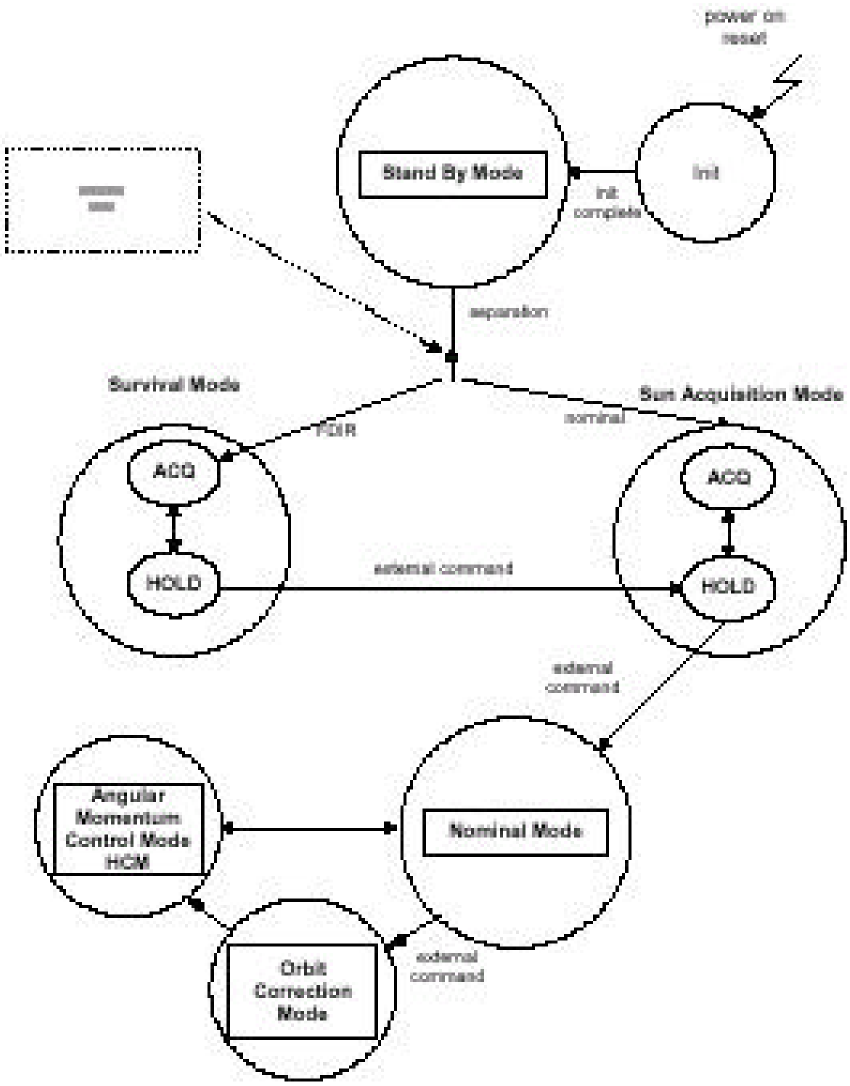
Baseline Interface with both ACC AIUs is analog. Option for a MIL1553B is existing. Decision will be taken during supplier selection.

6.3.2.2.4 Planck ACMS modes

5 Planck modes are considered:

- STAND BY MODE: is entered in case of PM power ON or reset.
- SUN ACQUISITION MODE: is the nominal active mode entered after launcher separation. It consists in the sun acquisition along satellite X axis from the initial orientation and in maintaining this orientation. It is based on QRS1 and SAS1&2A sensors and RCSA actuators. RWL are not used in that mode. 2 sub modes are used: one active (ACQ) and one passive (HOLD) when no attitude correction are needed.
- SURVIVAL MODE: is the safe mode entered in case of system ACMS level 4 alarms. Based on the redundant path of hardware (SAS1&2B, QRS3 and RCSB) and same algorithms as sun acquisition mode, it is also composed of 2 submodes: ACQ for active acquisition and maintain the sun and HOLD is passive.
- NOMINAL MODE: it is the science mode. It is entered from Sun Acquisition Mode via an external command from the CDMU. It is passive.
- ANGULAR MOMENTUM CONTROL MODE (HCM): entered from Nominal Mode, it performs according to scanning law profile provided by CDMU, the autonomous reorientation of the satellite angular momentum using 1N thruster and attitude knowledge provided by STR.
- ORBIT CORRECTION MODE: is also entered from Nominal Mode; it is performing orbit correction. Attitude is controlled with STR1 sensing and RCSA actuating. The performance are reached thanks to thruster on-board book-keeping.

The Planck mode diagram is:



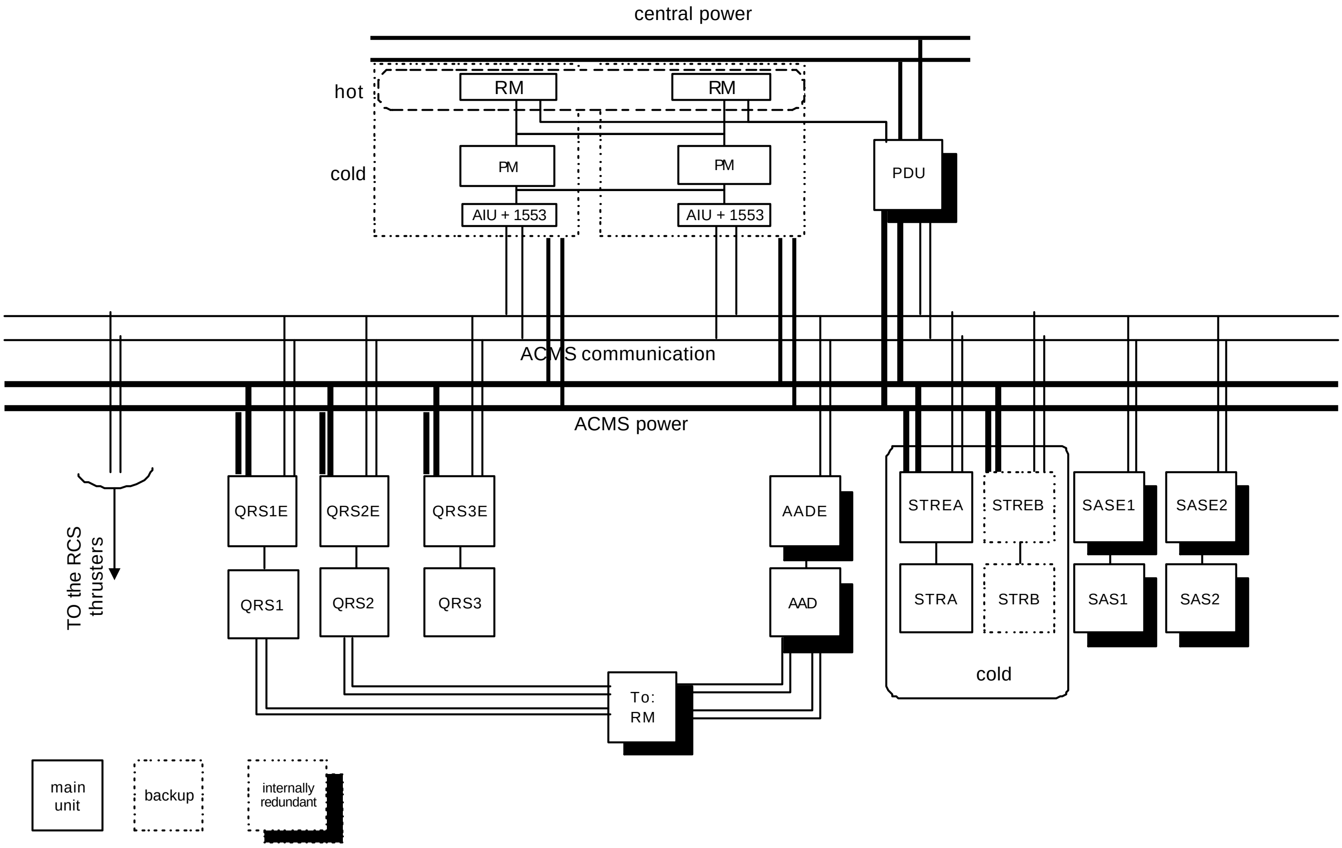
Following table is providing summary of the sensor and actuator configuration per mode. It also provide, per mode, the sensors used for checking the mode health.

Mode	ACMS units for nominal control		sensors for checking	redundant sensor/ actuator	sensors for Attitude Anomaly
SBM	PDU/A	1553bus/1			
SAM/ACQ	QRS/1 PDU/A SAS1/A SAS2/A	1553bus/1 10N RCS/1	QRS/1	SAS1/B, SAS2/B 10N RCS/2 PDU/B 1553bus/2	AAD/A AAD/B QRS/2
SAM/HOLD	QRS/1 PDU/A SAS1/A SAS2/A	1553bus/1	QRS/1	SAS1/B, SAS2/B PDU/B 1553bus/2	AAD/A AAD/B QRS/2
SM/ACQ	QRS/3 PDU/B SAS1/B SAS2/B	1553bus/2 10N RCS/2		N. Applicable	None: blocked
SM/HOLD	QRS/3 PDU/B SAS1/B SAS2/B	1553bus/2		N. Applicable	None: blocked
NOM	STR/1 PDU/A 1553bus/1		LV status CBH temp STR/1	STR/2 PDU/B 1553bus/2	AAD/A AAD/B QRS/1 QRS/2
HCM	STR/1 1N RCS/1 PDU/A 1553bus/1		LV status CBH temp STR/1	STR/2 1N RCS/2 PDU/B 1553bus/2	AAD/A AAD/B QRS/1 QRS/2
OCM	STR/1 10N RCS/1 PDU/A 1553bus/1		LV status CBH temp STR/1	STR/2 10 NRCS/2 PDU/B 1553bus/2	AAD/A AAD/B QRS/1 QRS/2

6.3.2.2.5 *Planck configuration*

6.3.2.2.5.1 *General architecture*

The Herschel ACMS subsystem electrical architecture is the following:



The associated equipment is:

COMPONENT	NUMBER	REDUNDANCY	ELECTRICAL I/F	COMMENT
AAD	2	2/2	• Analog • Cross strapped to ARAD • Cross strapped to AIU	Internally redundant Same component as Herschel
QRS	3	2/2+1	• Analog • 2 are cross strapped to ARAD • 3 are cross strapped to AIU	Same component as Herschel
SAS	4	1/2	• Analog • Cross strapped to AIU	Same component as Herschel (internally redundant)
STR	2	1/2	• MIL 1553B • Cross strapped to AIU	Same component as Herschel if possible
PDU	2	1/2	• MIL 1553B • Cross strapped to CPDU	Same component as Herschel

PLANCK EQUIPMENT LIST ANS I/F

A PDU is also baselined as for Herschel. The same trades apply.

6.3.2.2.5.2 Planck ACMS Sensors

Communality with Herschel sensors have been optimized.

SCIENCE MODE SENSORS

Star TRacker (STR)

Planck STR is the unique attitude sensor of the science mode. It is redunded (cold) and its line of sight is nominally aligned with payload LOS. The STR performances are driven by system AME requirement and on board autonomous replanning philospohy. On board replanning means that for each angular momentum correction requested by MTL, the actuation is dependant of the difference between spacecraft attitude estimated by STR and the new target. This allows drift effect avoidance.

The requested STR accuracy for that strategy is in the same order as the one requested for AME.

Main features required half cone Line of sight (LOS) accuracy are:

Bias: 9.6 arcsec (TBC) at 68% confidence level

NEA: 8.4 arcsec (TBC) at 68% confidence level

Bias variation 4.8 arcsec (TBC) at 68% confidence level

A fine control of the thermal gradient of the STR baseplate

2 cold redundant units with parallel lines of sight are accommodated on SVM so as to minimize aging, launch and thermal distortion. These lines of sight are nominally aligned with the Planck telescope line of sight. The maximum tolerable misalignment (including ground and orbital effects) between telescope and STRs lines of sight is 1.5° in order to achieve system calibration residual performances.

Each STR is connected to the ACC AIUs via MIL 1553B bus. Attitude frequency delivery is 2 Hz.

ACQUISITION AND SAFE MODE SENSORS

They are identical as Herschel ones. Only the number (see above list) and the accommodation is changing.

Attitude Anomaly Detector (AAD)

AAD is Along -X.

Rate Measurement Unit (RMU) or Quartz Rate Sensor (QRS)

2 units are located on -Y/+Z SVM panel.

Sun Acquistion Sensor (SAS)

Two units internally redundant are accommodated: 1 on -X cone and 1 on ±Y (TBC) face of the spacecraft. Boresights are along respectively along -X and ±Y axis.

6.3.2.2.5.3 Planck ACMS Actuators

No ACMS actuators are baselined: RCS is used for actuation.

6.3.2.2.6 ACC (Attitude Control Computer)

6.3.2.2.7 ACC General Overview

It is in charge of processing tasks related to ACMS. As the CDMU, the ACC has in charge of implementing some monitoring functions for on board software processes and FDIR purpose (e.g. equipment monitoring, …).

The breakdown that follows will present more in detail the ACC performances, for both Herschel and Planck, required to fulfil the mission.

6.3.2.2.7.1 ACC Breakdown

Except a TC function, a TM function and a mass memory the ACC is based on the same architecture than the CDMU (see § 6.3.2.1). Main differences concern the interfaces and the alarm signal that are monitored. The ACC receives commands and other configuration information from the CDMU by using the 1553 bus.

The ACC then provides a set of functionalities described hereafter that will allow to reach the necessary performance.

In a first part, each main ACC internal function is described. Subsequently, a each ACCs communication interface is briefly approached.

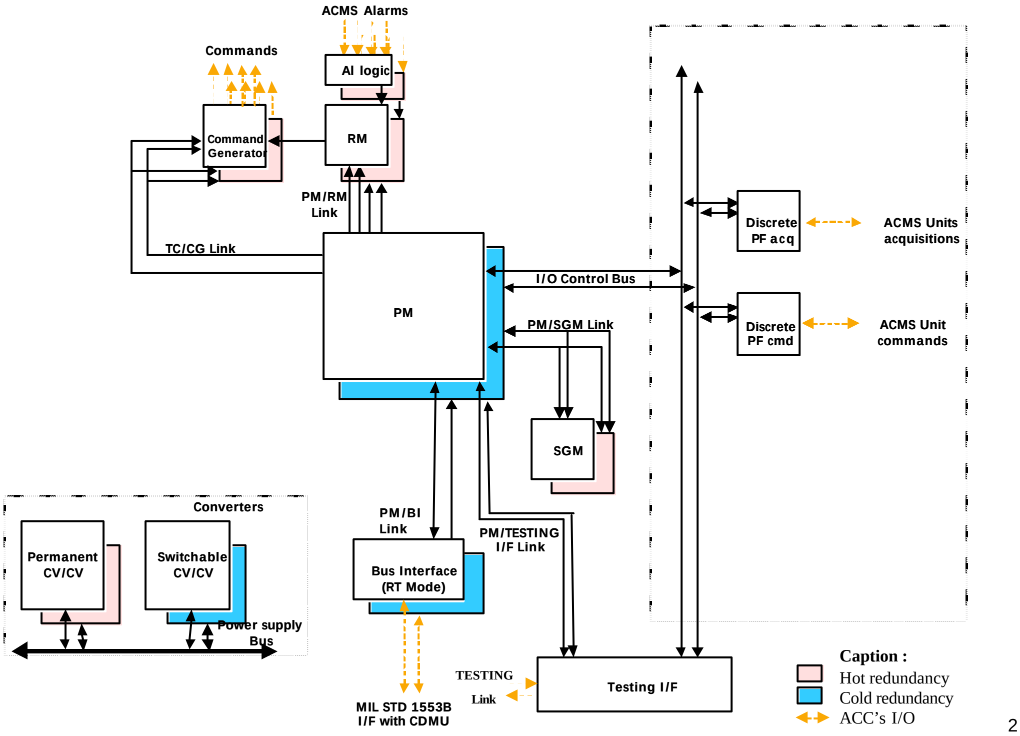


FIGURE 6.3.2.2 ACC FUNCTIONAL BREAKDOWN

[2] 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).

6.3.2.2.7.2 Processing Function

The Processing function, dedicated especially to run the On Board Software, is composed, as in the CDMU, mainly of a microprocessor, RAM protected by an EDAC and a companion chip to manage more efficiently the processor module interfaces (TM, 1553 interface, …).

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 handle the loading of the On Board Software from the program memory 1Mbytes EEPROM to the RAM.

6.3.2.2.7.3 OBT Function

The ACC provide a local time reference synchronized with the CDMU master On board Time function . Otherwise, the ACC OBT is quite similar to the CDMU OBT.

6.3.2.2.7.4 RM Function

The ACC provides one hot redundant reconfiguration module basically consisting in a state machine capable to issue sequences of pre-programmed ON/OFF commands to the different ACMS equipments, and for internal purpose.

The ACC RM function is associated, as in the CDMU, with a 2 x 512 kbytes safeguard memory for the storage of the ACMS context, to be used in case of reconfiguration after a failure and for post failure analysis.

This reconfiguration module is dedicated to high level FDIR (i.e. system level and computer level, see § 6.5.4).

The ACC Reconfiguration Module also receives the Launcher separation strap status and initiates the post separation activities.

6.3.2.2.7.5 CG Function

This is exactly the same function as provided in the CDMU (see §6.3.2.1). It is in charge of the ON/OFF switching of the ACMS sensors and actuators.

6.3.2.2.7.6 ACC Interfaces

6.3.2.2.7.6.1 1553 Interface

The ACC provides two 1553 bus interfaces one as a Remote Terminal and the other as Bus Controller.

The first one, already described in the CDMS part, is to allow communication between the CDMU and the ACC. The ACC is then connected to this bus as a remote terminal, the bus master being the CDMU.

The second one allows to connect some actuators:

- 2 star trackers
- 1x4 axis gyroscope (only for Herschel)
- 1x4 reaction wheels electronics (TBC, back up is analog commanding).

6.3.2.2.7.6.2 Sensor/actuator Interface

It is basically capable to handle both Herschel and Planck configurations.

It provides a cold redundant thruster interface to drive:

- 6 x 20 Newtons THR
- 2 x 1 Newton THR.

In addition, both Herschel and Planck ACC's provide specific I/O interfaces

- to acquire Tank temperature, Latch valves status
- to send latch valves commands
- to condition and acquire the pressure transducer
- to acquire 2 Sun Acquisition Sensors through an analog interface
- to acquire 1 Attitude Anomaly Detector AAD through an analog interface
- to acquire 3 Quartz Rate Sensors, QRS, through an analog interface
- to drive the reaction wheels and acquire the torque and speed parameters.

6.3.2.2.7.6.3 Alarm Interface

This interface is part of of the CDMS reconfiguration module and is used to acquire external, system leve,l and internal, CDMU level, alarms.

Through this interface the CDMU monitors especially the Power status of the satellite by the mean of a Bus Under Voltage alarm signal and a Depth Of Discharge alarm signal (see § 6.5.4).

The alarms are acquired as statuses and are, as part of the reconfiguration function, compared with alarm patterns which trigger the suitable reconfiguration sequence. This sequence issues CPDU TC packets towards the command generator. A series of ON/OFF or reset commands are then sent to configure the spaecraft in a safe status.

Through this interface the ACC can have a visibility on the sub-systems under the ACMS monitoring. When one alarm is raised the ACC reacts immediately to engage the corresponding action (reconfiguration sequence).

Through this interface the ACC monitors especially the rate and the pointing attitude by the mean of dedicated sensors such as AAD and QRS. These sensors are nominally monitored internally to the ACC by an independent electronics. This independent, electronics is able to trigger an out of limits alarm status which has in charge to initiate the proper reconfiguration (see § 6.5.4).

In addition, the ACC monitors the CDMU availability through SIR and CIR signals provided by the CDMU. Indeed, depending on the CDMU failure cause (level 3 or level 4 failures) the ACMS has to put the spacecraft either in a Sun Acquisition Mode or to command an Earth Acquisition from target pointing stored in its memory and updated daily from ground.

6.3.2.2.7.6.4 Command Interface

As in the CDMU, this is the interface to generate High Level Commands (ON/OFF commands, reset commands) inside or outside a computer, such a command being issued on request from either the On Board Software or the reconfiguration module.

6.3.3 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 files for the OBSW generation 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.

6.3.3.1 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 by means 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 ESA 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)
- Bootstrap Software, I/O drivers (when the used hardware is common), and scheduler 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 6.3.3.1-1.

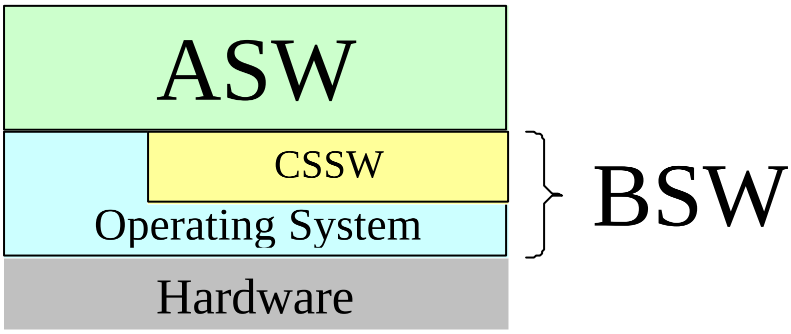


FIGURE 6.3.3.1-1 HERSCHEL/PLANCK CDMU/ACC OBSW BREAKDOWN

The ASW is the highest layer.

The BSW, under Saab Ericsson Space (SES) responsibility, 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).

The CDMU ASW supports the following main functionalities:

- 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 functionalities:

- Relevant Packet services
- FDIR
- ACMS Mode Management
- Sensors Data processing and actuators commanding
- Control law.

HERSCHEL and PLANCK ACMS specificity lead to the design of two distinct ACC ASW. 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 6.3.3.1-2:

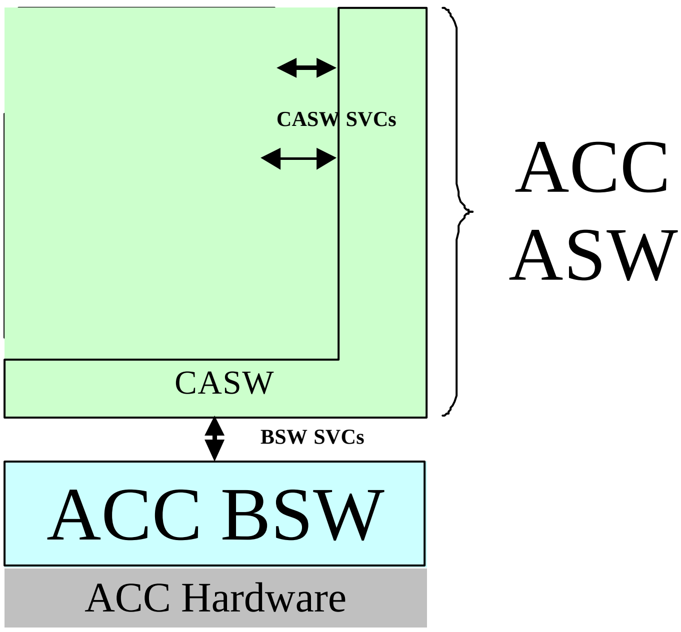
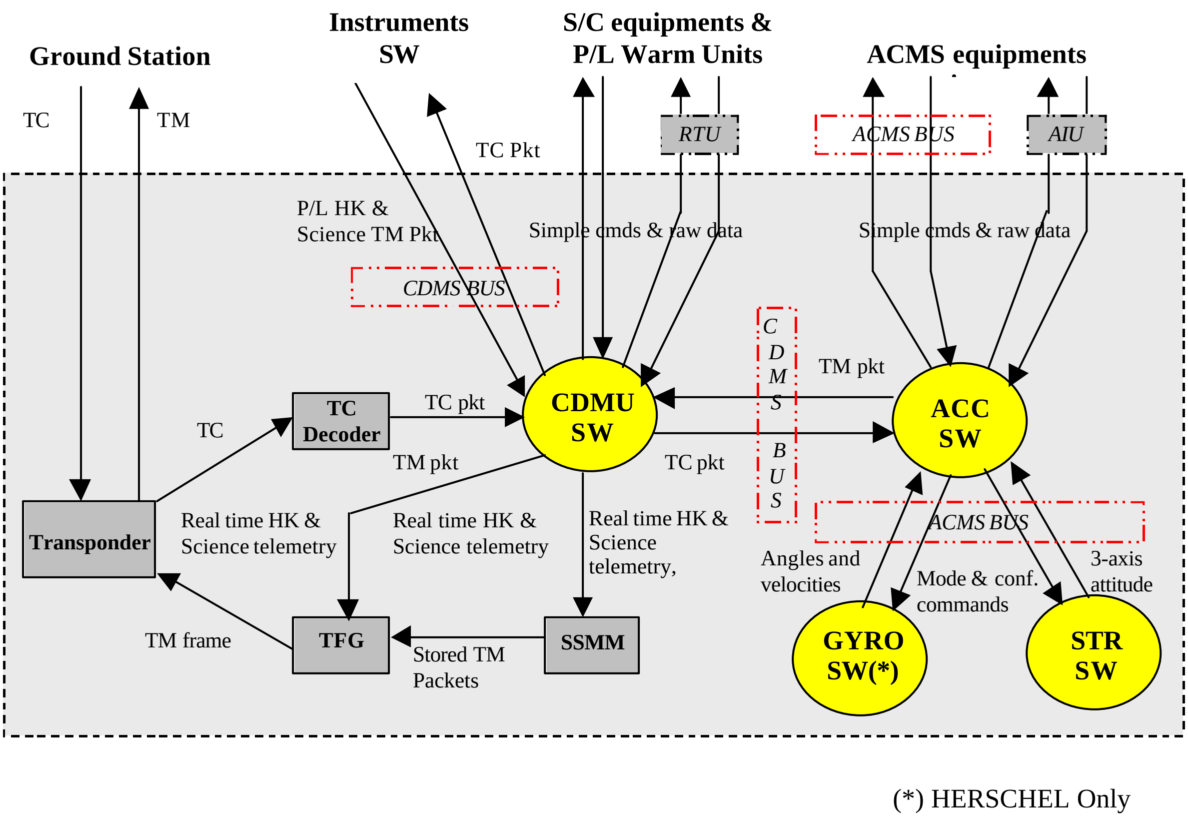


FIGURE 6.3.3.1-2 HERSCHEL/PLANCK ACC ASW BREAKDOWN

6.3.3.2 On-board Software Interfaces

The Figure 6.3.3.2-1 shows the interfaces between OBSW products and with the hardware addressed in § 6.3.1 and § 6.3.2.



(*) HERSCHEL Only

FIGURE 6.3.3.2-1 SATELLITE SOFTWARE ARCHITECTURE AND INTERFACES

6.3.3.3 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 ASPI 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 6.3.3.3-1.

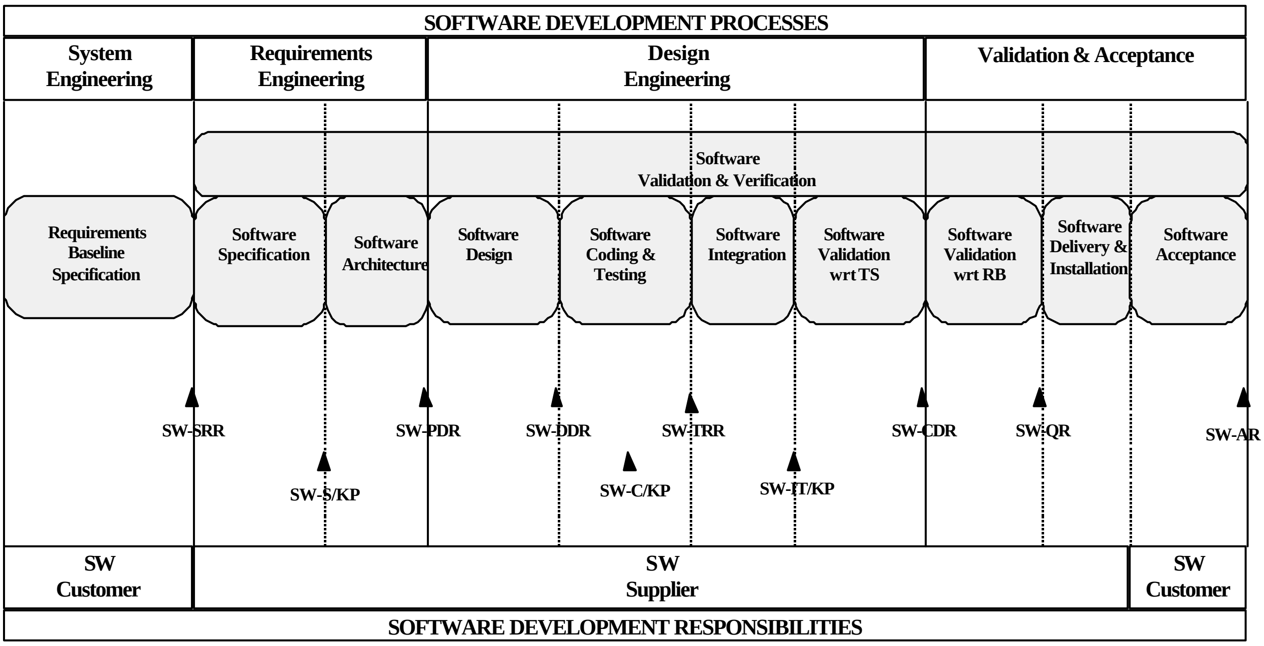


FIGURE 6.3.3.3-1 OBSW REVIEWS AND KEY-POINTS

The Figure 6.3.3.3-2 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).

The details of the OBSW organisation, with the definition of the content of the documents and the requested reviews are specified in the Technical Note RD03.14.

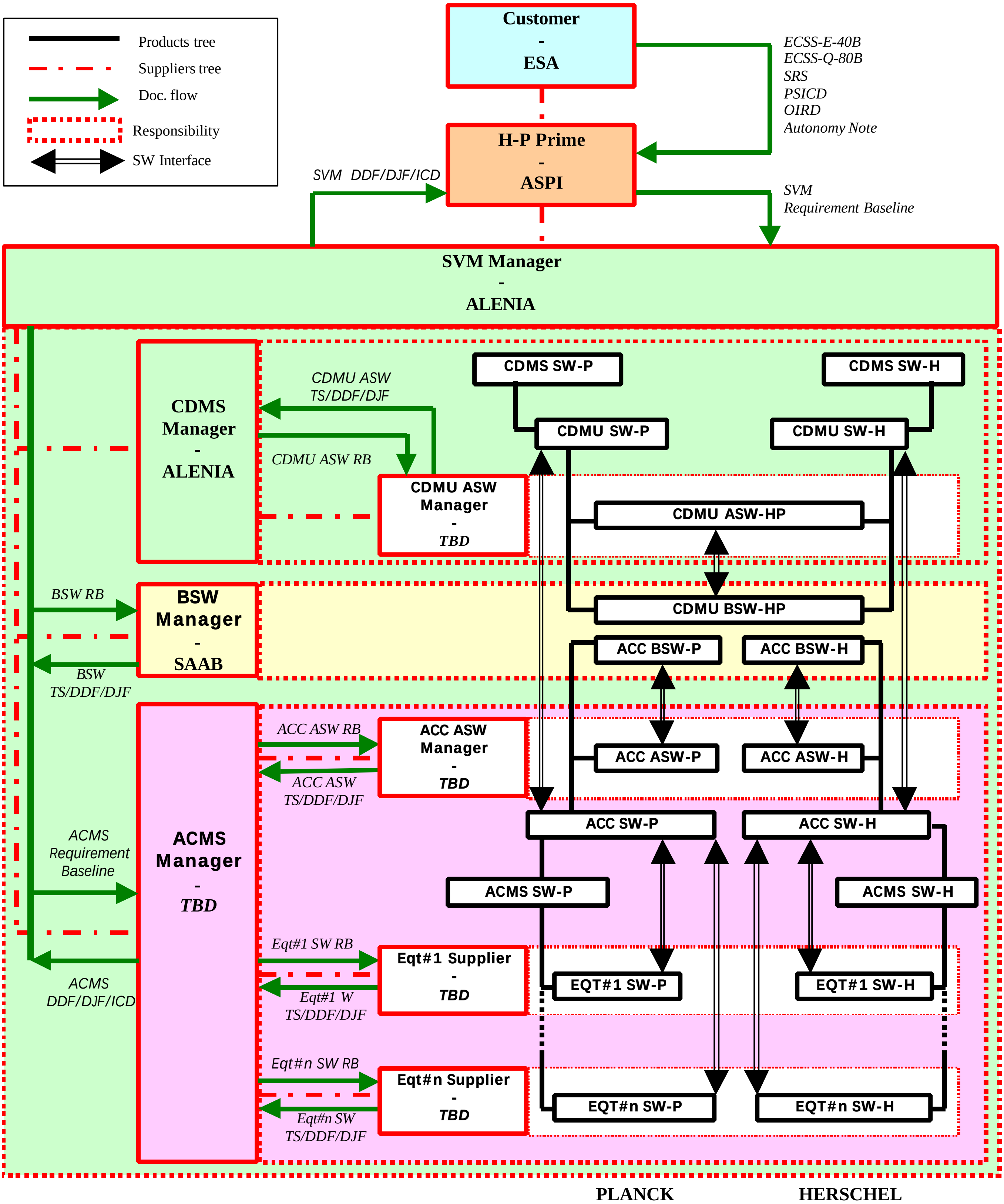


FIGURE 6.3.3.3-2 HERSCHEL/PLANCK OBSW PRODUCTS/SUPPLIERS/SPECIFICATIONS' TREES

6.3.3.4 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. However, it is clear that this requirement may hardly be applicable to reused OBSW (COTS).

The definition of this SDE is given in Table 6.3.3.4-1:

Requirements management tool	DOORS[3]
Processor	ERC-32
Design language	UML
CASE Tool	Rational ROSE
Host computer	Sun Workstation
Host OS	Solaris 8.0
Programming language	C
Compiler/Debugger	GCC/GDB
Target operating system	RTEMS 4.5.0
Cross compilation system	LECCS
Software testing tool[4]	CANTATA
Configuration management tool	CLEARCASE
ERC-32 simulator	<To be defined>

TABLE 6.3.3.4-1 SOFTWARE DEVELOPMENT ENVIRONMENT DEFINITION

The selection of the ERC-32 simulator shall be defined based on proposal from the relevant OBSW subcontractors. The same approach is followed concerning the selection of the tool (potentially probe, emulator, debugger, …) used for OBSW integration on the target board.

6.3.3.5 Software Validation Facility

6.3.3.5.1 SVF Purpose

The Software Validation Facility 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.

3 This is only an ASPI recommendation

4 Used for Static analysis, Unit tests and Dynamic analysis

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 6.3.3.7. As a consequence, ISVV will also be devoted to demonstrate the suitability of the SVF design with the OBSW maintenance needs.

6.3.3.5.2 SVF Components

The SVF is composed of two main components:

- the Software Maintenance Environment (SME) which is in fact divided into specific SME to each OBSW
- the SVF Environment which is a layer to manage all the different SMEs and the man-machine interface.

6.3.3.5.2.1 Software Maintenance Environment

Globally, all Software Maintenance Environments (SME) are based on the same architecture/design composed of:

- <u>a Software Development Environment</u> (as defined in § 6.3.3.4)
- <u>a Patch Facility</u>, which is used to generate patches and new OBSW images. In order to generate the telecommands to patch the OBSW, the Patch Facility is linked with the HERSCHEL/PLANCK System Database (HPSDB) via the SVF Environment. This component is expected to have strong commonality with the corresponding SDE (e.g. data and tools reuse)
- <u>a Test Facility</u>, which permits to test the OBSW, patches and new OBSW images. Its purpose is to validate the OBSW without possibly having the real target processor available. The OBSW could be a complete OBSW image built from the SDE or a patched OBSW built from the Patch Facility. The global performances of this bench shall be real time performances or higher.

6.3.3.5.2.2 SVF Environment

The SVF Environment component is a suite of standard commercial (mostly) software components/tools used to supports the software design, development and verification process.

The SVF Environment includes the following components:

- SVF core workstation software (operating system, user interface, communication software)
- Software test tools and test evaluation tools split between SDE and Test Facility (test definition tools, static and dynamic analysis tools, test executor, test result evaluation, …)
- HPSDB bridge files (linked to the HPSDB)
- OBCP tools (to write & generate OBCPs)
- SVF Environment Simulation.

6.3.3.5.2.3 SVF Architecture

The Figure 6.3.3.5-1 describes the overall architecture and relationships between the SME and the SVF Environment.

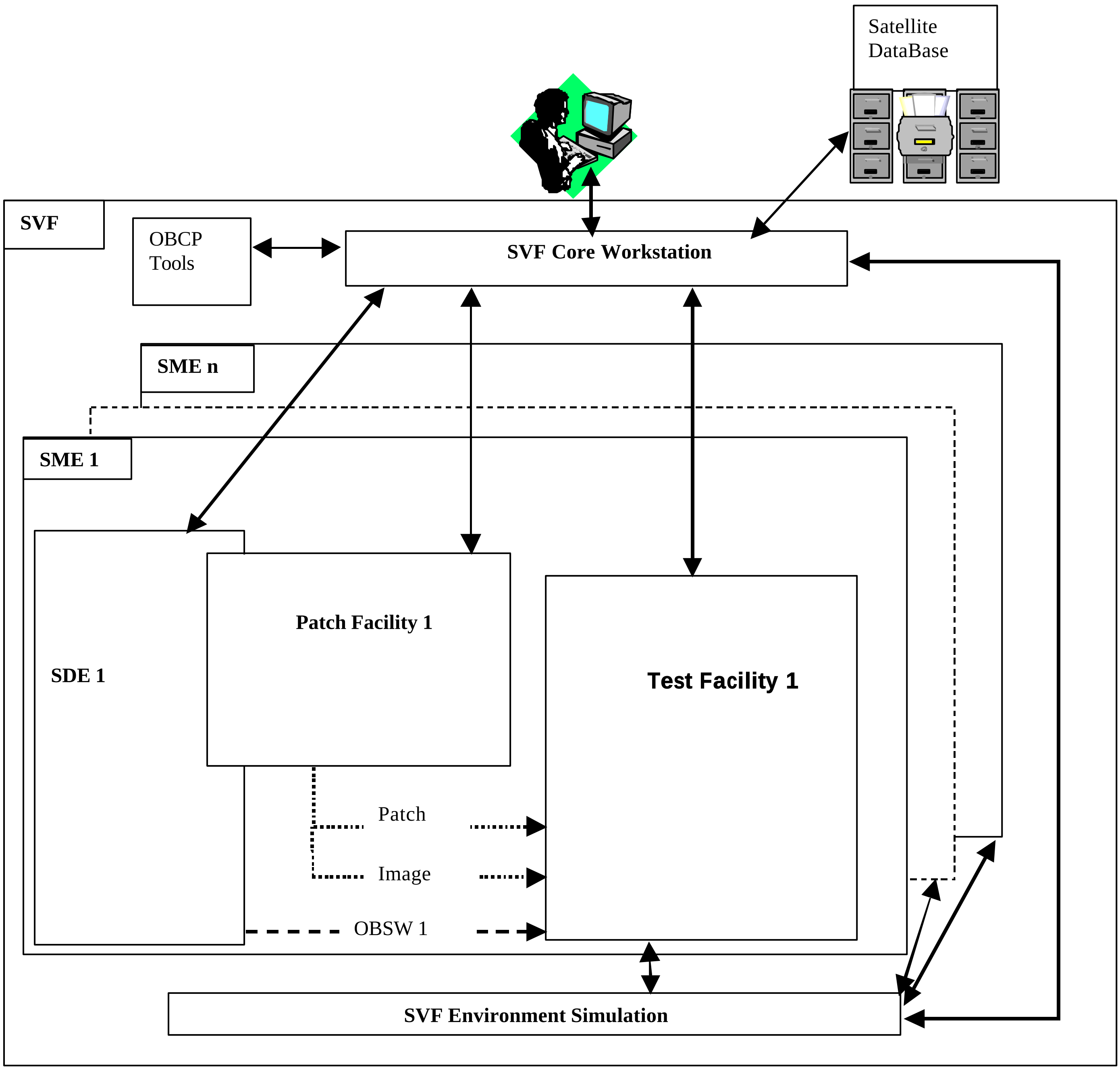


FIGURE 6.3.3.5-1 SVF ARCHITECTURE

6.3.3.6 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.

Such an approach increases OBSW flexibility and adaptability to functional parameters definition refinement, like:

- HK TM content
- FDIR threshold and monitored parameters identification
- Bus addresses and messages length
- Battery characteristics
- Thermal lines configuration
- AOCS adjustment parameters of control laws
- AOCS equipment calibration parameters
- …

It is known that most of these parameters are unlikely to being "frozen" before the completion of the related Subsystem AIT phase. 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. Thus, ASPI baseline is to use, at a given point before delivery, an automatic mechanism to build the OBSW from HPSDB bridge files.

The detailed rationale is as follows:

- 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). Such an automatic mechanism allows PROTEUS/JASON OBSW to be delivered in less than 3 days, including verification/validation, when only a new SDB has to be taken into account.
- 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. Effort is consequently nearly divided by two. This approach could be applied to STR SW (for one satellite and possibly both) and to a minor extent to the common parts of ACC OBSW.
- To ease ACC OBSW development as AOCS functional parameters to be taken into account are numerous and are subject to several refinements.

Eventually, the OBSW Building Procedure from HPSDB bridge files is nominally as described in Figure 6.3.3.6-1:

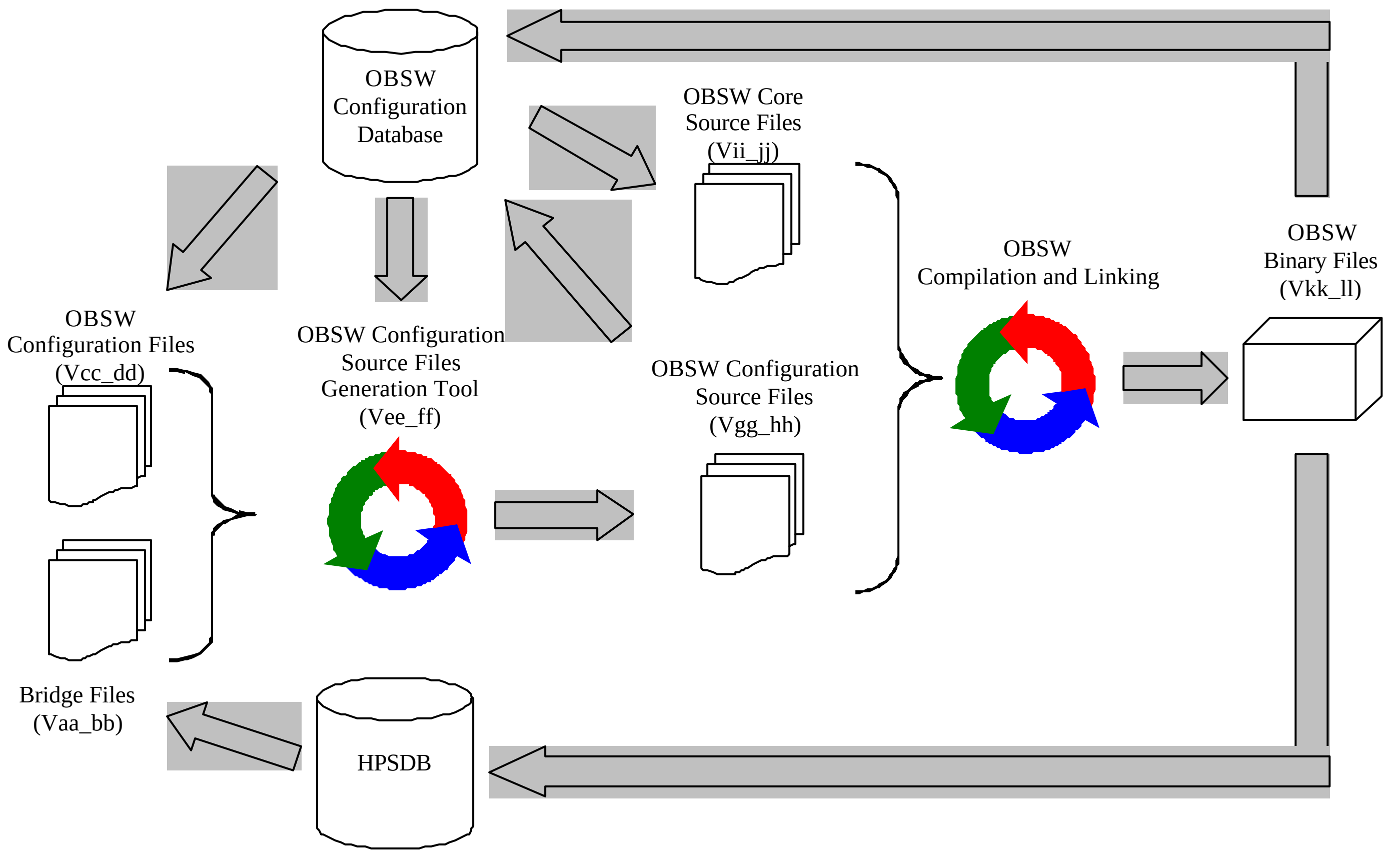


FIGURE 6.3.3.6-1 OBSW BUILDING PROCEDURE FROM HPSDB

Note that the same automatic mechanism shall be used to configure the OBSW validation tools (Benches, …).

Hereafter is given the description of the elements of the OBSW building procedure:

- Bridge Files: ASCII files as defined in ICD HPSDB/SW (H-P-1-ASPI-ID-0196).
- OBSW Configuration Files: ASCII files (.cfg) used as template for configuration source files (.h) generation, including mainly data and constants types definition and initialisation to default values represented at this step by their respective Mnemonics or Labels found in the Bridge Files.
- OBSW Configuration Source Files Generation Tool: Tool used to convert OBSW configuration files into configuration source files, replacing Mnemonics/Labels by their respective values extracted from Bridge Files.
- OBSW Configuration Source Files: Proper source code specification files (.h) configuring the OBSW, including mainly data and constants types definition and initialisation to their respective real default values.
- OBSW Core Source Files: All the OBSW generic source code (.c, .h) independent from the HPSDB configuration.
- OBSW Binary Files: OBSW binary image resulting from the compilation and linking of source files (generic core + specific configuration).

Nevertheless, to prevent any OBSW development to be disturbed by numerous modifications of the HPSDB content potentially to be taken into account by the OBSW, the selected approach is to leave free the OBSW subcontractors to use their own databases independent from HPSDB content refinement but to have their output files compatible with the HPSDB.

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.

6.3.3.7 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 shall 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 shall 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 shall also be subject to an ISVV.

The ISVV shall be performed on the Software Validation Facility (SVF) delivered by ASPI and installed at ISVV contractor's premises. The SVF is described in Chapter 6.3.3.5.

6.3.4 Power design

Power Subsystem Architecture:

The Herschel Planck power subsytems 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	$Trip_{min}$	$Trip_{max}$
ClassI	1A	1.2A	1.5A	2.25A	10mS	12mS
ClassII	2.5A	3.0A	3.75A	5.63A	10mS	12mS
ClassIII	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 $Ilimit_{max}$ and $Ilimit_{min}$.

For applications which require more than 5A (Sorption Cooler and 4k Cooler) several ClassIII 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 ClassIII 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 retrigerable 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 currently being studied in considerable depth. Since the first issue of the PCDU specification the eclipse requirement has been deleted, as a consequence the 5 A charging current requirement maybe relaxed to simplify the design. At the time of this design report preparation the final selection of the charging concept has not been made.

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 (several kHz) between shunt and mainbus.
- Battery Charge Domain - The last section 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 13 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 is performed by the Battery Discharge Regulator, which detects an end of charge voltage and effectively discharges the battery (and puts the power onto the mainbus) at the same rate as the battery is being charged. This solution removes the high current pulses applied to a battery if the regulation was performed at the input to the battery. The battery charging management is autonomously performed by the PCDU, using the battery voltage as an input for a taper charge control loop. The end of charge voltage may be modified by software programming.
- 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 utilising smaller ceramic capacitors in a quad configuration, 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. Prior to kickoff AEA have been encouraged to review their design and see if the mass and dimensions can be reduced at the expense of a reduced electrical margin. With the present proposed battery design the BOL energy capability is 842 Wh with a capacity of 37 Ah, the requirements are 654 Wh (actually expressed as 295 W for 133 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 for the Solar Arrays are summarised:

– Herschel BOL 1500 W, EOL (3.5 years orbit) 1350 W

– Planck BOL 1816 W, 21 months in orbit 1816 W, EOL (30 months in orbit) 1640 W.

As an option that will be considered by the bidder, the specified power needs are:

– Herschel BOL 1600 W, EOL (3.5years orbit) 1400 W

– Planck BOL 1816 W, 21months in orbit 1900W, EOL (30months in orbit) 1700W.

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	NO	II
HIFI HRV	**FHHRV**	LCL	NO	II
HIFI ICU Nom	**FHICU**	LCL	NO	II
HIFI ICU Red	**FHICU**	LCL	NO	II
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 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	I
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**	15A-LCL	YES	15A
HFI 4KC Drive bus Nom	**PHDC**	15A-LCL	YES	15A
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

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.

6.3.5 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.

Several critical areas have been identified for the harness design, 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 critical, and although there are solutions to reduce the harness resistance, care must be taken since although this will work for the minimum PCDU output voltage, a current greater than the specified 3.75 A may be taken at maximum PCDU output voltage conditions. The PCDU supplier has been requested to study the impact of managing 4 A heater loads, initial feedback indicates that this should not be a major concern.

- 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 5 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 50 Ohms.

- 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.

6.3.6 TTC Subsystem

This section describes the proposed architecture and design of the TTC subsystem on both HERSCHEL and PLANCK satellites.

This subsystem will communicate with the ground stations, Kourou and New Norcia, via received telecomands and sent telemetries and Instruments data.

Both Herschel and PLANCK TTC subsystems use X-Band frequency for up and downlinks.

The spacecraft to Earth aspects angles from telecommunication point of view are similar for both spacecraft: 15° maximum for Planck (10° in case of Kourou G/S) and 10° for HERSCHEL.

The uplink and downlink data rates requirements, mainly driven by the science data, are identical between the 2 spacecraft.

Considering here above, high level of hardware commonality between HERSCHEL and PLANCK TTC subsystems has been achieved, since the Transponders, TWTA and Antennas are fully identical on both spacecraft's. Only the PLANCK RFDN (RF distribution network) slightly differs form the Herschel one, due to an increased number of redundant LGA on PLANCK.

6.3.6.1 TTC subsystem architecture

The Herschel/Planck TTC subsystem is based on a standard architecture:

- 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 are commanded and monitored via 1553 Bus interfaces, while the TWTA's and RFDN are activated by High level and Extended High Level Commands. The TTC configuration commands are issued:

- nominally by the Mission TimeLine
- by ground
- by FDIR recovery actions.

The overall PLANCK and HERSCHEL TTC subsystem architectures are very similar and the redundancy concept differs only, because of the different mechanical constraints, on the number of redundant antennas. It is of two on Planck (LGA2 & LGA3) to reach the required omni directional coverage, instead of one only on Herschel (LGA2).

Redundant units and cross-strapping between TTC transponders and CDMU redundant TC decoders are shown on the following figures 6.3.6-1 and 6.3.6-2.

The design also offers range measurements capabilities through the ranging channel. These capabilities will be available only when the downlink medium rate is selected. (see later).

It is to be pointed out that the Multi Purpose Tracking Standard (MPTS) as defined in ESA PSS 04 104 is applicable on Herschel-Planck programme. Special care shall be taken to the choice of the ranging tone frequency, between 300 Khz and 1.5 MHz, such that it does not interfere with the TM and TC spectra.

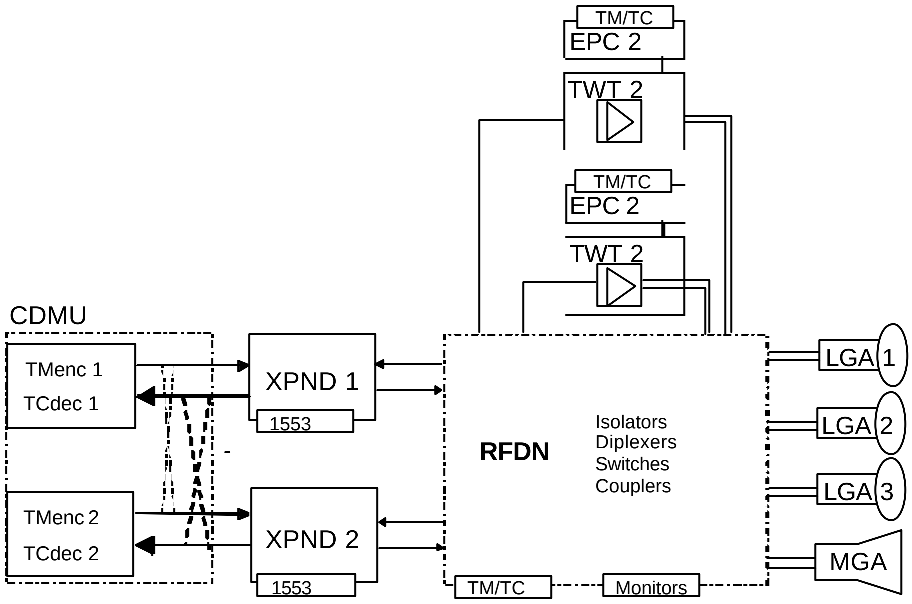


FIGURE 6.3.6-1 PLANCK TTC SUBSYSTEM REDUNDANCY CONCEPT

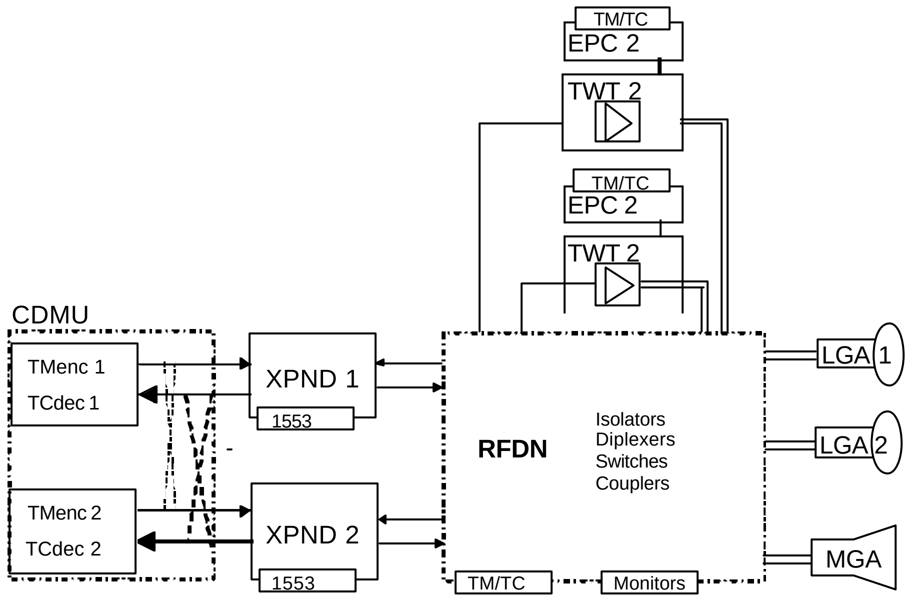


FIGURE 6.3.6-2 HERSCHEL TTC SUBSYSTEM REDUNDANCY CONCEPT

6.3.6.2 Antennas Configuration

For both Herschel and Planck satellites, omni-directional coverage of the low gain antennas is provided in order to keep the contact with the ground stations during:

- Launch: at separation from launcher, the Sun/SC/Earth angle is above 90 deg during around 20 minutes, and then the nominal LGA1 does not point in the Earth direction.
- Survival Mode: in case of attitude loss, omni-directional coverage is compulsory to be able to establish communication with the spacecraft.

While this is not a constraint for Herschel, the specific configuration of Planck makes it more difficult to achieve.

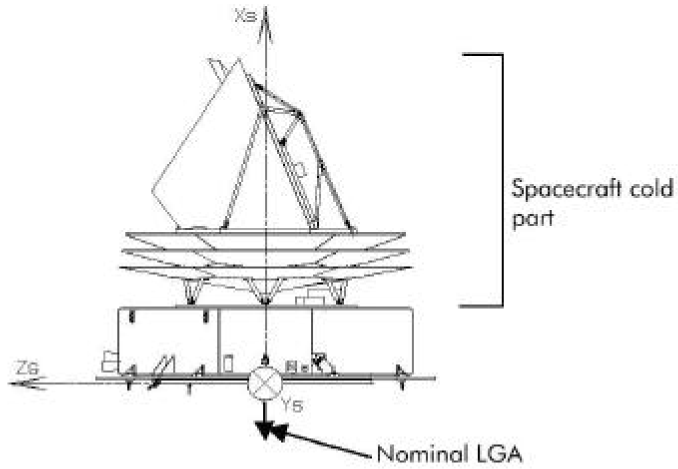


FIGURE 6.3.6-3 PLANCK NOMINAL LGA POSITION

As shown in the figure above, the nominal LGA is implemented on the spacecraft -X side which is nominally facing Sun and Earth. Ideally, to complete the coverage, an antenna on +X side would have been used, i.e. on top of the PLANCK PayLoad Module (PLM) in order to have two hemispherical complementary coverages.

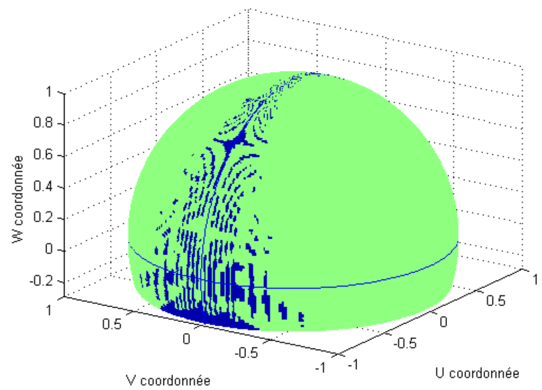
This architecture has been rejected for the following reasons:

1. modularity: the antenna belongs to the SVM and would have to be connected to it by a long waveguide. This would have created a complex interface between SVM and PLM, plus a direct thermal link between the cold PPLM (< 60 K) and the warm SVM (...300 K). Very efficient thermal decoupling would have had to be implemented to avoid heat leaks to the PLM and performance degradation.
2. antenna environment: the thermal environment at the PLM top is below 60 K. Qualification of an antenna at that temperature would have been too complex.

An alternative configuration has been preferred which avoids the above mentioned drawbacks. It consists in implementing, on the SVM, a pair of LGA connected by an hybrid coupler. The antennas are implemented in the (X,Y) plane, on the +Y and -Y panels.

In order not to induce thermal fluctuations on the PPLM, it has to be located inside the shadow of the PLANCK SVM Solar array. This leads to an accommodation in a narrow space below the grooves, almost like a cavity and this results in a slightly distorted pattern of the LGA as the structural environment generates reflections and therefore some phase interference phenomenons within the antenna field of view.

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 redundant LGA tilt angle (35°).



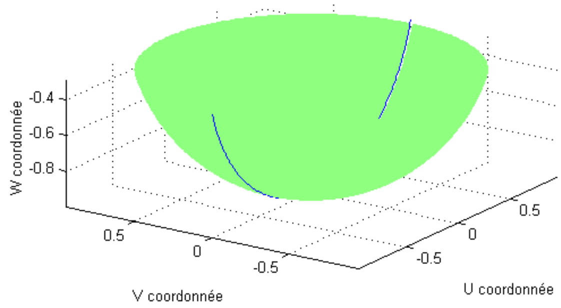


FIGURE 6.3.6-4 GTD ANALYSIS OF THE REDUNDANT LGAS 2 & 3, AND NOMINAL LGA1 – 3DBI GAIN COVERAGES

The GTD results in fact show a coverage of 94.85 % with a - 3 dBi level.

So far the – 3dBi gain/hemispherical coverage is achievable by the selected Antenna supplier. Anyway a refinement of the Antenna individual pattern will be done in the frame of the project and the GTD modelling will be later on verified accurately on a satellite mock-up with the actual antennas.

In addition to the LGA network, needed to achieve the omni directional coverage, one X-Band Medium Gain Antenna is used on each satellite, to perform the High and Medium data rate downlink during the planned telecommunication sessions. It can also be used for Telecommand Uplink.

The typical features of the MGA are a main lobe aperture of about 120° and a gain of 16dBi at 10° and of 13dBi at 10°.

The following pictures show the overlapping of main and redundant Low Gain Antennas (LGA) on both spacecrafts, as well as the location of the Medium Gain Antenna (MGA).

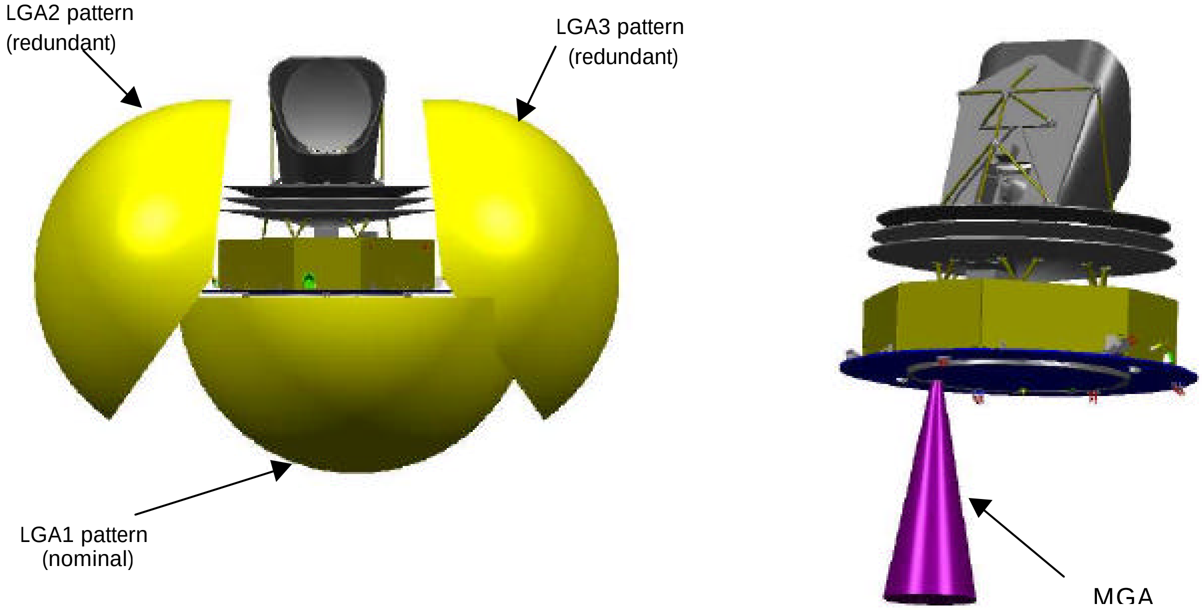


FIGURE 6.3.6-5 PLANCK ANTENNAS CONFIGURATION

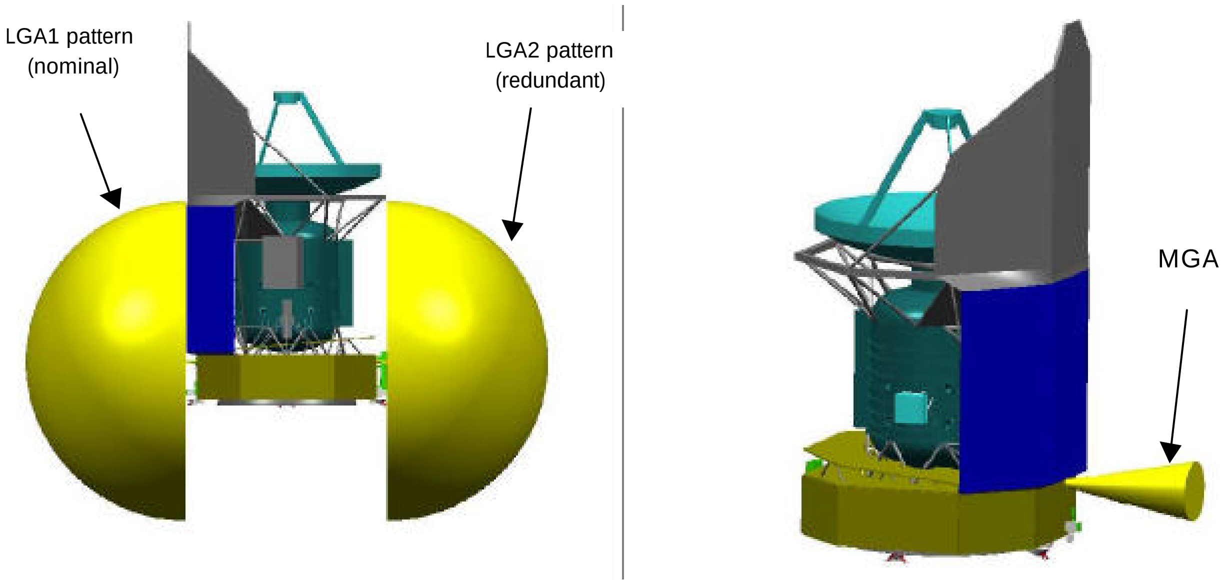


FIGURE 6.3.6-6 HERSCHEL ANTENNAS CONFIGURATION

6.3.6.3 Antennas Switching Network (RFDN) architecture

The main requirements of this network are first to allow all possible combinations of Antennas (LGA & MGA) with the TTC receive and transmit sections, satisfying all Mission modes, while minimizing the passive losses (direct impact on link budget margins) and second shall be SPF free (except the radiative elements as per SRS requirement SMTT-160 & SMTT-175).

The proposed RFDN architecture can be split in a low power section connected to the TC receivers, and a high power section connected to the high power tube amplifiers (TWTA). To minimize passive losses from the transmit section to the Antennas, waveguide technology is the baseline.

The following sketches present the respective HERSCHEL and PLANCK RFDN architectures.

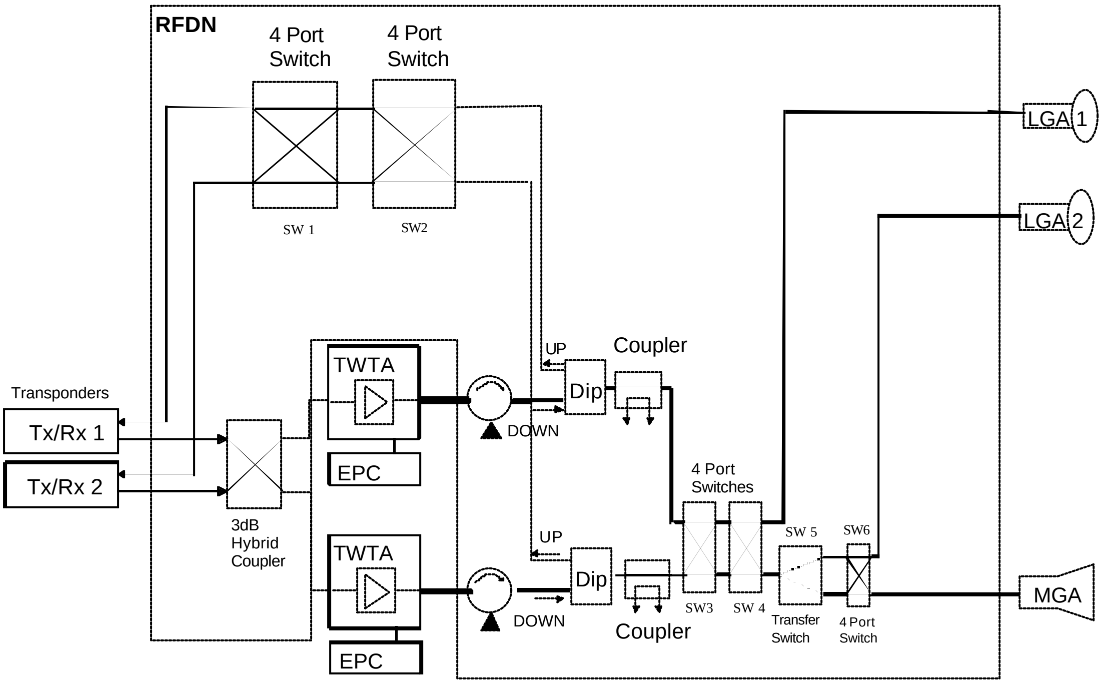


FIGURE 6.3.6-7 HERSCHEL RFDN ARCHITECTURE

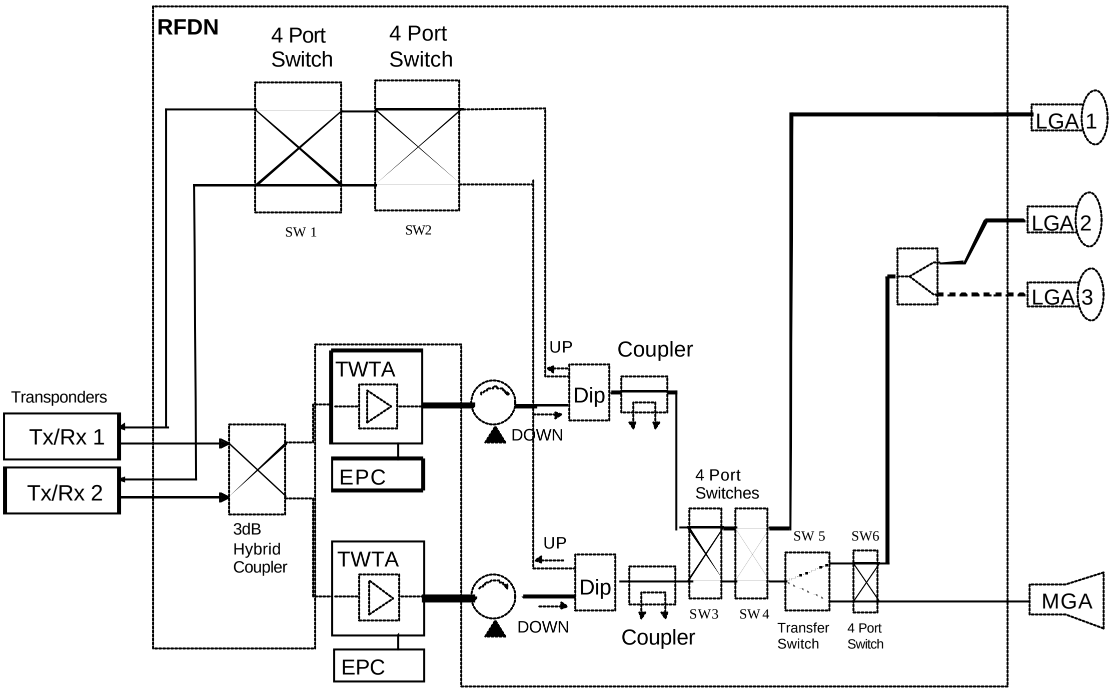


FIGURE 6.3.6-8 PLANCK RFDN ARCHITECTURE

NOTA: the use of three LGAs on PLANCK imposes the use of a 3 dB Hybrid Coupler to distribute the RF output signal from the two TWTA to LGA2 or LGA3 antenna, and the receive signal from LGA2 or LGA3 to both transponders.

In uplink the received signal from the two LGAs passes through SW3 and SW4 towards the two Diplexers and then the Transponders RX inputs.

In downlink the output from one of the two transponders feed a 3 dB Hybrid Coupler that supply contemporarily the two TWTA's. This solution is more reliable with respect to 4 Port Switch solution because it is only passive connection without any moving mechanical parts. The RF losses due to the 3 dB Hybrid Coupler insertion are not relevant because the RF signal is then amplified by the TWTA.

The TWTA's are in cold redundancy: this means that only one is powered on at the same time. Each TWTA output supplies an isolator to protect it from mismatches then a Diplexer and two 4 Port Switches. From these 4PS it is possible to feed directly the LGA1 or another two Switches (SW5 and SW6) to route the RF output signal toward LGA2 or the MGA.

Two Directional Couplers are also foreseen to permit RF output power measurements without disconnecting the RFDN inputs/outputs.

Concerning uplink path the two 4PS are made by a reliable relay switch designed and already space qualified for coaxial connection.

This RFDN concept is based on the use of two cascaded 4 port switches to assure that the configuration chosen is single point failure tolerant.

6.3.6.4 Design issues

6.3.6.4.1 General

The complete TTC subsystem (up and down link) is operating at X-Band frequencies, around 7.2 GHz in uplink and 8.5 GHz in downlink. The on-board generated RF power is about 32W at TWTA output level.

From a design point of view X-Band horn antennas are used both for LGAs and MGAs. This technology is well suited at that frequency and offers a very robust design from a mechanical point of view and a very good power handling capability.

Phase modulations only are used for both links, with as a "premiere" the GMSK modulation on downlink for the high data rate transmission (1.5 Mbps information rate).

This modulation technique offers better performances than the standard OQPSK modulation even when operating in deep saturation (TWTA).

Digital Shaping is used to implement GMSK (better phase linearity) and to limit the RF spectrum bandwidth for SP-L modulation.

The standard concatenated encoding scheme convolutional ½ plus Reed-Solomon (223, 255) is implemented on the downlink for all three data rates. It is also anticipated to implement a data scrambler for the high, GMSK modulated link. The encoding and scrambling functions are performed within the CDMU. The modulation schemes shown here below for all low, medium and high data rates, together with the convolutional encoding and scrambling for the high rate guarantee in any cases a bit transition density at ground station level consistent with the ESA PSS 04 105 standard.

The following combinations modulation ⇔ data rates are implemented:

TC Rate	TC Rate	Modulation scheme	TC SubCarrier
LOW	**125**	PCM(NRZ-L)/PSK/PM	**16 kHz**
HIGH	**4000**	PCM(NRZ-L)/PSK/PM	***16 kHz***

TABLE 6.3.6-1 TC DATA RATES AND MODULATION

TM Rate	Information Rate fb	Transmitted Symbol Rate fs'	Modulation scheme	Subcarrier frequency
LOW-1	500.0065	***1147.1000***	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
LOW-2	**5000.0645**	***11471.0000***	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
MEDIUM	**150001.93511**	***344130.0000***	PCM(SP-L)/PM	Not applicable
HIGH	**1500019.3511**	***3441300.0000***	GMSK	Not applicable

TABLE 6.3.6-2 TM DATA RATES AND MODULATIONS

The link budgets are shown in document RD02.3.

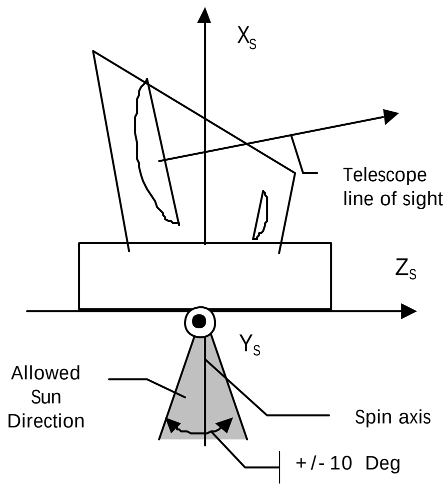
6.3.6.4.2 PLANCK mission/MGA reduced aperture

During commissioning phase with Planck satellite, the transmission of science data at medium data rate with Kourou ground station showed negative link budget margins.

To recover the specified TM link budget quality, two alternatives have been then envisaged, either to implement the Turbo encoding on-board, which would have improved the link margin by more than 2 dB, or to restrain the satellite attitude control in order to limit the maximum Antenna to Earth angle to 10°, instead of 15° nominally. Such a reduction in the antenna pointing is leading to an increase of the gain of about 3 dB (from 13 dBi to 16 dBi).

The second solution has been adopted, after discussion with both ESA and the SVM supplier due to the significant hardware impact of implementing the turbo encoding, both on-board (CDMU + TTC transponder) and on-ground (EGSEs + gnd stations decoders).

As a consequence for downlink Medium bit rate transmission with Kourou ground station, the MGA half angle is limited to 10° as shown on the following figure.



6.3.7 EMC approach

6.3.7.1 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.

6.3.7.2 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.

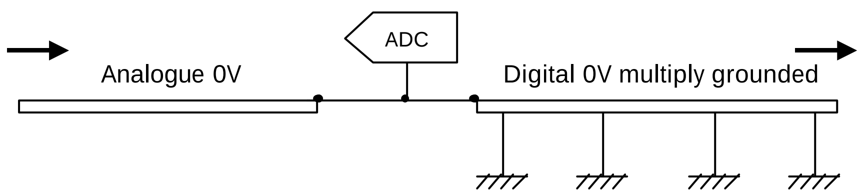
Secondary zero volts grounding

The secondary power return grounding rules specified in the GDIR are the following:

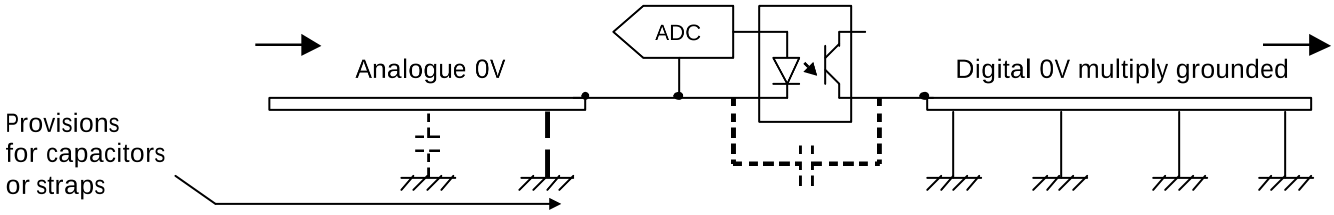
- GDEL-240: Each user secondary power return shall be connected to a single ground (ground point/ground plane). This ground point/ground plane shall be connected to chassis.
- GDEL-270: When a single converter via multiple windings supplies one or more equipment, the secondary power return shall be grounded 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.

6.3.7.3 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 additionnal 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:

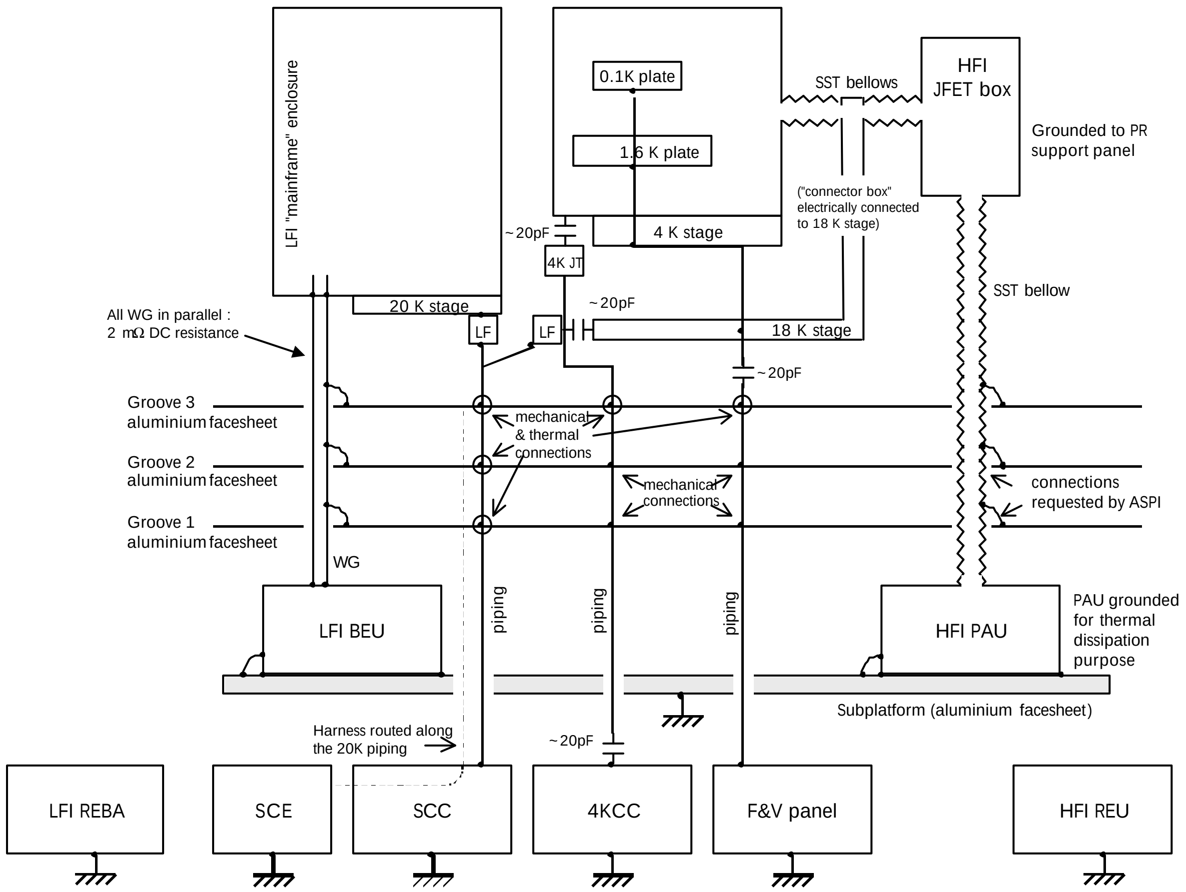
– The three coolers pipings

– 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:



6.3.7.4 Survival to ESD

The components the most liable to the damaged as a consequence of an ESD are the Instruments interface components of both FPU and Warm Units interfacing with external cryo-harness (potential coupling path).

In order to comply with SRS requirement SENV-155: "[…] The spacecraft shall withstand without being disturbed, the following levels: for Conducted Electrostatic Discharge (current injected anywhere in the structure): energy: 15 mJ, voltage: 15 kV (may be reduced to 4 kV if risk for is apparent) […]", it has been decided to protect Herschel external cryo-harness bundles with overshields (although it is not the only reason for doing it, the overshield also protecting the cryo-harness against most kinds of high frequency coupling).

In order to demonstrate the compliance with the requirement, a method has been proposed in H/P EMC analyses (RD04.3), § 5.9.

For Herschel, the conclusion is that we expect positive margins (with reasonable assumptions on the overshields transfer impedance) as long as either standard integrated circuits are used or interface RF components are properly protected (the concerned Instruments are LFI and HIFI, the RF interface components of which need to be protected also against human or furniture ESD that may happen during AIT). This is to be confirmed when a consolidated assessment of the overshields transfer impedance is available from ASED and when consolidated transfer impedance needs (based on analyses) are available from the Instruments.

Concerning Planck, HFI cryo-harness is very well protected against ESD by the bellows. A draft analysis has been performed by HFI that shows excellent margins, thanks to the skin effect (the bellows are made of a full material, not of a mesh like Herschel external overshields). It should be included in their next EMC Control Plan issue.

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 how the propulsion subsystem for both Herschel and Planck are dimensioned and how the thrusters are used. Though the subsystem is under SVM responsibility, the thruster layouts has been kept under Prime responsibility because of its close relation with the mission analysis.

The thrusters are commanded by the ACMS. The ON-OFF commands are sent by the ACC, as for the ACMS sensors and actuators.

6.4.1 Herschel propulsion

6.4.1.1 Thruster configuration optimisation

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
- use of thrusters similar to Planck, for commonality reasons.

The System Requirements Specification requires the following manoeuvres on Herschel:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [deg]
Perigee velocity correction	5	Any
Removal of launch dispersion	ESV launch: 52 ECA launch: 40	Any
Manoeuvre on day 12	4	Any
Mid-course correction	3	Any
Orbit maintenance	6	28.4 ± 180

Most of the 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, but its contribution is relatively small, and therefore does not require any specific optimisation.

Herschel thruster configuration consists of 6 nominal thrusters (and 6 equivalent redundant):

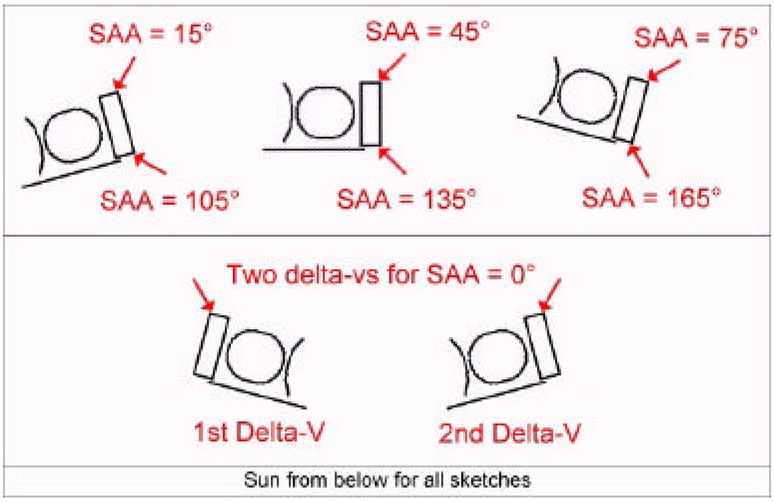
- 4 control ("C") thrusters, located on the –X side of the SVM to avoid contamination of the payload, to generate torques. Choosing 2 thrusters among these 4 leads to 6 possibilities, creating torques in +X, -X, +Y, -Y, +Z and –Z.
- 2 "A" thrusters used to create the delta-vs. The "A" thrusters are used one at a time. They are pointing to the average centre of mass (with a tilt angle of about 45° from X axis).

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, since only two thrusters can be used. 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.

This attitude capacity allows to orient one of the delta-v thrusters in any direction when the Sun Aspect Angle is in the range [15°-75°] and [105°-165°]. For delta-vs with SAA in the range [0°-15°], two delta-vs are performed using the same thruster; between the two thrusts, Herschel is reoriented by a rotation of 180° around the sun-line. A similar process is made for manoeuvres with a SAA in the range [165°-180°]. When the SAA in the range [75°-105°], the two thrusters are used, with a similar principle.



The chosen thrusters are in the range [10-20] N at BOL.

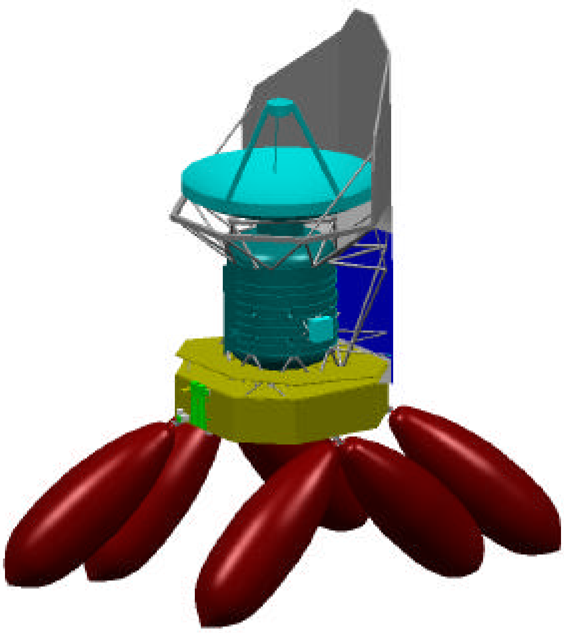
The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN S/C FRAME			DIRECTION IN S/C FRAME		
			x [mm]	y [mm]	z [mm]	x	y	z
Branch A	10N	A1A	-7.4	790.7	1863.8	-0.67096	0.28995	0.68245
		A2A	-7.4	-790.7	-1863.8	-0.67096	-0.28995	-0.68245
		C1A	-41.4	1770.0	-141.4	-0.70711	0.00000	-0.70711
		C2A	-41.4	1770.0	141.4	-0.70711	0.00000	0.70711
		C3A	-41.4	-1770.0	141.4	-0.70711	0.00000	0.70711
		C4A	-41.4	-1770.0	-141.4	-0.70711	0.00000	-0.70711
Branch B	10N	A1B	-7.4	855.3	1835.0	-0.67096	0.31359	0.67192
		A2B	-7.4	-855.3	-1835.0	-0.67096	-0.31359	-0.67192
		C1B	-41.4	1710.0	-141.4	-0.70711	0.00000	-0.70711
		C2B	-41.4	1710.0	141.4	-0.70711	0.00000	0.70711
		C3B	-41.4	-1710.0	141.4	-0.70711	0.00000	0.70711
		C4B	-41.4	-1710.0	-141.4	-0.70711	0.00000	-0.70711

The torques generated by the nominal thrusters (10N), around the average centre of mass are (for a force of 10N):

	TORQUE IN S/C FRAME		
	Tx [N·m]	**Ty [N·m]**	**Tz [N·m]**
A1	0.0	0.0	0.0
A2	0.0	0.0	0.0
C1	12.5	14.0	-12.5
C2	-12.5	-14.0	-12.5
C3	12.5	-14.0	12.5
C4	-12.5	14.0	12.5

The thruster configuration is still subject to optimisation, keeping the principles exposed in this section. The optimisation is mainly due to the mechanical levels that the thrusters can sustain.



NOTE:
Due to the high random level assessed by the SVM subcontractor, an alternate configuration defined in the SVM Design Report and SVM Configuration Requirements has been proposed. This alternate configuration has similar mission and ACMS performances (TBC).

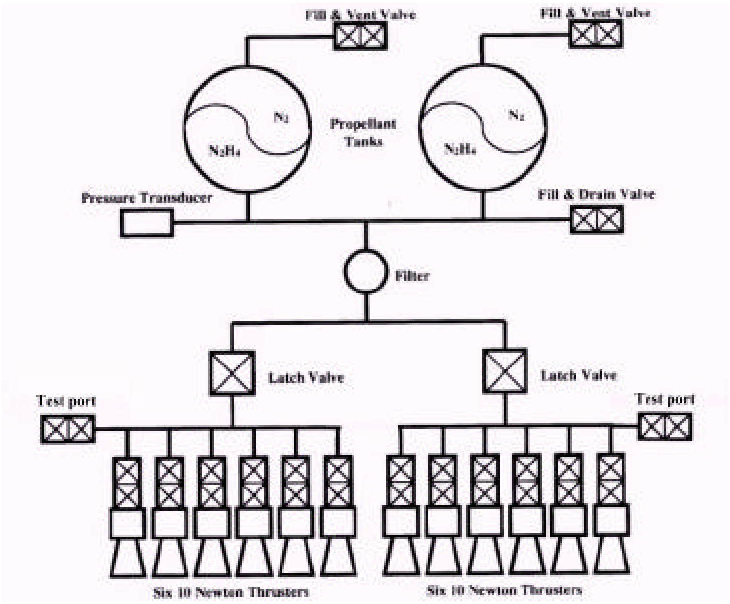
6.4.1.2 Thruster usage

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

6.4.1.3 S/S configuration

The baseline S/S configuration is the following:



6.4.2 Planck propulsion

6.4.2.1 Thruster configuration optimisation

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
- use of thrusters similar to Herschel, for commonality reasons

To perform the delta-vs, the thrusters are chosen in the range [10-20] N at BOL.

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 System Requirements Specification requires the following manoeuvres on Planck:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [deg]
Perigee velocity correction	5	Any
Removal of launch dispersion	ESV launch: 52 ECA launch: 40	Any
Manoeuvre on day 12	4	Any
Orbit injection	ESV: 187.5 ECA: 312.5	125
Injection correction	5	Any
Mid-course correction	3	Any
Orbit maintenance	6	28.4 ± 180

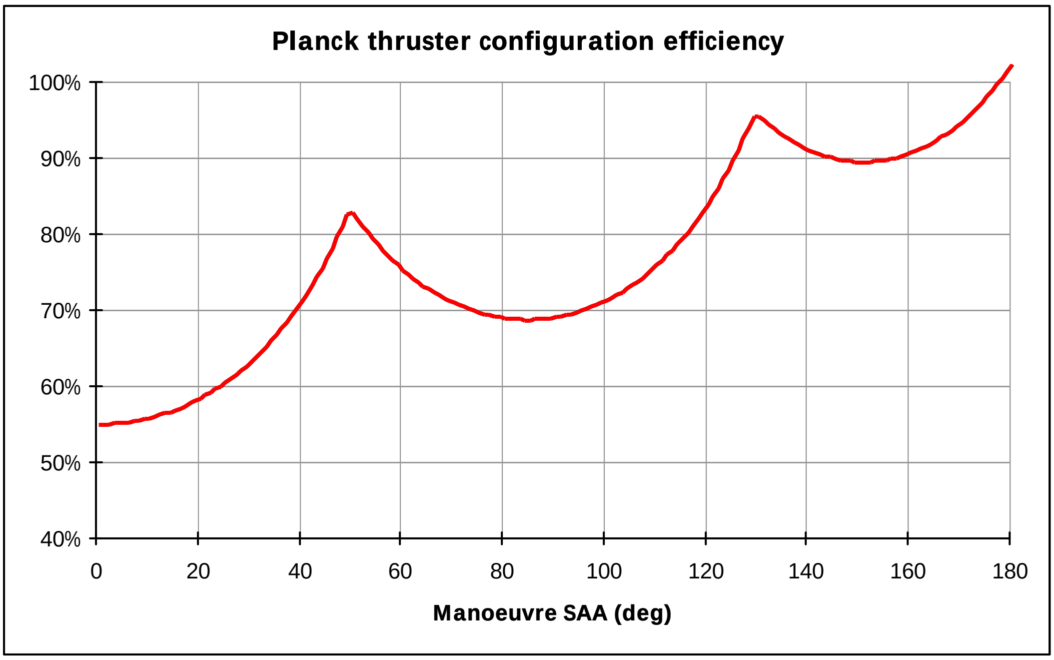
Most of the manoeuvres have no deterministic orientations. They will be calculated on-ground from the Doppler measurements, and commanded to the spacecraft. The injection manoeuvre is systematically performed along the non-escape-velocity direction. Since it is the main contributor to the overall delta-v, some specific thrusters (Flat) have been accommodated to perform this manoeuvre (SAA = 125°) with the maximum efficiency. Two other pairs of thrusters have been accommodated to provide the capacity of manoeuvre for SAA lower than 125° (Down), or over 125 (Up).

The fact that Planck is spinning provides two degrees of freedom that allow to avoid re-orientation manoeuvres prior to the Delta-V:

- phase at which the thrusters are activated
- duration of the thrust (for Up and Flat thrusters), since it changes the thrust efficiency in the YZ plane.

For the main thrust, that is done only once, it is envisaged to profit by the ±10° re-orientation capacity in order to optimise the direction of the effective thrust.

The following graph shows the thruster efficiency with respect to the Sun Aspect Angle, with the assumption that –X is pointing towards the Sun.



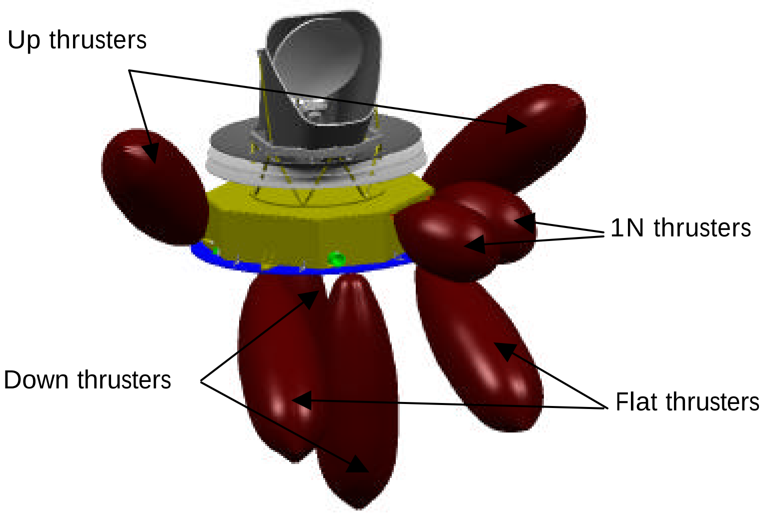
The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN SVM FRAME			DIRECTION IN SVM FRAME		
			x [mm]	y [mm]	z [mm]	x	y	z
Branch A	10N	Down 1 (D1A)	-73.5	30.0	1690.0	-1.00000	0.00000	0.00000
		Down 2 (D2A)	-73.5	-30.0	-1690.0	-1.00000	0.00000	0.00000
		Flat 1 (F1A)	-65.2	-1407.6	1439.4	-0.53377	-0.14684	0.83278
		Flat 2 (F2A)	-65.2	1407.6	1439.4	-0.53377	0.14684	0.83278
		Up 1 (U1A)	348.0	1932.2	-625.7	0.56197	0.49997	0.65896
		Up 2 (U2A)	348.0	-1932.2	-625.7	0.56197	-0.49997	0.65896
	1N	Spin Down (A1A)	840.1	-762.0	1672.9	-0.28343	-0.67811	0.67811
		Spin Up (B1A)	840.1	-1672.9	762.0	-0.28343	-0.67811	0.67811
Branch B	10N	Down 1 (D1B)	-73.5	-30.0	1690.0	-1.00000	0.00000	0.00000
		Down 2 (D2B)	-73.5	30.0	-1690.0	-1.00000	0.00000	0.00000
		Flat 1 (F1B)	-65.2	-1348.9	1449.8	-0.53377	-0.14684	0.83278
		Flat 2 (F2B)	-65.2	1348.9	1449.8	-0.53377	0.14684	0.83278
		Up 1 (U1B)	298.5	1950.0	-597.0	0.56197	0.49997	0.65896
		Up 2 (U2B)	298.5	-1950.0	-597.0	0.56197	-0.49997	0.65896
	1N	Spin Down (A1B)	785.0	-762.0	1672.9	-0.28343	-0.67811	0.67811
		Spin Up (B1B)	785.0	-1672.9	762.0	-0.28343	-0.67811	0.67811

The torques generated by the nominal thrusters (10N and 1N), around the average centre of mass are (for a force of 10N):

	Torque in S/C frame		
	Tx [N·m]	Ty [N·m]	Tz [N·m]
Down 1	0.0	16.9	0.0
Down 2	0.0	-16.9	0.0
Flat 1	9.6	0.0	6.1
Flat 2	-9.6	0.0	-6.1
Up 1	-16.0	0.0	13.5
Up 2	16.0	0.0	-13.5
Spin Down	-0.61	0.39	0.14
Spin Up	0.61	0.14	0.39

The thruster configuration is still subject to optimisation, keeping the principles exposed in this section. The optimisation is mainly due to the mechanical levels that the thrusters can sustain.



The 1-Newton thrusters are accommodated so that:

- one thruster (spin-up) has a lever arm of + 0.6 m around –X
- the other thruster (spin-down) has a lever arm of - 0.6 m around –X
- both thruster provide a lever arm of 0.45 m 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. The spin-up and spin-down thrusters are used alternatively (according to a plan commanded by the ground) to maintain the spin rate at 1 rpm ± 1.5 %, in accordance with the SRS requirement MOOF-050.

NOTE: Due to the high random level assessed by the SVM subcontractor, an alternate configuration defined in the SVM Design Report and SVM Configuration Requirements has been proposed. This alternate configuration has similar mission and ACMS performances (TBC).

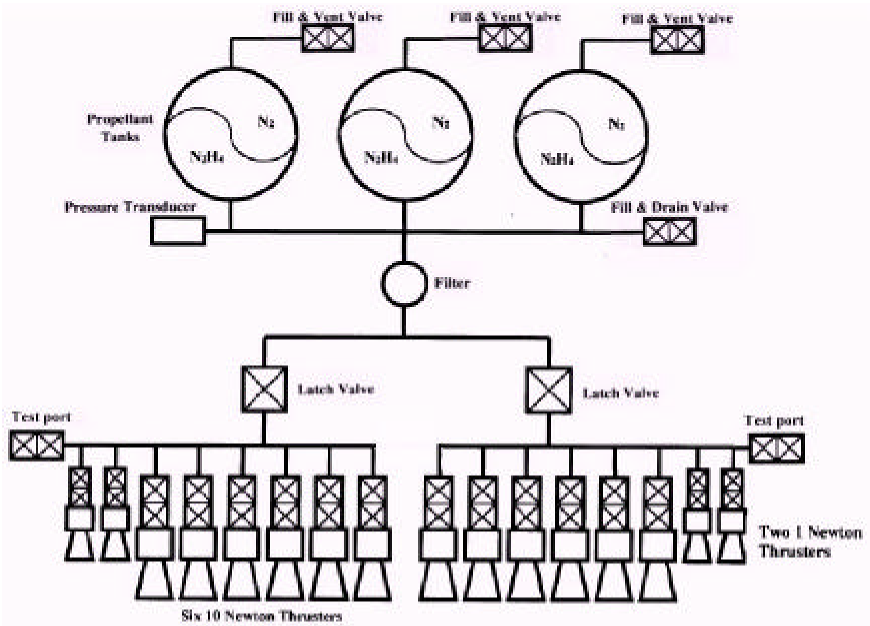
6.4.2.2 Thruster usage

The following table describes the different possibilities to use the thrusters.

TYPE OF MANOEUVRE	DOWN THRUSTERS	FLAT THRUSTERS	UP THRUSTERS	1N THRUSTERS
Orbit correction SAA<50°	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	On-modulated to generate torque.	Not used
Orbit correction 50°<SAA<125°	On-modulated to generate torque.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Not used
Orbit correction 125°<SAA<180°	On-modulated to generate torque.	On-modulated to generate torque.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Not used
Torque generation	Pulse mode	Pulse mode	Pulse mode	Not used
Re-orientation manoeuvre	Not used	Not used	Not used	A single thruster used three times (one pulse each time).

6.4.2.3 S/S configuration

The baseline S/S configuration is the following:



6.5 Mission operations and autonomy

6.5.1 Operations concept

6.5.1.1 Commonalties

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 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 design for electrical subsystem of HERSCHEL and Planck

– identical data rates to ground.

Commonality in operation concepts will lead to reduction of 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 for both TM and TC. TC is nominally via the Low Gain Antenna (LGA). TC via MGA at high bit rate is possible.

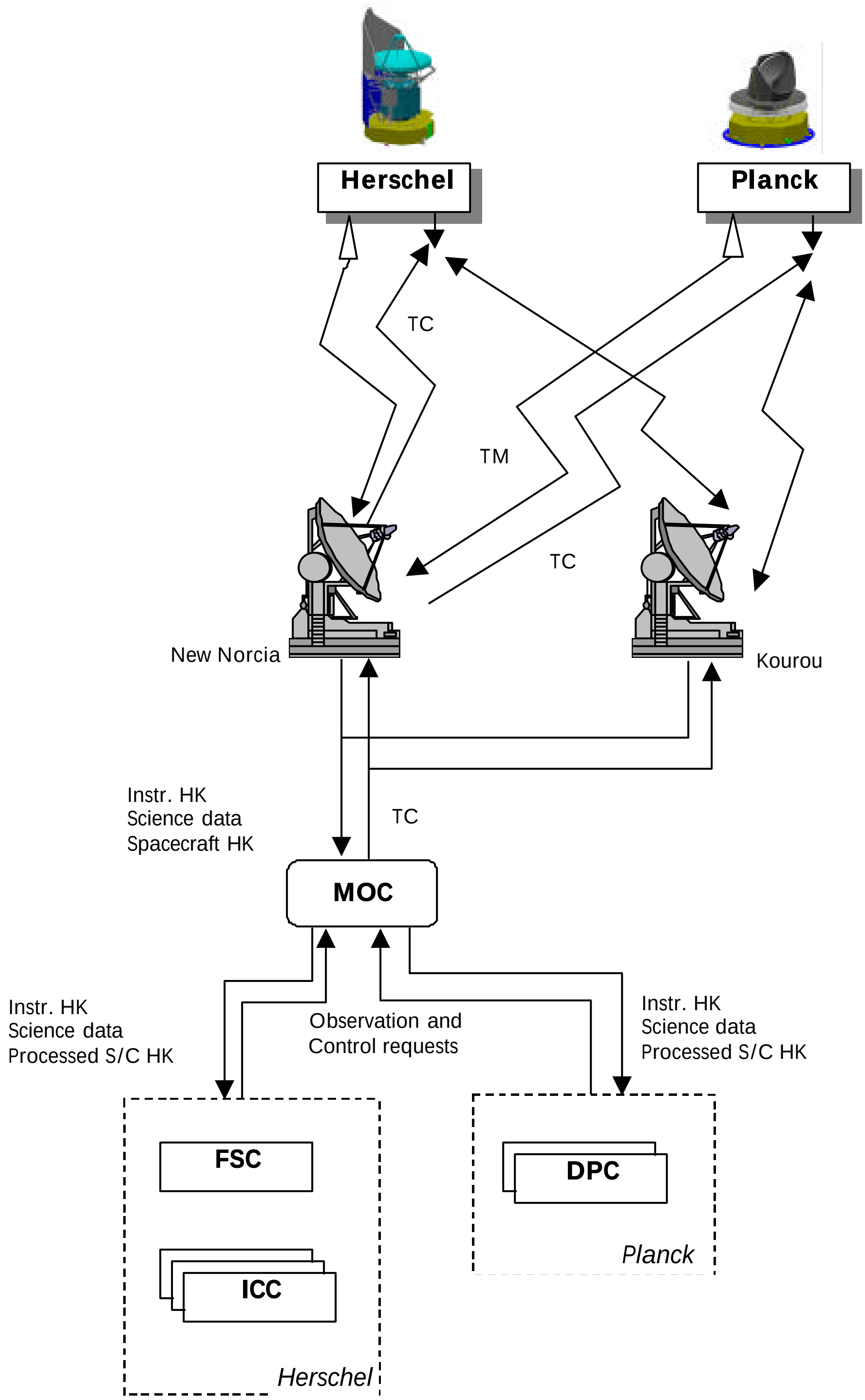
For telemetry, various modes are envisaged as shown in the following table. For commonality reasons, the same data rates have been selected for Herschel and Planck.

	Antenna	Ground Station	HERSCHEL	Planck	TM/TC mode
TM Hi-rate	MGA	New Norcia	1.5 Mbps	1.5 Mbps	Real time HK + mem. dump. Real time HK + real time science + mem. dump.
TM medium-rate	MGA	New Norcia/ Kourou	150 kbps	150 kbps	Real time science + real time HK.
TM low-rate	LGA	New Norcia	5 kbps	5 kbps	Real time HK (S/C + P/L)
		Kourou	500 bps	500 bps	Real time HK with Kourou 15 m.

Nominal TC rate is 4 kbps via LGA when communicating via New Norcia, and 125 bps when Kourou is used. In addition, commanding via MGA at 4kbs is also possible. The various TC mode are 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	LGA or MGA	New Norcia	4 kbps	

The figure hereafter summarises the ground segment for Herschel and Planck satellites.



The basic concept of operations for the satellites is that all activities will be performed according to the on-board Mission TimeLine (MTL). This is the operational mode of the spacecraft during nominal scientific operations, even if the spacecraft is in ground visibility. 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. As far as ground contact takes place each day, the update of the mission time line consists in adding 24 hours of operation for the next day.

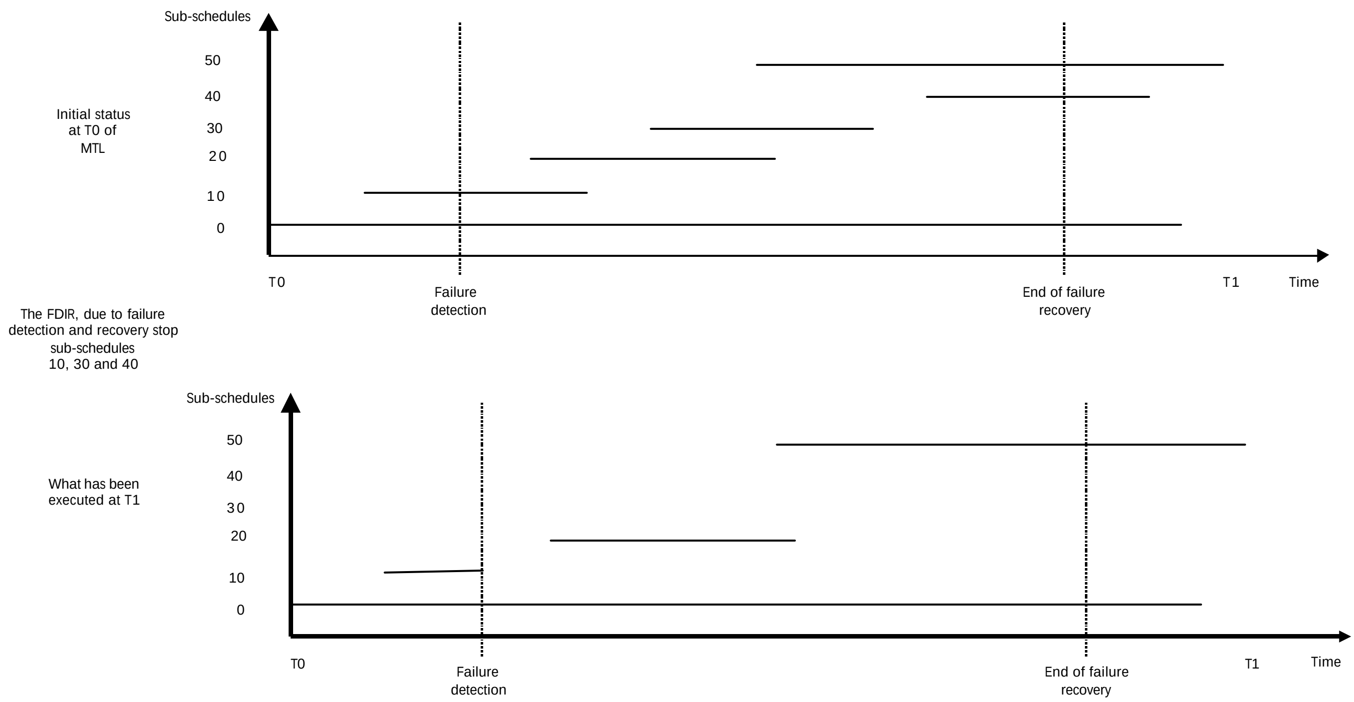
Real time commanding of the spacecraft is also possible. However, when the spacecraft is under ground control, autonomy functions are still active on-board and ground commands are not required to maintain spacecraft safety. This is in accordance with the requirement that ground reaction within less than 3 minutes shall not be required (OIRD, CTRL-1). When, direct commanding is used, there is always the risk that the actual spacecraft status is different to the one known on-ground on which the command has been based. For instance, a reconfiguration can have occurred which is not taken into account on-board. Failure protection on-board includes protection mechanisms to avoid that such inconsistency leads to hazardous situations.

The operation of spacecraft will be done using a set of services provided via the PSICD. Independently from classical facilities (TC acknowledge, Monitoring …), two facilities will be used to support the autonomy required for the spacecraft: On board scheduling and On Board Control Procedure (OBCP).

On-board scheduling

This facility allows to execute autonomously, even during spacecraft visibility, any kind of commands which have been loaded from ground during DTCP into the on-board Mission Time Line (MTL) and which shall be executed at a predefined on-board time. This facility is implemented inside CDMS which distributes the telecommands to the different users as soon as they should be executed.

In order to allow parallel execution of several independent activities, the MTL supports sub-schedules which can be managed independently (enable, disable, report …). 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 has 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 will 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 cannot 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. The independent MTL TC are never locked by FDIR except in case of level 4 or 3 (TBC) failures. The two next figures illustrate a mission timeline with a failure occurrence (Figure 1) and the execution result (Figure 2).



In addition when the FDIR stops one or several sub-schedules, the associated OBCP or software functions shall be stopped too. This will necessitate to have links between sub-schedules and FDIR, those links are TBD (could be affectation of sub-schedule number per function or subsystem …)

Only the ground can update the MTL. A telecommand loaded in the MTL can be executed only when the corresponding sub-schedule is enable and when the on-board time is equal to the time of release associated to the telecommand inside the MTL.

If the activity to be executed cannot be implemented in a simple way inside the MTL due to its duration, to the number of telecommands, to its complexity (conditions), the MTL can activate an OBCP, described below, or activate functions.

On-Board Control Procedure

A principle mode of operation of spacecraft will be by execution of pre-defined on-board control procedures (OBCP's) initiated from the mission time line. OBCP's are flight procedures, which are resident on-board of the Herschel or Planck satellite. They are written by using a Spacecraft Control Language (SCL).

After activation they are executed in the on-board system. Their use is restricted to CDMS and possibly to other intelligent on-board user within the instruments. They serve 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 may be involved.

In order to retain predictable and robust behaviour of the spacecraft and its systems the number of OBCP's shall be kept to a minimum, and the internal structure of each OBCP must be kept simple.

OBCP's can be activated by:

- MTL (Mission Time Line),
- Ground command
- On-board event, automatically (e.g. FDIR)
- Other OBCP.

6.5.2 Spacecraft system modes

The satellite modes aim to predefine a spacecraft configuration for a given life phase of the mission in order to simplify the testing and the design cases.

They have been established following the definitions given in the SRS (AD01.1). Correspondence between the defined modes and the various phases of the mission is presented to ensure 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 minimize the number of modes and maximize commonality between Herschel and Planck, in order to simplify on-ground operations

6.5.2.1 Pre-Launch/Launch Mode

This mode corresponds to a waiting mode of the spacecraft up to the spacecraft separation from ARIANE. It ends by separation detection, which is made by majority voting in the CDMU Reconfiguration module (CDM_RM) on the one hand, and in the ACC Reconfiguration Module (CDM_ACC) on the other hand.

During this mode the following equipment units have to be powered on:

- CDMU Nominal
- ACC Nominal

- CDMS S/W (booted and in a standby mode)
- ACMS S/W (booted and in a standby mode)
- PCDU
- CCU (nominal and redundant) for Herschel
- TTC Receiver (Nominal and Redundant) and EPC in pre heating mode.

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 however 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 Housekeeping mode 1 is engaged.

6.5.2.2 Housekeeping Modes

The housekeeping modes are the nominal system modes when no scientific operations are performed.

Two housekeeping modes have been defined:

- HK1, which is the initialisation mode at separation
- HK2, which corresponds to the routine mode in absence of routine scientific activity.

6.5.2.2.1 HK1

The aim of HK1 mode is to reach and maintain a safe sun-pointing attitude. Launcher separation detection initiates the separation sequence program running in the CDMU which commands all activities to perform Sun acquisition and acquire link with Earth.

The separation sequence will power ON the following units :

- RF Transmitter and associated TWTA (the EPC is already in pre heating mode)
- ACMS sensors and actuators for Sun acquisition mode
- Thruster drivers and cat bed heaters
- RCS latch valve

20 second after separation, the spacecraft is able to transmit telemetry and the ACMS is fully operational. Then, spacecraft can reach and maintain a sun-pointing attitude. Once sufficient sun-pointing is achieved, power generation is automatically switched to Solar Array. Sun-pointing will be observed by the Sun acquisition sensors of ACMS; alternatively it can be detected by monitoring of Solar Array delivered power.

On Planck, the initial spin direction is defined by the launcher and will not change during the mission.

During HK1 mode, communication with Earth on both TM and TC will be performed using omni-directional coverage provided by the LGA. This is imposed by the fact that, at launcher injection and for few tens of minutes, the angle between Earth and Sun seen from the spacecraft is above 90 deg. In that case, if the spacecraft is Sun-pointed, communication is ensured by the antennas covering the - Z hemisphere on Herschel and the + X hemisphere on Planck.

In HK1 mode, after separation from the launcher, the TM link budget permits to download at 5 kbps with both New Norcia and Kourou. In this mode, the spacecraft real-time housekeeping rate will be kept low enough such that progressive download of the housekeeping data stored during launch is performed.

In this mode, the payload instruments are "off".

Transition from HK1 mode to HK2 mode will only be performed by ground command.

6.5.2.2.2 HK2

HK2 mode is the basic housekeeping mode. It is used at the beginning of the mission, during platform commissioning phase. HK2 mode is also used to resume scientific operation after a transition to survival mode.

HK2 mode can be divided into 2 sub-modes:

- When the spacecraft is in ground visibility: HK2/V sub-mode
- When the spacecraft is not in ground visibility: HK2/NV sub-mode.

Transition between the two HK2 sub-modes (i.e. HK2/V and HK2/NV) will be performed by ground command but could also be done by timeline service.

HK2/V

In HK2/V mode it is possible to use all modes of the following subsystems:

- ACMS
- CDMS
- TM/TC
- Payload and Instruments
- Power Control Subsystem
- Thermal Control Subsystem.

Instruments are individually powered on by ground TC or MTL service and set to a safe mode, following procedures defined by the instruments.

During HK2/V sub-mode, only housekeeping data from the instruments will be collected and transmitted to the ground. The spacecraft receives TC from ground and downloads housekeeping telemetry.

HK2/NV

During HK2/NV sub-mode, Herschel spacecraft will nominally remain in operational pointing mode, 3-axis stabilised with the Z-axis Sun-pointed. Planck will nominally remain in operational pointing mode with the spin axis Sun pointed. Spin axis re-orientation manoeuvres can be commanded in order to maintain the S/C Sun pointed.

Housekeeping data from the instruments (if switched ON) and platform is stored in the mass memory during HK2/NV mode.

6.5.2.3 Science Modes

Science modes are the spacecraft modes of operation during scientific mission. They can only be entered from HK2 mode and only under ground telecommand or time tagged command from the MTL service.

Science modes can be exited to:

- HK2 mode under ground telecommand or time tagged command
- Survival Modes in case of major failure.

Science modes can be decomposed into 2 modes:

- Scientific autonomy mode (SCI/AUT), which corresponds to the nominal science observation without ground contact

– Telecommunication mode (SCI/TC), which corresponds to phases in ground contact during science activities.

Transition between the two science modes will be triggered by ground command or by time tagged command.

Line of sight calibrations will be conducted in science modes during science commissioning phase. It will consist in measuring the relative angles between instruments line of sight with respect to the attitude reference sensors, or to calibrate attitude sensors between them. On Planck, line of sight calibration will be performed by observing sources both in the instrument detectors. Science modes will also be used during science commissioning phase to validate proper functioning of the satellite and payload.

During science modes (i.e. both scientific autonomy mode and telecommunication mode), the operations on both Herschel and Planck will follow the commands defined by the on-board mission timeline service.

6.5.2.3.1 SCI/AUT

On Herschel, the observations will consist in a succession of slew and fixed pointing. Complex TC (observation) sequences will be executed from subschedules of the MTL without ground contact. These observation modes, executed from the MTL are:

- Raster pointing with or without OFF position
- Position switching
- Nodding.

In addition, a scanning mode is also specified for Herschel. It is used for Line scanning with or without OFF position. Similarly, orbit control manoeuvres can be programmed in the timeline and performed without ground link.

▼ The Herschel scientific observation is basically performed by one instrument, which is in Prime mode while the other instruments are in standby. There are two other possible operational modes for the payload: SPIRE in Prime mode, PACS in parallel mode performing photometer observations with a degraded sensitivity and spatial resolution. HIFI is in standby mode.

During slew, HIFI and PACS are in standby. SPIRE can perform useful observations with its photometer in the so-called "serendipity" mode.

The following table summarises the Herschel payload modes.

MODE	HIFI	PACS	SPIRE	COMMENTS
1	Prime	Standby	Standby	
2	Standby	Prime	Standby	
3	Standby	Standby	Prime	
4	Standby	Parallel	Prime	TM rates will be shared between PACS and SPIRE. PACS and SPIRE observe at the same time.
5	Standby	Standby	Specific mode: “Serendipity”	During slew. All TM bandwidth available for SPIRE.

▼ On Planck, the basic operational mode is based on parallel operation of HFI and LFI. Alternative modes exist with one of the experiment in Prime mode and the other in standby mode, as shown in the following table.

MODE	HFI	LFI
1	Prime	Prime
2	Prime	Standby
3	Standby	Prime

The instruments are constantly scanning the celestial sphere and the spin axis direction is adapted regularly to follow the Planck scanning law at up to 10 deg. from the Sun, as defined in the on-board mission timeline.

During science autonomy mode, the housekeeping data from the platform and instruments, as well as scientific data, are collected and stored in the mass memory for subsequent downloading during a telecommunication period. Instruments data acquisition bandwidth is identical for Heschel and Planck, i.e. 130kbps.

6.5.2.3.2 SCI/TC

During science telecommunication mode, the spacecraft is Earth pointed to download the scientific data stored in the mass memory during the whole duration of the visibility period. Communication nominally uses the MGA for high rate telemetry. Telecommanding nominally uses the LGA1 (in the Planck -X and Herschel+Z S/C axis) with the MGA kept as back up. This is considered preferable mainly because it does not require the S/C to be properly Earth pointed to receive TC which is of particular importance on Herschel which may need a large slew to point the MGA pointing towards the Earth.

On Planck, the scientific observation will continue nominally in parallel to telecommunication.

On Hershel, the observations will also be carried out in SCI/TC mode provided the antenna earth-pointed constraint is respected. This is ensured by a ± 10 deg field of view MGA, compatible with the maximum Sun/SpaceCraft/Earth (SSCE) angle during mission.

The scientific observations will be limited to attitude compatible with Earth pointing and compliance with the ACMS sensors constraints. As a MGA field of view of ± 10 deg. has been considered for Herschel, some flexibility exists in Herschel pointing, allowing to perform raster pointing or line scanning (with a limitation in the line length). Scientific data collected during telecommunication mode are either transmitted real time or stored in the mass memory for transmission at the end of the telecommunication period or during a subsequent one. (Herschel) wheel unloading will be performed during Telecommunication mode (SCI/TC).

For both spacecraft, the payload modes of operations are similar to the ones in science autonomy mode (SCI/AUT). However, on Herschel, some specific payload housekeeping tasks such as coolers recycling will be preferably conducted in science telecommunication mode (SCI/TC).

6.5.2.4 Survival Modes

When reached in one of survival modes, the spacecraft will be put in **safe conditions** and it shall be able to survive for at least 7 days without ground contact.

Survival modes are only reached in case of major on-board failures (i.e. system failures).

The safe conditions are defined from a spacecraft safe state (i.e. a configuration of each subsystem, which allow the spacecraft to be safe) **and** an instrument state (i.e. safe or OFF).

Communication to ground during survival modes is performed using the LGAs for TM and TC. Omni-directional coverage is provided by the LGAs which allows to receive TC and send TM in any spacecraft attitude.

Transition to survival modes from any other system mode (except HK1 and Launch modes) can be initiated in two ways (TBC) :

- From a ground command (TBC). It happens when, the spacecraft being under ground control, the ground detects an on-board failure.
- After a major on-board failure (e.g. attitude loss). The spacecraft autonomously performs a reconfiguration of the whole system.

The only way to exit from survival mode shall be on ground TC.

Survival modes can be decomposed into two modes:

- SM1 for which spacecraft is in a Safe state and the instruments are in a safe mode
- SM2 for which the whole spacecraft is in a Safe state and the instruments are powered off.

The survival mode in which the spacecraft is transitioned (i.e. SM1 or SM2) depends on the kind of failure.

6.5.2.4.1 SM1

The spacecraft switches to ACMS survival mode[5] and the instruments are transitioned to a safe mode. A safe mode message will be sent to the instrument to initiate proper reconfiguration.

SM1 is entered in case of :

- Loss of proper Sun Pointing (SP) and/or
- Violation of Thruster on Time (TOT) (TBC) and/or
- Rate Anomaly Detection (RA).

6.5.2.4.2 SM2

In case of transition to SM2, the spacecraft will be put in a safe state (i.e. optimum power generation, stable temperature conditions…) and the instruments will be switched off (including the active cooling system on Planck).

As this could result in the loss of a significant mission time, spacecraft will switch to SM2 only in case of:

- Bus Under Voltage (BUV)
- Battery Depth of Discharge (DOD).

6.5.2.5 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.

[5] The complete primary ACMS-branch with all its units becomes deactivated or switched off and the essential units of the redundant branch of the ACMS starts operating in safe sun pointing mode.

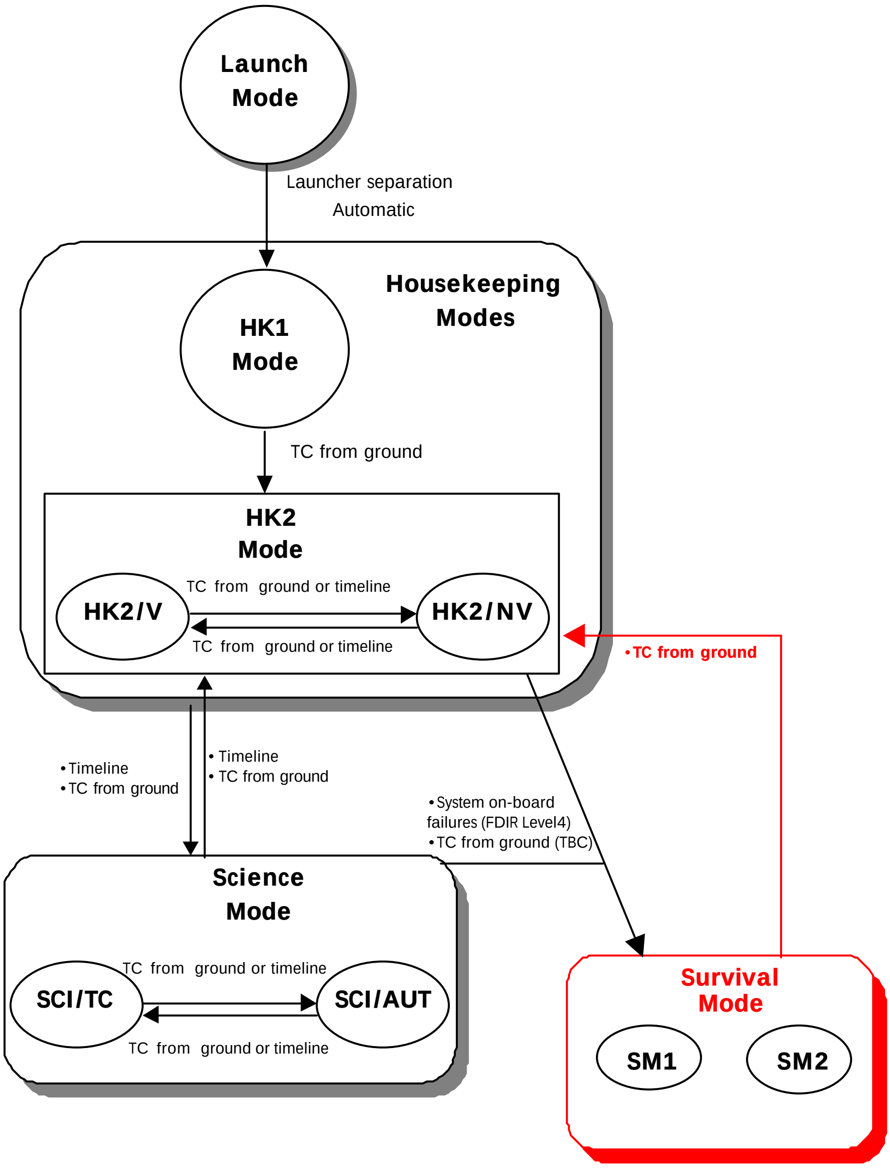


FIGURE 6.5.3-1 SYSTEM MODES TRANSITION LOGIC

6.5.2.6 Modes links and transitions

The following table summarizes the Herschel operational modes. For each of them, the TM/TC mode is driven by the dowlink rate and the Virtual Channels allocation and prioritisation.

SATELLITE MODE	SUB-MODE	TM/TC ANTENNAS	TM DATA RATE	ACMS MODE	PAYLOAD MODES	POWER MODE
Launch		N/A	N/A	SBM	Instruments OFF.	Battery
HK1		TM/TC by LGA + Z/- Z	TM Low-rate	AM	Instruments OFF.	SA
HK2	V	TM/TC by LGA + Z or TM by MGA	TM Medium-rate or High-rate	AM ; SCM; OCM	Instruments OFF or in a safe mode.	SA
	NV	N/A	N/A	SCM; AM		SA
Science (SCI)	Autonomy (AUT)	N/A	N/A	SCM	- 1 instrument Prime; others in a safe mode. - PACS Prime, SPIRE parallel. - SPIRE in serendipity.	SA
	Telecom-munication (TC)	TM = MGA TC = LGA + Z	TM Hi-rate TM Hi-rate TM Medium-rate	SCM OCM	- 1 instrument Prime; others in a safe mode. - PACS Prime, SPIRE parallel.	SA
Survival	SM1	TM/TC by LGA + Z/- Z	TM Low-rate	SM	Instruments in a safe mode	Battery or SA
	SM2	TM/TC by LGA + Z/- Z	TM Low-rate	SM	Instruments OFF	Battery or SA

TABLE 6.5.3-1 HERSCHEL OPERATION MODES

SCM: Science Mode – AM: Acquisition Mode – SM: Survival Mode – SBM: Stand By Mode – OCM: Orbit Correction Mode

The following table summarizes the Planck operational modes. For each of them, the TM/TC mode is driven by the dowlink rate and the Virtual Channels allocation and prioritisation.

SATELLITE MODE	SUB-MODE	TM/TC ANTENNAS	TM DATA RATE	ACMS MODE	PAYLOAD MODES	POWER MODE
Science (SCI)	Autonomy (AUT)	N/A	N/A	NOM HCM	- 2 intruments Prime - 1 Prime, 1 in a safe mode	SA
	Telecom-munication (TC)	TM = MGA TC = LGA -X	TM Hi-rate	NOM HCM OCM	- 2 instruments Prime - 1 Prime, 1 in a safe mode	SA
			TM Hi-rate			SA
			TM Medium-rate			SA
HK1		TM/TC by LGA -X	TM Low-rate	SAM/AI	Instruments OFF.	SA
HK2	V	TC = LGA – X TM = LGA – X TM = MGA	TM Medium-rate Or high rate	SAM/AI ; NOM ; HCM ; OCM	Instruments OFF or in a safe mode.	SA
	NV	N/A	N/A	NOM ; HCM		SA
Survival	SM1	TM/TC by LGA + Z/- Z	TM Low-rate	SAM/SM	Instruments in a safe mode.	Battery or SA
	SM2	TM/TC by LGA + Z/- Z	TM Low-rate	SAM/SM	Instruments OFF	Battery or SA
Launch		N/A	N/A	SBM	Instruments OFF.	Battery

TABLE 6.5.3-2 PLANCK OPERATION MODES

NOM: Normal Operation Mode – HCM: Angular Momentum Correction Mode – SAM: Sun Acquisition Mode – SBM: Stand By Mode – OCM: Orbit Correction Mode

6.5.3 Mission scenario

6.5.3.1 Preparation

The interfaces between spacecraft and ground stations are validated before launch using a RF "suitcase". The suitcase is representative of spacecraft in what concern the RF interface but also the frame interface and packet interface. The suitcase includes all facilities to analyse received TC and to send representative TM packets.

The MOC functionality and procedures, including the common AIT and operations system database (HPSDB: Herschel/Planck System Data base), are validated first against spacecraft simulator, using representative telemetry generated during spacecraft AIT activities, then against spacecraft itself during System Validation Test (SVT). Three SVT tests are foreseen. During SVT, the spacecraft is controlled from the MOC, however it is still monitored in parallel from the CCS which can take over the spacecraft control in case of anomaly. Additionally, during specific AIT phases, it is possible to perform listen-in tests, during which the spacecraft is fully controlled by the CCS, but the MOC receives in parallel telemetry from spacecraft.

6.5.3.2 Non routine scenario

The non routine scenario includes all the operations which shall be performed between the launch and the normal operations of the spacecraft (routine scenario). Even if some operational activities could differ between Herschel and Planck, the major part of the activities are common and, unless otherwise specified, the description of the non routine scenario is common for both Herschel and Planck. This scenario is composed of the following phases:

- Launch and early orbit phase (LEOP)
- Commissioning phase
- Performance and verification phase

prior to start the launch phase, the initial spacecraft configuration shall be determined.

Initial configuration

The initial configuration is set via the CCS. The power is provided by the batteries. The SVM subsystems are powered as defined in §6.5.2.1, the instruments are not except power applied to launch lock devices. Some CDMS and ACMS functions are inhibited up to the separation detection.

Launch and early Orbit Phase (LEOP)

This phase start at launch time (T0) and ends after the second trajectory correction which is planned at T0 + 12 days

During launch phase ARIANE provides "dry loop" relay commands to Herschel CCU to allow opening of cryostat valves. The telemetry emission is inhibited.

After separation detection, the CDMS and ACMS switche autonomously to HK1 mode in order to reach a stable sun-pointed attitude safe for payload, power and communications. 20 seconds after separation the spacecraft is able to transmit HK TM via the LGA and the ACMS is fully operational. Once sun acquisition is achieved transition to HK2 is performed by ground command.

All the operations during this phase are conducted from ground. New Norcia,Kourou and Villafranca ground stations provide a ground coverage of approximately 22 hours per day. During the non visibility period the HK data are stored inside the Solid State Mass Memory (SSMM).

Three manoeuvres are performed during this phase. The first manoeuvre is aim to correct the speed variation at perigee and takes place as soon as possible during the first day. The second manoeuvre is intended to remove the launcher dispersions and takes place at T0 plus 2 days. The third manoeuvre is aimed to remove the previous manoeuvre execution error and takes place at T0 + 12 days and marks the end of the LEOP phase. No other manoeuvres, other than the ones for orbit maintenance at L2, are foreseen for Herschel.

The operations will be centred on the checkout of the spacecraft subsystems and the correct transfer trajectory to L2. The following operations are carried out during this phase:

- Establish the correct spacecraft configuration (RF, Thermal control, power, data handling, ACMS, etc .)
- Establish basic spacecraft properties (centre of gravity, moments of inertia)
- Determine spacecraft attitude (and spin rate for Planck)
- Correct attitude (spin rate) if necessary)
- Carry out orbit determination
- Determine optimal attitude and magnetude of the trajectory correction manoeuvre
- Slew to correct firing attitude
- Thruster calibration (TBC)
- Refine magnitude and timing of the burn
- Execute trajectory correction #1
- Determine the orbit
- Repeat for trajectory correction #2
- Slew to optimal attitude for transfer
- (for Planck) Adjust spin rate if necessary
- begin of telescope decontamination heating.

Timeline summary:

TIME	EVENT	DESCRIPTION
T0	Lift-off (H0)	
T0+144.9 sec	Acceleration threshold detection (H1)	
T0+145.7 sec	Booster jettisoning (H1 + 0.78 sec)	
T0 + 196.3 sec	Fairing jettisoning (FJ)	Herschel sun solar aspect constraint applies
T0 + 539.2 sec	End of EOC thrust phase (H2)	
T0 + 545.2 sec	Lower composite jettisoning (H2 + 6 sec)	
T0 + 116 mn	End of coast arc Upper stage ignition (K2.1)	
T0 + 133.2 mn	Spacecraft separation (H3)	Herschel is separated in three axis mode, Planck is separated in spin mode
D1	Manoeuvre	Perigee velocity correction
D2	Manoeuvre	Removal LV dispersion
D12	Manoeuvre	Remove previous manoeuvre correction

Commissioning phase

The commissioning phase starts after the second trajectory correction which is planned at T0 + 12 days and ends at the beginning of performance verification phase.

During this phase, the New Norcia and Kourou ground stations are used, insuring a 10 hours per days of coverage to be shared by Herschel and Planck.

Some operations are performed from the ground, some others are performed autonomously from the MTL.

The mains operations performed are:

- Complete check out of spacecraft functions and verification of all subsystems performances
- Verification of the spacecraft-instrument interfaces
- Instrument switch on and functional check out
- End of telescope decontamination heating
- For Herschel: telescope cool-down and cryo-cover opening
- For Planck: passive cool down to 50 K. Switch-on 20 K cooler and cool down to 20 K. Switch-on 4 K cooler and cool down to 4 K. Switch-on 0.1 K cooler and cool down to 0.1 K.

The commissioning phase duration is expected to be 4 to 5 weeks for Herschel and 4 months for Planck.

For Planck, three manoeuvres are foreseen during this phase. The first manoeuvre is aim to removed accumulated error during cruise and fine targeting and takes place 20 days before injection. The second manoeuvre is intended to inject Planck on its final orbit (15°). The third manoeuvre is aimed to remove injection manoeuvre execution error and takes place at injection + 2 days. No other manoeuvres, other than the ones for orbit maintenance at L2, are foreseen for Planck.

For Planck, during the transfer to L2, the sun spacecraft earth angle which is limited to 15 deg. will be violated during 72 days from day 36 up to day 108 after separation and during 43 days from day 54 to day 97 after separation this angle will be greater than 25 deg. In this last case, in order to keep the sun direction in the allowed range (10 deg. from spin axis), Planck will be re-oriented and the telecommunication via MGA will no more be possible, LGA has to be used.

Timeline summary:

TIME	EVENT	DESCRIPTION
Day 36	SSCE becomes > 15 deg	Planck: angle spin axis / sun direction lower than 10 deg applies. MGA usage is limited
Day 54	SSCE becomes > 25 deg.	Planck : angle spin axis / sun direction lower than 10 deg applies. MGA no more available
Day 97	SSCE becomes < 25 deg.	Planck : angle spin axis / sun direction lower than 10 deg applies. MGA available but usage limited
Day 108	SSCE becomes < 15 deg.	Planck : no more limitation on MGA usage
Injection - 20 days	Planck manoeuvre	remove accumulated error during cruise
Injection	Planck manoeuvre	Planck injection
Injection + 2 days	Planck manoeuvre	remove injection manoeuvre execution

Performance verification phase

The performance verification phase starts after the commissioning phases.

During this phase, the New Norcia and Kourou ground stations are used, insuring a 10 hours per days of coverage to be shared by Herschel and Planck.

Some operations are performed from the ground, some others are performed autonomously from the MTL.

The mains operations performed are:

- performance verification of CDMS and ACMS
- ACMS sensors calibration
- Instruments performance determination and calibration
- Verification/optimisation of instrument operations.

At the end of PV phase the spacecraft and instrument nominal configurations have been established and all tunable spacecraft and instrument parameters have been set to their optimal operating value.

For Herschel, this phase shall end during the transfer to L2 and routine operations can be started.

For Planck this phase cannot be completed during the transfer to L2.

From launcher separation until completion of this performance verification phase, the operations are planned to be run in FDIR Autonomous Fail Safe (AFS) mode (see later FDIR and mode description).

6.5.3.3 Routine scenario

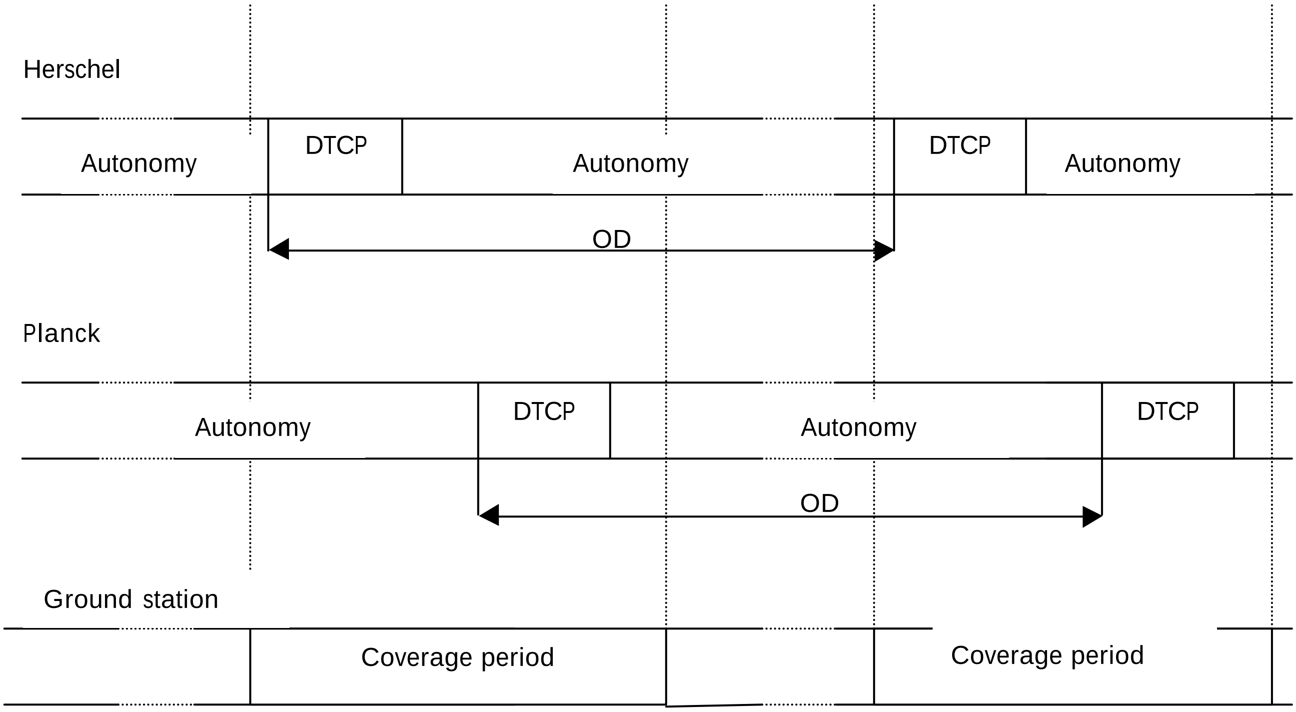
During normal routine operations in L2, Herschel and Planck share the same ground station: New Norcia. This ground station assures a variable daily coverage for both spacecraft depending of spacecraft position on its orbit and of season. The minimum daily coverage period is 7 hours. The daily coverage is shared by Herschel and Planck. As a consequence, for each spacecraft, each 24 -hour operational day (OD) is divided in two periods:

1. The DTCP (Daily Tele-Communication) Period during which the spacecraft is in visibility of the ground station and communicating with the ground (duration between 2 and 3 hours).
2. The "autonomy" period during which no communication with the ground takes place and the satellite are operating without ground support (autonomous operations - Duration between 21 and 22 hours).

During this phase orbit maintenance is carried out on the basis of once per month.

DTCP

By convention the DTCP will be at start of the OD. The Herschel and Planck DTCP are run consecutively, the order in which they are run will depends of operational or spacecraft constraints.



When the DTCP period starts the spacecraft should have the following configuration:

- TM is medium rate via MGA (that means that the spacecraft is pointed to earth)
- TC is nominal rate via LGA1/Transponder1 and LGA2 / Transponder2 (which insures that the TC can be sent to the spacecraft even if the earth pointing is not met).

During DTCP period the following activities shall be performed by ground (unless disabled, the autonomous activities from MTL continue to be carried out):

<u>Initial activities</u>

- Signal acquisition at medium rate
- perform ranging for some minutes (TBD) (TM can be received and TC can be send in parallel)
- Switch to high rate

<u>Spacecraft assessment</u>

- Assess spacecraft and instrument health
- Assess the status of the operations which happened during the 'autonomy' period

<u>Housekeeping activities</u>

- Carry out specific spacecraft operations e.g. reaction wheel unloading, star tracker calibration, etc …
- Carry out specific instrument housekeeping activities e.g. cooler recycling for PACS and SPIRE
- Uplink a new schedule for up-coming operations

- Implement any diagnostic procedure planned during the DTCP e.g. dump of specific parameters or memory areas (spacecraft and/or instruments)
- Implement any corrective action required
- Re-plan for failure cases

Science data recovering (this activity is run in parallel with the other as far as a dedicated low priority virtual channel is allocated)

- Recover the stored scientific data

Completion activities

- Switch to medium rate
- perform ranging for some minutes (TBD) (TM can be received and TC can be send in parallel)
- stop TM transmission.

During DTCP, for Planck, the scientific operations continue autonomously from MTL, for Herschel they can continue autonomously from MTL according to constraints of the spacecraft pointing to earth, to constraints associated to cooler recycling for PACS / SPIRE and to constraints associated to incompatibility of HIFI with X-band TM. In both cases the scientific data are recorded in the SSMM and simultaneously dumped to ground.

Autonomy

During autonomy period, the spacecraft normal activities are driven from the MTL. The MTL is such that it covers all the activities to be performed during the next 48 hours in case the next DTCP is missed. In case of failure detection, to the maximum extend the scientific mission will be carried out. Depending of failure gravity, either the normal MTL will continue, or the current sub-schedules impacted by the failure will be stopped but the other running sub-schedules and the future ones are executed nominally.

An Herschel, oversimplified autonomous sequence operation can be:

- ACMS calibration (10 minutes)
- Instrument initialisation: transition from stand-by to prime, warm up, stabilisation, selection of instrument mode (30 minutes)
- Slew to target # 1 (10 minutes)
- End of slew: On Target Flag (OTF) set high in spacecraft TM
- Pointing on target #1, data collection, HK and science TM to CDMS (duration 60 minutes)
- Slew to target #2: OTF set low in spacecraft TM
- (Optionally) mode change (a few seconds up to a few minutes)
- End of slew: OTF set high in spacecraft TM
- Pointing on target #2, data collection …
- time slot blocked for spacecraft activities (duration 15 minutes)
- …
- …
- Pointing on target #n (last target)
- Instrument from prime to stand-by.

A Planck autonomous sequence operation can be (Planck is a survey type mission and as the instruments operate in parallel autonomous sequence of operations are simpler than the Herschel ones):

- ACMS calibration (10 minutes)
- Every 45 minutes (in average), precession manœuvre to follow scanning law.
- Spacecraft activities (if needed, in parallel to scientific observation)

During autonomy period the ground prepares the activities which will be carried out during the DTCP and the MTL which shall cover the next 48 hours.

6.5.3.4 Calibration

This section provides the basic operational concept for the Herschel system pointing calibration. Note that Planck calibration is performed by instrument teams according to SRS 3.0.

6.5.3.4.1 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.

Section 4.2.3.5 (Routine Operations Phase) of system requirement specification issue 3.0 mentions that "The OP (observation period) will in general start with a brief calibration period, still under ground control".

The calibration will be performed such as to point both the instrument and the ACMS sensors (Star Sensors, Sun Sensors, ...) toward targets with well known directions. The resulting ACMS attitude estimation will be compared with payload attitude data. The calibration will take few minutes in order to reduce the uncertainty due to random sources.

The result of the calibration process is used for target attitude generation (bias compensation). The frequency of the calibration of target attitude generation correction will depend on ground routine calibration results as mentionned in SRS 3.0 (as a comment "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").

6.5.3.4.2 System requirement specification issue 3.0 requirement 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.

Discussion: 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.

The nominal operational procedure which is in line with the pointing philosophy defined in IID-A 3.0 and which assumes all healthy instruments, is:

First to 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 of the document.

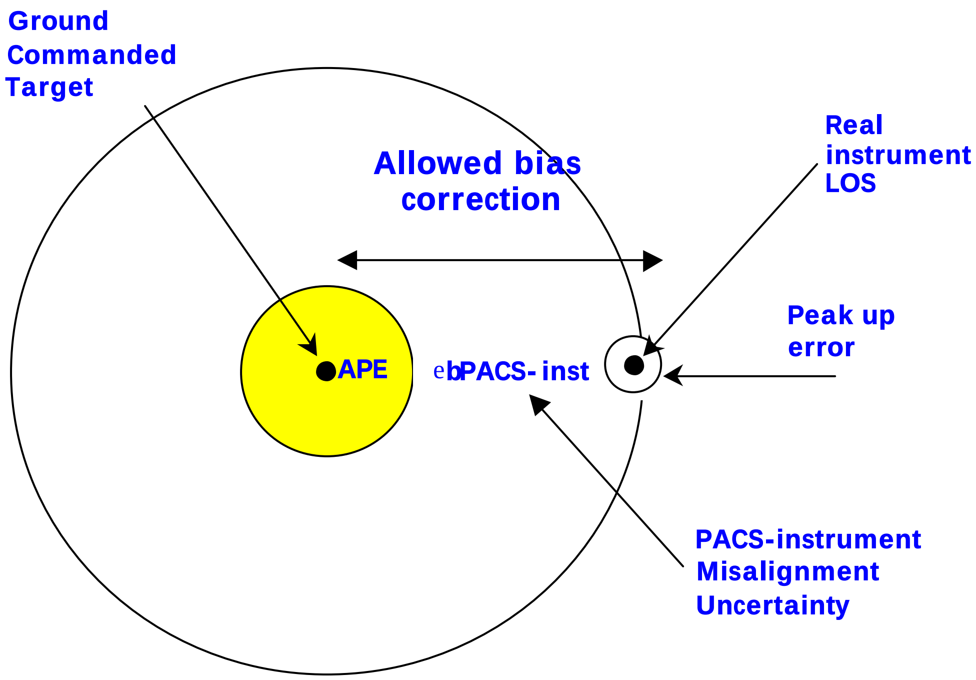
With the ACMS & PACS raw telemetry acquired during these observations, the bias between PACS LOS and ACMS sensor LOS will be estimated at ground level.

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 3.0 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.

Discussion: these 3 last requirements have been implemented at SVM level by GOF-165-H, GOF-170H, GOF-175H requirements and at ACMS level by section 4.1.3.9 and 4.1.3.9.1 requirement (H-P-SP-AI-0011 issue 2). Note that these requirements are concerning "on board" calibration without ground intervention. 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 and the raster pointing sequence (part of peak up procedure) to the ACMS.

The system alignment requirements between PACS and others instruments are presented in Herschel system alignment plan (reference H-P-2-ASPI-PL-0276). They are such, that combining them with the peak up bias correction error (given to be less than 1 arcsec), the real pointing of the SPIRE or HIFI LOS will stay in the allowed domain required by MOOM-115 i.e. 10 arcsec.



The current required misalignment knowledge between PACS LOS and other instrument LOS is better than 3.6 arcsec.

So, the constraint APE (3.7")+ PACS/instrument misalignment uncertainty (3.6") + peak up accuracy (1") < allowed correction (10") is verified.

In these conditions, peak up procedure will work and correction will be sent to ACMS and ground. Pointing will be corrected by ACMS and the correction value transmitted to ground may be used for future pointing.

No new correction will be transmitted during next single observation (as written in MOOM-105). The notion of_single observation should be clarified by ESA in particular wrt tot Herschel pointing modes defined in SRS annex.

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.

6.5.3.4.3 Recall of assumption taken in the pointing allocation

It is clear that at least, an initial calibration is needed since ground, launch and orbital effects will induce such misalignment that pointing performance will not be reached without calibration. It has to be noted that a maximum misalignment (0.3°) is specified via TN "Inputs to Herschel system alignment plan" reference H-P-2-ASPI-TN-0217. This value is considered in the system alignment plan.

The performance of that calibration shall provide (see TN [Herschel and Planck pointing budget module allocation reference H-P-1-ASPI-BT-176 issue 3.]) a residual value better than 0.67 arcsec (68 % confidence level).

The residual calibration error is computed by:

$$\Phi_{rc}(68\ \%) = \sqrt{[(\Phi_{ib}^2 + \Phi_{sb}^2)/n_{obs}]} + \sqrt{[(\Phi_{in}^2 + \Phi_{sn}^2)/n_{samp}]}$$

where:

Φ_{ib}(68 %) Instrument bias error of each observation in the functional reference frame of the instrument

Φ_{in}(68 %) Instrument noise in each read out sample

Φ_{sb}(68 %) ACMS estimation bias error of each observation in the functional reference frame of the sensor

Φ_{sn}(68 %) ACMS estimation noise in each read out sample

n_{obs} Number of observed calibration sources

n_{samp} Number of samples used for filtering

This 0.67 arcsec value takes into account the following conditions:

- Number of observation: 3 observations are considered to minimise bias effects in residual value
- Number of samples: at least, 100 samples are considered to filter noise.
- STR performance: 0.8 arcsec absolute bias value, 0.0053 arcsec bias stability during calibration period, 0.064 arcsec noise (68 % confidence level). Values are taken from "ACMS baseline overview" TN reference H-P-4-DS-TN-009.
- Instrument performance: 0.33 arcsec absolute bias value, 0.05 arcsec bias stability during calibration period, 0.05 arcsec noise (68 % confidence level). Values are defined in IID-A 3.0.

6.5.3.4.4 Associated constraints

6.5.3.4.4.1 Field of view constraints (instrument & ACMS STR)

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 is1.75' x 3.5' (= 0.0291° x 0.0583°). 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° x 0.058°) = 52 points shall be commanded. This will not be the case for following calibrations since requested half cone LOS variation are far less than instrument FOV.

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.

- **First calibration shall be performed in DTCP**
- **For first calibration, a raster pointing (small rotation of field of view size) shall be initiated if object in PACS (or others instruments) FOV is not present.**

6.5.3.4.4.2 Duration of the calibration

The duration of the first 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 STR frequency is 2 Hz. Instrument frequency is higher. It means that 52 minutes for the first calibration (around 1 minute for each raster point) and around 1 minute for the following calibrations per observation are necessary.

Then, satellite has to rotate to the next observation. A worst case of 30° rotation is considered. Maximum specified slew speed is 7 deg/min. But as it will takes time to reach full velocity, a rough order of 10 minutes for the slew is allocated (will be refined when consolidated ACMS performances will be available).

- **As 3 observations are baselined, the total duration of the calibration is thus around 3 hours for first calibration and 40 minutes for the following calibrations. The slew time and the temperature stabilisation period may be added in case the attitude during calibration leads to a significant variation of temperatures compared to the attitude prior to calibration.**

6.5.3.4.5 Calibration periodicity

6.5.3.4.5.1 daily 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 the bias variation amplitude with respect to last calibration. This variation shall be less than the specified value: 0.22 arcsec for HPLM and 1.15 arcsec for SVM. Applying a RSS sum, it gives 1.17 arcsec half cone. The criteria shall be valid with a margin associated with the calibration residual for one observation (0.9 arcsec at 68 % confidence level). This 0.9 arcsec value is computed with formula and value of section 4 except nobs = 1.

So each day, current bias between ACMS LOS and instrument will be computed choosing 1 minute of observation period. And following check will be performed:

- **Proposed daily check is |Current bias - last calibration bias|<3*(1.17 + 0.9) arcsec.**

NOTE: the factor 3 takes into account the fact that 1.17 and 0.9 values are given at 68 % confidence level.

6.5.3.4.5.2 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) 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.**

6.5.3.4.6 Conclusion

A basic operational concept for the Herschel system pointing calibration has been proposed. After the first calibration is based on 3 observations, a daily operation applied on nominal telemetry will check if new calibration is necessary. The expected calibration period is 1 month.

All figures given in that section (calibration duration, daily check threshold, …) will be updated along the project life.

6.5.4 FDIR

6.5.4.1 High level requirements

The main drivers for the FDIR strategy elaboration 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 optimized, Herschel cryostat Helium shall be preserved, and reconfiguration and equipment loss shall be minimized.

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.

6.5.4.2 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 will lead to reduction of the operational costs by allowing the use of the same FDIR concept for both spacecraft.

6.5.4.2.1 Failure Classification

According to potential effects on equipment units, function, computers (CDMU and ACC) or system performance, several failure levels have been defined. The different levels are detailed in the following sections, while the overall breakdown is summarized in Table 6.5.4.2-1.

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 6.5.4-1 FAILURE CLASSIFICATION

Failure types have been split up into **5 main levels** (Level 0 to Level 4) characterized by:

- The failure severity
- The recovery sequence
- Functions involved in the detection (H/W or S/W functions).

The different levels are detailed hereafter.

6.5.4.2.1.1 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.
- Arithmetic error in processor module, detected by Software, which raises an internal interruption. A specific recovery procedure is then carried out by software application. This procedure shall contain at least an arithmetic error counter increase and a TM report. The impact on the involved application is negligible and is null on the other applications.

Multiple (number selectable by ground) occurrences of Level 0 failure shall lead to higher level recovery actions (unit/coupler/computer reconfiguration). Then, level 0 failures will be reported to the higher level.

6.5.4.2.1.2 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 surveillance 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.

The status of each equipment unit is monitored by the CDMS S/W or the ACMS S/W depending on the unit. This status will be compared to unambiguous thresholds to possibly initiate recovery actions. 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.

Two sub levels are considered, 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:

- ACMS sensors
- ACMS actuators
- PCDU
- TTC transponders
- CCU for Herschel
- TWTA
- Thermal Control Equipment
- Instruments.

Failure of these equipment units are detected by related ACC or CDMU software application. Failure detection is based on unit specific health data and operational parameters.

Any ACMS unit reconfiguration action shall be reported to the CDMS, with the past and current unit contexts, and the safeguard memories shall be updated in accordance with the updated spacecraft configuration.

Level 1b relates to failures at communication units level, and as such can be considered as multi-application related.

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 described in the appendix 9 of the PS-ICD (AD03.3), 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.

6.5.4.2.1.3 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 implicated in, by either the two CDMS or ACMS on-board Software.

6.5.4.2.1.4 Level 3

A level 3 failure is considered as an internal computer unit (CDMU or ACC) failure, more severe than Level 0, such that the computer unit cannot neutralize it autonomously.

FDIR Level 3 corresponding errors will be 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).

Level 3 failures are typically:

- PM bus error, detected by H/W
- Memory protection violation, detected by H/W
- Any hardware watchdog
- CPU instruction error, detected by S/W.

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 (reset for a 3a alarm or switch to the redundant unit for a 3b alarm).

6.5.4.2.1.5 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 shall be detected by dedicated independent system alarms and directly hardwired to the relevant reconfiguration module (ACC_RM or CDM_RM).

Level 4 recovery action shall be performed by the proper reconfiguration module (CDM_RM or ACC_RM).

The following table lists the minimum failure cases to be 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 angles
	Thruster over activation or Thruster failure
	Fuel over consumption (Thruster over activation or Thruster failure)
Power supply function	Battery overcharge
	Bus undervoltage
	Power loss

TABLE 6.5.4-2 SYSTEM FEARED FAILURES

From this list of system potential failures, 5 system alarms have been considered. Retained alarms are at a minimum (TBC):

- Loss of proper Sun Pointing **(SP)**
- Violation of Thruster On Time **(TOT)**
- Depth of Discharge **(DOD)**
- Bus Under Voltage **(BUV)**
- Rate Anomaly **(RA)**.

SP, RA and TOT alarms are handled by the ACC_RM.

DOD and BUV alarms are handled by the CDM_RM.

It has to be 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 shall be instantaneously taken into account and satellite shall directly go to survival mode 1.

When a level 4 alarm is activated on CDMU, it shall be instantaneously taken into account and satellite shall directly go to survival mode 2.

6.5.4.2.2 FDIR Modes

To fit the mission requirements, FDIR concept is organized around two main points:

- The failure classification, which has been exposed in the two previous sections
- The FDIR modes.

FDIR modes are associated to System modes and aim to support the mission observation. 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 System mode is associated to one of these FDIR autonomy modes.

6.5.4.2.2.1 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 minimizing 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.

6.5.4.2.2.2 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 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.

6.5.4.2.2.3 Relation between Satellite modes and FDIR modes

A FDIR strategy is applied according to the current satellite mode, this FDIR strategy being defined by an adapted FDIR mode (i.e. AFO or AFS).

For each satellite mode, the corresponding FDIR modes shall be as described in the table hereafter.

Satellite Modes		Sub-mode	AFS	AFO	N/A
Launch Mode	LM				x
Housekeeping Modes	HK1		x		
	HK2	V	x		
		NV	x		
Survival Modes	SM1				x
	SM2				x
Science Mode – Autonomy	AUT			x	
Science Mode - Telecom	TC			x	

TABLE 6.5.4-3 RELATION BETWEEN SATELLITE ET FDIR MODES

For launch mode and both survival modes (i.e. SM1 and SM2), FDIR modes concept is not applicable.

Indeed, for part of the launch mode, Herschel/Planck spacecraft are still inside the launcher. Then it has to be impossible to switch System mode into one of both survival modes.

Similarly the Survival Modes are not directly concerned by FDIR modes. As explained earlier in the chapter, FDIR modes correspond to a reconfiguration strategy. One of the several actions included in a reconfiguration sequence could lead (after failure detection and Identification) to a switch into survival mode which is the ultimate status.

6.5.4.3 General 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 periodically saved 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 memorize all the system and units configuration necessary to ensure autonomous failure recovery, and to save the failure context for later analysis (eg. attitude data). Note that the design of 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 issueing High Priority Commands called HPC_CDM when originated from the CDM_RM, and HPC_ACC when generated from the ACC_RM.

CDMS FDIR and ACMS FDIR communicate via either S/W messages (e.g. events TM packets, TC accepatance report packets) for low level alarms, and H/W signals for high level/system alarms. An important feature is that any failure detection isolation and recovery procedure can be individually enabled or disabled by ground commands.The CDMS is in charge of the management of the Mission TimeLine and sends dedicated time-tagged commands to the ACMS. It is thus necessary to ensure a coherence in the satellite behavior even in case of failure of the CDMS-ACMS communication link. Additionally in case of ACC or CDMU reconfiguration, the ACMS or the CDMS respectively is unavailable for a certain time (e.g. reboot/init time). 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 recommandations partly driving the present implementation are detailed in RD03.20.

ACMS unavailability

The ACC_RM reports a status signal to the CDMS, via a reliable status link called AIR[6], to inform of its unavailability. For failure tolerance reason the status link is hardware and independent from the communication link.

[6] AIR : ACMS in Reconfiguration

CDMS unavailability

During the CDMS unavailability, Herschel and Planck spacecraft have to be maintained in a safe mode, command/control function and Mission Timeline service being temporarily unavailable. The spacecraft shall be put in a safe attitude by the ACMS.

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 SIR[7] status signal in case of CDMS reconfiguration triggered by a level 4 alarm (power alarm : Battery DoD or Bus undervoltage), to request ACMS to reach a status and put the spacecraft in an attitude, safe w.r.t. power generation ; in Sun Pointing Mode.

– The CIR[8] status signal in case of CDMS reconfiguration triggered by a level 3 alarm (computer level anomaly), to request ACMS to put the spacecraft in an Earth pointing attitude 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.

Communication link unavailability

Some information (e.g. synchronization words) 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.

The basic mechanism is such that if the CDMU doesn't receive the information expected from the ACC Remote Terminal through the nominal bus, the CDMU switches over to the redundant bus. If the ACC doesn't receive the regular information expected from the CDMU (e.g. time synchronization messages), a time-out alarm inside the ACC is triggered to initiate a reconfiguration of the ACC remote terminal.

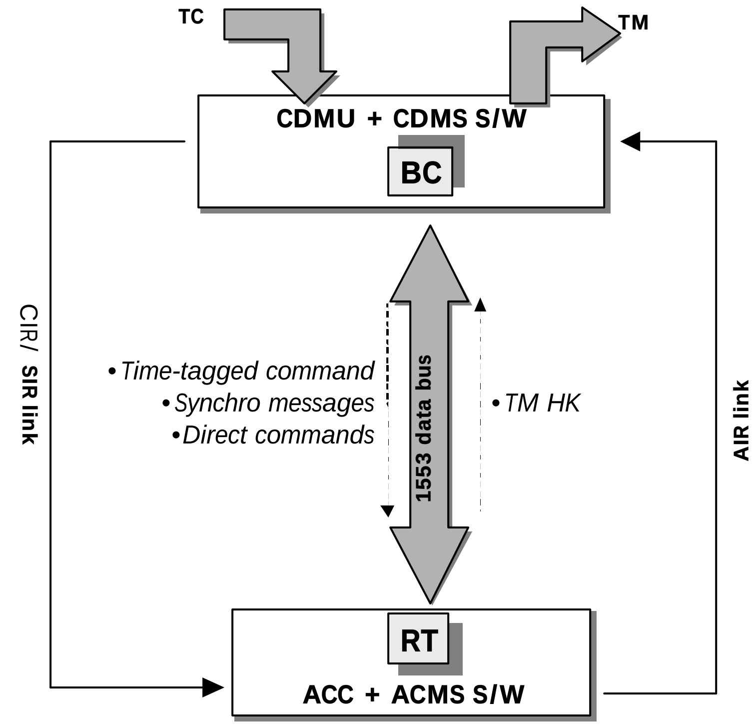


FIGURE 6.5.4-1 CDMS/ACMS COMMUNICATION

[7] SIR : Satellite in Reconfiguration
[8] CIR : Computer In Reconfiguration

6.5.4.4 FDIR Strategy

The FDIR strategy is defined for both spacecraft : each phase, from an autonomy and FDIR point of view is declared as autonomous fail safe or autonomous fail operational. For each system mode, depending on the operational life phase, the top level requirements (AFO, AFS) are refined at lower levels.

The proposed principles and protocol for the system level FDIR implementation, i.e. the synchronization of the two FDIR subsets, are based on some general rules detailed hereafter.

6.5.4.4.1 Platform

The hierarchical failure detection identification and recovery architecture allows to satisfy the top level requirement to have a visible impact on the mission operation, 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 System mode, 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 security, are detected by dedicated hardware alarms and handled independently from on-board software tasks (by the mean of high level commands issuing).

For the functions, units and the interfaces, software monitoring is implemented within one of both computing subsystem (i.e. ACMS and CDMS), depending on their respective control.

6.5.4.4.1.1 MTL Management associated to FDIR actions

As expressed is §6.5.1, one of the main features of the operational concept is the Mission TimeLine which execution is centralized at the level of the CDMS. The MTL is stored in the CDMU, in a non volatile memory area. The MTL represents the mission plan, and as mentionned in §6.5.4.1, one of the drivers of the FDIR strategy is, as far as possible, to help to pursue this plan.

However, as a consequence of failures, reconfigurations are performed, depending on the failure type and the spacecraft mode (which drives the FDIR mode, AFS or AFO, see table 6.5.4-3); these reconfigurations may interfere with the MTL execution, and the present section addresses the way the interfaces between the MTL and the failure cases are managed such that the MTL can be continued. This issue is detailed in a dedicated Technical Note RD03.20.

Failure at CDMS level

As long as the CDMU processor modules states are not involved in the detected failures nor in the reconfiguration sequences, i.e. for levels 0 to 2 CDMS failures, the MTL can and will be continued with no significant impact.

If the CDMU processor modules are involved in the reconfiguration processes, two distinct conditions are considered :

1- the reconfiguration is due to a CDMU level 3 failure

As it has been presented before, the first occurrence is labeled level 3a. In this case, the baseline is to restart the MTL only for the telecommands addressed to the CDMS and to the units directly managed by the CDMS (PCDU, TTC, …). All the subschedules “belonging” to the instruments are disabled, and the ACMS configuration is described in section 6.5.4.3 “CDMS unavailability” : a Safe, Earth pointed, attitude is adopted.

The second occurrence is labeled level 3b. In that case, the baseline for a level 3b is to not restart the MTL : the failure 3b recovery sequence is then such that :

- the CDMS and related units are in a stable "safe mode"
- the ACMS is requested to initiate an Earth Pointing as for level 3a failure
- the instruments are put in a defined Standby Mode

2- the reconfiguration is due to a CDMS level 4 failure

It leads to a complete CDMS level reconfiguration with a switch over to the redundant units, including the processor module. Level 4 failures are system level "critical" failures and a restart of the MTL in these conditions is consequently not baselined.

The ACMS configuration is described in Section 6.5.4.3 "CDMS unavailability": a Safe w.r.t. power, Sun Pointing Mode is triggered..

The configuration of the other satellite units, including the instruments is established by the reconfiguration sequence. Basically, only the essential loads are kept ON, and the instruments are turned OFF via CDM_RM HLC.

Failure at ACMS level

The general consequences of any reconfiguration are that :

- The expected performance (pointing, orbit correction) may not be ensured during the time of reconfiguration: the instruments will be mis-pointed with respect to ground planning via the MTL. Note that this is definitely not considered as a critical issue, just a mission degradation:

It may happen only in case of specific maneuver / reconfiguration

It will be reported in the down-linked telemetry data and be signified to the involved instrument (s).

- The reconfiguration sequence may not be achieved when the next MTL command occurs. In that case, the ACMS may not be ready to immediately execute the received command (because still under reconfiguration).

Two cases must be considered :

1 -the recovery is fast enough to maintain the control error within acceptable limits which depend on the controller implementation.

This is the nominal case in the sense that by design, no anticipated single failure should prevent the satellites to catch up with their pointing target in Spacecraft Science Mode. The Reaction Wheels unloading activity , for Herschel, will be programmed via the MTL to prevent any wheel saturation in normal operation.

In order that the ACMS can propagate the targeted attitude, regardless of the failure (levels 0 to 2 failures), the relevant MTL commands sending to the ACC will never be interrupted.

2- The recovery is such that the requested control error cannot be kept within the acceptable limits.

As mentioned above the ACMS is designed not to face this situation in case of single failure at ACMS level. Nevertheless a failure at CDMS level followed by a reconfiguration, or an erroneous MTL TC, may indirectly induce an interruption, momentarily or permanently of the MTL commands issuing, which could eventually result in having, in the case of Herschel, an autonomous reaction wheels unloading sequence to be started, or a non optimum pointing attitude to be kept. This case actually corresponds to the one addressed in section 6.5.4.3 “CDMS unavailability” : it leads a “safe attitude” to be adopted (Sun or Earth pointing depending on the failure). When in one of these modes, routine MTL telecommands be ignored.

Failure at instrument level

It is anticipated that the instruments will not be in a position to receive and process the MTL commands at the same time than the recovery activities or commands (OBCP's) possibly triggered by the reception of the "event TM" signaling an anomaly to the CDMS.

Consequently, upon instrument failure notification, the MTL commands related to this instrument within the running subschedule belonging to the failed instrument will be disabled.

Because the number and type of commands which would be missed by the instrument while it is recovered is not predictable, the MTL commands for this instrument will be re enabled only if:

- the instrument has notified its return to a nominal operating mode
- **and** the running subschedule belonging to the failed instrument is completed.

After an instrument failure is recovered, its activity is resumed at the next subschedule.

6.5.4.4.1.2 Failure recovery strategy

The following tables illustrate the CDMS failure recovery strategy. 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	• Stop boost (if applicable) • Save failure context • 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	• Stop boost (if applicable) • Save failure context • Switch over to the redundant bus coupler or direct interface using SGM configuration • Resume operations

TABLE 6.5.4-4 LEVEL 1 FAILURE RECOVERY STRATEGY

FAILURE LEVEL		DETECTION PROCEDURE	FAILURE RECOVERY	
			AFS Mode	AFO Mode
2	Main function failure	OBSW performance check	• Detect failure only. Isolation and recovery will be performed if levels 3 or 4 are triggered	• Stop boost (if applicable) • Save failure context • Identify the failed unit by a consistency cross check or possibly switch over to the redundant functional chain • Resume operations

TABLE 6.5.4-5 LEVEL 2 FAILURE RECOVERY STRATEGY

<table>
<tr><th colspan="2" rowspan="2">FAILURE LEVEL</th><th rowspan="2">DETECTION PROCEDURE</th><th colspan="2">FAILURE RECOVERY</th></tr>
<tr><th>AFS Mode</th><th>AFO Mode</th></tr>
<tr><td>3a</td><td>CDMU or ACC internal failure – first occurrence</td><td>Nominal processor module HW alarm or SW watch dog</td><td>• Stop boost (if applicable)
In case of CDMU internal alarm: Send a CIR signal to the ACMS, to ask for an Earth pointed attitude
• Save failure context
• Reset the nominal processor module.
• Load SGM context
• Wait for Ground TC to re-engage MTL service</td><td>• Stop boost (if applicable)
• In case of CDMU internal alarm: Send a CIR signal to the ACMS, to ask for an Earth pointed attitude to be adopted
• Save failure context
• Reset the nominal processor module.
• Load SGM context
• Disable all instruments subschedules
• Autonomously re-engage the MTL service for the CDMS controlled units</td></tr>
<tr><td>3b</td><td>CDMU or ACC internal failure – second occurrence</td><td>Nominal processor module HW alarm or SW watch dog</td><td colspan="2">• Stop boost (if applicable)
• In case of CDMU internal alarm: Send a CIR signal to the ACMS, to ask for an Earth pointed attitude to be adopted
• Save failure context
• Switch over to the redundant processor module from SGM
• Load SGM context
• Wait for Ground TC to re-engage MTL service</td></tr>
</table>

TABLE 6.5.4-6 LEVEL 3 FAILURE RECOVERY STRATEGY

FAILURE LEVEL		DETECTION PROCEDURE	FAILURE RECOVERY	
			AFS Mode	AFO Mode
4	Global satellite malfunction	System Alarm	• Stop boost (if applicable) • Disconnect non essential loads • Suspend MTL service • In case of CDMU internal alarm: Send a SIR signal to the ACMS, to trigger a Sun Pointing Mode • Save failure context • Switch over to the redundant processor module from PROM • Switch to satellite survival mode : SM2 • Wait for ground TC to re-engage MTL service	

TABLE 6.5.4-7 LEVEL 4 FAILURE RECOVERY STRATEGY

6.5.4.4.2 Instruments

Instruments function is obviously fundamentally different from the platform units one: the instruments perform the scientific mission while the SVM provides the operational means to support these instruments.

However, as far as FDIR is concerned, the baseline principle is to manage the instruments as ordinary units through the hardware connecting them to the CDMS. Instruments failures shall therefore be treated as level 1a failures, with the following noticeable differences though:

- the instruments failures detection and recovery is nominally ensured:

by the instruments themselves, spacecraft actions being possibly requested via the emission of event TM packets. The failures requesting the intervention of the spacecraft and the associated reconfiguration procedures are defined by the instruments.

by the CDMS SW via a monitoring of the amount of science data delivered by the instruments (number of TM packets) : if the data generated is not the expected one, it is assumed that this reflects an instrument anomaly (e.g. the instrument software has got stuck), and will basically lead to a switch over to the redundant instrument electronics (TBC by instruments).

- an instrument anomaly detected by or reported to the CDMS implies, as detailed in previous chapters, that the running subschedule belonging to the failed instrument is temporarily disabled.

6.6 External interfaces

6.6.1 Ground segment interfaces

This chapter describes all the means, hardware and software, by which the satellites interface with the ground segment. These means are all the tools available to support the overall concept of operations which has been addressed in the dedicated section § 6.5.1.

6.6.1.1 General

This chapter describes all the means, hardware and software, by which the satellites interface with the ground segment. These means are all the tools available to support the overall concept of operations which has been addressed in the dedicated section § 6.5.1.

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.

During scientific observation, Herschel and Planck share the same Prime ground station: New Norcia 35 m. The main features of the interface with the ground are:

- daily ground contact of 3 hours for each spacecraft. During this ground contact the spacecraft shall as a minimum dump 24 hours of stored telemetry, and receive upload of the mission timeline. In fact, the memory is sized to store 48 hours of scientific data: to be able to download 2 days data, some margin shall be available in the daily time communication period in order to be able to recover from the loss of one telecommunication pass

– during Initial Orbit Phase and transfer, alternative ground stations are planned to be used. These are 15 m ground stations with characteristics similar to the Kourou one. In case of emergency, such ground stations are planned to be used in order to increase the daily coverage. Daily contact is however limited to 6 hours in case of emergency.

Herschel and Planck ground interface is illustrated in Figure 6.6.1-1.

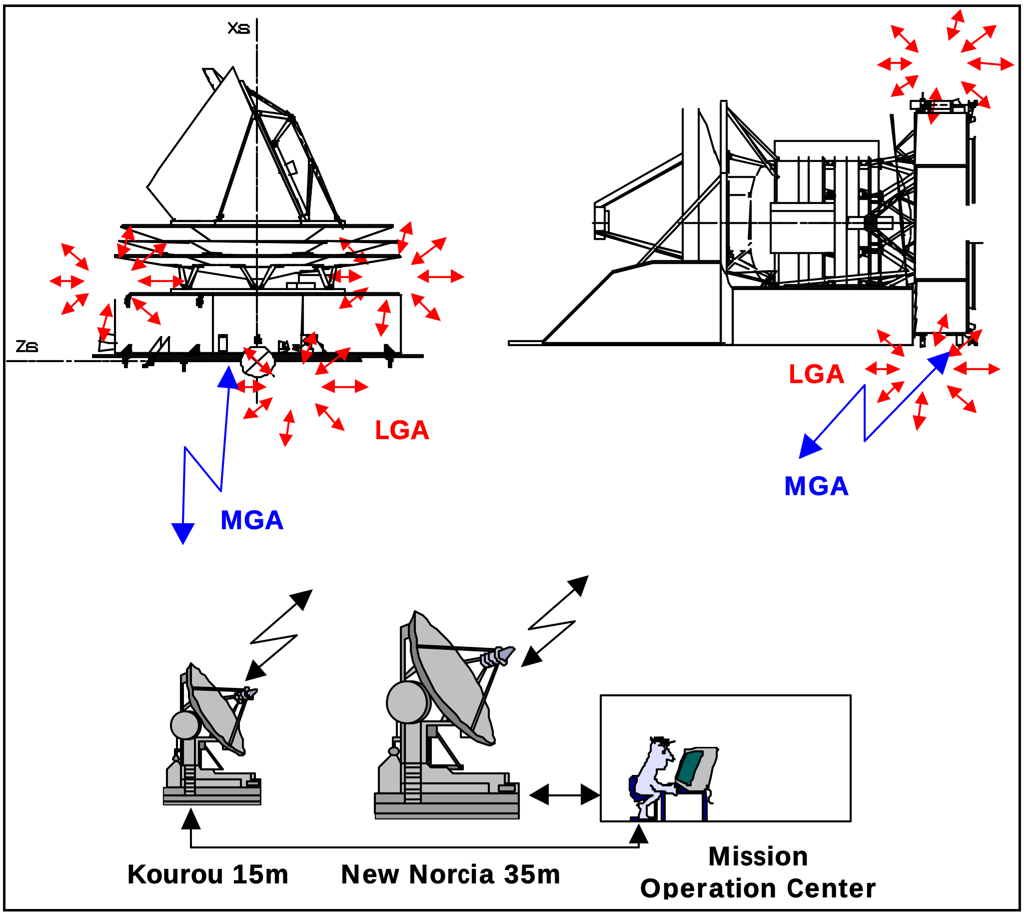


FIGURE 6.6.1-1 SPACECRAFT GROUND INTERFACE

6.6.1.2 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
- 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 may be selected for the GMSK modulated high rate to guarantee the proper transition density at the ground station level.

6.6.1.3 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.

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.

6.6.1.4 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.

6.6.1.5 Operations

6.6.1.5.1 Operational interface

The main interface with operations is represented by the packet telemetry/telecommand protocol, enriched by the specification of eighteen Services which mainly define the types of packets, and the way to elaborate and process them.

6.6.1.5.1.1 General spacecraft control

The following general features are implemented within the on-board telemetry/telecommand system of Herschel and Planck.

Telecommand

– All telecommands are received from ground as TC packets, and similarly, commands generated on-board and addressed to intelligent users (namely payload instruments and ACMS Computer) are forwarded as TC packets. Each addressee of the telecommands is nominally identified by a unique APID, while each TC packet type is itself identified by a unique SID. The total number of SID depends on the operational interfaces with the reception, but is kept as low as possible.

  All telecommand received on Board are stored in Mass Memory for possible checking purpose.

– Execution of Critical Commands (no hazardous commands is identified on Herschel/Planck) is implemented via 2 “arm” and “fire” commands. This shall basically be the case, for Herschel, of the commanding of the NCA to open the cryo cover after Launch. For the Execution of vital functions, which may cause mission degradation if not executed, is implemented via 2 differently routed, down to the source, main and redundant telecommands. For instance, LCLs switching is performed via the commanding of the nominal (resp. redundant) CDMU, then the transmission via the nominal (resp. redundant) bus interface to the nominal (resp. redundant) PCDU branch to switch the nominal and/or redundant limiter. These features rely on the electrical architecture design.

– A telecommand packet contains only one telecommand function.

– All on-board devices, i.e. units can be commanded individually from ground, except TC decoder modules, Reconfiguration electronics, RF receivers and survival heaters which are permanently supplied via FCLs (see § 6.3.4).

– An adequate buffering of transmitted commands is foreseen on-board to allow a verification, validation and unimpeded execution of the received TC in parallel to the reception of TCs with the maximum specified rate (4 kbps). Commands not compliant with the packet standard are rejected at decoder level then at software level.

– Besides general SW memory load commands, special commands are foreseen to change dedicated parameters and on-board data.

Telemetry

– Symmetrically, telemetry is collected from the intelligent units as TM packets, identified by the same APID than the one used for telecommanding.

– Data acquired as discrete signals or non packetised formats, from a given unit are packetised by the CDMS SW and stamped with the APID corresponding to that given unit. Nominally status information is provided from direct measurements instead of from secondary effects.

– TM packets are organised in:

housekeeping packets

science packets

TC report packets

Event report packets

Memory dump packets

context packets (TBC).

Instrument science packets acquisition is performed according to a Data Bus Profile which allocates an agreed bus bandwidth and further a storage capability to each instrument depending upon its mode of operation and corresponding data rate.

– A predefined bandwidth is reserved for the event packets collection, i.e. the packets generated to signal an event. All data which is collected on board is stored in Solid State Mass Memory.

– The housekeeping telemetry is generated such that the S/C status, performance, and the current on-board activities are recorded and stored, then transmitted to ground.

This means that TM is prepared such that:

the S/C status can be determined directly without need to request further information by TC

the status of the command executed on-board is provided

all parameters used as inputs to OBCP's, Functions, and all changeable parameters are available in TM

units level raw housekeeping data is accessible to ground

critical TM data is provided under redundant paths, independently routed.

Autonomy and fault protection

The Autonomous phase is specified as 48 hours without ground contact and without mission interruption, and 7 days in a safe mode, without ground intervention.

– Sufficient memory is allocated to the Mission Timeline and control procedures buffers to cope with the 48 hours mission autonomy. Also, the size of the Mass Memory is adjusted to cope, with margins and in End of Life, with the storage requirements induced by the autonomy duration specification.

– As a design principle in Science Mode (see § 6.5.2), the management of anomalies is hierarchical, such that the anomalies are sought at the lowest possible level and does not lead to higher level recovery until low level reconfigurations have been tried. This ensures the best satisfaction of the 48 mission autonomy requirement.

– The survival Mode is entered:

manually upon ground telecommand (TBC)

autonomously (default) when all possible lower level recoveries to an anomaly have been exhausted, in line with Satellites Modes description in §6.5.2 and FDIR strategy in § 6.5.4.

– When in survival Mode, the spacecraft:

maintains essential on-board functions, including fault protection mechanisms

reports via event packets the anomaly conditions and the recovery actions

generate a minimum set of TM packets to allow immediate identification of the survival mode, and makes available, stored in Mass Memory and in Safeguard Memory, the spacecraft detailed history before and after the anomaly occurrence.

– The fault protection system is detaily addressed in Section 6.5.4; it is designed such that:

the fault protection processes can be individually enabled/disabled

all the parameters used in the fault protection processes can be read and updated

the spacecraft configuration is continuously saved in protected memory, nominally the Safeguard Memory (either the CDM_SGM or the ACM_SGM) to permit a safe automatic transition.

Packet services

As mentioned previously, eighteen services define the main tools made available for the satellites operation, based on the TM/TC packet protocol. These can be broken down into 3 categories: commanding, monitoring, management.

Services related to the **commanding** of the satellites:

- **Service 2** device commanding, defines the capability to directly command the hardware devices via the TC decoder and using specific APID. Service 2 is fully applied to CDMS. However, as far as Attitude Control Computer is concerned, the TC decoder being obviously not present, it is anticipated this service to be handled at the level of the 1553 protocol, via the use of Command Words.
- **Service 19** is a complement to service 5 addressed later. It implements the capability to react to an "exception event" by issuing a telecommand depending on, the event identifier. The service is table driven via the maintenance of an "action list".
- **Service 20** information distribution, establishes the principles of the distribution to all intelligent users connected on the spacecraft data bus (namely instruments and Attitude Control Computer), of a broadcast telecommand containing information of interest to the users.

Services related to the **monitoring** of the satellites:

- **Service 1** Telecommand Verification, defines dedicated TM packets indicating within TBD seconds from the TC reception, the status of reception, execution and completion of the TC. The application source of the TC, (ground, mission timeline, OBCP,...) is clearly identified. It shall be pointed out that clustered acceptance and verification packets are foreseen to reduce the total number of TM packets related to TC verification. A realistic alternative is to implement this service using the service 5, event packets.
- **Service 3** deals with the expression of the spacecraft observability. It is implemented via 2 ways, and an appropriate downlink bandwidth is reserved accordingly:

synthetic pre defined TM to characterize the status of the spacecraft and indicate whether anomalous conditions have occurred. This TM is permanently generated and stored for transmission

special diagnostic TM packets to make possible accurate failure analysis or analysis of an event.

This implementation principle is applicable to CDMS SW and to ACMS SW.

- **Service 5** supported by the Service 19, defines one of the principles of operation of the spacecraft. It is based on the events reporting, which consists in pre defined TM packets triggered upon the occurrence of on board events classified into:

normal events, which refer to all important on-board activities, autonomous actions

exception events, which refer to anomalies to be handled by the board. This category is the one involved in the Service 19

Alarms events, which refer to anomalies to be managed by the ground.

Each type of event packet is uniquely identified via its own APID, which permits its immediate detection on-ground thus making possible a reaction in less than 3 mn, as specified, when in visibility.

The downlink bandwidth allocated to events reporting is reduced by reporting anomalies in nominal on their first occurrence only.

- **Service 16** a TM packet is defined to report the status and performance of the on board traffic, at packet level. Some statistics on the packet bus management are made available to ground. The on-board implementation of the packet management is table driven, which permits by simple telecommands to disable the routing of TC packets.
- **Service 17** in addition to the possible self checks, the capability for the ground to ask a synthetic "are you alive?" question to all intelligent users (TBC for payload, but desirable) is defined. "Yes I'm alive" TM packet type is expected in response.

- **Service 21** the science data, as mentioned before, is table (IPT) driven; this table can be changed such that packet collection from a given instrument is enabled/disabled.

Services related to the **management** of the spacecraft:

- **Service 6** it relates specifically to the memory management

  As a major principle, any SW, e.g. any memory area, except PROMs, can be loaded/patched from ground using a dedicated TC. Three types of memory areas are distinguished: code, fixed data variables and parameters.

  Any memory load TC packet is self consistent and does not depend on previous packets. This TC is:

capable to load contiguous memory area

protected by CRC such that it can be checked on-board for consistency, and rejected before execution.

  Symmetrically, any memory area (including non volatile and mass memories) can be dumped. Contrarily to the Memory Load TC, there is one single Dump TC for a given Dump, even though the area to dump is distributed over a number of TM source packets.

  In addition, a check of a defined memory area can be commanded, consisting in the computation and report to ground of the checksum of this area.

- **Service 8** is related to the control of spacecraft Functions, possibly mixing hardware and software. Functions provide essential spacecraft functionality (e.g. Thermal Control is a Function). It is a major operation feature giving the possibility to act at Function level via dedicated TC packets. Functions can be started/stopped and received parameters.

- **Service 9** deals with the Time management: The spacecraft time reference (CTR) is maintained within the CDMU and is distributed to intelligent users, ACC and instruments) to have a common datation basis (e.g. to make ACMS sensors acquisition synchronised with payload datation). The synchronisation protocol is detailed in the Herschel/Planck Packet Structure ICD, AD03.3.

  Specific TM permit to verify the proper units synchronisation.

- **Service 11** addresses the scheduling of the planned operations of the spacecraft. These are based on the Mission TimeLine, which is a facility to control and execute at pre defined times commands which have been loaded in advance from ground during visibility periods. Any telecommand, but those explicitly excluded, can be used in the MTL. The MTL runs only at CDMU level and the service is always active at start-up. It can however be suspended/resumed by TC.

  Without stopping the MTL, it is possible to prevent the execution of a specified subset of commands using their APID, and to insert, append and delete commands to/from it. The deletion is performed using different filters:

all commands

from a specified time onwards

between specified times

individual commands

commands within a dedicated APID.

  For commands with the same execution time, the order of the uplink is applied.

  The MTL granularity is 1 s and as mentioned, the MTL buffer is sized to comply with 48 hours autonomous operations.

- **Service 12** addresses a major operation concept, the On-Board Monitoring Function. It is implemented solely in CDMU, on which it is active by default, and basically consists in monitoring defined parameters against limits and in initiating an event in case of out of limit detection.

All S/C housekeeping packets can be used for monitoring while it is not planned to apply this service to any instrument packet type. The parameters to be monitored are handled via a monitoring list including the following specifications per parameters:

parameter identification by a unique mnemonic

upper and lower limits

enable/disable flag defining the status of the monitoring

the monitoring time interval

the number of allowed out of limits before triggering an event

the identifier of the event triggered by the monitoring.

It is possible to modify only a subset of the monitoring list parameters, and the monitoring information.

Telemetry report packets containing the value which is out of limit, the limit itself and possibly the event triggered are generated.

On telecommand request, the monitoring list can be reported to ground.

- **Service 14** provides the facility, using dedicated TCs, to enable/disable the generation and/or transmission to ground and/or another user of selected TM packets. The selection is at the level of the APID and can include the following types:

all packets

specified types/subtypes

specified HK packets

specified diagnostic packets

specified report packets.

Furthermore, each Application Process can provides a status information defining which packets are selected for transmission to ground and/or another Service, and the generation frequency.

- **Service 15** is related to the management of the storage unit. This capability is centralised at CDMU level only. All TM packets are stored on-board, regardless of the status of transmission to ground.

The storage is organised in virtual stores containing given packets identified by their APID and type. Storage is cyclic within a store: the oldest data is overwritten when the store is full.

The storage capability, i.e. the size of the SSMM is defined to cope with the storage of all packets generated on board over 48 hours + margin.

A selected privileged retrieval of stored packets is possible.

Dedicated HK TM provides status of the storage:

the number of stored packets

the size in words of the occupied storage

the allocation for the different available subsets of telemetry which can be dumped independently.

The ground is allowed to enable/disable the storage of selected packets.

Finally, only the ground is authorised to clear the content of the Mass Memory (per APID, per packet store, type, ...).

- **Service 18** defines the management of the On-Board Control Procedures. OBCPs are Flight Control Procedures which execute on board. They are controlled via specific TC packets which:

load OBCPs

start OBCPs

stop OBCPs

suspend OBCPs

resume OBCPs.

OBCPs are nominally initiated from the MTL and FDIR and are able to access TM, issue telecommands and event packets, execute simple mathematical expressions and logical functions Several OBCPs can run concurrently without interference. They are developed in a simple language, the Spacecraft Control Language.

It is possible to communicate with an OBCP, i.e. pass parameters or modify OBCPs variables).

Nominally, CDMS SW and ACMS SW could be users for spacecraft OBCP's. However, to simplify the management of the overall operations of the satellites, the baseline is to restrict the use of OBCPs to the CDMS only.

- **Service 22** defines the implementation for all intelligent users of a service to store and retrieve the contexts, on request of these users.

6.6.1.5.2 Applicability to ACMS

The applicability of all the features stated in the previous chapter to the other users on-board, and especially to the ACMS Control Computer can be discussed. As a matter of fact, referring to the architecture description in § 6.3, ACC does not interface with ground, but with the CDMU via a 1553 bus I/F. Also, the ACC may not be connected to users featuring a TM/TC packet interface. It is nevertheless of the highest interest to have available within the ACC, a limited set of Services in order to standardise some of the operation principles.

As a consequence, the basic services related to commanding are extended to ACC and ACC SW, but applied to the CDMU-ACC link:

- device commanding to implement the ACMS units direct commanding
- event/action, as support to the event/reporting service, to initiate a telecommand as answer to an exception event.

Some services related to monitoring are also applied to ACC SW:

- telecommand verification, to report to CDMU, for storage or transmission, the status of TC reception and execution
- periodic reporting, as an extension of the service to ACMS to define synthetic TM and trouble shooting TM to report the health of ACMS
- event reporting, to trigger pre defined TM in case of an ACMS related event occurrence. Events are classified into normal, exceptions and alarms, as per CDMU.

Finally, a few management services are extended to ACC and ACC SW:

- the memory management service, to take profit of the commonality of processor modules and memory arrangement between CDMU and ACC, and support the ACC memory load, memory check, and memory Dump
- Functions management service give to the ground the capability to control the execution of the Functions related to ACC SW.

It shall be pointed out that the Timing Management, On-Board Monitoring Function, Mission TimeLine services are centralised within the CDMU only, to simplify the ground management.

In the same attitude, On-Board Control Procedure service is not made available at ACMS level.

6.6.1.5.3 On-Board Control Procedures

Thanks to their simple interface to operations (via spacecraft development language), and their flexibility, the OBCPs are a principle mode of operation of the satellites.

However, OBCPs as implemented via an On Board Interpretation of uplinked procedures have been recognised to have major drawbacks:

- their execution time on-board, when compared to processes in native language is long.
- This approach, indubitably questions the validity of the On Board Software acceptance, pronounced at a given time, since it integrates the fact that later OBCPs development does not significantly impact the software behaviour and does not impose a full revalidation. Although strict rules can be applied to OBCPs development to at least partly overcome this problem, it remains an issue of concern.

OBCP use is therefore foreseen to be restricted to activities which mimic the ground control and for which the risk to have them definitely frozen very late is high:

- Non real time units or modes initialisation procedures
- Failures recovery procedures.

6.6.2 Launcher interfaces

Details concerning Launcher interfaces are provided by document:

Application to Use Ariane (DUA) n° H-P-1-ASPI-IS-0066

6.6.2.1 Launch configuration

Both Satellites will be launched on the same ARIANE 5 ESV in dual launch configuration as illustrated by Figure 6.6.2-1:

- Planck Satellite in lower position

on top of ACU 2624 (mass = 98 kg)

with USF (mass = 50 kg).

- Herschel satellite in upper position

on top of the SYLDA 5 (mass = 425 kg)

on top of ACU 2624 (mass = 98 kg)

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 will have a reference diameter of 2624 mm at the interface Satellite/launch vehicle interface plane.

Herschel and Planck will rest on the forward frame of the Arianespace 2624 standard adapters and separation systems.

At separation, the clampband 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 TBD for Planck
– drawing HES TBD 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 5.

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
– Thruster below separation plane
– Additional volume above top of SYLDA 5.

Herschel

– Top of the sunshade.

6.6.2.5 RF transparent window

During POC activities RF link (TM only) in X-Band between the satellites and the DIANE Station is required (to be confirmed).

For that purpose a RF transparent window and/or a Passive Repeater (SRP) is requested in case the fairing does not provide sufficient RF transparency (TBC by analysis to be performed by Arianespace).

The antenna locations are defined by:

- drawing PLS A15N S 010S A for Planck
- drawing HES A15N S 010S A for Herschel.

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 Video signal link to the decoder
- TM Video 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	6 x 2	6 x 2
Spares	3	3
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
- Imax = 0.5 A (relay closure duration).

The timing of initiation in flight is:

- Command #1 = after FJ (fairing jettisoning) + TBD s
- Command #2 = after FJ (fairing jettisoning) + TBD s
- Command #3 = after beginning of EPS main thrust phase + TBD s
- Command #4 = after beginning of EPS main thrust phase + TBD s.

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:	6 x 2	6 x 2
Spares	11	11
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 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 AR5 SCA & EPS loading (during these tasks, all activities on Satellite are forbiden) and to continue it up to fairing closure.

In order to provide the neccessary autonomy during S5 to BAF transportation (at J-8) and during the combined operations in BAF up to launch (requirement of 6 days including 25 hours for launch delay) an additional auxilliary tank filled with He I is necessary (HOT) with a last refilling at J-2.

NOTE: the HOT will be emptied just prior to lift-off.

These specific Herschel activities are summarised here-after:

- S5 to BAF transportation at J-8
- refilling of HOT at J-7
- AR5 SCA & EPS loading at J-6 (up to J-5 morning)
- HTT reconditioning below 1.7K (by pumping operations) starting at J-5 (afternoon) up to J-4 (noon) including two "extended J-5" as this operation will take 68 hours
- Fairing integration at J-4
- Additional HOT refilling at J-4
- Dress rehearsal at J-3
- HOT refilling at J-2
- ….

So four access doors to Herschel through fairing is requested for HOT refilling at J-2:

- Door #1 is needed for He-filling tube and operator support
- Door #2 is needed for operator access to the filling port and to some connectors using a diving board (like ISO)
- Door #3 is needed for the venting tube during re-filling operations
- Door #4 is needed for operator access to the outlet valve and to connectors using a diving board (like ISO).

The locations of these doors to be refined according final clocking are preliminary defined by:

– drawing HES S0A0 A 003S A.

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 Design specification PTPE-025	Telescope self emission increase	Spec < 5 %, goal < 2 %
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	<3.5 % (TBC)at cryostat opening(*)
		<4.2 % (TBC) end of nominal mission (*)
H-PLM Straylight	The straylight induced by contamination shall be taken in the straylight analyses	Cf ASED Straylight analysis

(*) The requirement has been changed in SRS 3.0 and is now not only the contamination allocation, but the total amount of transmission losses (including for example coating performance, ageing…). However, the current analysis is based on the requirement of SRS2.1, stating that contamination should not make the transmission decrease by more than 3 % End of life

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

- Inside cryostat
- LOU windows on CVV
- Mirrors (optical surfaces).

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_20	NH_3	On ground contaminants	
Focal Plane Unit	$7\ 10^{-6}$			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_20	NH_3	On ground contaminants	
Telescope M1	$1.5\ 10^{-6}$	10^{-6}	10^{-6}	4650
Telescope M2	$1.5\ 10^{-6}$	10^{-6}	10^{-6}	4300
PACS FPU (outside)	$6\ 10^{-6}$			1500
SPIRE FPU (outside)	10^{-4}			N/A
HIFI FPU (outside)	$6\ 10^{-6}$			1200
HIFI LOU CVV windows	$8.5\ 10^{-6}$			1200
LOU inside	$4\ 10^{-6}$			300

6.7.1.4 System performance impact of Planck contamination

This section presents the impact of contamination (as specified in the preceding section) on the performances.

REFERENCE	REQUIREMENT	CONTAMINATION ALLOCATION	SPECIFIED CONTAMINATION LEVELS IMPACT	
			IMPACT (+DRIVER)	Ref
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 2µm roughness	TIS <25% roughness (driver: particulate contamination on reflectors)(*)	RD03.16
SRS SPER-065	internal straylight requirements.	RF budget allocates 0.1 as the maximum emissivity increase due to the contamination on the internal side of the baffle.	Δe=0.05 (driver: molecular contamination on baffle inner side)	RD03.16
Planck Telescope Design specification PTPE-025	Telescope self emission increase	0.01 emissivity increase is allocated to contamination	Δe=0.01 (driver: particulate contamination on the reflectors)(*)	RD03.16
Telescope Design specification PTPE-035	Contamination shall be sufficiently low to keep antenna gain in the specified requirements	Allocation in gain budget 10-2dB at 857GHz (worst case frequency)	ΔG=6 10^{-3}dB (@857GHz) (driver: particulate contamination on the reflectors)	RD03.16
P-PLM internal needs	Emissivity increase on low emissivity V-Groove surfaces	0.025 emissivity increase is allocated in thermal budgets	Δe=0.025(*)	RD03.16
	Emissivity increase on high emissivity V-Groove and baffle surfaces	0.02 emissivity decrease is allocated in thermal budgets	Δe=0.02(*)	RD03.16

(*) These budgets show no margin because margin is managed at upper level budget.

6.7.1.5 System performance impact of Herschel contamination

This section presents the impact of contamination (as specified in the preceding section) on the performances.

Reference	Requirement	Contamination allocation	Specified contamination levels impact	
			Impact (+driver)	Ref
SRS SGEN-200	Herschel Telescope Transmission losses	<3.5% (TBC)at cryostat opening	1.3% transmisson (driver: particulate contamination on the mirrors). Telescope contribution to be added	RD03.16 RD03.21
		<4.2% (TBC) end of nominal mission		
H-PLM Straylight	The straylight induced by contamination shall be taken in the straylight analyses	Cf ASED Straylight analysis	Contamination is not a major contributor to Herschel Straylight	Cf ASED Straylight analysis

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	7.1 10^{-7} g/cm^2	1.36 10^{-6} g/cm^2	1.39 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 Launcher interface

As agreed in the cleanliness team (H-P-1-ASPI-RP-0314), the figure for the molecular contamination is 4 10^{-7} g/cm^2 .

6.7.2.1.3 In orbit

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.

It is supposed in the outgassing simulations that the materials have not been baked out.

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).

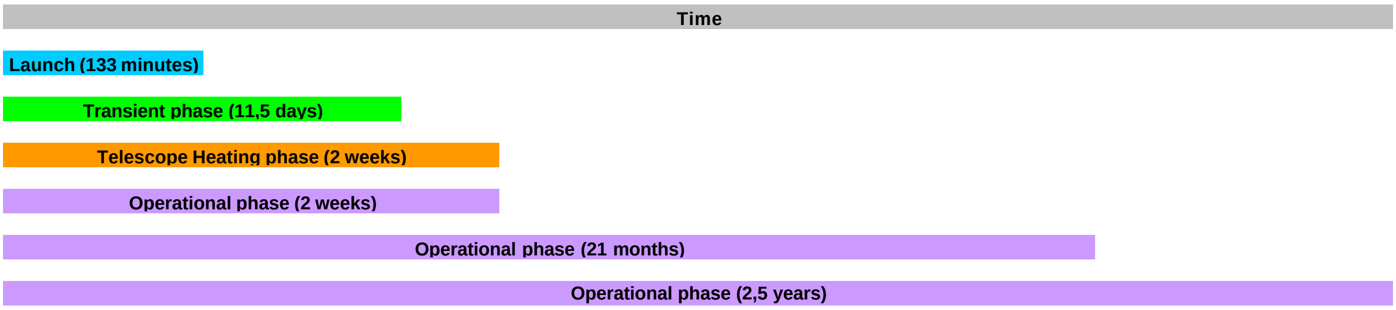


FIGURE 6.7-1 PLANCK OUTGASSING SIMULATIONS STRATEGY

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.

$$\frac{dW}{dt} = 4{,}36.10^{-3} * P_s * A * S_1 * \sqrt{\frac{M}{T_s}} \quad \text{(in kg/s)}$$

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 mechanical model.

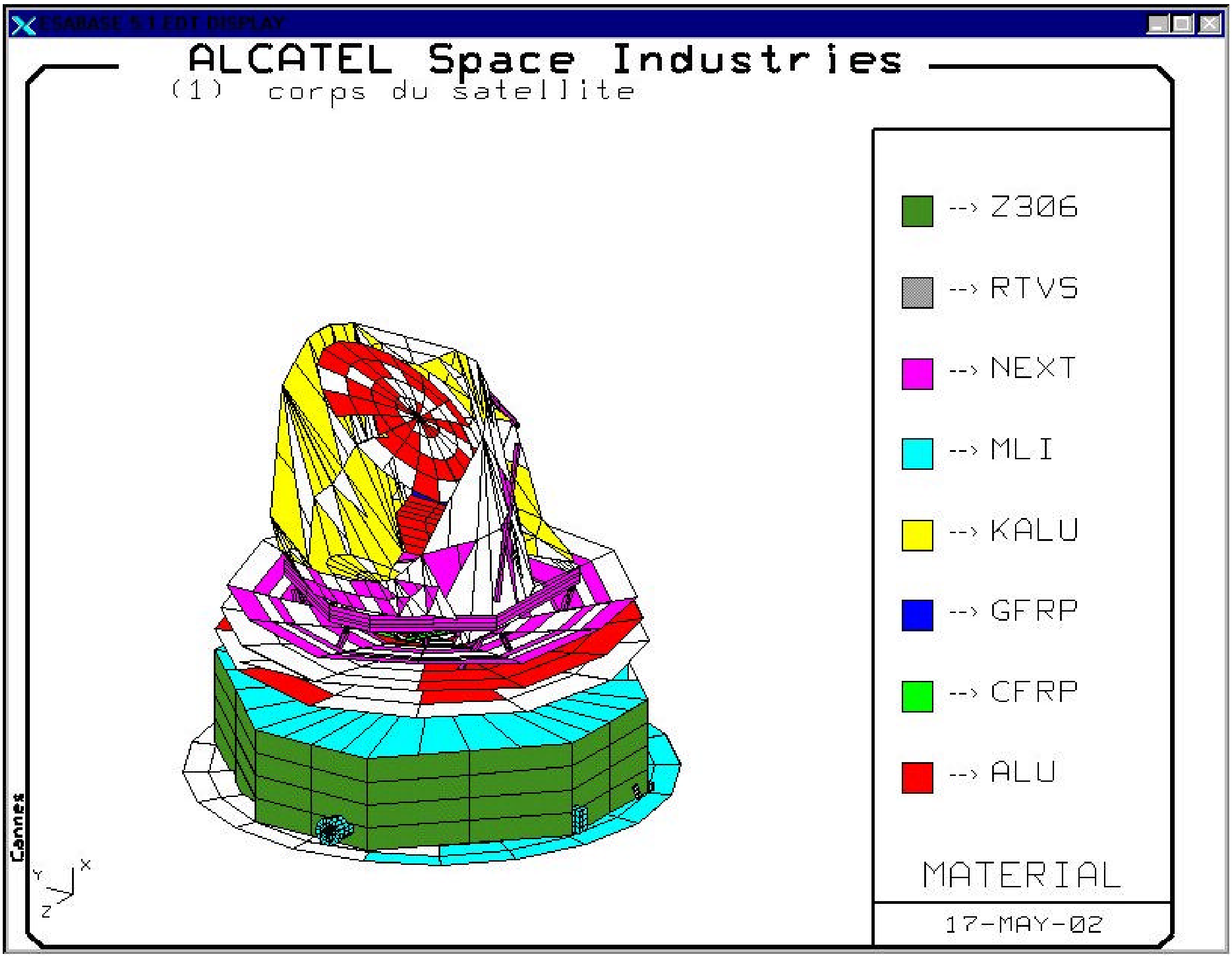


FIGURE 6.7-2 - PLANCK OUTGASSING MODEL

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 during 133 minutes.

The results of the ESABASE simulations and of the evaporation estimation are presented in Table 6.7-1.

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
Groove #1 +X	NO OUTGASSING	0,000	10,590	293,1	3,00E-05	2,52E-01	1,20E-04
Groove #1 -X	KALU	1,186	10,590	293,1	3,73E-07	2,52E-01	3,07E-06
Groove #2 +X	NO OUTGASSING	0,000	10,098	293,1	2,81E-05	2,52E-01	1,21E-04
Groove #2 -X	KALU	1,131	10,098	293,1	9,49E-08	2,52E-01	2,26E-06
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	293,1	3,04E-05	2,52E-01	1,22E-04
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	293,1	3,09E-05	2,52E-01	1,29E-04
Groove #3 -X	KALU	0,903	8,060	293,1	4,15E-04	2,52E-01	1,67E-03
FPU (active side)	NO OUTGASSING	0,000	0,260	293,1	4,31E-06	2,52E-01	1,71E-05
Baffle internal side	NO OUTGASSING	0,000	8,022	293,1	2,38E-04	2,52E-01	1,90E-03
Baffle external side	NEXTEL	5,615	8,022	293,1	2,19E-06	2,52E-01	5,13E-05
M2 front side	NO OUTGASSING	0,000	0,957	293,1	2,52E-05	2,52E-01	1,00E-04
M2 rear side	KALU	0,134	0,957	293,1	1,24E-06	2,52E-01	4,93E-06
M1 front face	NO OUTGASSING	0,000	2,764	293,1	2,23E-05	2,52E-01	3,00E-04
M1 rear face	KALU	0,387	2,764	293,1	9,94E-07	2,52E-01	4,62E-05

TABLE 6.7-3 PLANCK CONTAMINATION DURING LAUNCH PHASE

The amount of cumulative contamination during the launch is quit high, but it do not take into consideration the competitive phenomenon of evaporation.

Like presented in the last column of the Table 6.7-1, the time necessary for a complete re-evaporation of the cumulative contamination at the maximum location is very short (1.9 ms for the greater time).

In conclusion, it can be said that there is no more contamination at the end of the launch phase on the Planck satellite.

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 (ie: 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.

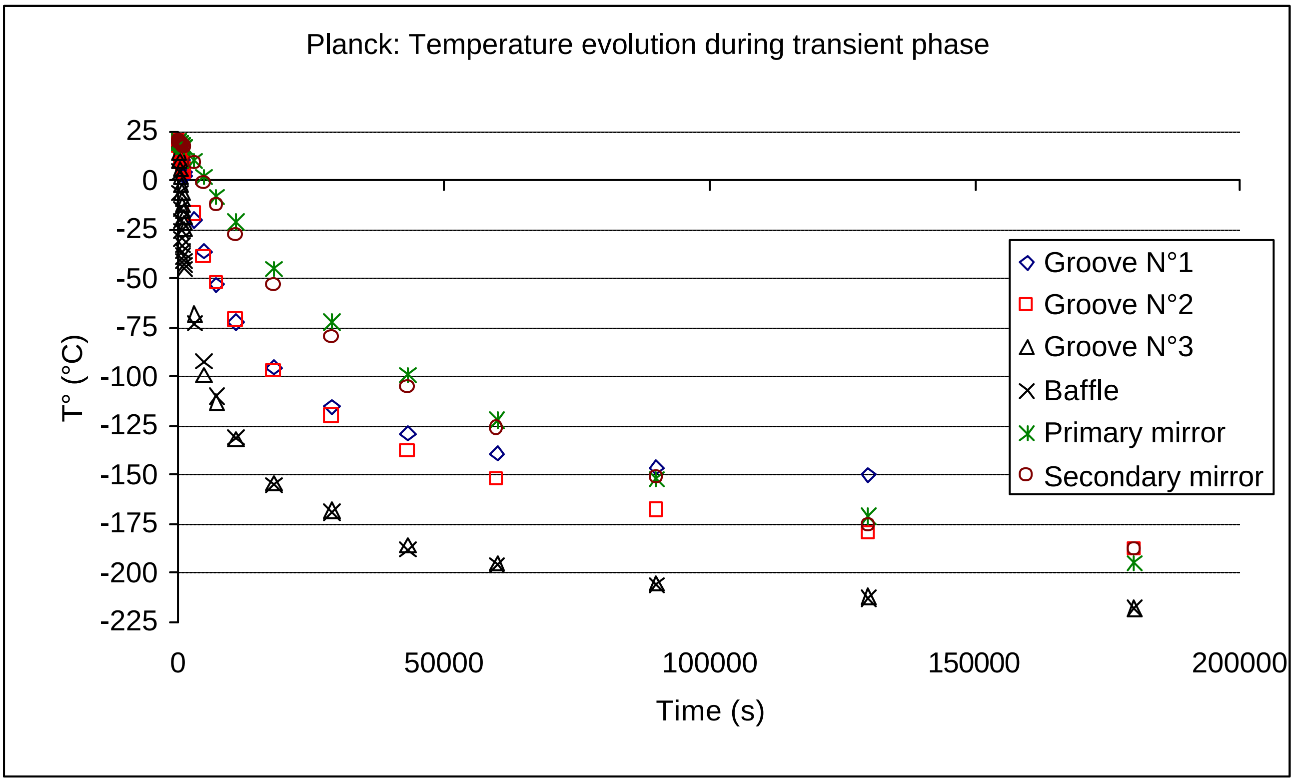


FIGURE 6.7-3 PLANCK TEMPERATURE EVOLUTION DURING TRANSIENT PHASE

The total contamination during the transient phase is presented in Table 6.7-2.

Sum-up	Contamination (kg/m²)	Contamination (g/cm²)
Groove #1+x	6,42E-06	6,42E-07
Groove #1 -x	0,00E+00	0,00E+00
Groove #2+x	1,54E-06	1,54E-07
Groove #2-x	1,47E-04	1,47E-05
Groove #3 +x (Nextel)	5,58E-08	5,58E-09
Groove #3 +x (Alu)	1,33E-05	1,33E-06
Groove #3-x	1,45E-04	1,45E-05
Baffle : internal	5,00E-06	5,00E-07
Baffle : external	5,66E-08	5,66E-09
PM front	1,29E-06	1,29E-07
PM rear	5,46E-07	5,46E-08
SM front	2,60E-06	2,60E-07
SM rear	1,08E-05	1,08E-06
FPU (active side)	4,51E-06	4,51E-07

TABLE 6.7-2 PLANCK CONTAMINATION DURING TRANSIENT PHASE

6.7.2.1.3.1.3 Contamination during operational phase

The simulations were performed for the operational phase, ie 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 6.7-3 to 6.7-5.

The contamination amount on sensitive elements such as V-groove #1 to #3 and FPU, primary and secondary mirrors is quite low (average values not greater than 2.5 10^{-6} g/cm²).

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
Groove #1 +X	NO OUTGASSING	0,000	10,590	117,2	0,00E+00	N/A	N/A
Groove #1 -X	KALU	1,186	10,590	117,2	2,88E-07	N/A	N/A
Groove #2 +X	NO OUTGASSING	0,000	10,098	83,2	3,32E-07	N/A	N/A
Groove #2 -X	KALU	1,131	10,098	83,2	3,87E-07	N/A	N/A
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	44,2	0,00E+00	N/A	N/A
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	44,2	0,00E+00	N/A	N/A
Groove #3 -X	KALU	0,903	8,060	44,2	3,43E-12	N/A	N/A
FPU (active side)	NO OUTGASSING	0,000	0,260	20,1	2,26E-09	N/A	N/A
Baffle internal side	KALU	0,886	8,022	45,2	3,89E-07	N/A	N/A
Baffle external side	NEXTEL	5,615	8,022	45,2	3,70E-07	N/A	N/A
M2 front side	NO OUTGASSING	0,000	0,957	40,2	2,37E-06	N/A	N/A
M2 rear side	KALU	0,134	0,957	40,2	7,04E-07	N/A	N/A
M1 front face	NO OUTGASSING	0,000	2,764	38,2	4,13E-07	N/A	N/A
M1 rear face	KALU	0,387	2,764	38,2	1,49E-09	N/A	N/A

TABLE 6.7-3 PLANCK CONTAMINATION DURING OPERATIONAL PHASE (21 MONTHS)

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
Groove #1 +X	NO OUTGASSING	0,000	10,590	117,2	0,00E+00	N/A	N/A
Groove #1 -X	KALU	1,186	10,590	117,2	2,89E-07	N/A	N/A
Groove #2 +X	NO OUTGASSING	0,000	10,098	83,2	3,37E-07	N/A	N/A
Groove #2 -X	KALU	1,131	10,098	83,2	3,97E-07	N/A	N/A
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	44,2	0,00E+00	N/A	N/A
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	44,2	0,00E+00	N/A	N/A
Groove #3 -X	KALU	0,903	8,060	44,2	3,91E-12	N/A	N/A
FPU (active side)	NO OUTGASSING	0,000	0,260	20,1	2,30E-09	N/A	N/A
Baffle internal side	NO OUTGASSING	0,000	8,022	45,2	3,71E-07	N/A	N/A
Baffle external side	NEXTEL	5,615	8,022	45,2	3,77E-07	N/A	N/A
M2 front side	NO OUTGASSING	0,000	0,957	40,2	2,46E-06	N/A	N/A
M2 rear side	KALU	0,134	0,957	40,2	7,19E-07	N/A	N/A
M1 front face	NO OUTGASSING	0,000	2,764	38,2	4,27E-07	N/A	N/A
M1 rear face	KALU	0,387	2,764	38,2	2,12E-09	N/A	N/A

TABLE 6.7-4 PLANCK CONTAMINATION DURING OPERATIONAL PHASE (2.5 YEARS)

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
Groove #1 +X	NO OUTGASSING	0,000	10,590	117,2	0,00E+00	N/A	N/A
Groove #1 -X	KALU	1,186	10,590	117,2	2,73E-07	N/A	N/A
Groove #2 +X	NO OUTGASSING	0,000	10,098	83,2	1,46E-07	N/A	N/A
Groove #2 -X	KALU	1,131	10,098	83,2	2,41E-07	N/A	N/A
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	44,2	0,00E+00	N/A	N/A
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	44,2	0,00E+00	N/A	N/A
Groove #3 -X	KALU	0,903	8,060	44,2	3,20E-13	N/A	N/A
FPU (active side)	NO OUTGASSING	0,000	0,260	20,1	9,53E-10	N/A	N/A
Baffle internal side	NO OUTGASSING	0,000	8,022	45,2	1,04E-07	N/A	N/A
Baffle external side	NEXTEL	5,615	8,022	45,2	1,80E-07	N/A	N/A
M2 front side	NO OUTGASSING	0,000	0,957	40,2	8,75E-07	N/A	N/A
M2 rear side	KALU	0,134	0,957	40,2	2,93E-07	N/A	N/A
M1 front face	NO OUTGASSING	0,000	2,764	38,2	3,33E-07	N/A	N/A
M1 rear face	KALU	0,387	2,764	38,2	3,26E-11	N/A	N/A

TABLE 6.7-5 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 6.7-6, 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 6.7.7.

This heating phase induces a contamination amount increase (average increase 1.4 x 10^{-6} g/cm², maximum increase 8.10^{-6} 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)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
Groove #1 +X	NO OUTGASSING	0,000	10,590	117,2	0,00E+00	N/A	N/A
Groove #1 -X	KALU	1,186	10,590	117,2	2,73E-07	N/A	N/A
Groove #2 +X	NO OUTGASSING	0,000	10,098	83,2	1,46E-07	N/A	N/A
Groove #2 -X	KALU	1,131	10,098	83,2	2,41E-07	N/A	N/A
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	44,2	0,00E+00	N/A	N/A
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	44,2	0,00E+00	N/A	N/A
Groove #3 -X	KALU	0,903	8,060	44,2	3,20E-13	N/A	N/A
FPU (active side)	NO OUTGASSING	0,000	0,260	313,1	9,53E-10	7,70E-01	1,24E-09
Baffle internal side	NO OUTGASSING	0,000	8,022	45,2	1,51E-06	N/A	N/A
Baffle external side	NEXTEL	5,615	8,022	45,2	1,80E-07	N/A	N/A
M2 front side	NO OUTGASSING	0,000	0,957	313,1	2,46E-05	7,70E-01	3,19E-05
M2 rear side	KALU	0,134	0,957	313,1	3,79E-06	7,70E-01	4,92E-06
M1 front face	NO OUTGASSING	0,000	2,764	313,1	2,46E-05	7,70E-01	4,73E-05
M1 rear face	KALU	0,387	2,764	313,1	2,15E-11	7,70E-01	1,33E-09

TABLE 6.7-6 PLANCK CONTAMINATION DURING HEATING PHASE

Element	Material	Mass (kg)	Surface (m²)	Delta Temperature (K)	Delta Average contamination (g/cm²)
Groove #1 +X	NO OUTGASSING	0,000	10,590	0,0	0,00E+00
Groove #1 -X	KALU	1,186	10,590	0,0	-2,33E-10
Groove #2 +X	NO OUTGASSING	0,000	10,098	0,0	-3,33E-11
Groove #2 -X	KALU	1,131	10,098	0,0	1,67E-10
Groove #3 +X (Nextel)	NEXTEL	5,889	8,412	0,0	0,00E+00
Groove #3 +X (Alu)	NO OUTGASSING	0,000	1,261	0,0	0,00E+00
Groove #3 -X	KALU	0,903	8,060	0,0	0,00E+00
FPU (active side)	NO OUTGASSING	0,000	0,260	293,0	-5,32E-08
Baffle internal side	NO OUTGASSING	0,000	8,022	0,0	1,41E-06
Baffle external side	NEXTEL	5,615	8,022	0,0	5,82E-12
M2 front side	NO OUTGASSING	0,000	0,957	272,9	-8,75E-07
M2 rear side	KALU	0,134	0,957	272,9	-2,93E-07
M1 front face	NO OUTGASSING	0,000	2,764	274,9	-3,33E-07
M1 rear face	KALU	0,387	2,764	274,9	-3,26E-11

TABLE 6.7-7 PLANCK CONTAMINATION DIFFERENCE BETWEEN HEATING PHASE AND NOMINAL CONDITIONS (2WEEKS)

6.7.2.1.3.2 PLANCK plume analysis

For a first assessment it is possible to evaluate the order of magnitude of the contamination by the thrusters using a similar approach as of the one used for ISO program.

During the Planck mission some 250 kg of hydrazine is expelled through the thrusters for attitude control of the satellite.

A preventive measure of pointing the thrusters plume as far as possible away from the PPLM cold parts has already been taken in the preliminary design of the spacecraft, however the contamination by the thrusters cannot be neglected.

When thrusters are fired, the plume is directed toward space and the back-flow from the plume will create a cloud around the spacecraft. The back flow is usually estimated to be between 0.1 and 1 % of the expelled flow. Molecular back scattering from the cloud around the satellite will cause contamination on the cold parts of the PPLM. It is usually estimated to be around 1 %.

The back-flow from the thrusters located at the base of the SVM is for a greater part shielded by the spacecraft itself. The telescope and the FPU are well protected by the main baffle. Thus only a fraction of the back-flow is expected to contribute to the telescope contamination. This fraction (shielding factor) is estimated to be less than 20 %. On an other hand only 40 % of the total mass of hydrazine is used by the thrusters pointing toward the PPLM, in worst case.

From the above assumptions, the contamination by the hydrazine thrusters can be predicted by the following formula:

$$C = M_h * D_f * B_f * B_s * S_f * \frac{A_{to}}{A_{ti} * S_s}$$

Where:

M_h: hydrazine mass	250 kg
D_f: Proportion consumed toward the PPLM	40 %
B_s: Back scattering	1 %
B_f: Back-flow	1 %
S_f: Shielding factor	20 %
A_{to}: Area of the main baffle opening	3 m²
S_s: Area of the spacecraft external envelope	90 m²
A_{ti}: Area of the telescope and internal main baffle	14 m²

The plume composition of an hydrazine catalytic thruster is available in Table 6.7-8.

COMPONENT	FORMULA	PROPORTION
Ammonia	NH3	34.31%
Nitrogen	N2	57.86%
Hydrogen	H2	6.22%
Water	H2O	0.65%
Hydrazine	N2H4	0.46%
Aniline	C6H5NH2	0.50%

TABLE 6.7-8 PLANCK - COMPOSITION OF AN HYDRAZINE CATALYTIC THRUSTER PLUME

The sticking temperatures of these plume components are presented in Table 6.7-9.

COMPONENT	STICKING TEMPERATURE (K)
Ammonia	102
Nitrogen	26
Hydrogen	4
Water	159
Hydrazine	165
Aniline	190

TABLE 6.7-9 PLANCK - STICKING TEMPERATURES OF THE PLUME COMPONENT

All these hypotheses lead to the contamination presented in Table 6.7-10.

Contaminant	Proportion	Telescope contamination (kg/m²)	Telescope contamination (g/cm²)
NH3	**34,31%**	**1,63E-06**	**1,63E-07**
N2	57,86%	2,76E-06	2,76E-07
H2	6,22%	2,96E-07	2,96E-08
H2O	**0,65%**	**3,10E-08**	**3,10E-09**
N2H4	0,46%	2,19E-08	2,19E-09
C6H5NH2	0,50%	2,38E-08	2,38E-09

TABLE 6.7-10 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.

The contamination of the telescope by plume components is not a critical point. These values will be validated with a more accurate modelisation of this phenomenon during phase C.

Concerning the V-grooves contamination by the plume thrusters, an estimation can be done by the help of the preliminary study performed by ESA (See draft report “Planck contamination analysis” edited by G. MARKELOV and L. WALPOT, 21/05/2002).

This study was performed by a resolution of the Navier-Stokes equation in the nozzle and in the near field region, and with a DSMC (Direct Simulation Monte-Carlo) software for the near field region and for the interaction with the Planck satellite and the contamination of the Planck V-grooves.

This analysis takes into consideration the proportion of each component present in the plume and also the sticking temperature of these components.

This contamination is very local like the results of the three different cross sections studied demonstrate it. For this reason the following “average” values can be considered in order to be not too pessimistic in the estimation of the degradations of the V-grooves thermo-optical properties.

Concerning the baffle contamination by the thruster exhaust plume, no specific data are available. Only two distribution cartography permit to determine that the contamination mass fluxes for ammonia and for water will not be greater than for the third V-groove.

	Ammonia (g/cm²/sec)	Water (g/cm²/sec)
First groove	1,00E-07	1,00E-10
Second groove	1,00E-10	5,00E-11
Third groove	1,00E-10	5,00E-11
Baffle	<1,00E-10	<5,00E-11

TABLE 6.7-11 PLANCK "AVERAGE" CONTAMINATION RATE ON V-GROOVES DUE TO PLUME ACTIVATION

These estimations of the average contamination rates on the Planck V-grooves lead to the results presented in the Table 6.7-12.

	Ammonia contamination (g/cm²)	Water contamination (g/cm²)
First groove	N/A	6,00E-07
Second groove	6,00E-07	3,00E-07
Third groove	6,00E-07	3,00E-07
Baffle	< 6,00E-07	<3,00E-07

TABLE 6.7-12 PLANCK "AVERAGE" CONTAMINATION ON V-GROOVES DUE TO PLUME ACTIVATION

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 Tables 6.7-13 and 6.7-14) have to be considered on Planck satellite.

(g/cm²)	Launch	Transient	Operationnal (21 months)	Plume NH3 contamination (ISO approach)	Plume H2O contamination (ISO approach)	Plume NH3 contamination (ESA results)	Plume H2O contamination (ESA results)	Total contamination
V-groove#1 +X	0	6,42E-07	0,00E+00			0,00E+00	0	6,42E-07
V-groove #1-X	0	0,00E+00	2,88E-07			0,00E+00	6,00E-07	8,88E-07
V-groove #2 +X	0	1,54E-07	3,32E-07			0,00E+00	0	4,86E-07
V-groove #2 -X	0	1,47E-05	3,87E-07			6,00E-07	3,00E-07	1,60E-05
V-groove #3 +X (part Nextel)	0	5,58E-09	0,00E+00			0,00E+00	0	5,58E-09
V-groove #3 +X (part Alu)	0	1,33E-06	0,00E+00			0,00E+00	0	1,33E-06
V-groove #3 -X	0	1,45E-05	3,43E-12			6,00E-07	3,00E-07	1,54E-05
Baffle internal part	0	5,00E-07	3,89E-07	1,63E-07	3,10E-09			1,06E-06
Baffle external part	0	5,66E-09	3,70E-07			6,00E-07	3,00E-07	1,28E-06
Primary mirror front	0	1,29E-07	4,13E-07	1,63E-07	3,10E-09			7,08E-07
Primary mirror rear	0	5,46E-08	1,49E-09	0,00E+00	0			5,60E-08
Secondary mirror front	0	2,60E-07	2,37E-06	1,63E-07	3,10E-09			2,80E-06
Secondary mirror rear	0	1,08E-06	7,04E-07	0,00E+00	0			1,78E-06
FPU (active side)	0	4,51E-07	2,26E-09	1,63E-07	3,10E-09			6,20E-07

TABLE 6.7-13 PLANCK IN ORBIT CONTAMINATION BUDGET WITHOUT TELESCOPE HEATING PHASE

(g/cm²)	Launch	Transient	Operationnal (21 months) + heating (2 weeks)	Plume NH3 contamination (ISO approach)	Plume H2O contamination (ISO approach)	Plume NH3 contamination (ESA results)	Plume H2O contamination (ESA results)	Total contamination
V-groove#1 +X	0	6,42E-07	0,00E+00			0,00E+00	0,00E+00	6,42E-07
V-groove #1-X	0	0,00E+00	2,88E-07			0,00E+00	6,00E-07	8,88E-07
V-groove #2 +X	0	1,54E-07	3,32E-07			0,00E+00	0,00E+00	4,86E-07
V-groove #2 -X	0	1,47E-05	3,87E-07			6,00E-07	3,00E-07	1,60E-05
V-groove #3 +X (part Nextel)	0	5,58E-09	0,00E+00			0,00E+00	0,00E+00	5,58E-09
V-groove #3 +X (part Alu)	0	1,33E-06	0,00E+00			0,00E+00	0,00E+00	1,33E-06
V-groove #3 -X	0	1,45E-05	3,43E-12			6,00E-07	3,00E-07	1,54E-05
Baffle internal part	0	5,00E-07	1,79E-06	1,63E-07	3,10E-09			2,46E-06
Baffle external part	0	5,66E-09	3,70E-07			6,00E-07	3,00E-07	1,28E-06
Primary mirror front	0	1,29E-07	8,00E-08	1,63E-07	3,10E-09			3,75E-07
Primary mirror rear	0	5,46E-08	1,46E-09	0,00E+00	0,00E+00			5,60E-08
Secondary mirror front	0	2,60E-07	1,50E-06	1,63E-07	3,10E-09			1,93E-06
Secondary mirror rear	0	1,08E-06	4,11E-07	0,00E+00	0,00E+00			1,49E-06
FPU (active side)	0	4,51E-07	1,31E-09	1,63E-07	3,10E-09			6,19E-07

TABLE 6.7-14 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
1895 ppm	1895 ppm	1000 ppm	1000 ppm	2135 ppm

6.7.2.2.2 Launcher interface

As agreed in the cleanliness team (H-P-1-ASPI-RP-0314), the Alcatel figure for the molecular contamination is 1000 ppm to be negotiated with Arianespace .

6.7.2.2.3 In orbit

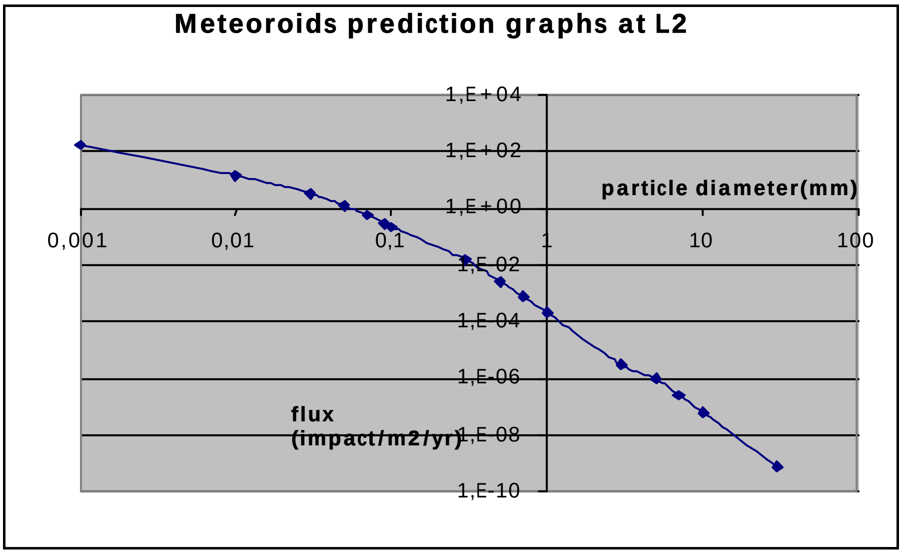
The in-orbit particulate contamination on Planck, orbiting around L2, come from two different sources: in-orbit redistribution and micrometeoroids. These two sources are analysed in the following sections, and their impact are quantified.

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:



These data where delivered by NASA in the frame of NGST programme. 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 0.3ppm. 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. It can be noted, that for the secondary mirror, the molecular contamination reaches 3.84 10^{-6} EOL, for a requirement expressed by the instruments of 4 10^{-6}. However, what is important is the total telescope emissivity increase, and so only the sum of the contamination on SR and PR is significant. PR+SR contamination = 1.75^{e}-6+3.87^{e}-6=5.61^{e}-6, which is below the 8^{e}-6 total maximum contaminant thickness required with margins.

Given the fact that the requirements are met without mirrors decontamination heating and the system impacts of such heating:

- 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

It is recommended not to implement the decontamination heating on Planck. The capability of heating is available in the PDR design (heating lines output in the PCDU, thermal sensors acquisition in the CDMU) and heaters are planned to be implemented on both mirrors and on FPU's. It is recommended to only use the heaters to limit contamination during on-ground activities (e.g. heat-up at the end of cryogenic testing). The source of contamination on the secondary mirror will be further investigated for the PDR collocation to refine the computation and possibly find ways of reducing it.

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 encapsulation) is:

PLM inside CVV	FPU and optical bench	telescope	S/C outside
3 10^{-7} g/cm^2	144.5 10^{-7} g/cm^2	2.87 10^{-7} g/cm^2	15 10^{-7} g/cm^2

6.7.3.1.2 Launcher interface

As agreed in the cleanliness team (H-P-1-ASPI-RP-0314) the Alcatel figure for the molecular contamination is 4 10^{-7} g/cm^2.

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.

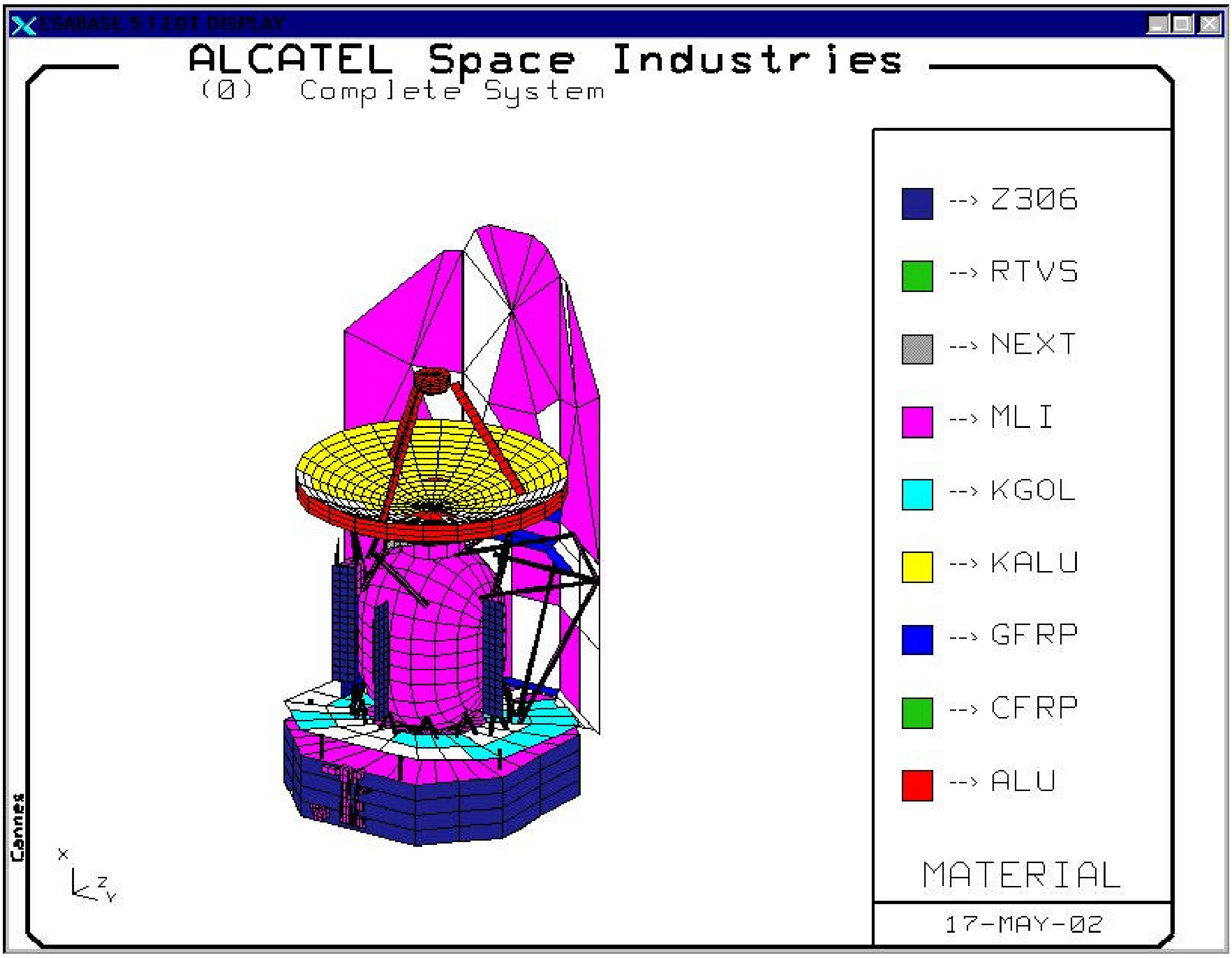


FIGURE 6.7-4 HERSCHEL OUTGASSING MODEL

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 sensitive elements, M1 and M2, there is no contamination possible during the transient phase. The contamination will not remain on M1 and M2 due to the consideration of the re-evaporation phenomenon. This part will not be more investigated, the outgassing of materials during this phase being covered by the heating phase study and by the operational study.

6.7.3.1.3.1.2 Outgassing analysis during operational phase

The simulations were performed for the operational phase, ie 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 Tables 6.7-15 to 6.7-17.

It is also important to notice that most of the contamination is reached after 3 weeks. Only a slight variation of the amount of contaminants can be observed between 3 weeks and 3.5 years simulations results.

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/s/cm²)	Time for a complete evaporation at the maximum location (s)
M1 active side	NO OUTGASSING	0,000	20,760	79,2	3,66E-06	N/A	N/A
M2 lower cylinder	NO OUTGASSING	0,000	0,314	79,2	4,13E-06	N/A	N/A

TABLE 6.7-15 HERSCHEL OUTGASSING CONTAMINATION AFTER 3.5 YEARS

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/s/cm²)	Time for a complete evaporation at the maximum location (s)
M1 active side	NO OUTGASSING	0,000	20,760	79,2	3,66E-06	N/A	N/A
M2 lower cylinder	NO OUTGASSING	0,000	0,314	79,2	4,14E-06	N/A	N/A

TABLE 6.7-16 HERSCHEL OUTGASSING CONTAMINATION AFTER 6 YEARS

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/s/cm²)	Time for a complete evaporation at the maximum location (s)
M1 active side	NO OUTGASSING	0,000	20,760	79,2	3,02E-06	N/A	N/A
M2 lower cylinder	NO OUTGASSING	0,000	0,314	79,2	3,41E-06	N/A	N/A

TABLE 6.7-17 HERSCHEL OUTGASSING CONTAMINATION AFTER 3 WEEKS

6.7.3.1.3.1.3 Outgassing analysis during heating phase

An outgassing simulation was performed with ESABASE software, taking into consideration the telescope (M1, M2) heating phase during 3 weeks at 40°C, while the other parts of the Herschel satellite stay at the operational temperatures.

The results of the simulation are available in Table 6.7-18, with the contaminant evaporation estimation as presented in the in orbit contamination Planck introduction. At the end of the heating phase no contamination on the sensitive elements is foreseen (see evaporation rates on theses equipment).

The difference between the results obtained with the telescope heating phase and the results obtained for the operational conditions after 3 weeks are available in Table 6.7-19.

In order to estimate the amount of contamination on Herschel satellite at the end of nominal life (3.5 years) and with the consideration of the heating phase, the contamination is calculated by substracting the results of nominal contamination after 3 weeks to the nominal results of contamination after 3.5 years and by adding the results of the simulations of the heating phase after 3 weeks. 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 6.7-20.

These results show the heating imperative on Herschel Satellite in order to meet the specifications.

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/cm²/s)	Time for a complete evaporation at the maximum location (s)
M1 active side	NO OUTGASSING	0,000	20,760	313,1	2,34E-05	7,70E-01	7,92E-05
M2 lower cylinder	NO OUTGASSING	0,000	0,314	313,1	3,35E-06	7,70E-01	8,16E-06

TABLE 6.7-18 HERSCHEL OUTGASSING CONTAMINATION AFTER HEATING PHASE (3 WEEKS)

Element	Material	Mass (kg)	Surface (m²)	Heating temperature (K)	Nominal temperature (K)	Delta temperature	Delta on Average contamination (g/cm²)
M1 active side	NO OUTGASSING	0,000	20,760	313,100	79,200	233,9	-3,02E-06
M2 lower cylinder	NO OUTGASSING	0,000	0,314	313,100	79,200	233,9	-3,41E-06

TABLE 6.7-19 HERSCHEL DELTA CONTAMINATION BY OUTGASSING DUE TO HEATING PHASE (3 WEEKS)

Element	Material	Mass (kg)	Surface (m²)	Temperature (K)	Average contamination (g/cm²)	Evaporation rate (g/s/cm²)	Time for a complete evaporation at the maximum location (s)
M1 active side	NO OUTGASSING	0,000	20,760	79,2	6,35E-07	N/A	N/A
M2 lower cylinder	NO OUTGASSING	0,000	0,314	79,2	7,19E-07	N/A	N/A

TABLE 6.7-20 HERSCHEL OUTGASSING CONTAMINATION HEATING PHASE CONSIDERATION (3.5 YEARS)

6.7.3.1.3.2 HERSCHEL plume contamination analysis

For a first assessment it is possible to evaluate the order of magnitude of the contamination by the thrusters using a similar approach as of the one used for ISO program.

During the Herschel mission some 150kg of hydrazine is expelled through the thrusters for attitude control of the satellite.

A preventive measure of pointing the thrusters plume as far as possible away from the HPLM cold parts has already been taken in the preliminary design of the spacecraft, however the contamination by the thrusters cannot be neglected.

When thrusters are fired, the plume is directed toward space and the back-flow from the plume will create a cloud around the spacecraft. The back flow is usually estimated to be between 0.1 and 1 % of the expelled flow. Molecular back scattering from the cloud around the satellite will cause contamination on the cold parts of the HPLM. It is usually estimated to be around 1 %.

The back-flow from the thrusters located at the base of the SVM is for a greater part shielded by the spacecraft itself. Thus only a fraction of the back-flow is expected to contribute to the telescope contamination. This fraction (shielding factor) is estimated to be less than 10 %.

From the above assumptions, the contamination by the hydrazine thrusters can be predicted by the following formula:

$$C = M_h * B_f * B_s * S_f * \frac{1}{S_s}$$

Where:

M_h: hydrazine mass 150 kg

B_s: Back scattering 1 %

B_f: Back-flow 1 %

S_f: Shielding factor 10 %

S_s: Area of the spacecraft external envelope 120m²

The plume composition of an hydrazine catalytic thruster is available in Table 6.7-21.

COMPONENT	FORMULA	PROPORTION
Ammonia	NH3	34.31 %
Nitrogen	N2	57.86 %
Hydrogen	H2	6.22 %
Water	H2O	0.65 %
Hydrazine	N2H4	0.46 %
Aniline	C6H5NH2	0.50 %

TABLE 6.7-21 HERSCHEL - COMPOSITION OF AN HYDRAZINE CATALYTIC THRUSTER PLUME

The sticking temperatures of these plume components are presented in Table 6.7-22.

COMPONENT	STICKING TEMPERATURE (K)
Ammonia	102
Nitrogen	26
Hydrogen	4
Water	159
Hydrazine	165
Aniline	190

TABLE 6.7-22 HERSCHEL - STICKING TEMPERATURES OF THE PLUME COMPONENT

All these hypotheses lead to the contamination presented in Table 6.7-23.

Contaminant	Proportion	Telescope contamination (kg/m²)	Telescope contamination (g/cm²)
NH3	**34,31%**	**4,29E-06**	**4,29E-07**
N2	57,86%	7,23E-06	7,23E-07
H2	6,22%	7,78E-07	7,78E-08
H2O	**0,65%**	**8,13E-08**	**8,13E-09**
N2H4	0,46%	5,75E-08	5,75E-09
C6H5NH2	0,50%	6,25E-08	6,25E-09

TABLE 6.7-23 HERSCHEL TELESCOPE CONTAMINATION DUE TO PLUME ACTIVATION

The contamination by N2 and H2 are presented for information only, due to the fact that surfaces at 70K do not trap these components.

The contamination of the telescope by plume components is not a critical point. These values will be validated with an more accurate modelisation of this phenomenon during phase C.

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 Tables 6.7-24 and 6.7-25) have to be considered on Herschel satellite.

It is important to notice that the heating phase is necessary for the Herschel telescope, in order to meet the instruments requirements.

(g/cm²)	Transient	Operationnal (3,5 years)	Plume NH3 contamination (ISO approach)	Plume H2O contamination (ISO approach)	Total contamination
M1 active side	0	3,66E-06	4,29E-07	8,13E-09	4,09E-06
M2 lower cylinder	0	4,13E-06	4,29E-07	8,13E-09	4,57E-06

TABLE 6.7-24 HERSCHEL IN ORBIT CONTAMINATION BUDGET WITHOUT TELESCOPE HEATING PHASE

(g/cm²)	Transient	Operationnal (3,5 years) + heating (3 weeks)	Plume NH3 contamination (ISO approach)	Plume H2O contamination (ISO approach)	Total contamination
M1 active side	0	6,35E-07	4,29E-07	8,13E-09	1,07E-06
M2 lower cylinder	0	7,19E-07	4,29E-07	8,13E-09	1,16E-06

TABLE 6.7-25 HERSCHEL IN ORBIT CONTAMINATION BUDGET WITH TELESCOPE HEATING PHASE

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 encapsulation) is:

PLM inside CVV	FPU and optical bench	telescope	S/C outside
354.5 ppm	375 ppm	1900 ppm	2060 ppm

6.7.3.2.2 Launcher interface

As agreed in the cleanliness team (H-P-1-ASPI-RP-0314), the Alcatel specified figure for the molecular contamination is 1000 ppm to be negotiated with Arianespace.

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 5ppm 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 0.7 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 shows that all requirements are met.

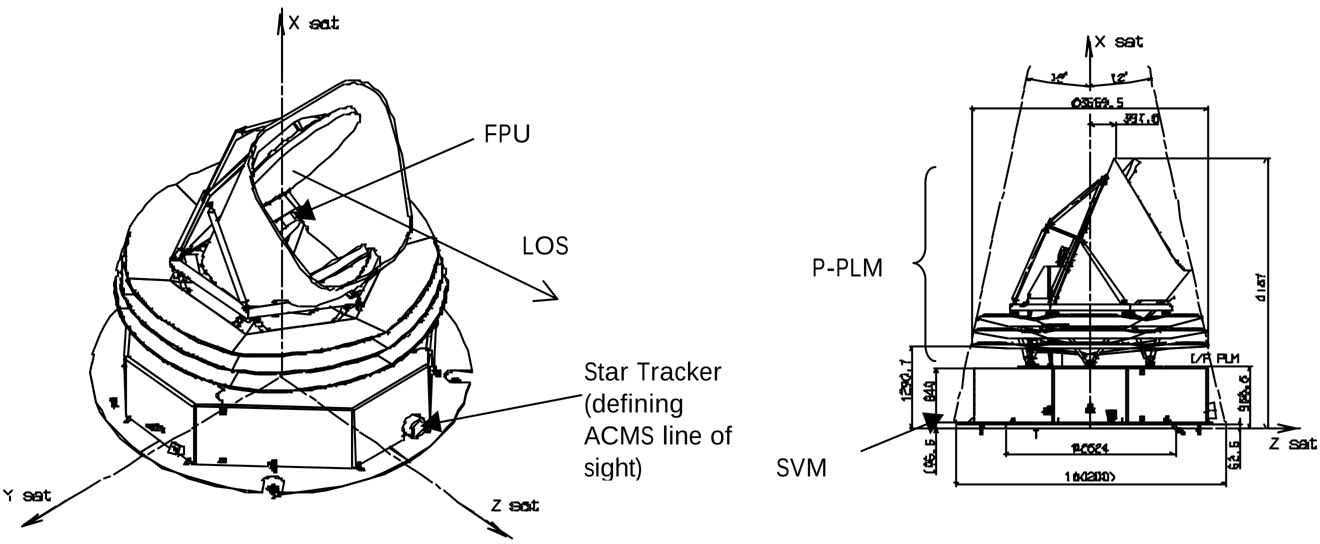
6.8 Alignment

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.



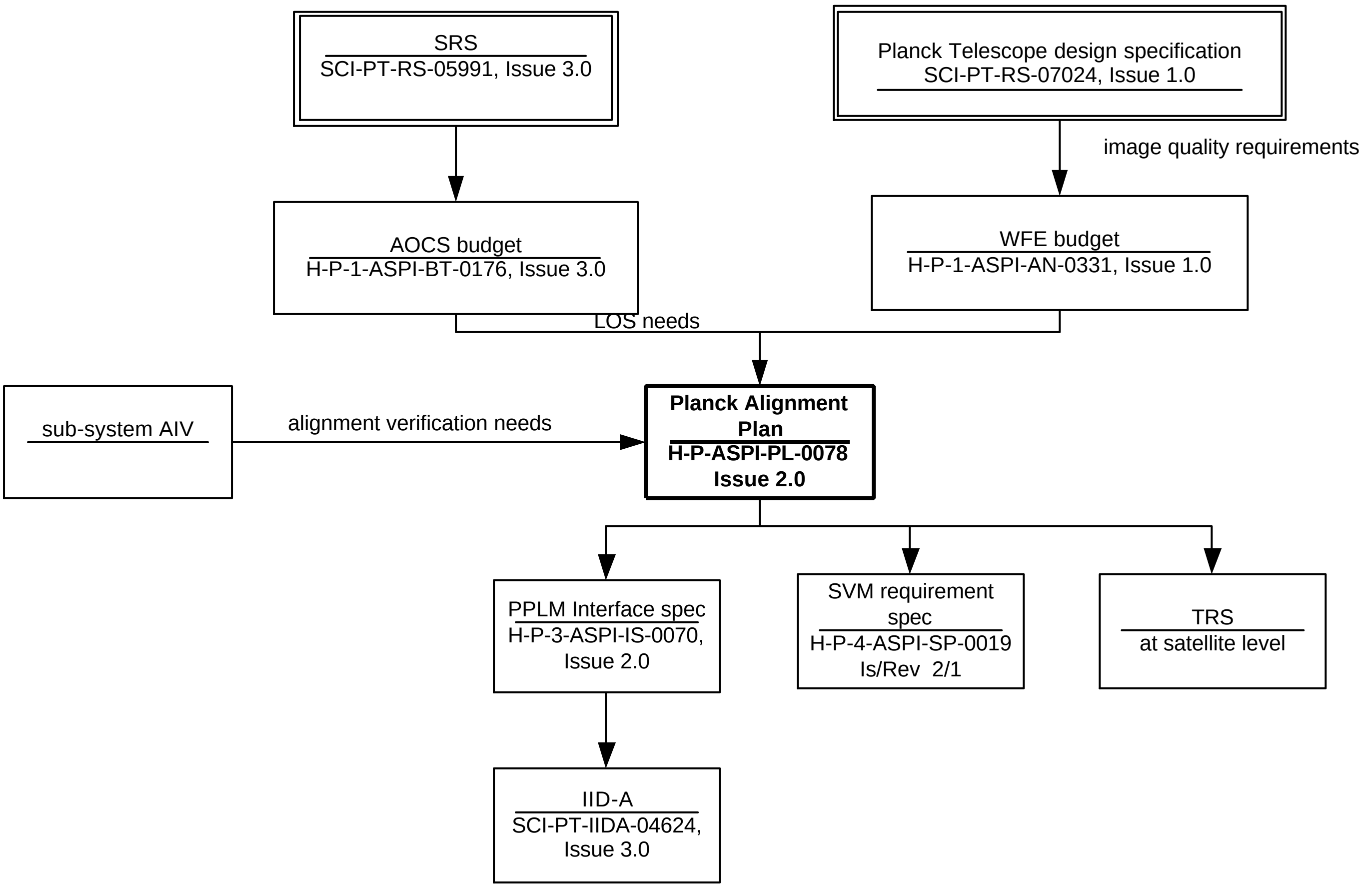
System alignment needs come from two origins:

- 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:

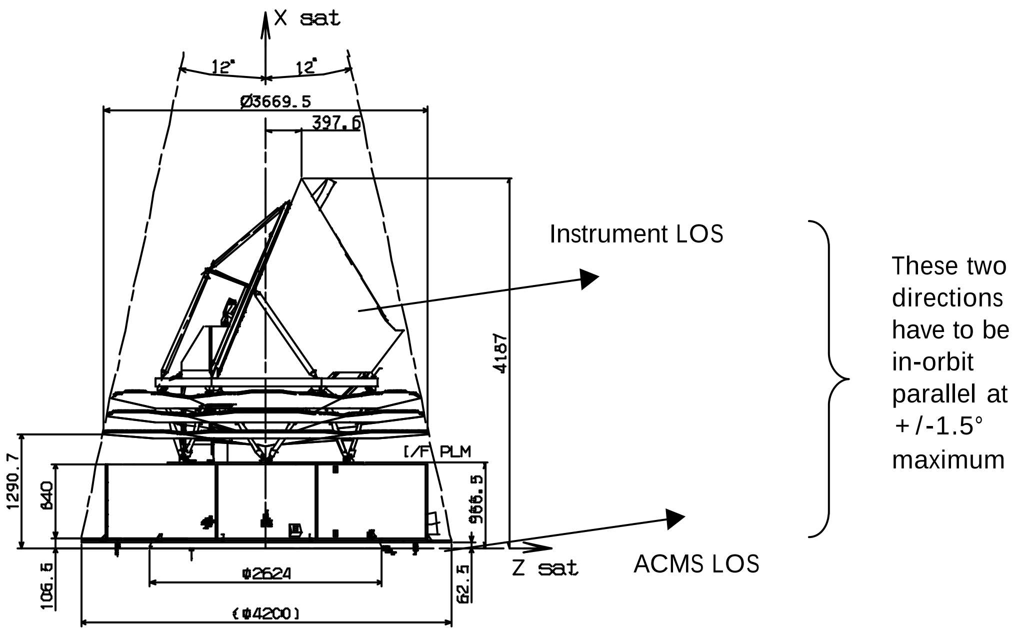
- alignment requirement to instruments (internal alignment), expressed in the IID-A
- alignment and stability requirements to PPLM, expressed in the "P-PLM Interface and Applicability Specification" [AD07.3]
- alignment and stability requirements to SVM, expressed in " SVM Requirement Specification "
- 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 (cf. "ACMS inputs to Planck System Alignment Plan"H-P-3-ASPI-TN-0245 Issue 1/0, and [RD03.7])

- Req 1

  The Planck instrument LOS shall be aligned with ACMS LOS with an accuracy of 1.50 degree maximum.

- Req 2

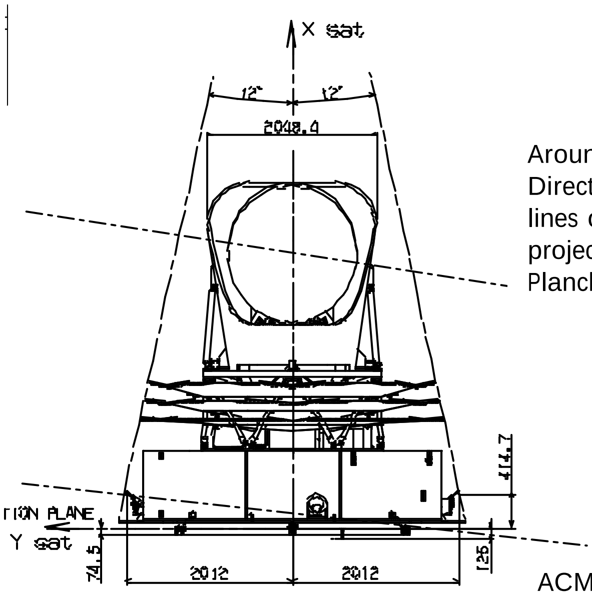
  The stability around LOS_{PLM} axes with regards to AOCS axes (due to launch and in orbits effects) shall not exceed 3.8 arcmin at 68 % confidence level.

- 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.



Around-LOS:
Direction of detectors lines on the sky, projected by the Planck Telescope

After their alignment, these two directions have to be stable better than 3.8 arcmin with 68% confidence level. (except the pre-compensated distortions)

ACMS Around-LOS:

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

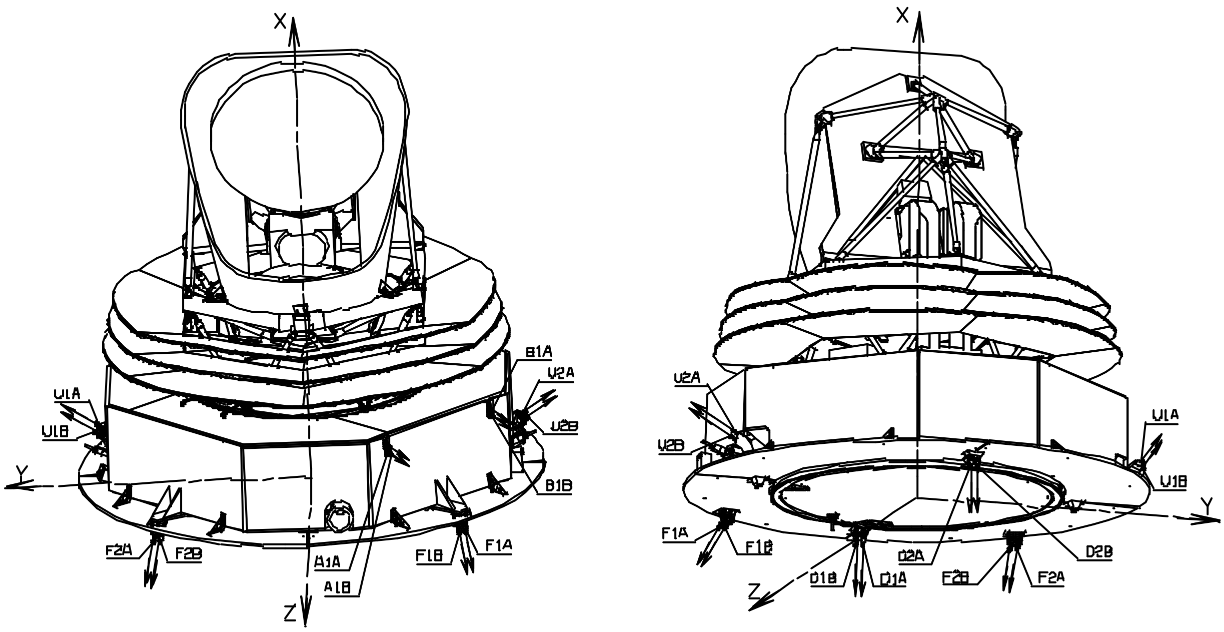
They are derived in "ACMS inputs to Planck System Alignment Plan" H-P-3-ASPI-TN-0245 Issue 1/0.

- 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.

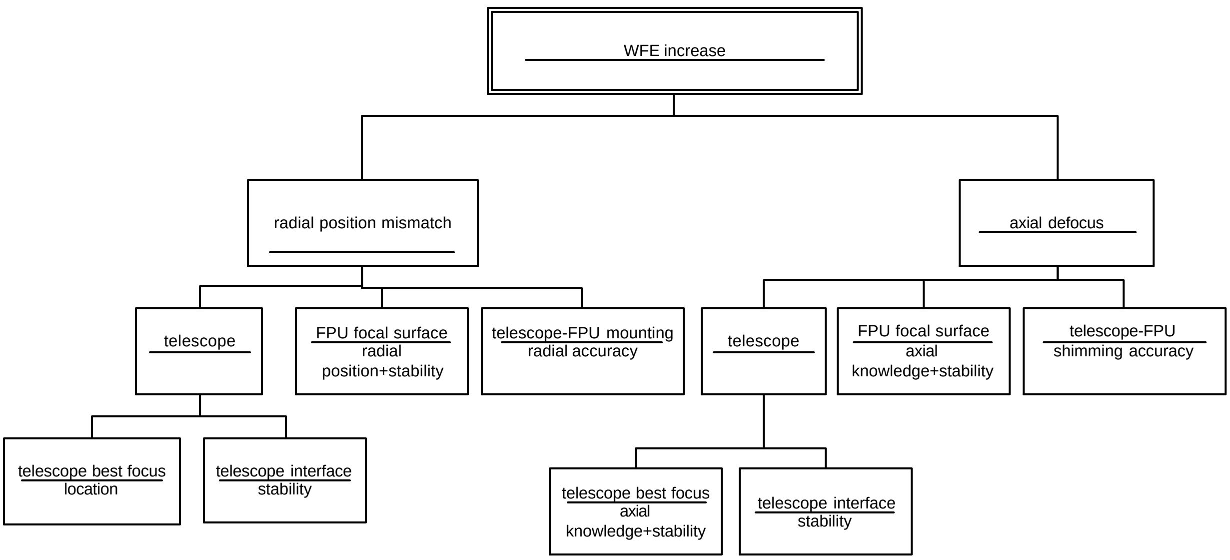


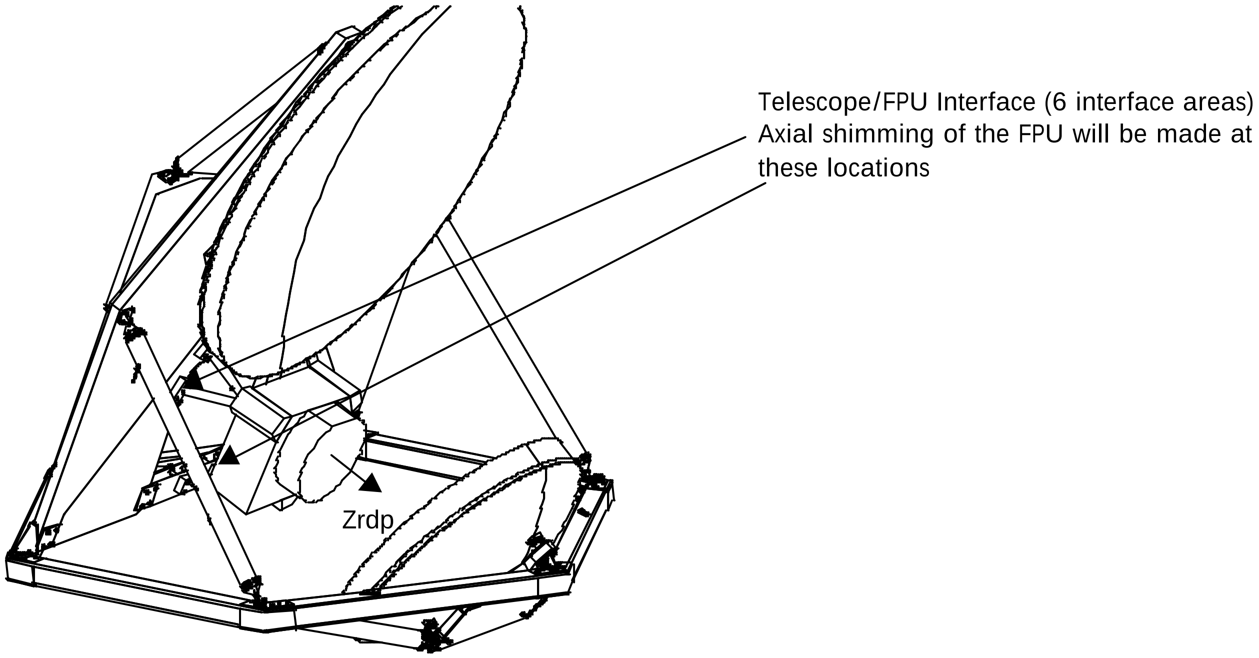
Each one of these thrusters shall be aligned with regards to the satellite CoG.

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



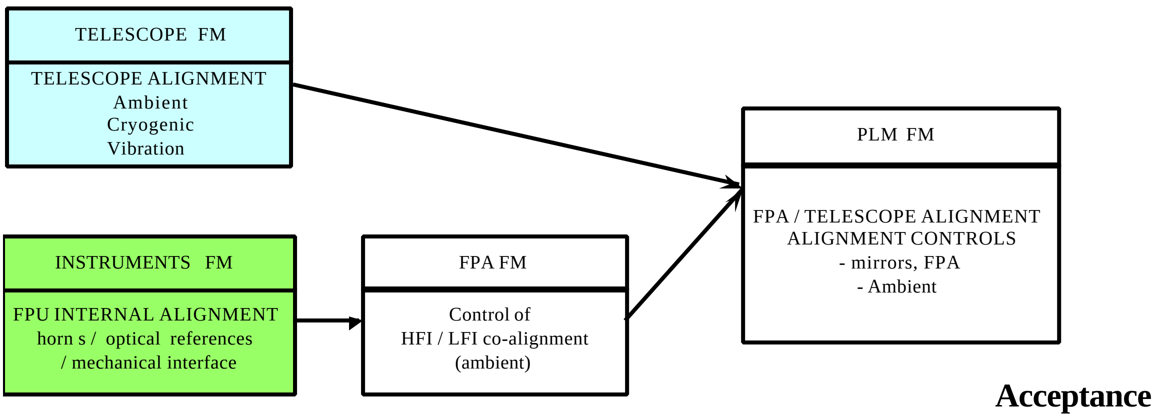


The compliance to these needs is justified in the Planck Alignment Plan, and in the Planck PLM optical performance analyses. The alignment is described in the P-PLM PDR design report.

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: no alignment. 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.

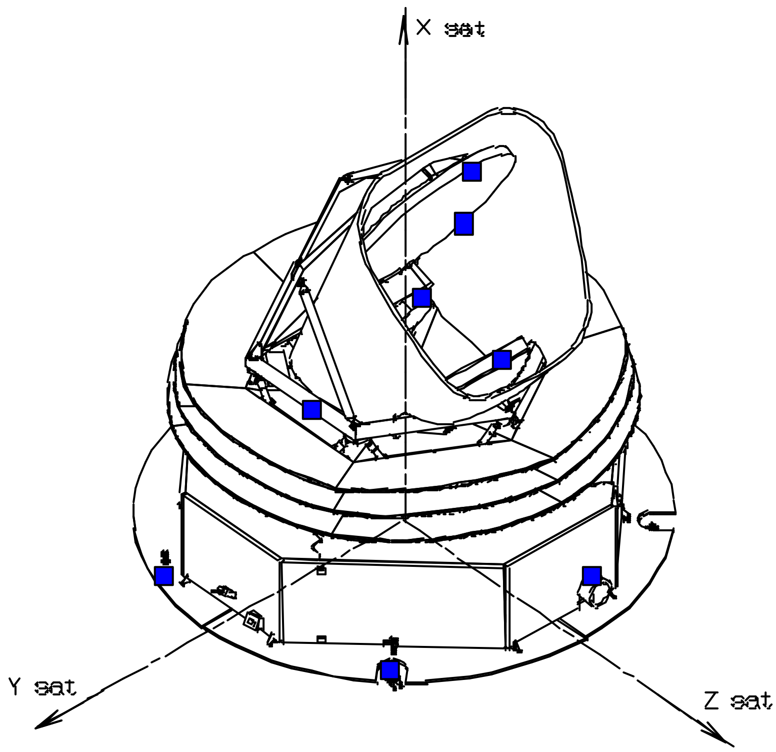
Then the telescope is mounted on the cryostructure: no alignment

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:

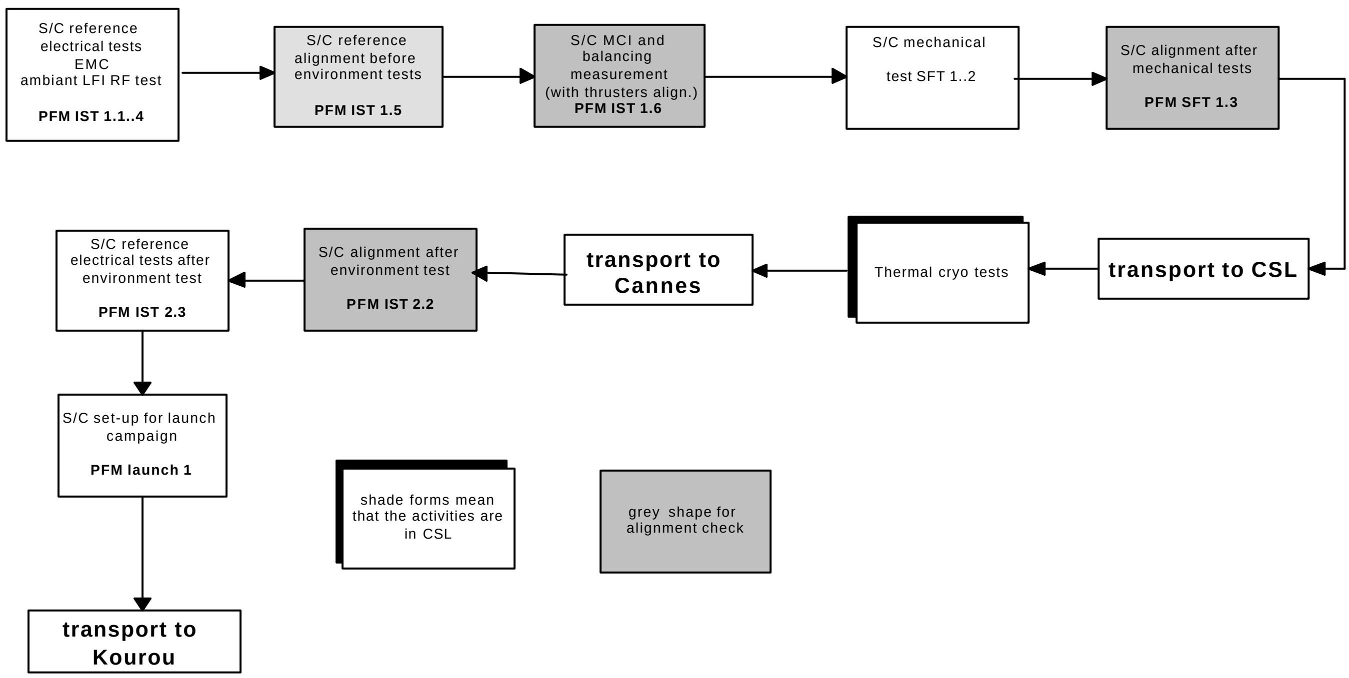
- FPU
- Reflectors
- Telescope frame
- SVM optical reference
- Star trackers
- Spacecraft optical references



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 contributions, present status and the relevant references

CONTRIBUTOR		LOS POSITION WORST CASE	STATUS	REFERENCE
PPLM	Telescope+ cryostructure	+/- 50 arcmin	specified	PPLM interface specification (AD07.3)
	PFU internal	+/- 0.9arcmin	Specified	IID-A (AD04.1)
SVM		+/- 30 arcmin	specified	SVM Structure specification (AD06.9)
Mating		5 arcmin	Requirement to AIT	
budget		86 arcmin	Compliant	

6.8.1.3.2 Around LoS instability (Req. 2)

The budget is as following:

CONTRIBUTOR		AROUND-LOS STABILITY 68 % CONFIDENCE LEVEL	STATUS	REFERENCE
PPLM	Telescope+ cryostructure	+/- 3.4 arcmin	specified	PPLM interface spec PPLM optical performances analysis [RD01]
	FPU internal	+/- 0.33 armin	Specified	IID-A
Budget		+/- 3.77 arcmin	Compliant	+/- 3.8 arcmin are required

6.8.1.3.3 Around LoS misalignment knowledge with regards to the satellite frame (Req. 4)

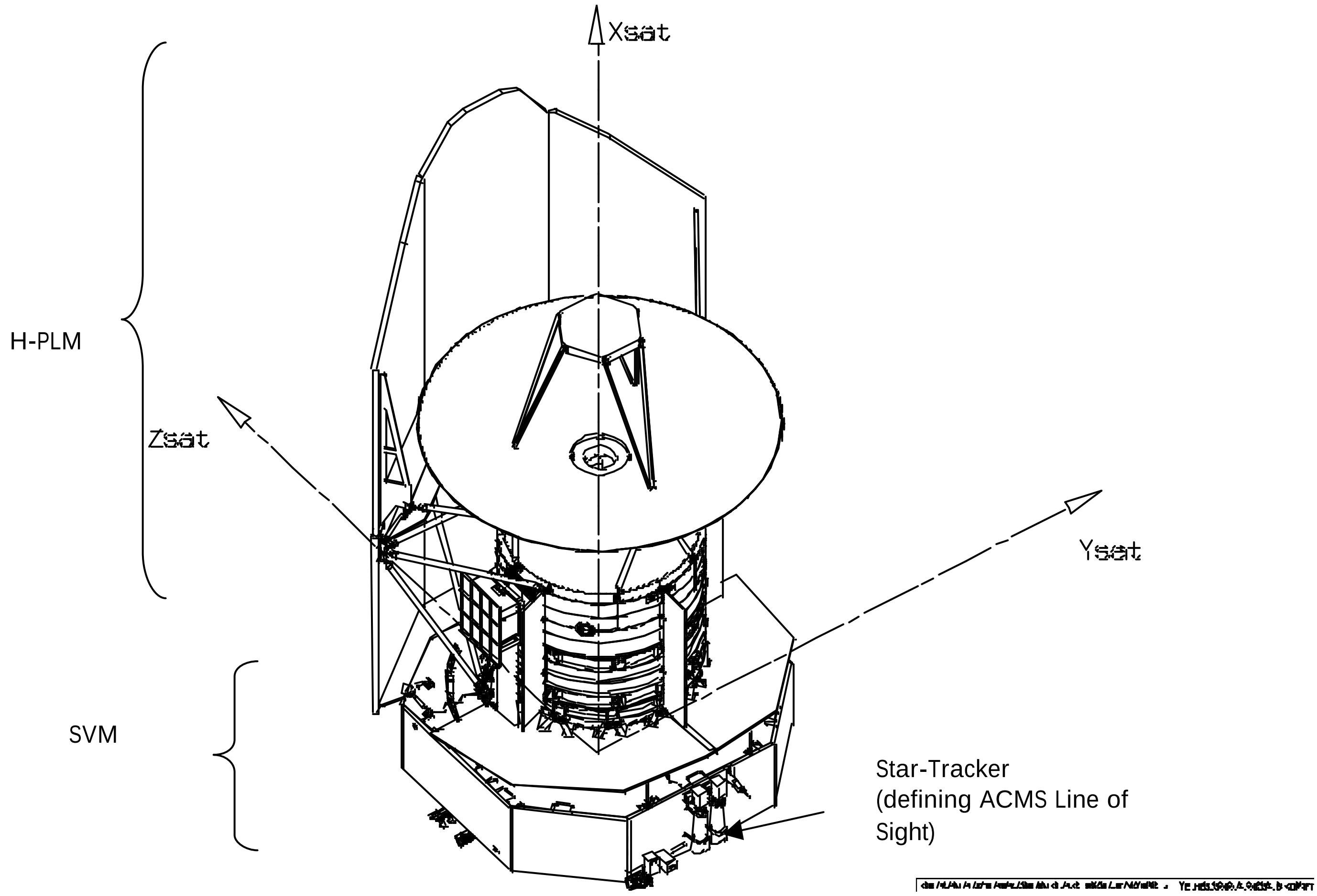
CONTRIBUTOR		AROUND-LOS KNOWLEDGE 68 % CONFIDENCE LEVEL	STATUS	REFERENCE
PPLM	Telescope	+/- 1 arcmin	specified	PPLM interface spec PPLM optical performances analysis [RD01]
	FPU internal	+/- 0.33 armin	Specified	IID-A
Telescope frame orientation measurement with regards to launcher I/F		+/- 1 arcmin	State of the art	
Contingency		0.67arcmin		
total		+/- 3 arcmin	Compliant	Spec = +/- 3 arcmin

6.8.1.3.4 Thruster plume alignment accuracy

	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	To be included in system level TRS
S/C CoG on-ground knowledge accuracy	+/-12 (TBC)	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.



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].

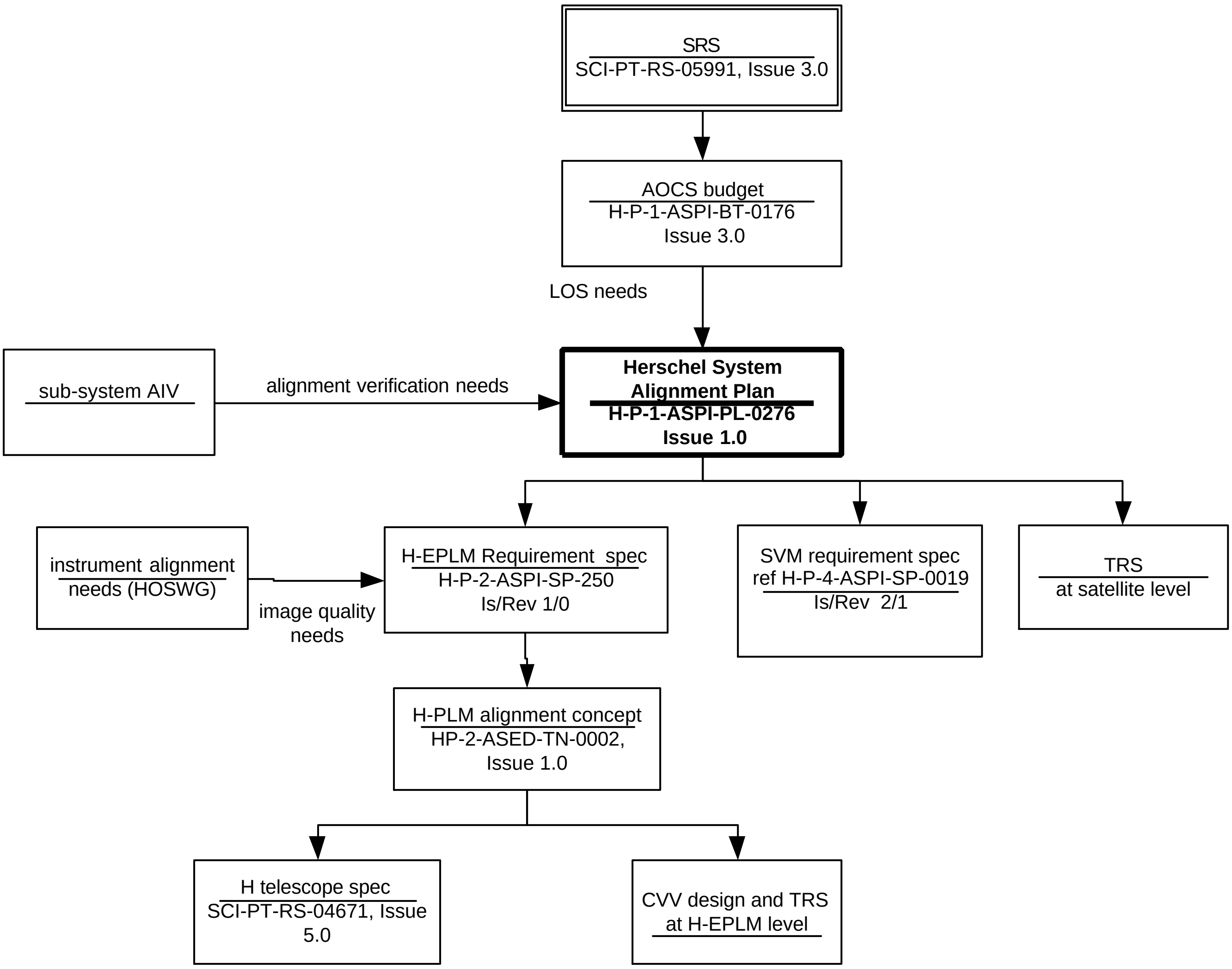
On top of that, alignment check verification might be requested by SVM as far as optical references are visible at satellite level.

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

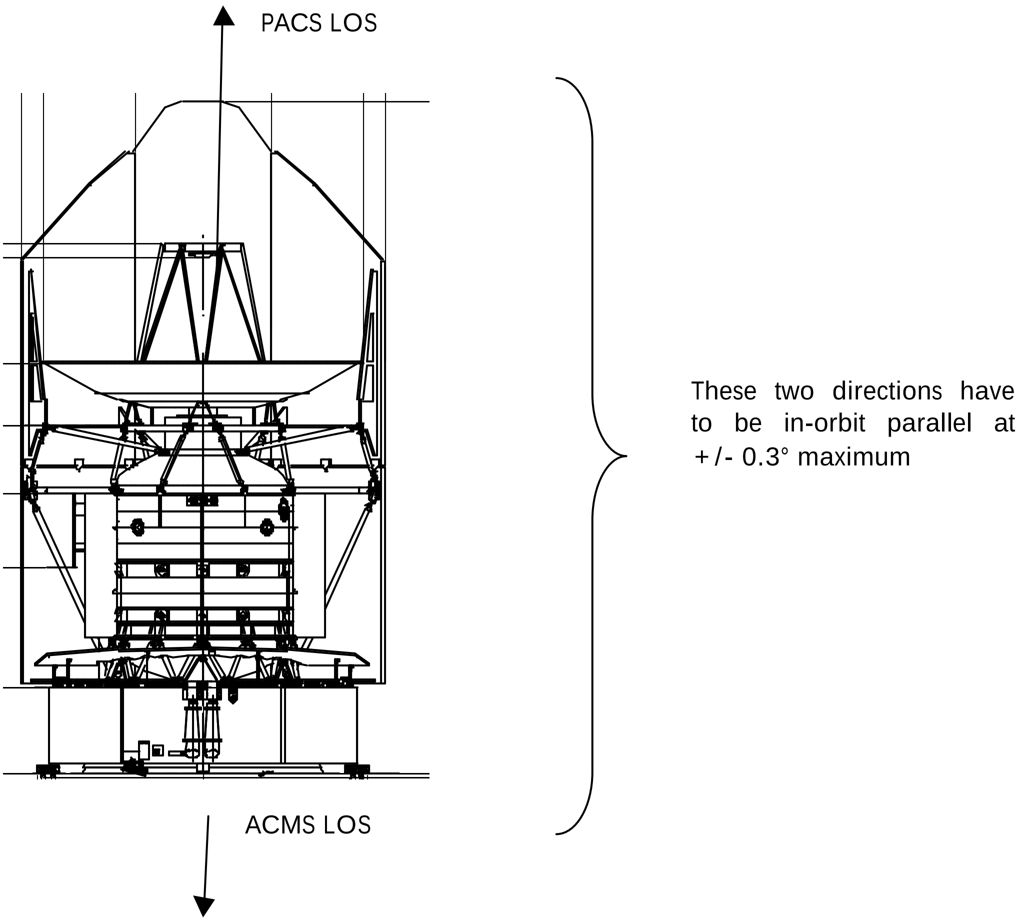
As presented before, the alignment requirements come from both pointing and orbit correction and maintenance. These needs are precisely expressed in the "Herschel system alignment Plan" [RD03.4] , and briefly presented in the two following subsections.

6.8.2.1.1 System needs coming from pointing:

They are declined in 4 requirements:

- Req 1

  The PACS LOS shall be aligned with the opposite ACMS sensor LOS with an accuracy of 0.30 degree maximum (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).



- Req 2

  The SPIRE LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]), required in AD05.7.

- Req 3

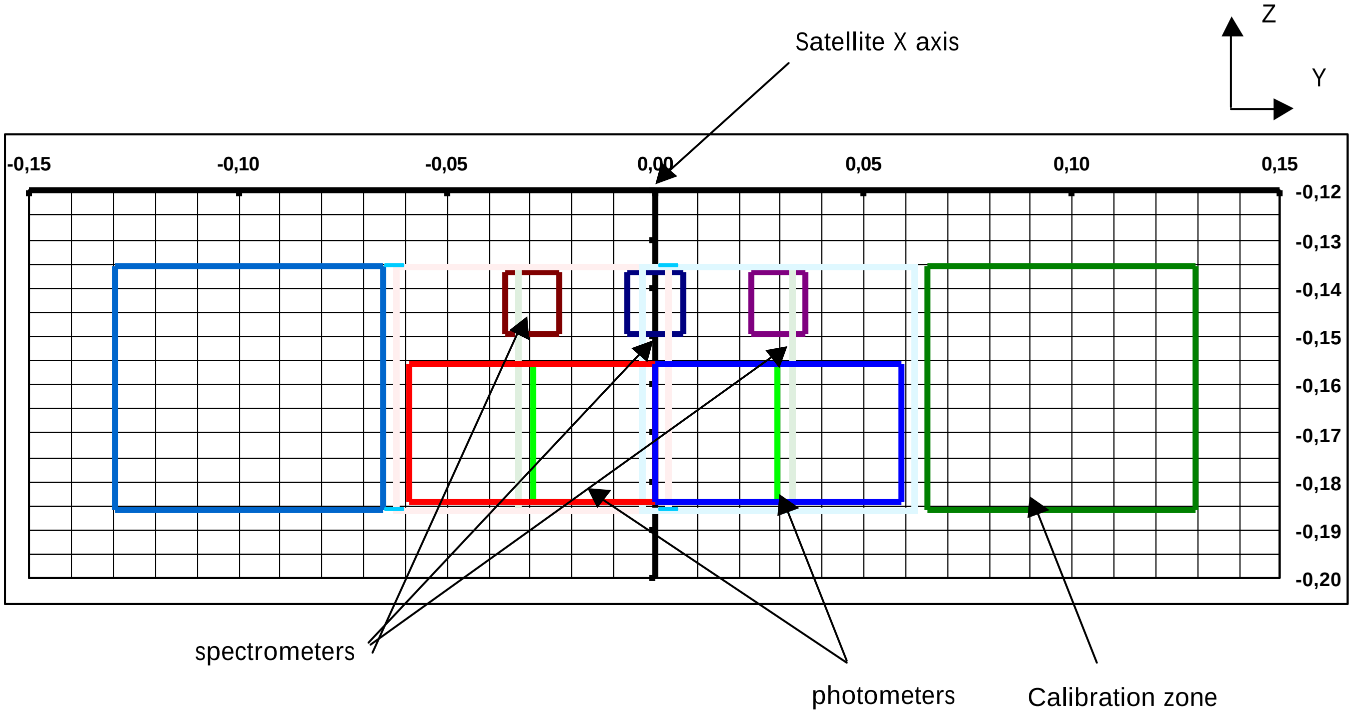
  The HIFI LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]), required in AD05.7.

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 0.3 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.

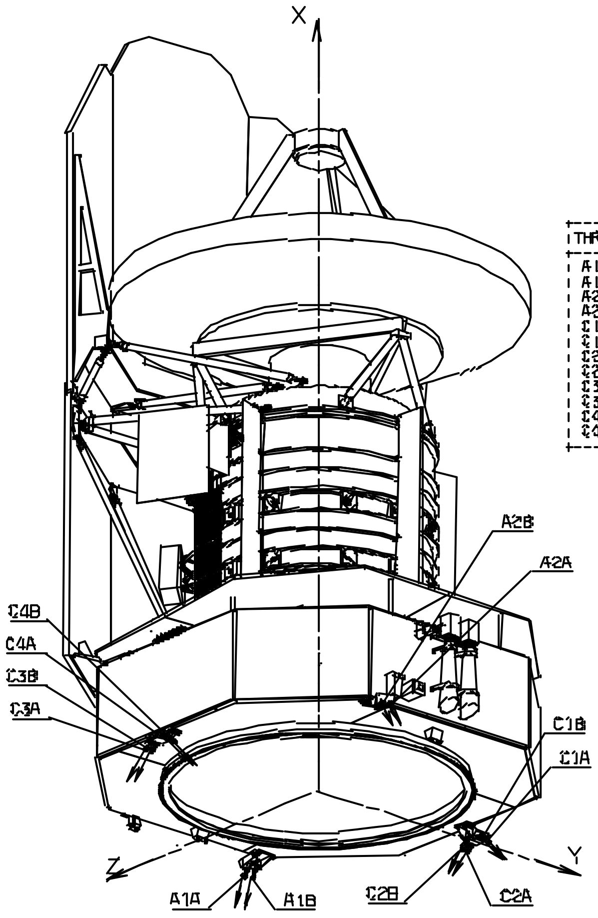
6.8.2.1.2 System needs coming from orbit correction and maintenance

– 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.

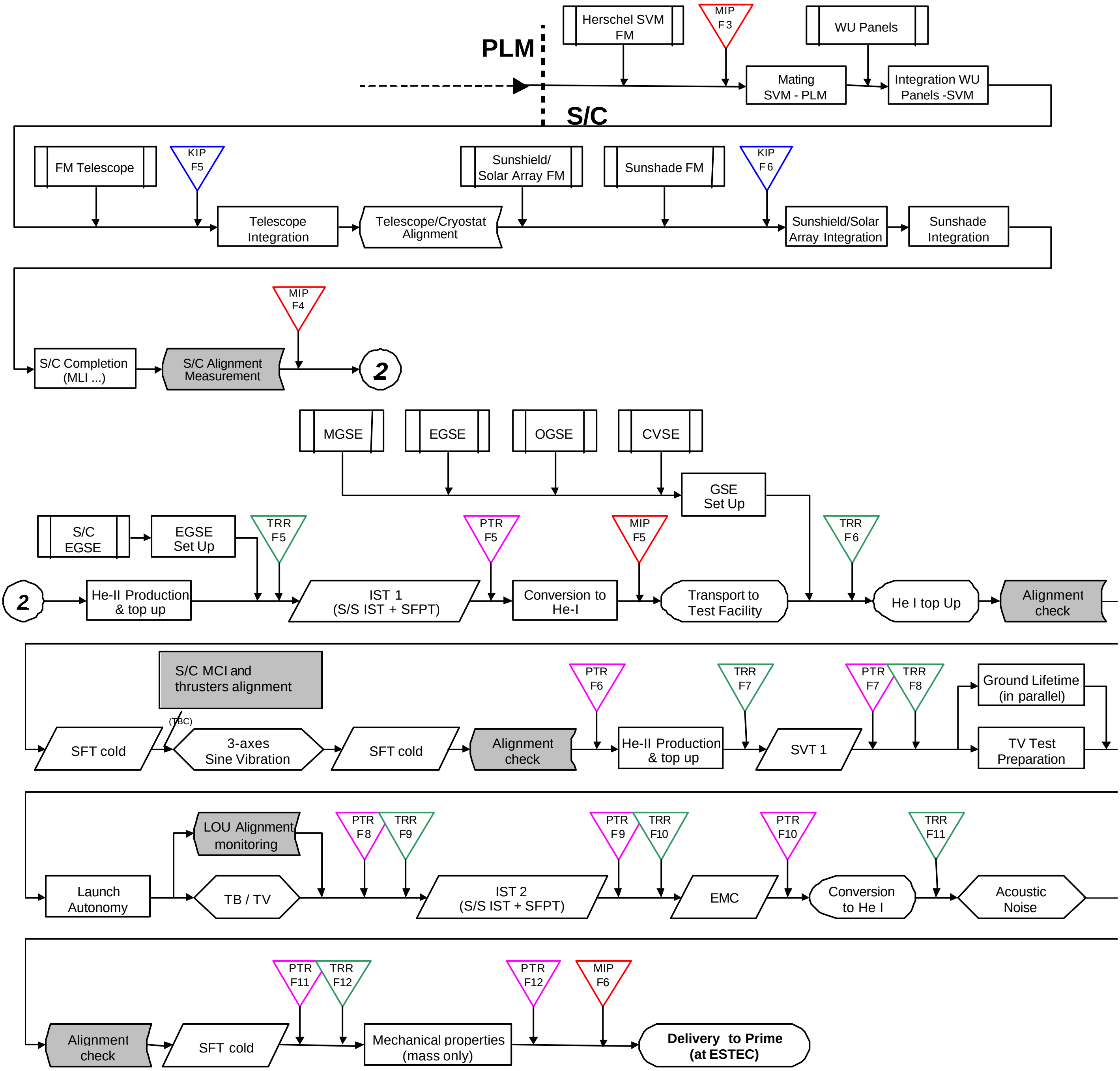


THRUSTER	X
A1A	-7.3
A1B	-7.3
A2A	-7.3
A2B	-7.5
C1A	-41.4
C1B	-41.4
C2A	-41.4
C2B	-41.4
C3A	-41.4
C3B	-41.4
C4A	-41.4
C4B	-41.4

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:



Alignment related steps are represented in the grey boxes

The preceding graph is based on the facts that, in the frame of the shimming, no "optical" alignment is made between the H-PLM and the SVM. A mechanical mounting is sufficient because:

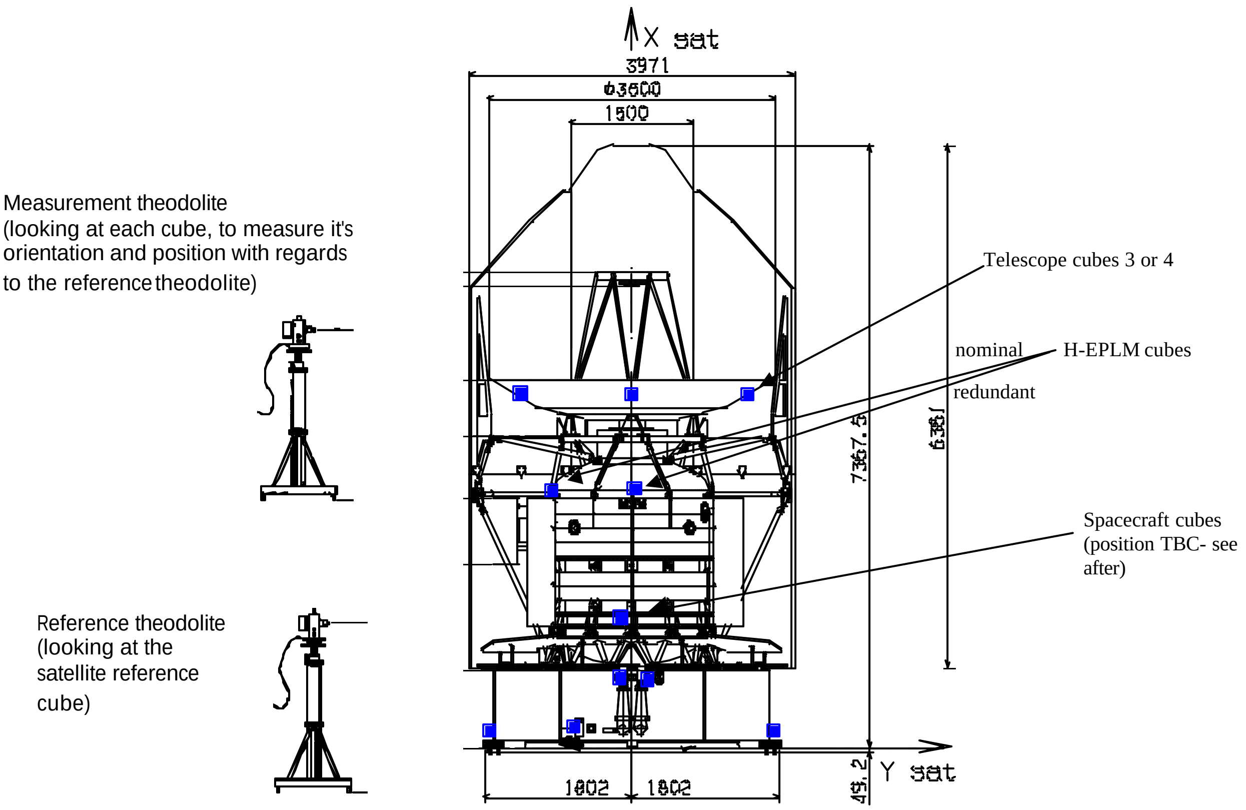
- the mating has no impact on the alignment of FPU with regards to the telescope, nor on the LOU alignment.
- the alignment of the star-tracker with regards to the SVM interface has a sufficient accuracy to limit the impact of the mating (as shows the budgets in section 6.1 of "Herschel system alignment Plan" [RD03.4])
- the alignment of the thrusters is performed after the spacecraft CoG measurement. Mating influence is canceled

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.



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	STATUS	REFERENCE
Stability	SVM	2 arcsec	In line with Pointing budget Module allocations	RD03-7
	HPLM	0.7 arcsec	From ASED study	HP-ASED-205/02
Bias	SVM	15 arcmin	Specified in the SVM structure specification	RD06.9, Table 5.1.2.1-1
	HPLM	5 arcmin	Specified in the H-EPLM Interface Specification	AD07.2
	Mating	1 arcmin	In line with current interfaces	F0278C HESA 180S000S A - Ind. D
Total(*)		16.8 arcmin	Compliant	18 arcmin are required

(*) Misalignments having the same frequency are summed quadratically. Misalignments having different frequency are summed linearly.

6.8.2.3.2 Around-LOS mis-alignment knowledge:

	CONTRIBUTION @ 68 % CONFIDENCE	STATUS	REFERENCE
HPLM bias	0.3	Required to H-EPLM	In line with "pointing budget module allocations" [RD03-7]
Mating	0.03 arcmin	State of the art	
Total(*)	0.3 arcmin	Compliant	0.3 arcmin are required

6.8.2.3.3 Thruster plume alignment accuracy

Req 5

	CONTRIBUTION TO ALIGNMENT ACCURACY	STATUS	REFERENCE
Thruster-plume knowledge & stability	+/-15	This is specified by Alenia	
System level thruster-plume alignment accuracy	+/-3arcmin	State of the art with margin	To be included in system level TRS
S/C CoG on-ground knowledge accuracy	+/-12arcmin	Specification to AIT	
Total	+/-30arcmin	Compliant	30 arcmin are required

6.9 Safety

The HERSCHEL/PLANCK safety analysis are described in the document "HERSCHEL/PLANCK Preliminary Safety analysis" – Doc. RD03.17.

This document is based on the subsystem safety analysis (H-EPLM, PPLM and SVM) and design summary.

6.9.1 Purpose

The primary objectives of the performed safety analysis 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.

This document constitutes the "back bone" of the safety analysis and is used as input for Safety Submissions. For Safety Phase 0, it is written for both HERSCHEL and PLANCK satellites and will be updated for Phases 1 and 2 in two separated documents, one by satellite.

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 analyzed shows noncompliance versus the Safety Launch Agency. This concerns:

For HERSCHEL and PLANCK SVM:

- RCS propellant tank: burst safety factor is 1.75, which is not compliant with a safety factor of 2. At the present time the LBB demonstration is not complete and must be developed. This point shall be treated by a NCR.
- Latch Valve Back Pressure Relief is not redunded. This point shall be treated by a NCR.
- Presence of electrical strap to disconnect battery on spacecraft. Risk of sparks at battery disconnection.This aspect in discussed in the technical note RD03.8. This point shall be treated by a NCR.

For HERSCHEL PLM:

- Cryogenic subsystem: presence of SPF (heater H501 on helium exhaust line) for the phase going from last Helium filling activities (under fairing) up to Helium one tank unfilling before launch. This point shall be treated by a NCR.

For PLANCK PLM:

- HFI experiment: two mechanical inhibits (serial pressure regulators) on each high pressure line in lieu of three required for catastrophic event. The design must be updated or shall be treated by a NCR.

Moreover, complete information is not available concerning:

- Battery: Li-ion battery present an hazardous point in case of external short circuit, over discharge and overcharge. Complete information is not available due to the fact that the contractor has not yet been kicked-off. This point shall be treated in safety submission Phases 1 and 2.
- Ground support equipment (electrical, mechanical, tanking, cryogenic, optical and for experiment). As for the battery, the contractors kick-off are either recent or not yet performed. This point shall be treated in safety submission Phases 1 and 2.
- Launch site ground operations: this point shall be treated in safety submission Phases 1 and 2.

HERSCHEL and PLANCK experiment. This point shall be treated at "Experiment Safety Analysis" document reception, in ALCATEL CANNES, in case of hazardous aspects.

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).

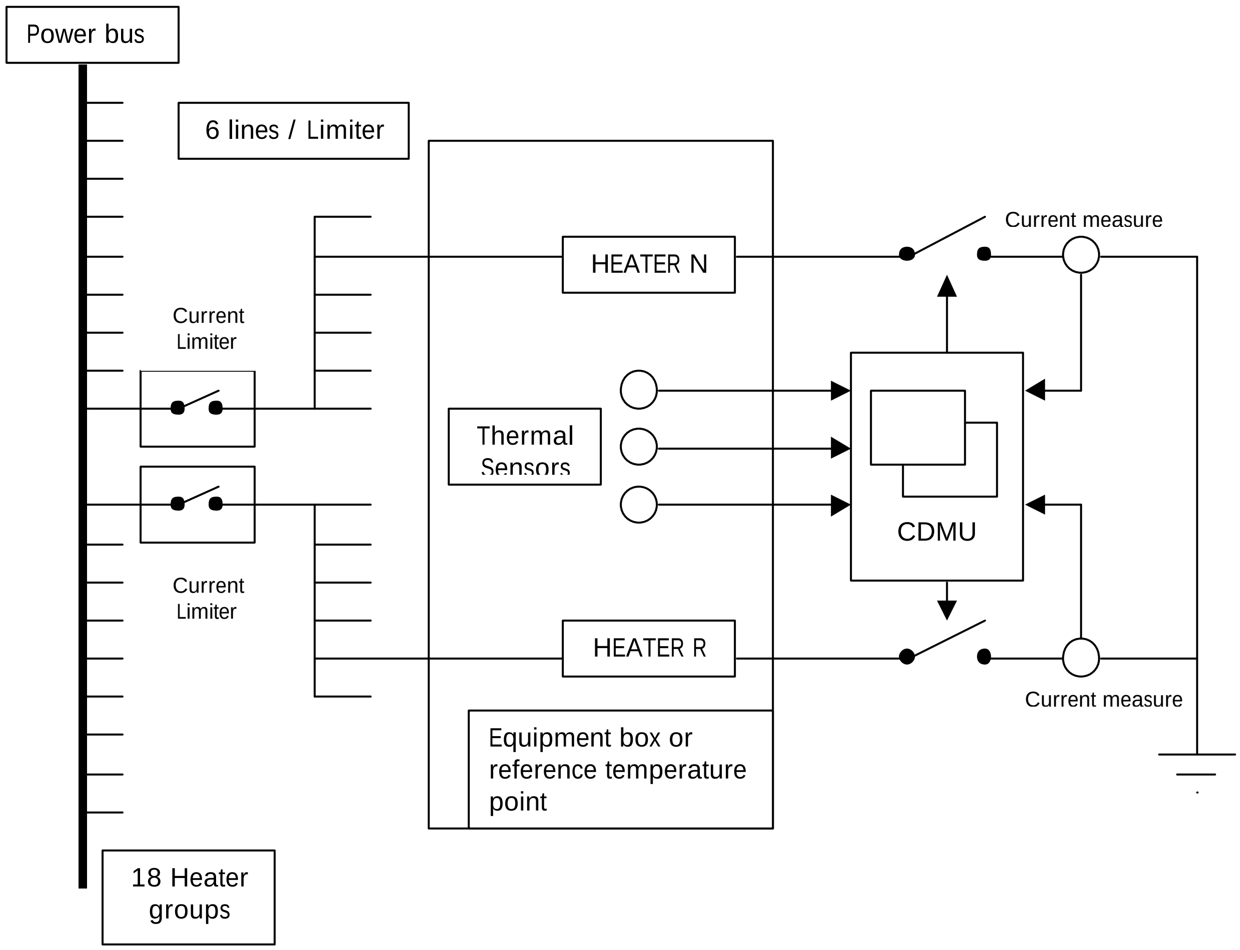


FIGURE 6.10.2-1 HEATER LINES

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 (battery, tanks...) without any unit turned on (apart from the PCDU itself). Thermostat switching temperatures limits will be chosen lower than temperatures assured by nominal thermal regulation, so that no thermostat switching should occur on normal operation.

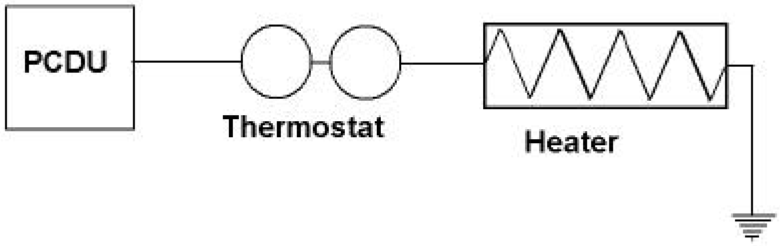


FIGURE 6.10.2-2 SURVIVAL HEATER LINE

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 (or 6 strings) + 1 string out of 180 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 3.9 %
- 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 6.10.2-3 it exhibits the following reliability features:

Battery

One battery is provided and is SPF free. It is composed of 156 cells (TBC) (6 series of 26 (TBC) 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 cut 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 2 SA sections in cold 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.

  Those users which turn off is critical:

from a power budget point of view or

for operational constraints reasons.

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.

Survival heater distribution

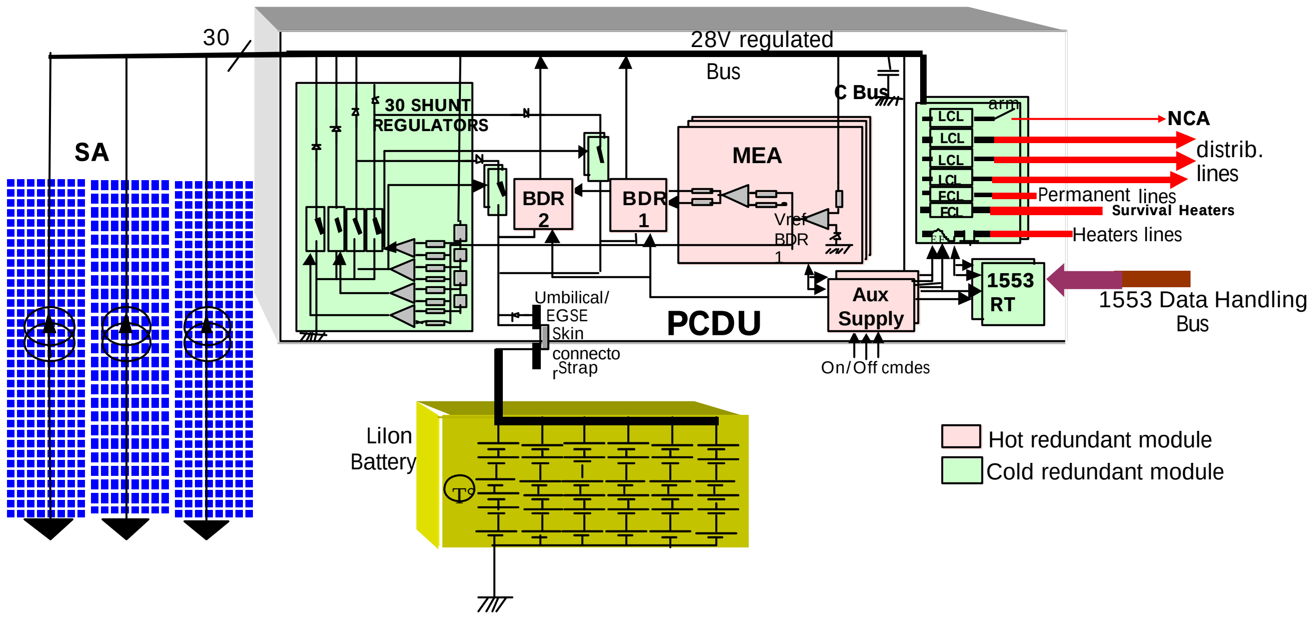


FIGURE 6.10.2-3 POWER SUBSYSTEM FUNCTIONAL DESCRIPTION

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 comprizes 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 cold 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).

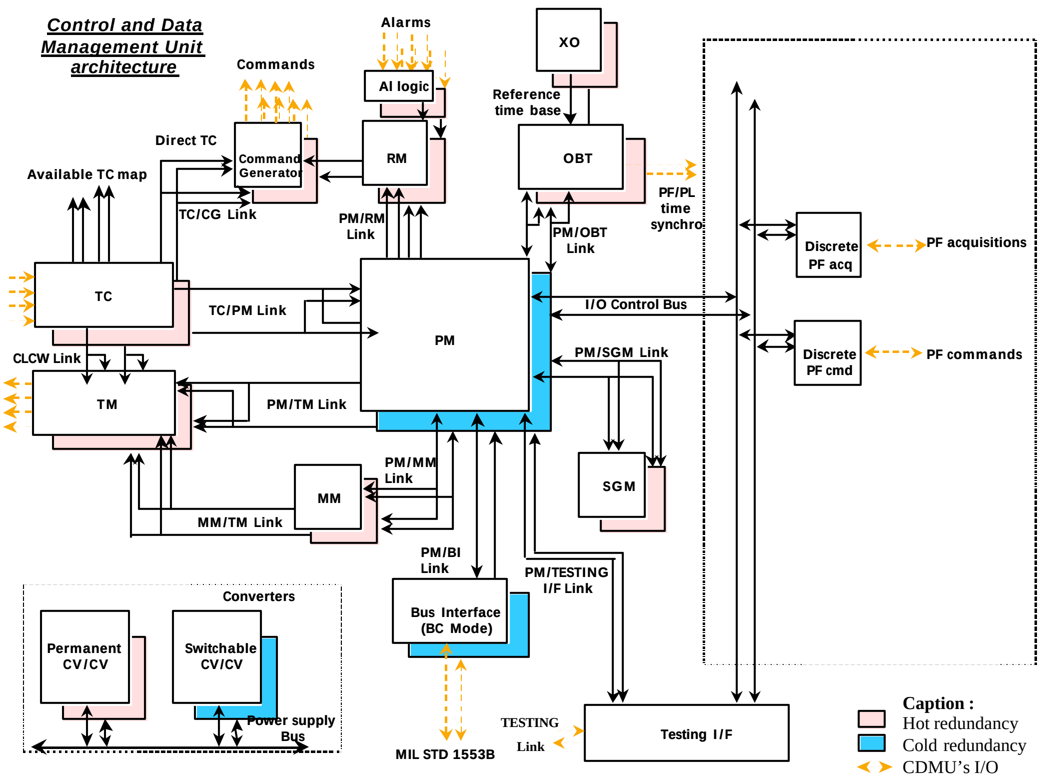


FIGURE 6.10.2-4 CDMU FUNCTIONAL BLOCK DIAGRAM

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 6.10.2-5, 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 Quartz Rate Sensors (QRS) used in 2 for 1 hot redundancy

1 GYRo blocks (GYR) of 4 skewed axes 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

2 cold redundant branches of 6 x10N 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 Quartz Rate Sensor (QRS) in 2 for 1 hot redundancy (nominal mode)

1 Quartz Rate Sensor (QRS) (survival mode)

2 Star TRackers (STR) in 2 for 1 cold redundancy.

– Actuators for PLANCK

2 cold redundant branches of 6 x10N thrusters plus 2x1N thrusters each.

The functional connections of Planck (resp. Herschel) sensors and actuators to the ACC are shown in Figure 6.10.2-6 (PLANCK) and Figure 6.10.2-7 (HERSCHEL).

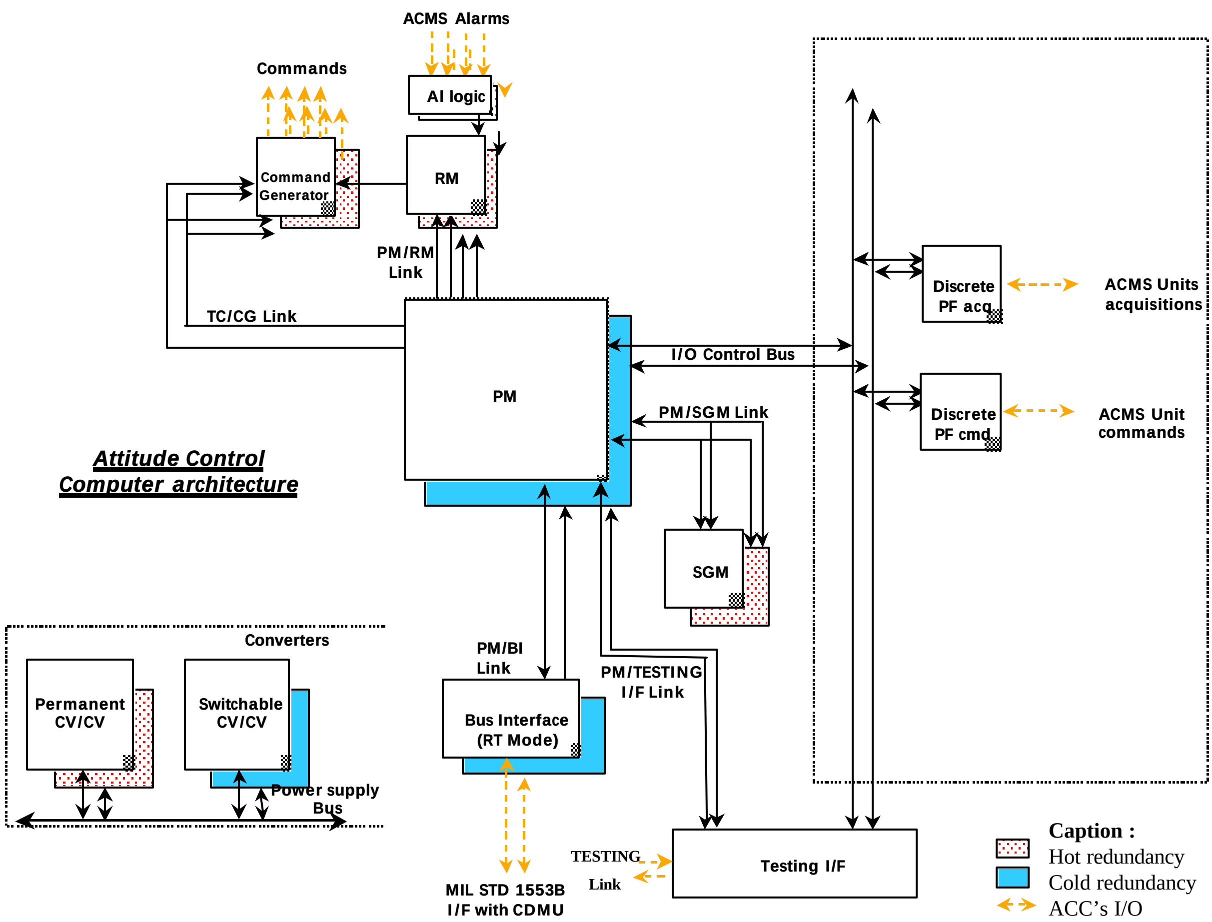


FIGURE 6.10.2-5 ACC FUNCTIONNAL BLOCK DIAGRAM

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.

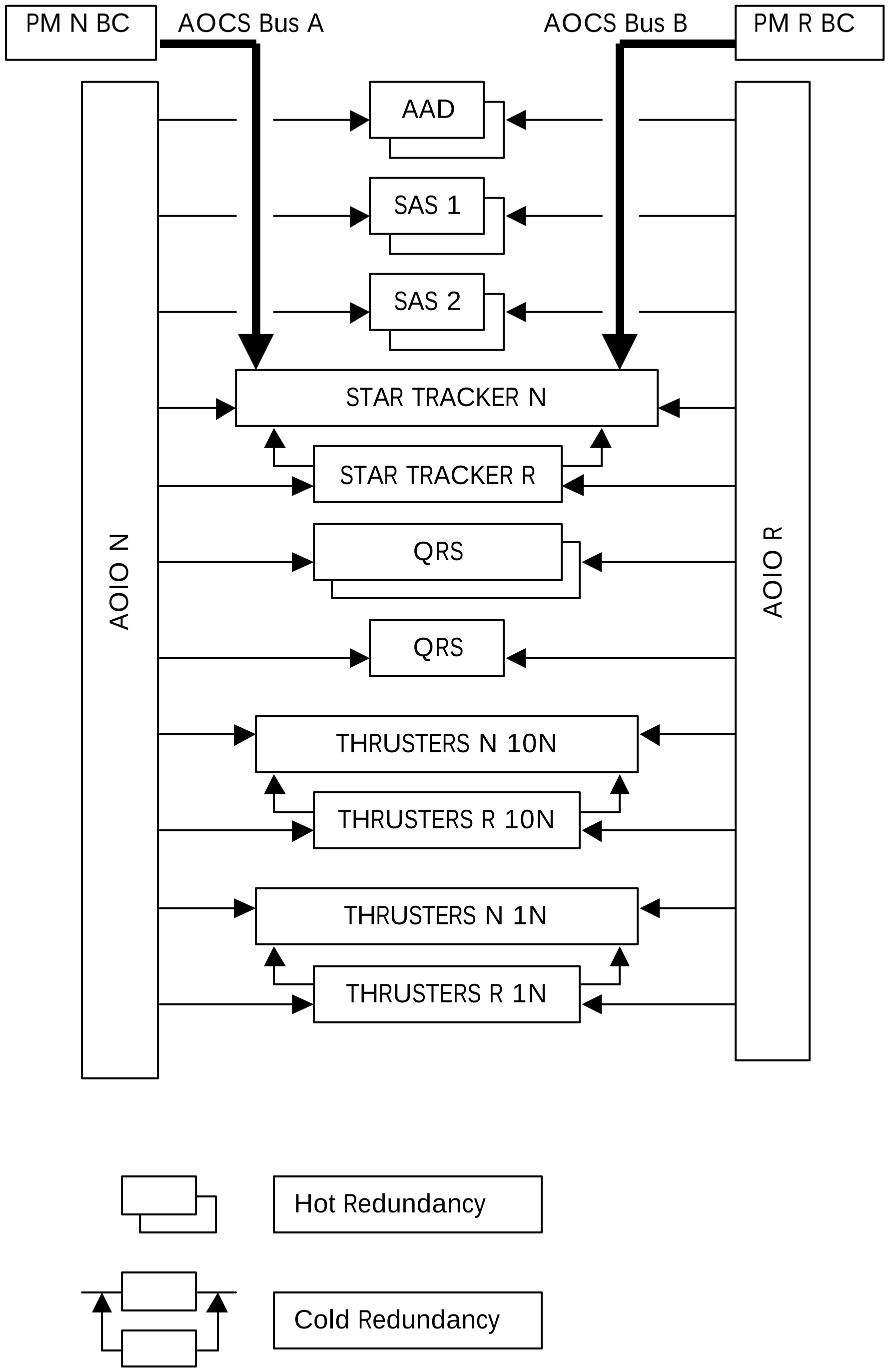


FIGURE 6.10.2-6 PLANCK SENSORS AND ACTUATORS INTERFACES

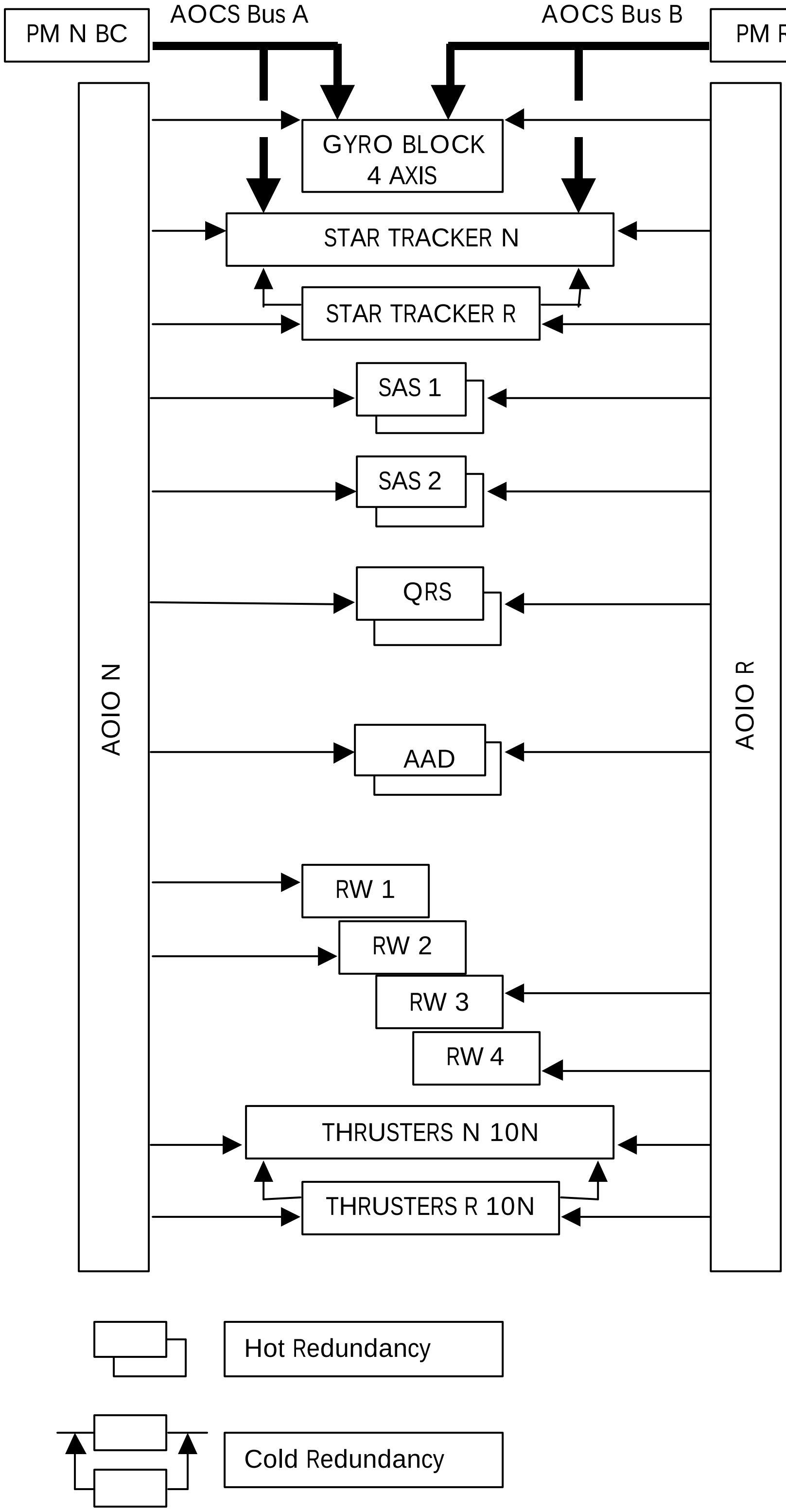


FIGURE 6.10.2-7 HERSCHEL SENSORS AND ACTUATORS INTERFACES

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 minimize 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 2 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.

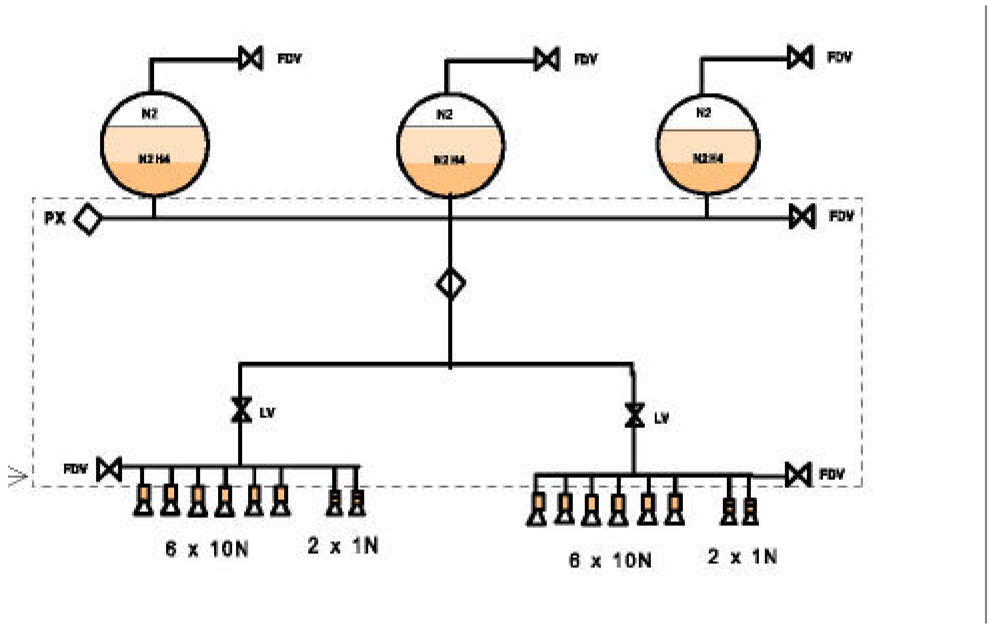


FIGURE 6.10.2-8 PLANCK PROPULSION EXAMPLE

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 MGA is a back up to LGAs 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).

6.10.2.10 Harness

The harness elements have the same level of redundancy than the units they connect. Besides, a verification of 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 will be performed from Phase B. 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 SPF is identified.

Helium tank SPF correspond to mechanical failures.

The Helium tank cover has no redundancy except that release of one NCA out of two is enough to assure the opening mechanism release and so the cryo cover opening. For Helium tank and its cover, the SPF list in provided in the table below.

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 Single Point Failures

From preceding paragraphs, the following list of hardware SPF 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.

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
Structure (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 (SVM)	MLI, paints, coatings, surface treatments, OSR	Tests, learned lessons (space proven materials)
	Short circuit between redundant heaters on same support	Tests showing isolation between tracks, electrical margin, robustness of Kapton layer, Thermal Control performance tests
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
	Mixing of propellant/pressurant in a tank (tanks diaphragm)	Qualified and space proven diaphragm with N2H4, leak tested diaphragm Thrust possible tolerance to N2/N2H4 mixing
Power S/S (SVM)	Short circuit of film resistors Short circuit of self healing capacitors	Non credible failure mode Non credible failure mode if 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

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
TTC Subsystem (SVM)	**HERSCHEL** Wave guides Coax cables and connectors 1 MGA 2 LGA 3 ports for the 2 LGA2/MGA RF SW 3 test couplers 1 filter 2 diplexers 2 ports for the 2 TWTA RF SW 2 ports for the 2 RF SW between LGA 1-2 and Rx	Simplicity of the items Functional tests after acceptance environmental tests Components with low failure rates Qualified technologies
	PLANCK Wave guides Coax cables and connectors 1 MGA 3 LGA 3 ports for the 2 LGA2-3/MGA RF SW 3 test couplers 1 filter 3 diplexers 2 ports for the 2 TWTA RF SW 2 ports for the 2 RF SW between LGA 1-2-3 and Rx	
	HERSCHEL/PLANCK LGA/MGA, RF SW blockage in intermediate position (6 SW)	**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

SUB ASSEMBLY	IDENTIFIED SINGLE POINT FAILURE	RISK REDUCTION
Helium S/S (HERSCHEL PLM)	External leakage of items containing Helium (tank, valves, pipes, seals ...) Internal leakage of Helium valves or safety valves or rupture disk.	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
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
	Cryo cover damaging other items when released	Safety margin Cover opening test Low probability for a free part to enter the cryostat
	Insufficient tightness of cover/tank interface	Tests before launch demonstrating correct tightness

7. HERSCHEL SYSTEM ANALYSES

7.1 Mechanical analyses

7.1.1 Introduction

The calculation detail is in the document RD04.10 "PDR HERSCHEL Mechanical analysis 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 HERSCHEL satellite (Launcher requirements)

– to define and update subsystem (H-PLM and SVM) structural requirements

– to update and complete the environment specification for Herschel equipment

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.

7.1.2 Analysis of Herschel satellite dynamic behaviour

7.1.2.1 Subsystem mechanical performances

7.1.2.1.1 HERSCHEL Service Module

General

The Service Module (SVM) finite element model has been defined by CASA and checked by ALENIA (HERSCHEL SVM configuration is the FEM model dated 7/02/2002 by mail: "H-model.zip")

The references (location and name) of received FEM are in the following archive directory:

Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/DYN/ h-model.zip

This model has been modified. The modification are the following:

– - 3 layers for the cone. (G969/M18 35°/-35°/+35°). This modification was introduced because the cone stiffness in the model was too high. This definition was in line the one presented at structure PDR.

– - HPLM mass and inertia

This mathematical model has sufficient detail for the stiffness simulation in the dynamic analyses.

SVM FE model description

The model description is in the document RD06.1" Herschel SVM FEM Description".

The main characteristic are the following:

– SVM cone:

Honeycomb: height H/C=15 mm core Hexcel 3/16-5056P-.001 [4-28]

Three layers composite face sheet: resin epoxy G969/M18 35°/-35°/+35°

thickness for each sheet: t= 3 x 0.19 mm

Local reinforcements have been implemented on the cone in the interface areas around the GFRP struts fixations. These reinforcements consist in increasing the stiffness of the upper interface ring of the cone. The total number of the plies of the composite face sheet has been increased, the honeycomb properties remaining unchanged. The core thickness of the upper reinforced ring is about 12 mm.

- SVM upper/lower closure platform:
  - Honeycomb: total height H=20 mm core 4-20: 3/16-5056P-.0007
  - Four plies composite face sheet: resin epoxy G801/M18 45°/0°/-90°/-45°
  - thickness for each sheet t= 4 x 0.1 mm
- SVM lateral panels:
  - Honeycomb: height H/C=35 mm core 4-20: 3/16-5056P-.0007
  - Aluminium face sheet: skin AA7075 T6

    Total thickness for each sheet: t= 0.3 mm
- SVM shear webs:
  - Honeycomb: height H/C=15 mm core 4-28 3/16-5056P-.001
  - Four plies composite face sheet resin epoxy G969/M18 60°/-60°/-60°/60°
    thickness for each sheet: t= 4 x 0.19 mm
- H-PLM sub platform/ RCS panel

The mechanical characteristics of the H-PLM sub-platform and RCS panel are:

- Honeycomb: height H/C = 20mm core 4-20 : 3/16-5056P-.0007
- Three plies composite face sheetresin epoxy G801/M18 45°/0°/-45°
  thickness t for each face sheet =3 x 0.1 mm

HERSCHEL SVM model characteristics

The FEM model has been set up to the maximal mass. The main characteristics of the model are:

- Number of Nodes : 6950
- Number of Element : 8509
- SVM FEM has : 41700 d.o.f
- SVM FEM mass is : 909.3 Kg

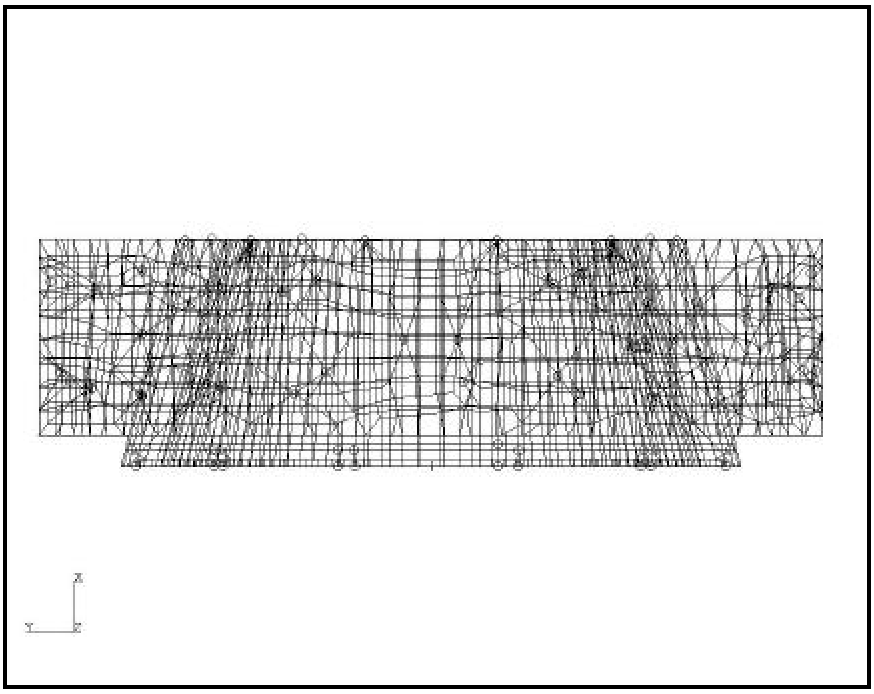


FIGURE 7-1 HERSCHEL SERVICE MODULE MATHEMATICAL MODEL [Z VIEW]

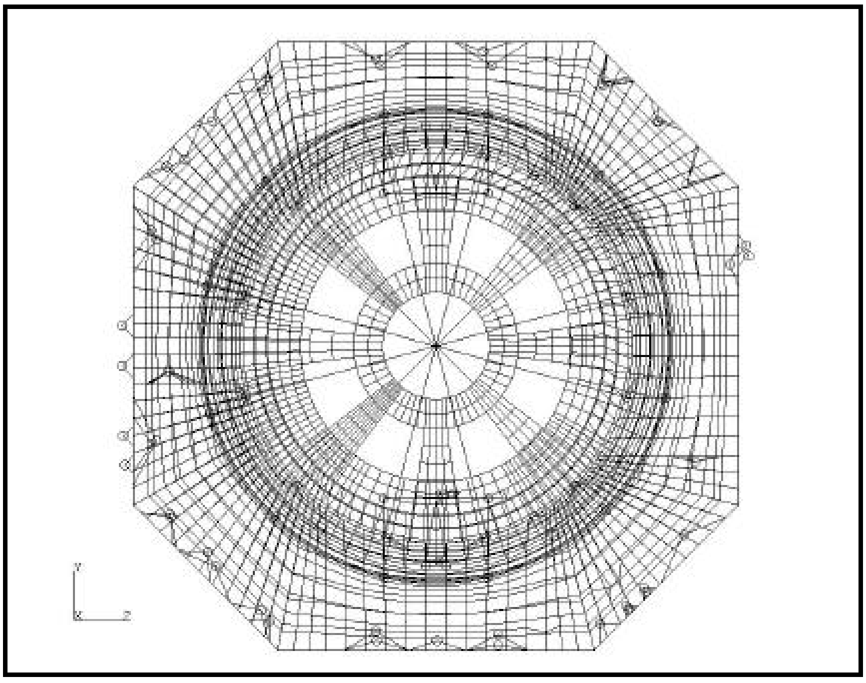


FIGURE 7-2 HERSCHEL SERVICE MODULE MATHEMATICAL MODEL [X VIEW]

HERSCHEL SVM Dynamic performances

Herschel SVM dynamic global (global box modes, global lateral and longitudinal ones) and local stiffness (panels ..) are obtained from a modal analysis performed with a rigid Herschel PLM mass (2400 Kg) taking into account inertia (I_{xx}=2000m²Kg and I_{yy}=I_{zz}=3500m² Kg) located at the centre of gravity of the Payload (boundary conditions of the dynamic SVM specifications: CoG =1627mm from PLM/SVM interface).

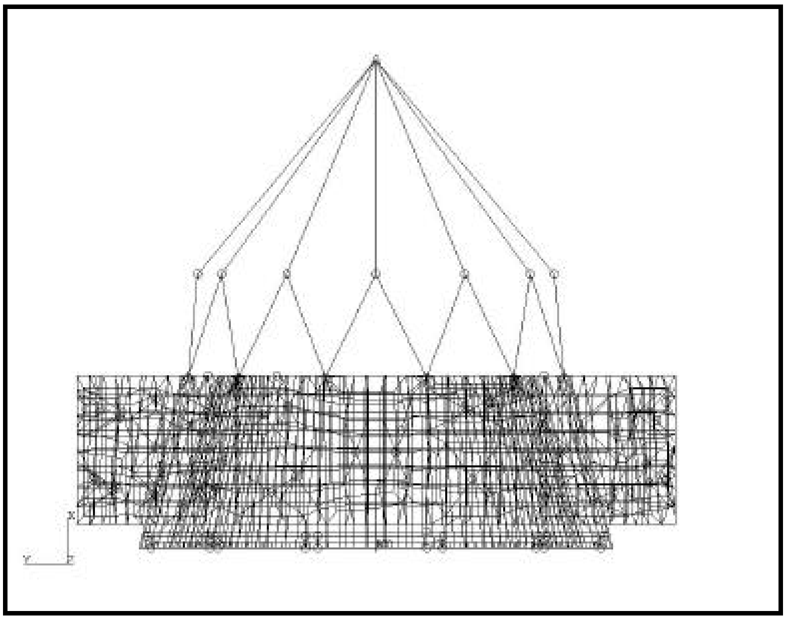


FIGURE 7-3 HERSCHEL SVM MATHEMATICAL MODEL WITH RIGID PAYLOAD

The main modal results (main modes) of the modal analysis are summarised in the following table.

Mode Frequency	Effective Masses (Kg)			
(Hz)	**Mx**	**My**	**Mz**	**Mode description**
25.3	/	4	2095	First lateral global Z mode
25.5	/	2055	4	First lateral global Y mode
47.9	84	7	8	First axial global box mode
49.4	/	30	20	First out of plane panel mode
51.2	124	41	9	Second axial global box mode
68.3	1546	2	24	First axial global X mode
71.6	24	27	348	First lateral global Z box mode
83	/	220	10	First lateral global Y box mode

TABLE 7-2 HERSCHEL SVM MAIN MODES WITH RIGID H PLM MASS

Comments:

These results have allowed to define SVM dynamic requirements given in chapter 7.1.4.

Evolution between model and baseline design:

Taking also into account a cone configuration with 4 layers M40 (thickness 0.135mm each), HERSCHEL SVM lateral main modes are above 23 Hz and the longitudinal one is above 65 Hz. All these main modes have effective mass higher than 20 % of the total mass of the satellite.

Global box modes are above 45 Hz in axial direction and above 63 Hz in lateral direction. HERSCHEL SVM is considered very stiff in the longitudinal direction.

HERSCHEL out of plane mode of lateral panel are located around 50 Hz which is very close to the SVM panel frequency requirements.

So, the dynamic behaviour with a cone configuration with 4 layers and 3 layers are very close. The analyses with 3 layers are coherent with the baseline design.

7.1.2.1.2 HERSCHEL Payload Module

General

The HERSCHEL PLM finite element model implemented in the satellite system FE model has been received from ASTRIUM. D with a new telescope received from ASTRIUM. F.

PLM FE model description

The model description is in the document RD06.4" H-EPLM FE Model Description".

HERSCHEL Payload module is defined from the following substructures.

Telescope

For this H-PLM configuration, HERSCHEL Telescope is represented through a detailed physical model coming from ASTRIUM F. This model is a CDR telescope model with hexapod as secondary mirror support (delivery date to ALCATEL SPACE 13/03/2002 by mail:"modal_CDR_12_03_02.dat").

The references (location and name) of received FEM are in the following archive directory:

Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/TELESCOPE/ modal_CDR_12_03_02.dat

The model used for the PDR system analyses is this intermediate model with hexapods referenced here above. However, an updated model was received afterwards, but was not implemented because of the very few changes between these two models in term of modes and coupling, which should not affect the dynamic analyses for the PDR. Moreover, the model did not meet the ALCATEL specification for FEM model (Strain Energy Check).

We did not receive any documentation concerning the intermediate telescope model and the reference document is only about the last CDR model (ref RD06.6 "HERCHEL TELESCOPE Finite Element Model Description").

The differences between the two models are the following:

- reduction of hexapod bar width from 20 to 18mm
- update of hexapod fitting design
- update of glued I/F stiffness
- update of bipod dimensions (length and section : but same stiffness)
- update of Mass budget.

The CDR fem description report is almost representative of the intermediate delivery of March, especially when considering the M1.

The same modes remain but:

- the coupling between lateral M1 and bipod mode is slightly increased (Effective weight of M1 mode around 46.5 Hz become 78 kg instead of 60 kg, mode not presented in the Table 1).
- the hexapod modes appear at lower frequency: 62 Hz lateral, 87 HZ axial and 82.6 Hz torsion (instead of 64.6, 100.5 and 91.4 respectively, mode not presented in the table 1). As a consequence the coupling with the bipods increases a little.

So, these modifications should not affect the dynamic Telescope behaviour.

The total mass of the Telescope is around 297 Kg.

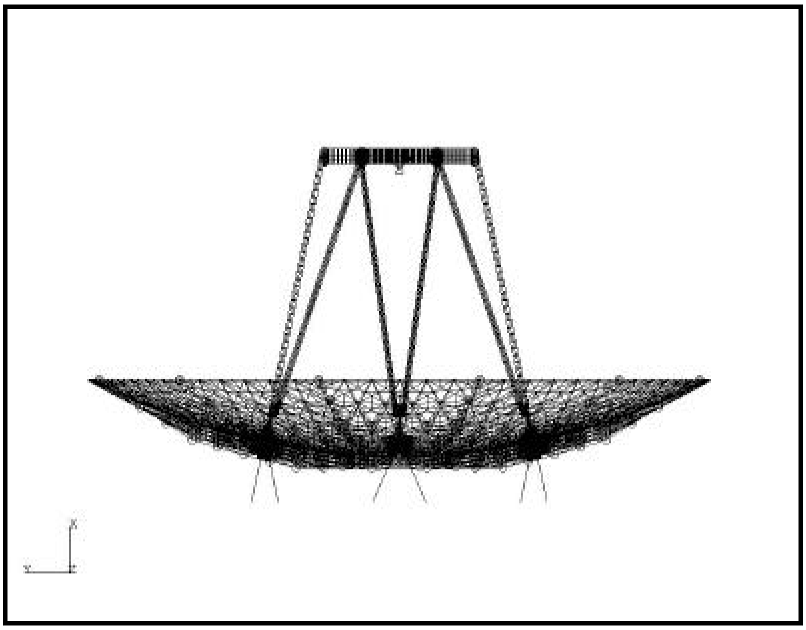


FIGURE 7-4 HERSCHEL TELESCOPE

With simply supported boundary conditions the telescope main modes have been computed and presented in the following table

Frequency [Hz]	Mass X [Kg]	Mass Y [Kg]	Mass Z [Kg]	Mode shape description
45.11	/	/	216	First lateral Z mode
45.13	/	213	/	First lateral Y mode
96.57	117.4	/	/	First longitudinal mode

TABLE 7-3 TELESCOPE MAIN MODES

Comments:

The frequencies of the new Telescope configuration fulfil the frequency requirements described in the doc ref AD02.1" Herschel Telescope Specification".

- Lateral frequency > 45 Hz
- Longitudinal frequency > 60 Hz.

Sunshield/Sunshade structure

This model is the H PLM FEM model dated 15/02/02 by mail: "Model send 150202.zip".

The model description is in the document RD06.4 "H-EPLM FE Model Description".

The meshing of the sunshield / sunshade mathematical model is presented on the following figure .The total mass of the sunshield / sunshade structure is 188.1 Kg.

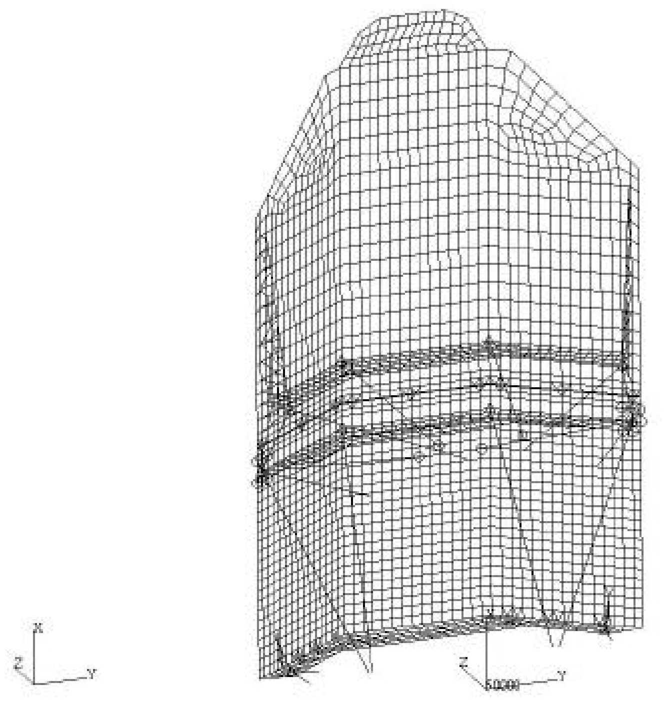


FIGURE 7-5 SUNSHIELD/SUNSHADE MATHEMATICAL MODEL

With simply supported boundary conditions the sunshield/Sunshade main modes have been computed and presented in the following table

Frequency [Hz]	Mass X [Kg]	Mass Y [Kg]	Mass Z [Kg]	Mode shape description
24.3	/	9.6	/	First lateral SSD Y mode
25.7	2.7	/	29.3	First lateral SSD Z mode
35.3	3.5	2	19.3	Second lateral SSH Z mode
38.6	/	68	1.4	First global SSD/SSH lateral Y mode
85.3	55	/	1	First global SSD/SSH axial mode

Table 7-4 SSD/SSH main modes

Comments

Sunshield/Sunshade structure is not a stiff structure because first modes of the structure are located in a frequency band [20Hz-30Hz].

To avoid coupling with substructure or satellite global modes, the frequencies of Sunshield/Sunshade main modes have been specified in a frequency requirement presented in following chapters.

Note: There is a potential coupling between the first lateral Y and Z mode and the second S/C lateral mode. This coupling should be taken into account for the Q. S. SSH/SSD load determination.

HERSCHEL Cryostat and GFRP struts support

CRYOSTAT strut support considered in these technical analyses is a 24 struts configuration which is the baseline strut configuration. This CRYOSTAT configuration is a 60mm shifted model along Z axis.

This model is the H PLM FEM model dated 15/02/02 by mail :"Model send 150202.zip"

The references (location and name) of received FEM are in the following archive directory:

Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/DYN/ Model send 150202.zip.

This model has been modified. The modification are the following:

- Telescope with hexapod (see § Telescope)
- thickness of the strut has been reduced down to about 1.4 mm (baseline design).

HERSCHEL PLM FE model

The model description is in the document RD06.4 "H-EPLM FE Model Description".

The main characteristic are the following:

The Physical FEM model has been set up to the maximal mass. The main characteristics of the H-PLM FE model are:

Number of Nodes	: 35730
Number of Element	: 36356
HERSCHEL PLM FEM has	214380 dof
HERSCHEL PLM FEM mass is	2376 Kg

The physical mathematical model is shown hereafter on the next figure.

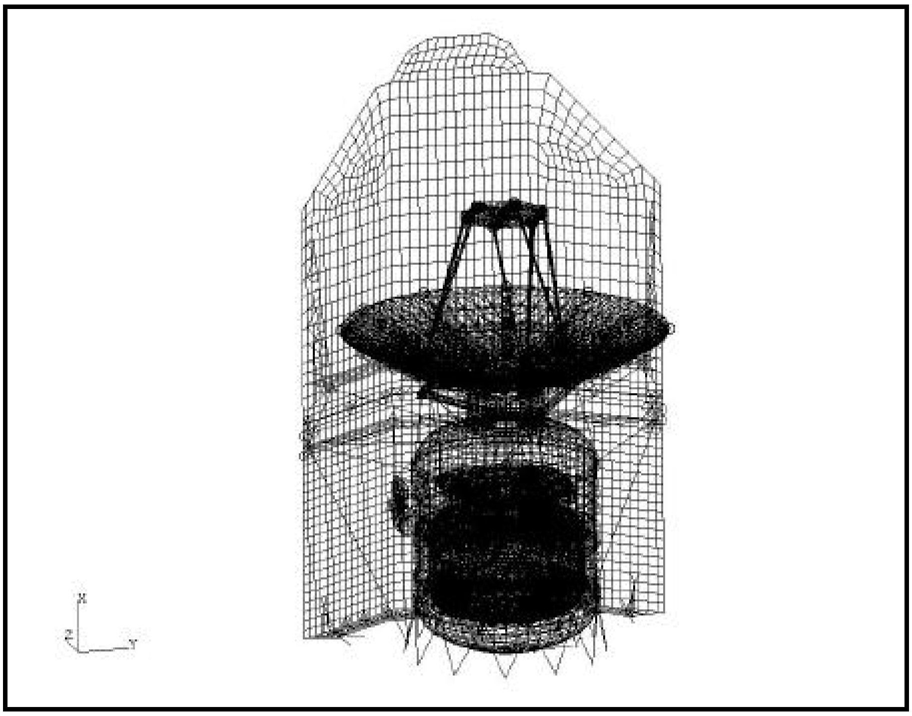


FIGURE 7-6 HERSCHEL PLM MATHEMATICAL MODEL

7.1.2.1.3 HERSCHEL Satellite mathematical model

The mathematical model of the whole HERSCHEL satellite is assembled using the models of the various subsystems previously described: service module, and Herschel payload module (see FEM description in the precedent chapters). The SVM shield is not represented in the global satellite mathematical model. The SVM shield mass is low (25 Kg) and linked with rigid SVM I/F, so the impact on S/C internal specification should be negligible.

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: 42653

Number of elements: 44916

Total number of degrees of freedom: 255918.

The references (location and name) of NASTRAN files used for the following analyses are defined in the next table.

Modal analysis	Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODAL/*h_2_modal.dat*
Sine analysis	Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/SINUS/ *reponse_dyn_hss_2.dat*

Global Mass budget :

The following table presents the mass budget of HERSCHEL satellite

Subsystem	Mass in the model [Kg]
Telescope	297
SSH/SSD	188
Cryostat	1891
SVM	909
Total mass	3285

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           3.284952E+03     -1.520875E-19 -1.125758E-02 -2.061521E-03
    Y           3.284952E+03      2.002381E+00 -5.001991E-18 -2.061521E-03
    Z           3.284952E+03      2.002381E+00 -1.125758E-02 -4.190857E-18

                                 I(S) [INERTIA MATRIX]
                    *  3.698523E+03 -1.136379E+02  5.174560E+02 *
                    * -1.136379E+02  7.202062E+03  3.149386E+01 *
                    *  5.174560E+02  3.149386E+01  7.383817E+03 *

                               I(Q) [MAIN INERTIA VALUES]
                    *  3.623968E+03                             *
                    *                7.196897E+03               *
                    *                              7.463537E+03 *

                                Q [MAIN EIGEN VECTORS]
                    *  9.902427E-01 -5.276662E-03  1.392539E-01 *
                    * -3.025213E-02 -9.835917E-01  1.778540E-01 *
                    *  1.360305E-01 -1.803314E-01 -9.741541E-01 *
```

The FEM mass budget covers the baseline (3133 Kg; X cog 2.040 m) (see RD02.3)

The Meshing of HERSCHEL mathematical model is presented hereafter on next figures.

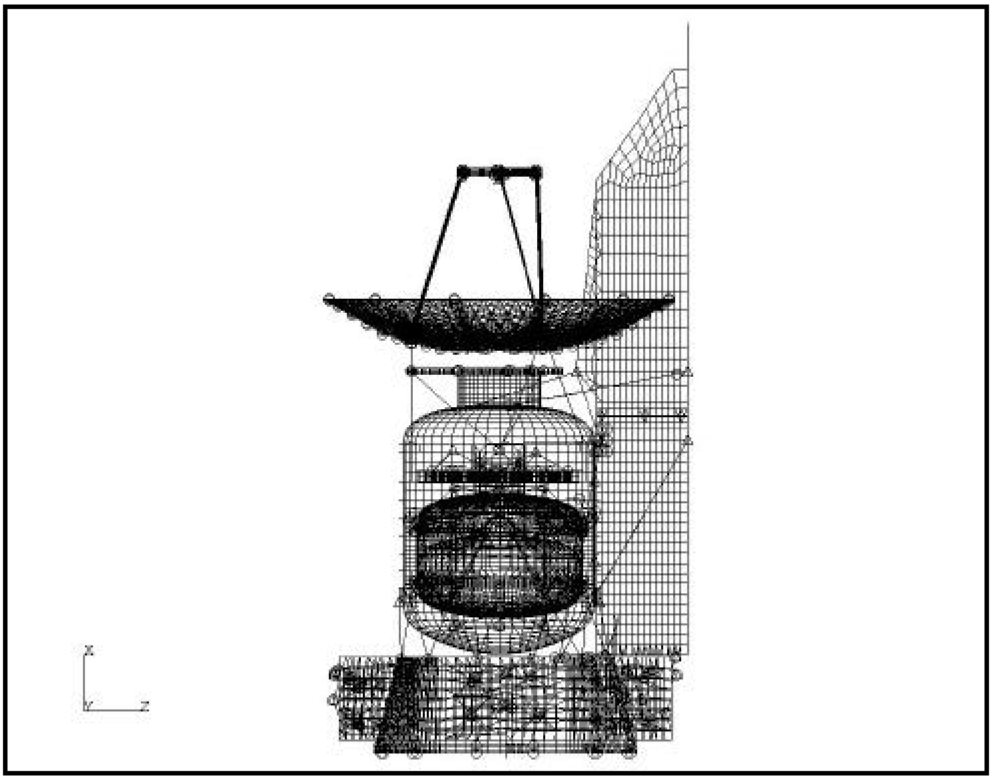


FIGURE 7-7 Y VIEW OF HERSCHEL MATHEMATICAL MODEL

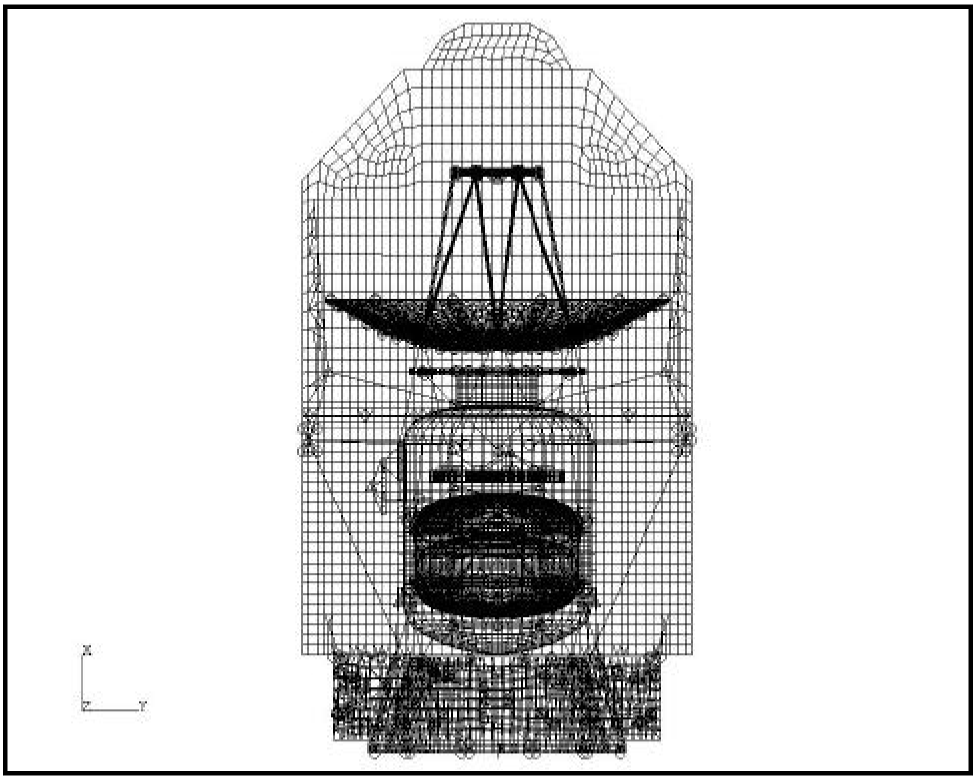


FIGURE 7-8 Z VIEW OF HERSCHEL MATHEMATICAL MODEL

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 100 Hz which corresponds to the frequency bandwidth of the sine vibration tests.

The boundary conditions applied at the interface of the spacecraft are simply boundary conditions (123 degrees of freedom and clamped).

Modal analysis

HERSCHEL satellite main modes with effective mass higher than 5 % of the total mass are presented in next table.

Mode Frequency	Effective Masses [Kg]			
(Hz)	Mx	My	Mz	Mode shape description
13.5	/	5.9	1926	HERSCHEL lateral global Z mode
14	/	1978	6.4	HERSCHEL lateral global Y mode
23	/	56	1.5	First Lateral Y mode of Sunshade
25.2	11.2	33.2	378.5	First Lateral Z mode of Sunshade + second lateral global Z mode
26.2	/	215.6	1.4	second lateral global Y mode
33	123.5	0.2	15.2	1rst longitudinal mode of sunshield / sunshade
35.3	1905	/	2	HERSCHEL longitudinal global X mode
37	32.3	11.2	0.6	First lateral Y mode of sunshield
41.7	5.2	15	7.2	First Bending mode Y- side of telescope
47.	52.7	4.8	4.3	Axial mode of (Y+Z-)corner of SVM
54.5	73.7	11.3	68.9	X bendig mode of Z side of SVM

TABLE 7-5 HERSCHEL SATELLITE MODAL ANALYSIS RESULTS

Comments:

HERSCHEL satellite main modes

The HERSCHEL satellite main modes are located at the following frequencies:

- HERSCHEL longitudinal mode = 35.3Hz (Margin >12 %)
- HERSCHEL lateral mode = 13.5 Hz (Margin >50 %).

HERSCHEL longitudinal mode is driven by the longitudinal mode of CRYOSTAT suspended masses (located around 43 Hz). 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 (> 31Hz) in longitudinal direction.

HERSCHEL lateral main modes are determined by the stiffness of the primary structure (SVM cone, CRYOSTAT struts support). 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 (> 9Hz).

The second lateral main modes of HERSCHEL satellite are located around 25.4 Hz and are driven by the stiffness of GFRP struts and HERSCHEL lateral mode of CRYOSTAT suspended masses (located around 28-29 Hz).

HERSCHEL satellite secondary modes

HERSCHEL Sunshade modes are found at 23 Hz and 25.1Hz and are mainly global modes (high effective mass). Lateral SSD Z mode located around 25.1 Hz is not coupled with the first longitudinal main mode of the satellite (35.3Hz) but a slight coupling occurs with the second lateral Z main mode of the satellite located around 25.4 Hz. This modal coupling is identified by the significant effective mass in the longitudinal axis Z (115 Kg) at the frequency of the SSD lateral Z mode (25.1Hz). This modal coupling is due to the proximity of the two modes and should be in particular checked for the further analyses to avoid significant increase of HPLM loads.

First HERSCHEL Sunshield modes are mainly local bending modes of panels (out of plane mode) and are identified around 37Hz. The first global sunshield sunshade mode is identified in the longitudinal direction at 33 Hz.

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 35.3 Hz. The control the of longitudinal mode of the telescope has to be checked to avoid overpassing the telescope loads.

The HERSCHEL service module modes are found above 47 Hz which ensure the modal de-coupling with HERSCHEL satellite main modes (lateral and longitudinal ones).

Dynamic Sine Response analyses

- Methodology

The dynamic response analysis is performed using the qualification levels specified by ARIANE5 user's manual.

- **Longitudinal axis :** ±1.25g from 5Hz to 100Hz,
- **Lateral axis :** ±1g from 5Hz to 25 Hz,
  ±0.8g from 25Hz to 100Hz.

These qualification levels are applied at the base of the spacecraft. No notching is considered at this step of the analysis. The reduced damping factor considered in this analysis is 2 % for each mode which is usually consistent with most of the experimental tests.

Notching on the main modes

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 (6g longitudinal and 2g 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.

Item	ARIANE V QSL (g)	Quasi static Launcher interface loads	Dynamic Launcher interface loads	Frequency (Hz)	Flight Notching level	Qualif Notching level
Fx (N)	6	1,933 E+5	4,961 E+5	35,3	0,39g	0,49g
Fy (N)	2	6,443 E+4	3,729 E+5	14,0	0,138g	0,173g
Fz (N)	2	6,443 E+4	3,830 E+5	13,5	0,135g	0,169g
My (N.m)	2	1,289 E+5	1,181 E+6	13,5	0,087g	0,109g
Mz (N.m)	2	1,289 E+5	1,140 E+6	14,0	0,090g	0,112

For the primary main modes, the predicted qualification notching levels are:

- longitudinal direction 0.49g at 35.3Hz
- lateral Y direction 0.11g at 14 Hz
- lateral Z direction 0.11g at 13.5 Hz.

These values are consistent with usual values found on other satellites with a similar weight.

7.1.3 Inputs to support subsystem spec

Dynamic loads and mechanical environments of structures and instruments have to be evaluated and specified through EVTR and GDIR specifications. The following chapters give a descriptions of these loads, environment and the mechanical requirements applicable to subsystems.

Quasi static loads

The main design limit loads extract from the dynamic response analysis are presented in next tables. Notching on primary main modes are taken into account in these loads.

HERSCHEL TELESCOPE

Design limit loads

Design limit loads			
Axial (g)	Lateral (g)	Frequency (Hz)	Load Direction
±12 ±1	±4 ±11	35.3 26	X Y

TABLE 7-6 DESIGN LIMIT LOADS FOR HERSCHEL TELESCOPE

Comments:

These telescope design limit loads are close to the specified ones (12g axial +- 4.6g lateral and 3.2g axial + 10 g lateral ref AD02.1" Herschel Telescope Specification"). However, these loads are calculated with an intermediaite telescope model. They will be computed with the final telescope model (CDR) and dicussed after this analysis.

These telescope design limit loads aren't covered by ASTRIUM load used for sizing the telescope. (16g axial +- 3g lateral and 4g axial + 10 g lateral ref RD06.7 "Herschel E-PLM Structural Analysis Report"). Convergence meeting is planned with ASED.

The axial loads estimated at 36Hz have been computed with an updated CDR FEM Telescope. This modelling takes into account the flexibility of the Telescope and design limit loads are representative of the global dynamic behaviour.

This load case will have to be confirm in the next future CDR analyses with an updated SR support configuration.

HERSCHEL INSTRUMENTS

The main design limit loads of the HERSCHEL PLM instruments are presented hereafter.

Design limit loads

	Design limit loads			
Equipment	Axial **(X sat)** (g)	Lateral (g)	Frequency (Hz)	Load Direction
PACS/HIFI /SPIRE	±18 ±7	±5 ±8	35.3 41.8	X X
BOLA	±9 ±5	±1 ±3	35.5 67.8	X X
LOU	±14 ±7	±2.5 ±8	35.3 54.8	X X
Optical Bench	±16.25 ±5 ±2	±4 ±5 ±7.5	35.3 42 26	X X Z

TABLE 7-7 DESIGN LIMIT LOADS FOR PLM INSTRUMENTS

Comments:

For optical Bench instruments, design limit loads are lower than those of SRR.

For optical bench structure, design limit loads are not covered by the actual specifications (16,25g axial ± 2g lat ; 2g axial ± 7,5g lat) taken into account by ASED. Convergence meeting is planned with ASED.

For CVV instruments, the acceleration levels have also decreased and still remain low and acceptable.

SVM INSTRUMENT AND EQUIPMENT

The main design limit loads of the HERSCHEL SVM instruments are presented hereafter.

	Design limit Loads			
Equipment	⊥ (g)	// (g)	Frequency (Hz)	Load Direction
SVM lateral Panels	±25	±20	51	X
Fuel tanks	±14.5	±10	75	Z

TABLE 7-8 DESIGN LIMIT LOADS FOR SVM LATERAL PANELS/FUEL TANKS

Comments:

For SVM lateral panels, design loads have been condensed in one load case which takes into account the local acceleration of the equipment and the location on the panels.

Nota: The design loads of the Fuel tanks are the design limit loads used for testing the fuel tanks at qualification levels.

H PLM TANKS

For Tanks, design loads have been computed. The main design loads are listed hereafter.

	Design limit Loads			
Equipment	Axial **(X sat)** (g)	Lateral (g)	Frequency (Hz)	Load Direction
He II	±15 ±1.5	±2.5 ±7.5	35.3 25	X Z
He I	±30 ±2	±2.5 ±7.5	35.3 25	X Z

TABLE 7-9 H-PLM TANKS DESIGN LIMIT LOADS

Comments:

The new design loads of PLM tanks have not been significantly modified compared to the design loads discussed and presented for SRR phase.

The longitudinal loads have been maintained meanwhile the lateral loads slightly increased (for lateral load case) and are probably influenced by a slight modal coupling between lateral main modes of the satellite around 26 Hz and a lateral SSD modes around 24Hz-25Hz.

The 7.5 g lateral load on the He II is not in line with the value taken into account by ASED. Convergence meeting is planned with ASED.

– **Unit sine environments**

The sine environment are defined for qualification test from the quasi static loads in order to be consistent with quasi static loads and to be sure that the loads levels will be applied during these tests.

The sine vibration levels are defined between 10 Hz and 100 Hz. The acceleration levels applied in this range are the qualification levels defined from quasi static loads. Notching will be allowed not to exceed quasi static loads.

Equipment	Load Direction	Frequency Range	Acc Level [g]
FPU	^ (X sat)	5-100Hz	±18
	//		±8
LOU	^ (X sat)	5-100Hz	±14
	//		±8
BOLA	^ (X sat)	5-100Hz	±9
	//		±3
SVM	^	5-100Hz	±25
	//		±20

TABLE 7-10 SINE QUALIFICATION LEVELS

Comments:

These qualification levels are covered by the sine qualification levels given in IIDA.

H-PLM Design loads

The envelope of H-PLM Quasi static load cases computed for new CRYOSTAT strut support configurations are presented in the next table.

Load Case	X Axis	Y Axis	Z axis
1	±12.5g	/	±1.56g
2	±2.g	±4g	/
3	±2.g	/	±4g

TABLE 7-11 H-PLM DESIGN LOADS

These loads have to be applied to the whole H-PLM structure (the resultant force is applied to H-PLM centre of gravity). Global Quasi static loads generate equivalent sizing forces in the struts at the interface points with SVM.

These H-PLM quasi static loads are not covered by all ARIANE V quasi static loads. The ARIANE V quasi static load to be considered for H-PLM structural design are defined in the following table.

Load Case	X Axis	Y Axis	Z axis
4	-4g	±2.5g	/
5	-4g	/	±2.5g
6	-7.5g	±1.25g	/

TABLE 7-12 ARIANE V QUASI STATIC LOADS (QUALIFICATION LEVELS)

7.1.3.1 HERSCHEL Random vibration analyses

Methodology

The methodology for computing random acceleration levels on H-PLM equipment are based on two technical approaches which give estimated levels from the weight of the equipment (HERSCHEL approach with ESA formulae) and from experimental results (second approach with XMM experimental random curve) provided by ESA. The final random results presented in the technical HERSCHEL document RD04.7 " Herschel Random Environment Analysis "are defined from equipment location analyses on the panels.

The random vibration level evaluation of equipment located inside CRYOSTAT doesn't take into account the acoustic attenuation of HERSCHEL CVV structure. Moreover, the influence of structural damping at low temperatures is not considered in the random vibration evaluation.

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 [g²/Hz]
- 300Hz-2000Hz : -5dB/Oct

Maximal PSD values (PSD max) of qualification random spectrum are defined in the following tables.

H-PLM Equipment	In plane PSD [g²/Hz]	Out of Plane PSD [g²/Hz]
HIFI	**0.05**	**0.05**
PACS	**0.05**	**0.05**
SPIRE	**0.05**	**0.05**
LOU	0.05	0.1
BOLA	0.1	0.2

TABLE 7-13 H-PLM RANDOM VIBRATION SPECIFICATION

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 [Kg]	Mounted Panel	Panel mass/ surf [Kg/m²]	Out of Plane Level [g²/Hz]	In plane Level [g²/Hz]
FPDMDEC	18.8	[-Z;+Y]	58	0.2	0.1
FPBOLC	14.5			0.2	0.1
FPDPU	6.9			0.2	0.1
FPSPU	11.6			0.2	0.1
Battery	6.8	[+Y]	55	0.2	0.1
PCDU	18.2			0.2	0.1
ACC	8.69			0.2	0.1
CDMU	13.33			0.2	0.1
Gyroscopes	5.24	[+Z;+Y]	20.5	0.6	0.3
QRS	1.43			0.6	0.3
X/B transponders	3.46			0.6	0.3
TWTA	0.75			0.6	0.3
EPC	1.4			0.6	0.3
Diplexer	0.3			0.6	0.3
FHFCU	10	[-Y;-Z]	54.9	0.2	0.1
FHICU	7			0.2	0.1
FHWOH	7			0.2	0.1
FHWOV	7			0.2	0.1
FHWEH	9			0.2	0.1
FHWEV	9			0.2	0.1
RWDE	6.5	[+Z;-Y]	38	0.2	0.1
RWDS	7			0.2	0.1
FHLCU	11	[-Y]	38	0.2	0.1
FHLSU	12			0.3	0.15
FHHRI	11.1			0.2	0.1
FHHRH	5.3			0.2	0.1
FHHRV	5.3			0.2	0.1
FSDPU	8	[-Z]	53	0.2	0.1
Cryo elec	14	Side –Y		0.2	0.1
FSDCU	24	[-Z]	50.8	0.2	0.1
FSFCU		Side +Y		0.2	0.1
STR Elec		Web [- Z]		>1.5	>0.75

TABLE 7-14 QUALIFICATION RANDOM LEVELS FOR HERSCHEL SVM EQUIPMENT

These levels have been included in IIDA (ref AD04.1). These random loads will be confirmed after the vibroacoustic analyse with the S/C FEM.

7.1.3.2 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 7.9 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.

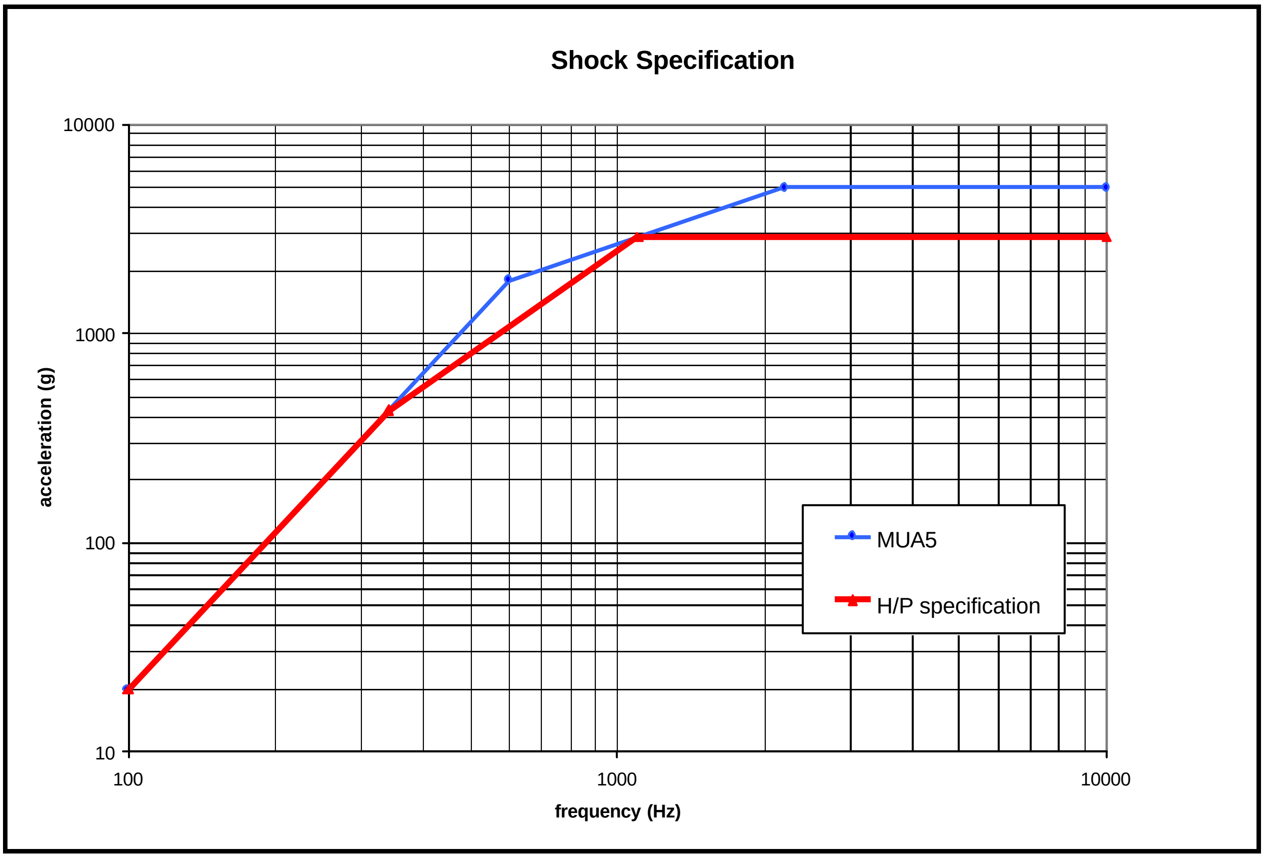


FIGURE 7-9 HERSCHEL/PLANCK SHOCK SPECIFICATIONS AT SPACECRAFT INTERFACE

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

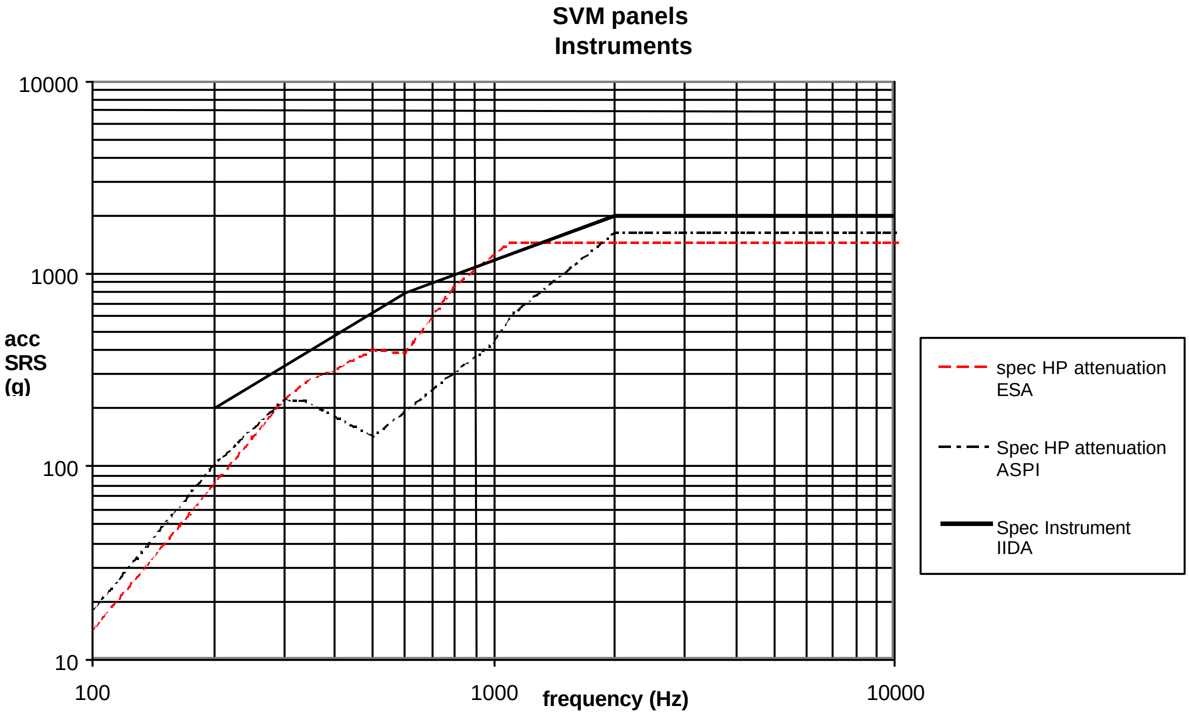
TABLE 7-15 H-PLM INTERFACE SHOCK RESPONSE SPECTRUM (SRS H-PLM, QUALIFICATION LEVELS)

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
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 7-16 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.

7.1.4 Inputs to HERSCHEL SVM structural requirements specification

The mechanical design of HERSCHEL SVM has to be defined from mechanical environment and stiffness requirement to fulfil the Launcher frequency specification. These mechanical have been defined with the latest HERSCHEL SVM mass configuration and mechanical design.

HERSCHEL SVM Dynamic requirement specification

In order to avoid modal coupling between substructure, SVM dynamic requirements have been defined and concerns the frequency location of:

– Global SVM modes with rigid Payload:

  In relation with the global stiffness of central tube, the global SVM modes with rigid Payload have to be defined to reach and fulfil the Launcher frequency requirements with HERSCHEL Payload.

  HERSCHEL axial main mode with effective mass > 20 % of total mass > 65 Hz

  HERSCHEL lateral main mode with effective mass > 20 % of total mass > 23 Hz

– SVM global Box modes:

  SVM global Box modes have to be de-coupled to HERSCHEL main modes (HERSCHEL longitudinal and secondary lateral). These technical considerations and the mechanical design lead to the following frequency requirements:

  HERSCHEL SVM axial global box mode with effective mass > 5 % of SVM mass > 45 Hz

  HERSCHEL SVM lateral global box mode with effective mass > 15 % of SVM mass > 60 Hz

– Tank support modes:

To avoid modal coupling between SVM modes located around 50 Hz and Fuel tank main modes, the frequency requirements

HERSCHEL fuel tank longitudinal X main mode > 145 Hz TBC

HERSCHEL fuel tank lateral main mode > 80 Hz

– SVM Lateral panels:

The lateral panel frequency requirements have been defined from the lateral behavior of HERSCHEL satellite for de-coupling out of plane modes of panels to second lateral Satellite main modes (around 30 Hz). With rigid and simply supported boundary conditions, the main lateral panel frequency requirement is:

Lateral panel out of plane mode > 50Hz .

HERSCHEL SVM Stiffness requirement specification

– Global lateral stiffness (central tube)

A global lateral and longitudinal stiffness is specified to ensure a satisfactory global dynamic behavior of HERSCHEL satellite with respect to the Launcher frequency specifications. The lateral and longitudinal stiffness requirements specified for central tube are

2.2 E8 N/m < $K_{lateral}$ (Y) < 3 E 8 N/m

2.2 E8 N/m < $K_{lateral}$ (Z) < 3 E 8 N/m

5.6 E8 N/m < $K_{longitudinal}$(X) < 6.5 E 8 N/m

Nota: The lower bound stiffness is defined to avoid a significant reduction of frequency of the longitudinal mode below 35 Hz.

– Local interface stiffness (interface SVM/H-PLM)

Local rotation stiffness at SVM interface points with GFRP strut support is specified in order to give a limit value and avoid problem of local free rotation. The local rotation stiffness at interface points with SVM have been estimated. These local rotation stiffness have to be specified for a good global satellite dynamic behaviour.

- $k\theta x$ longitudinal > 1.2 E5 N.m/rad
- $k\theta r$ radial > 1.0 E4 N.m/rad
- $k\theta\theta$circumference > 4.7 E4 N.m/rad.

HERSCHEL SVM Interface specification

The global dynamic behaviour of HERSCHEL satellite generates forces (during sine test) at SVM/GFRP struts interface points. These dynamic local loads depend on the frequency location of subsystem modes (mainly SSH/SHH and CRYOSTAT). These loads are specified for local and global SVM interface sizing.

The loads are computed for the 12 interface points (3 sizing cases)

F Radial [N]	F Tangential [N]	F Longitudinal [N]	Moment Mr [N.m]	Moment M_{tan} [N.m]	Moment M_z [N.m]
±1600	±11800	±5900	±92	±40	±35
±6700	±3900	±23500	±50	±125	±25
±4600	±9600	±21300	±85	±140	±22

Local Design limit Loads

Local loads coming from dynamic behaviour of Sunshield /Sunshade structure have been also defined and specified in terms of local axial struts forces inside interface struts with SVM.

7.1.5 Inputs to H-PLM structural requirements specification

The objectives of the H-PLM structural requirements are to ensure a satisfactory global satellite dynamic behaviour with respect to the Launcher frequency requirements and to define the main global H-PLM dynamic loads for Payload Module sizing .

H-PLM frequency requirements

– Global H-PLM Lateral and longitudinal stiffness

Taking into account the stiffness of the SVM structure, H-PLM frequency requirements are the following ones

H-PLM longitudinal global (X) mode > 34 Hz (*)

H-PLM lateral global (Y/Z) mode > 13 Hz

(*) for the longitudinal mode, the frequency target is 35 Hz

– Sunshield/Sunshade dynamic stiffness

The non symmetrical structure of Sunshade generates coupling motions mainly between lateral Z modes of SSD and lateral and longitudinal modes of Herschel Satellite. In order to decrease these modal coupling, the frequencies of Sunshade lateral main modes must avoid the frequencies of the SC lateral modes (located around 14 Hz and 28 Hz) and also the SC longitudinal one (around 34-35 Hz).

To reach the objective of de-coupling, the resulting frequency requirement of the Sunshade on rigid interface with simply boundary conditions are:

Sunshade requirement

First Sunshade lateral (Y or Z) mode > 24 Hz

Sunshield/Sunshade requirement

First Sunshield/Sunshade lateral mode > 38 Hz

First Sunshield/Sunshade axial X mode > 70 Hz

7.1.6 Herschel Thermoelastic analysis

7.1.6.1 Reference file:

SVM ALENIA received file: (received by mail dated 12/04/02)

Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/THERMO/svm_h.zip

Model description: see document RD06.3 “Stability Analysis Report”

H-EPLM ASTRIUM received file: (received by mail dated 22/03/02)

Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/THERMO/Thermal Dist Model send 220302.zip

Model description: see document RD06.5 "H-EPLM Thermal Distortion Analysis FE Model Description and Results".

Herschel spacecraft thermoelastique FEM :

Archive: Fuego:/data/herschel_struc/ARCHIVE_PDR/ANALYSES_PDR/CALCUL/THERMO/COMPLETE_MODEL/load_i.dat and load_i_dep_out.dat

The mathematical model of the whole HERSHEL satellite is assembled using the models of the various subsystems defined previously in this chapter: payload module (HPLM) and service module (SVM).

7.1.6.2 General

The reference document is RD04.10 " PDR HERSCHEL Mechanical analysis report"

The H-EPLM thermoelastic verifications are not in accordance with the ALCATEL requirements. However, the zero-stress analysis shows that the high stress values are very localised which is not the case for the SVM. So, we can predict that the displacements of characteristic grids on the HPLM can be evaluated with this model. The interface loads between the PLM and the SVM will be computed too (for information).

However, the model doesn't permit to compute displacement on the SVM.

7.1.6.3 Loads cases

The deformation is mainly du to the HPLM load cases (ref RD06.5 " H-EPLM Thermal Distortion Analysis Mode Description and Results")

Load case 1: Winter solstice with 0 degree solar aspect angle.

Load case 2: Winter solstice with +30 degree solar aspect angle.

Load case 3: Winter solstice with -30 degree solar aspect angle.

Load case 4: Summer solstice with 0 degree solar aspect angle.

7.1.6.4 Output location

To evaluate the real thermal distortion of the S/C, the following output information have been selected for each load case:

Relative displacement between (See plot and figure below):

Center of SR miror (point 3) / Optical bench (point 1)

Center of SR miror (point 3) / IF SVM- H-EPLM (point 4)

Center of PR miror (point 2) / Optical bench (point 1)

Center of PR miror (point 2)/ IF SVM- H-EPLM (point 4)

Center of SR miror (point 3) / Center of PR miror (point 2)

Optical bench (point 1) / IF SVM- H-EPLM (point 4)

	Point	Node	Analysis Coordinate	Coordinate in global CID
Center of OB	1	44998	0	3.0195 / 0 / -0.06
Center of PR miror	2	71000	0	4.0695 / 0 / -0.06
Center of SR miror	3	87045	0	5.6605 / 0 / -0.06
Center of IF SVM/ H-EPLM	4	1	0	0.9365 / 0 / 0

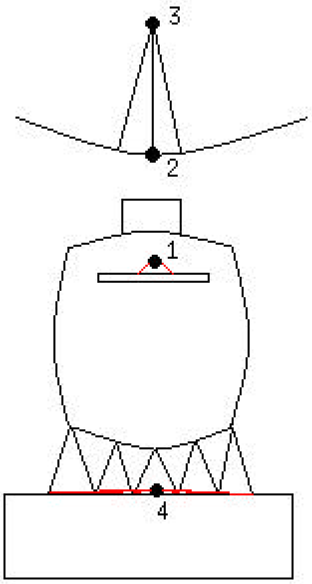


FIGURE 7-10

7.1.6.5 Results

Load case 1 :

Relative displacement :

	Tx (m)	Ty (m)	Tz (m)	Rx (°)	Ry (°)	Rz (°)
SR/OB :	-1,1080E-02	-2,6704E-04	8,4649E-04	-1,3167E-03	-9,8631E-04	4,3650E-04
SR/IF SVM-PLM :	-2,0044E-02	7,2509E-05	1,9611E-03	-6,2113E-04	-2,9502E-02	2,0726E-03
PR/OB :	-4,3806E-03	-3,0923E-04	1,6742E-04	-1,3082E-03	-9,8587E-04	4,3379E-04
PR/IF SVM-PLM :	-1,3345E-02	3,0323E-05	1,2820E-03	-6,1258E-04	-2,9501E-02	2,0699E-03
SR/PR :	-6,6994E-03	4,2186E-05	6,7908E-04	-8,5543E-06	-4,4118E-07	2,7095E-06
OB/IF SVM-PLM	-8,9642E-03	3,3955E-04	1,1146E-03	6,9558E-04	-2,8515E-02	1,6361E-03

Load case 2 :

Relative displacement :

	Tx (m)	Ty (m)	Tz (m)	Rx (°)	Ry (°)	Rz (°)
SR/OB :	-1,1219E-02	-2,7390E-04	8,3589E-04	-1,2910E-03	-9,2210E-04	3,4231E-04
SR/IF SVM-PLM :	-2,0133E-02	6,2163E-05	1,9355E-03	-5,7676E-04	-2,9251E-02	1,7626E-03
PR/OB :	-4,4408E-03	-3,1057E-04	1,6319E-04	-1,2824E-03	-9,2172E-04	3,3957E-04
PR/IF SVM-PLM :	-1,3355E-02	2,5498E-05	1,2628E-03	-5,6813E-04	-2,9251E-02	1,7598E-03
SR/PR :	-6,7781E-03	3,6665E-05	6,7270E-04	-8,6287E-06	-3,7815E-07	2,7382E-06
OB/IF SVM-PLM	-8,9144E-03	3,3607E-04	1,0997E-03	7,1426E-04	-2,8329E-02	1,4203E-03

Load case 3 :

Relative displacement :

	Tx (m)	Ty (m)	Tz (m)	Rx (°)	Ry (°)	Rz (°)
SR/OB :	-1,1234E-02	-2,6647E-04	8,7700E-04	-1,2750E-03	-9,4052E-04	3,5993E-04
SR/IF SVM-PLM :	-2,0260E-02	7,5477E-05	2,0266E-03	-5,4240E-04	-3,0029E-02	2,0787E-03
PR/OB :	-4,4531E-03	-3,0801E-04	1,7938E-04	-1,2664E-03	-9,4014E-04	3,5719E-04
PR/IF SVM-PLM :	-1,3478E-02	3,3937E-05	1,3290E-03	-5,3377E-04	-3,0029E-02	2,0759E-03
SR/PR :	-6,7812E-03	4,1540E-05	6,9762E-04	-8,6287E-06	-3,8388E-07	2,7382E-06
OB/IF SVM-PLM	-9,0252E-03	3,4195E-04	1,1496E-03	7,3260E-04	-2,9088E-02	1,7188E-03

Load case 4 :

Relative displacement :

	Tx (m)	Ty (m)	Tz (m)	Rx (°)	Ry (°)	Rz (°)
SR/OB :	-1,1423E-02	-2,8815E-04	8,3529E-04	-1,2117E-03	-7,8489E-04	2,0837E-04
SR/IF SVM-PLM :	-2,0558E-02	4,0307E-05	1,9775E-03	-5,6575E-04	-2,9403E-02	1,8464E-03
PR/OB :	-4,5284E-03	-3,1414E-04	1,6294E-04	-1,2029E-03	-7,8485E-04	2,0560E-04
PR/IF SVM-PLM :	-1,3664E-02	1,4319E-05	1,3052E-03	-5,5697E-04	-2,9403E-02	1,8437E-03
SR/PR :	-6,8945E-03	2,5988E-05	6,7236E-04	-8,7777E-06	-3,4377E-08	2,7645E-06
OB/IF SVM-PLM	-9,1355E-03	3,2846E-04	1,1422E-03	6,4591E-04	-2,8618E-02	1,6381E-03

To assess the impact on pointing, it is interesting to compare load cases 2,3 and 4 which represent the cryostat behaviour if during a day of operation the Sun Aspect Angle is varied between - 30 deg and + 30 deg. This corresponds to a worst case scenario in which during the same day the telescope will sweep the whole range of allowed SAA. As only one calibration check is planned to be performed at the beginning of the Observation Period, the thermo-elastic distortion due to variation of SAA will directly enter the APE, PDE and AME budget. The relevant information for pointing is the variation of distortion between the various cases. The worst case is found between case 3 and case 4 for which a maximum relative distortion of 0.6 arcsec is computed. This is in line with the results found by ASED (maximum of 0.86 arcsec): the difference can be explained by the fact that in the ASPI computation the H-PLM is assembled with the SVM rather than on a infinitely rigid interface as in the Astrium computation.

PLM/SVM interface loads

The loads are computed for the 12 interface points and compared with the sine ones:

	Maximal I/F load Sine analysis (N)	Maximal I/F load Thermoelastic analysis (N)	Ratio Sine/thermo
F R	6680	735	9
F Teta	11812	1350	8.7
F Z	23503	1470	16

The Thermoelastic loads are largely covered by the sine ones.

As a consequence, thermoelastic load cases should not be sizing for the HPLM interface brackets.

7.2 Micro vibration analysis

Reference files:

[1] Fuego/data/Herschel_struc/ARCHIVE_PDR/ANALYSE_PDR/MICROVIB/**h2_modal_micro.dat**

[2] Fuego/data/Herschel_struc/ARCHIVE_PDR/ANALYSE_PDR/MICROVIB/**Herschel_60Hz.fsd**: Microvision database

[3] Fuego /data/Herschel_struc/ARCHIVE_PDR/ANALYSE_PDR/MICROVIB/**depouil_herschel.m**: matlab file for microvision outputs post-processing.

Software version:

- Nastran 70.
- Microvision 4.2.
- Matlab6.

7.2.1 Introduction

Microvibration are critical for the SPIRE instrument of the Herschel spacecraft. They generate disturbing vibration on the equipment.

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 60 Hz. No AOCS profile is available yet, therefore the four wheels are considered independent. The wheels are characterized by their static and dynamic imbalance that respectively generate a radial force and a rotating moment perpendicular to the axis of the wheel. They are both applied at the center of Gravity of the wheel.

The aim of this analysis is to determine the level of acceleration at the center of gravity of the SPIRE optical instruments due to the reaction wheels perturbation.

7.2.2 Study logic

7.2.2.1 Model

The model used for this analysis is presented in section 7.1.2.1.3 (Figure 7-11)

Each reaction wheel is represented by a rigid body connecting together its 4 interface points enabling introduction of interface disturbances (Figure 7-13).

The disturbance is modeled as a radial force and a rotating moment perpendicular to the axis of the wheel. They are both applied at the center of Gravity of the wheel.

A local rectangular coordinate system is attached to each wheel and defined as follows:

- Origin at the center of gravity of the wheel.
- Z direction parallel to the wheel rotation with direction opposite to the Z+/Y- panel.
- X direction same as local 1002 X (see Figure 7-13) for reaction wheels 3 and 4.
- X direction same as local 1002 Y (see Figure 7-13) for reaction wheels 1 and 2.

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 350Hz. Outputs of the computations are presented at its CoG (Figure 7-12). The node corresponding to the optical instrument is node 45649.

(1) Nastran Analysis

The Nastran model was designed for sinus analysis, therefore the model is representative of the Herschel dynamic behavior up to 140 Hz. Results at higher frequencies must be considered with caution. Nevertheless the first two reaction wheel harmonics predominate, therefore main contribution to the Spire optical instrument occur below 120 Hz.

The Nastran analysis is a free-free modal analysis between 0 and 350Hz. The modes are normalized to the generalized mass of the Herschel spacecraft.

The output of the analysis includes the modal displacement at the SPIRE optical instrument as well as at the nodes representing the reaction wheels [1].

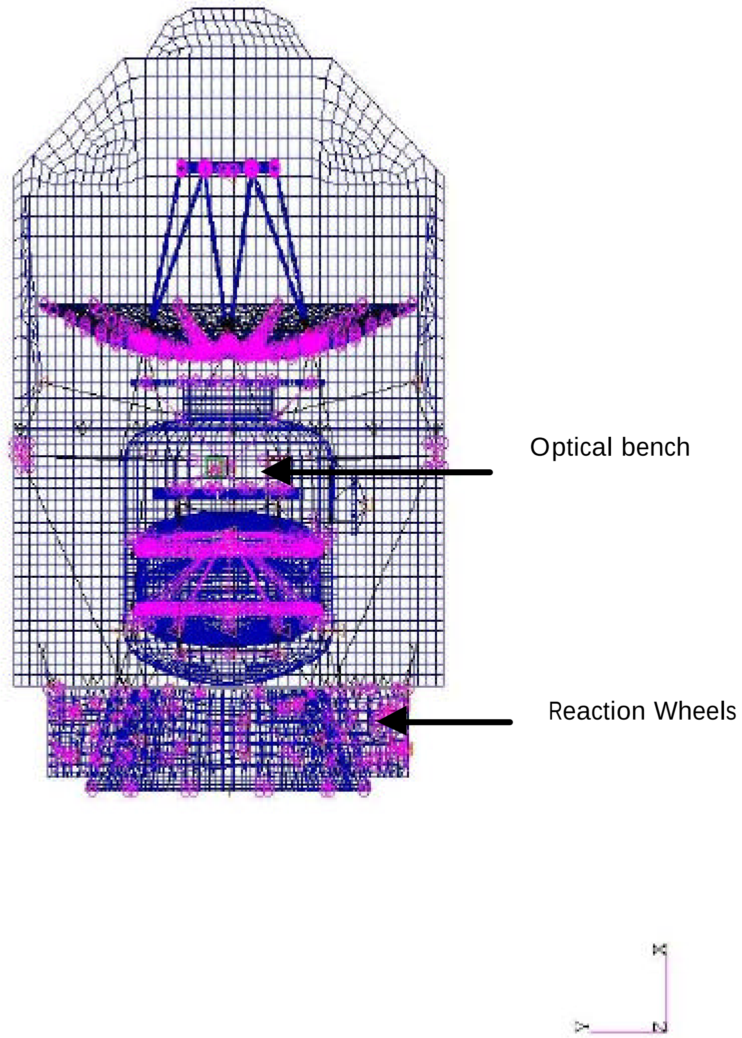


FIGURE 7-11 MODEL OVERVIEW

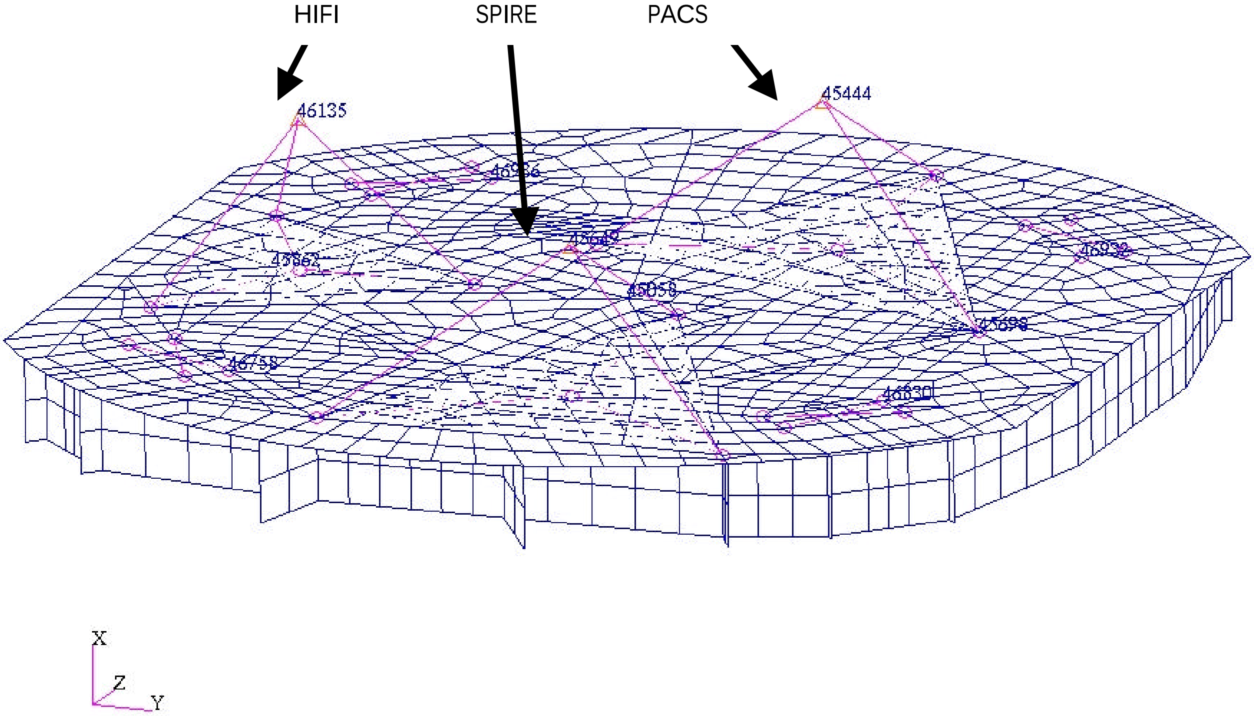


FIGURE 7-12 OPTICAL BENCH

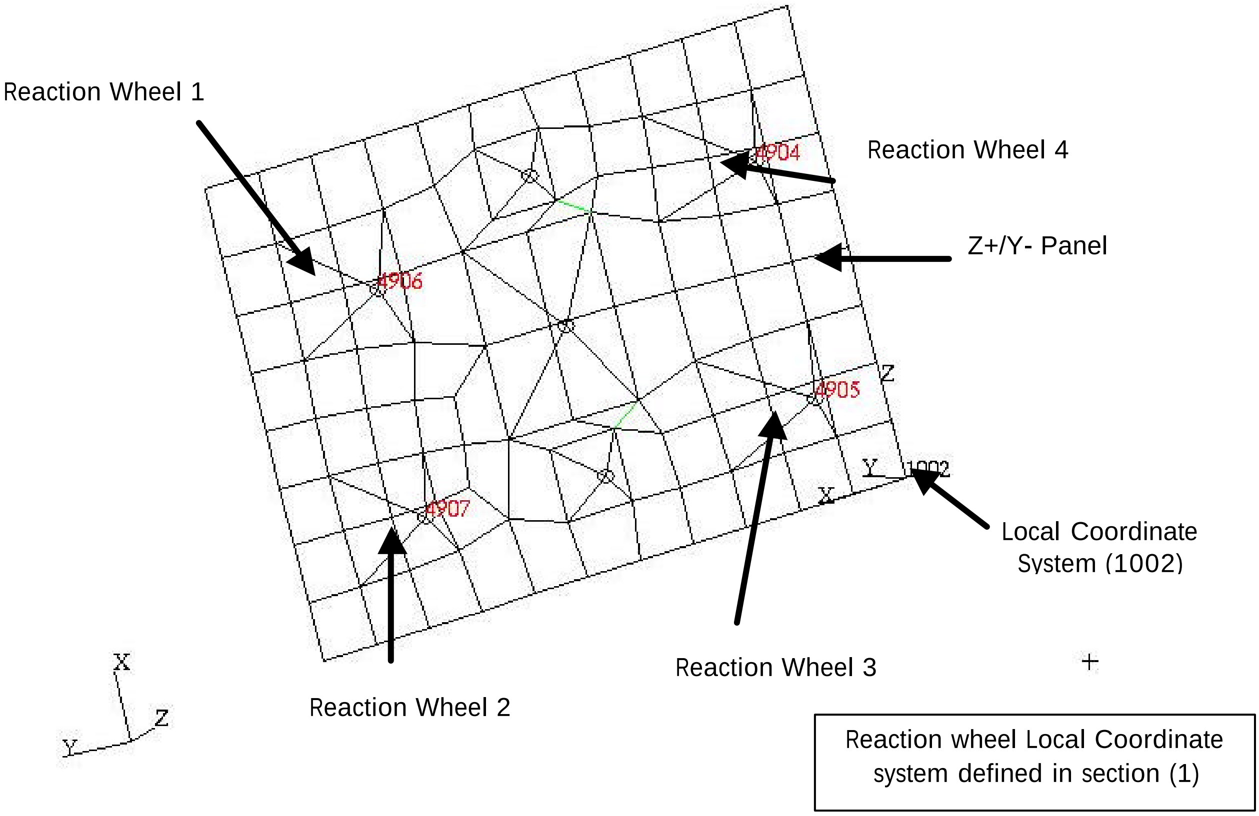


FIGURE 7-13 MODEL OF REACTION WHEELS MOUNTED ON Z+/Y- PANEL

(2) Microvision Analysis

The data required to perform the microvibration analysis are the following:

- A Nastran punch file containing the modes (up to 350 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 60Hz.
  - Static Imbalance: 2 e^{-5} kg.m for the first harmonic. The relative contribution of the harmonics is given in Figure 7-20 (the informations provided in Figure 7-20 are not specification but typical values). Twenty harmonics have been considered for this study. 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.
  - Dynamic Imbalance: 2 e^{-6} kg.m^2 (conservative amplitude) for the first harmonic. The relative contribution of the harmonics is given in appendix 1 (the pieces of information provided in Figure 7-20 are not specification but typical values). Twenty harmonics have been considered for this study.

– The analysis is conducted for frequencies from 0 to 300 Hz and for wheel velocity varying from 0 to 60 Hz. Results provided below are the quadratic sum of the contribution of all harmonics whose frequency is below 300 Hz.

– Outputs are provided at node 45649, CoG of the SPIRE instrument. No specification was provided, therefore results are given in the spacecraft coordinate system in the form of an acceleration in terms of the wheel rotation frequency.

7.2.3 Results

All results are expressed in the Spacecraft coordinate system.

(3) Contribution of Reaction Wheel 1 (located at node 4906)

Three configurations are presented for Reaction Wheel 1:

– Response due to the **Static Imbalance**:
  - Maximum acceleration occurs at 50.5Hz with an amplitude of **14.6 mg** in the X direction (see Figure 7-14).

– Response due to the **Dynamic Imbalance**:
  - Maximum acceleration occurs at 58Hz with an amplitude of **0.3 mg** in the Y direction (see Figure 7-15).

– Response due to both the Static and Dynamic Imbalance:
  - Maximum acceleration occurs at 50.5Hz with an amplitude of **14.6 mg** in the X direction (see Figure 7-16).

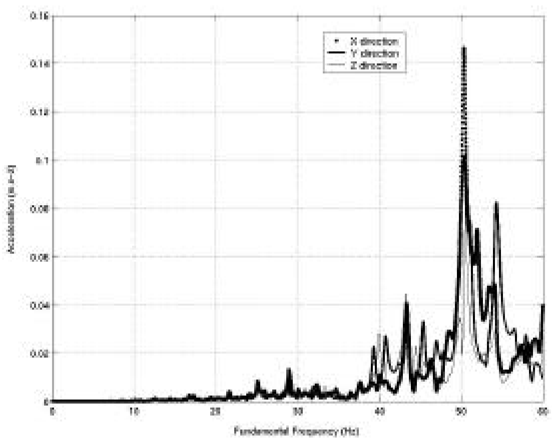


FIGURE 7-14 RESPONSE AT NODE 45649 DUE TO STATIC IMBALANCE ON REACTION WHEEL 1

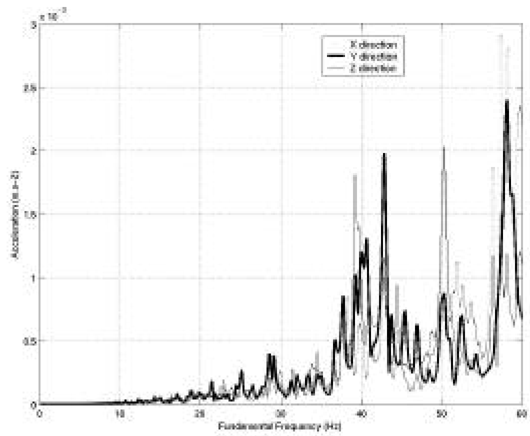


FIGURE 7-15 RESPONSE AT NODE 45649 DUE TO DYNAMIC IMBALANCE ON REACTION WHEEL 1

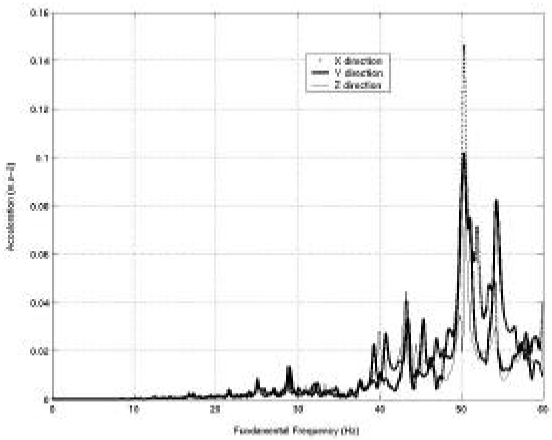


FIGURE 7-16 RESPONSE AT NODE 45649 DUE TO STATIC AND DYNAMIC IMBALANCE ON REACTION WHEEL 1

(4) Contribution of Reaction Wheels 2 to 4 (located respectively at nodes 4907, 4905 and 4904).

In this section the contribution of each wheel to the response at the SPIRE optical instrument is computed and presented below in Figures 7-17 to 7-19. Both static and dynamic imbalance are taken into account. The maximum acceleration is as follows:

- Due to Reaction **Wheel 1**: Maximum acceleration occurs at 50.5Hz with an amplitude of **14.6mg** in the X direction (see Figure 7-16).
- Due to Reaction **Wheel 2**: Maximum acceleration occurs at 50.5Hz with an amplitude of **10.8mg** in the X direction (see Figure 7-17).
- Due to Reaction **Wheel 3**: Maximum acceleration occurs at 50.5Hz with an amplitude of **12.0mg** in the X direction (see Figure 7-18).
- Due to Reaction **Wheel 4**: Maximum acceleration occurs at 50.5Hz with an amplitude of **15.2mg** in the X direction (see Figure 7-19).

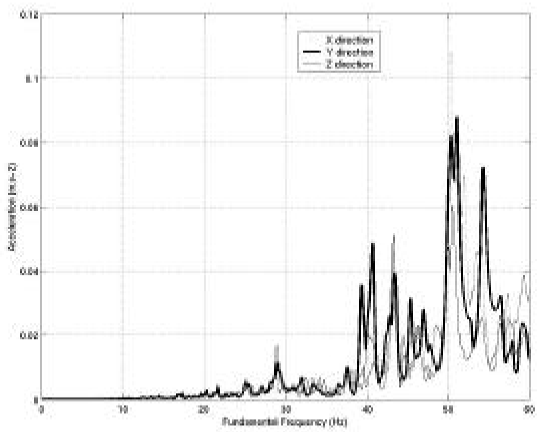


FIGURE 7-17 RESPONSE AT NODE 45649 DUE TO Reaction Wheel 2

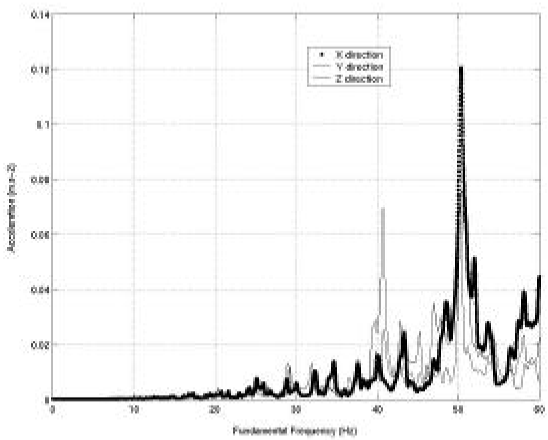


FIGURE 7-18 RESPONSE AT NODE 45649 DUE TO REACTION WHEEL 3

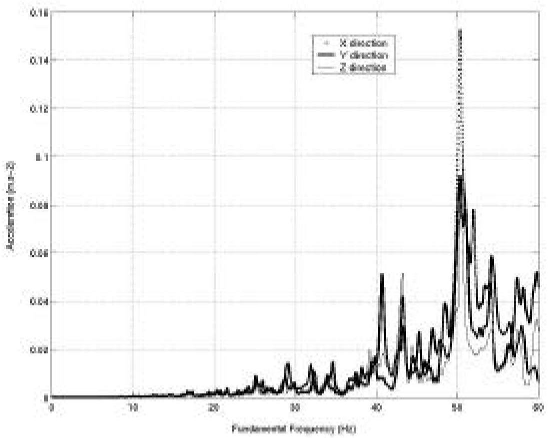


FIGURE 7-19 RESPONSE AT NODE 45649 DUE TO REACTION WHEEL 4

7.2.4 Conclusions

Maximum acceleration is obtained with reaction wheel 4. In this configuration the maximum amplitude is 15.2 mg at 50.5 Hz in the Spacecraft direction.

Acceleration levels obtained are coherent with those of previous analysis **(SRR design report).**

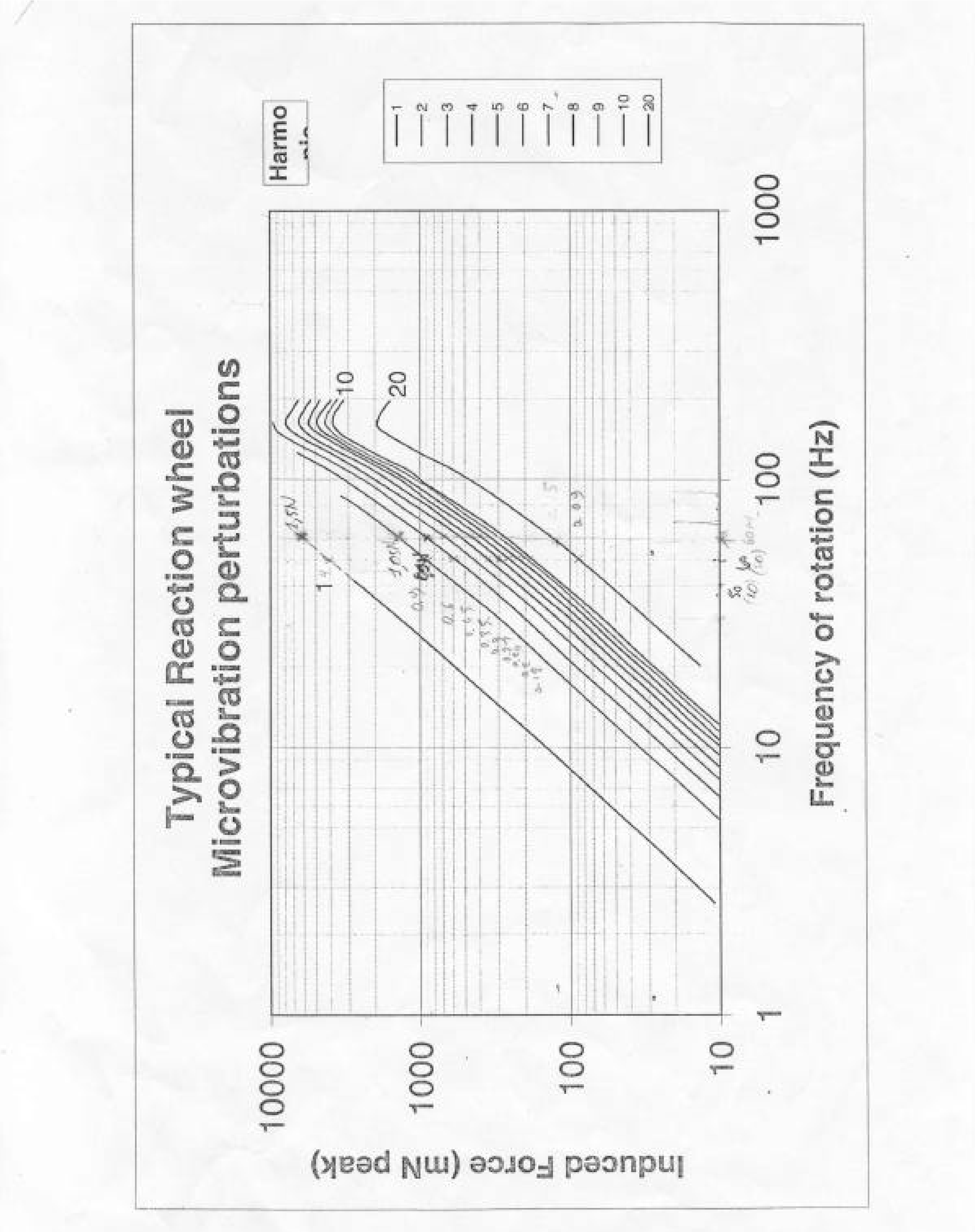


FIGURE 7-20 RELATIVE AMPLITUDES OF INDUCED FORCE FOR HARMONICS 1 THROUGH 20

7.3 Thermal analyses

The thermal analyses at system level are gathered in the Thermal Analyses Report (RD04.2). In this chapter, we only summarise the main results related to some critical items. On HERSCHEL, the thermal analysis performed to support the HERSCHEL Star Trackers accommodation trade-off is presented. The impact on the lifetime of the STR accommodation on the CVV, is estimated.

7.3.1 HERSCHEL Star Trackers accommodation

The baseline configuration for the star-trackers accommodation is a mounting onto the SVM -Z panel. Given the current alignment budget status, alternative implementation onto the CVV must be studied. The obvious drawback is a reduction of the CVV lifetime. Trade-offs activities have been therefore initiated in order to find configuration optimised in term of alignment, mechanical loads, lifetime, sun shadowing and integration purposes. From a thermal point of view, the following requirement shall be respected as far as possible:

- Star Trackers not located in front of the CVV radiative area (main and auxiliary radiators)
- Low supporting structure external area to reduce the radiative heat loads onto the CVV
- Minimisation of the thermal coupling between the SVM and the CVV radiators through reflection onto the Star-tracker support plate
- use of low thermal conductance supporting structure.

The preliminary trade-offs have ended in the selection of two configurations. They are described in Section 6.1.6. The first configuration studied for the thermal and lifetime assessment in described in Figure 7.3.1-1.

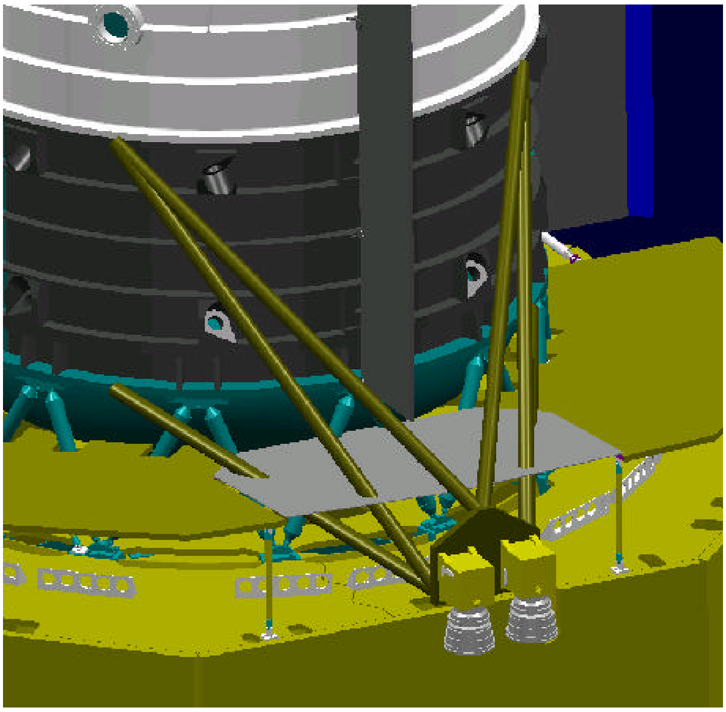


Figure 7.3.1-1 Possible Star tracker accommodation on CVV

For a preliminary computation of the heat loads onto the CVV, we have assumed the following hypotheses:

- three bipods in Glass Fiber Re-inforced Plastics
  - L1 = 1760 mm, L2 = 1660 mm, L3 = 1320 mm
  - strut external diameter = 50 mm, thickness = 8 mm
  - GFRP thermal conductivity data: from 0.35 W/Km² at 50 K to 0.8 W/Km² at 300 K (ASED values, see RD01.2).
- Star Trackers and supporting plate wrapped into MLI, external layer Aluminium coated.
- Star Trackers and supporting plate set at a boundary temperature of 323 K, which is the maximum design temperature of the STRs.

The computations have been carried out with the H-PLM TMM delivered by ASTRIUM (Issue 01). The results are gathered in the next table:

Radiative Heat Flux from STR/supporting plate	170 mW
Conductive Heat Flux	400 mW
MINIMUM Lifetime impact	70 days

The results presented above do not take into account the radiative loads from the supporting structure. Even optimising the coating in order to benefit from the cold environment, the additional loss in lifetime is estimated at least of 1 month. From this preliminary analyses, it is considered that the lifetime impact cannot be lower than three months.

The second configuration is depicted in Figure 7.3.1-2

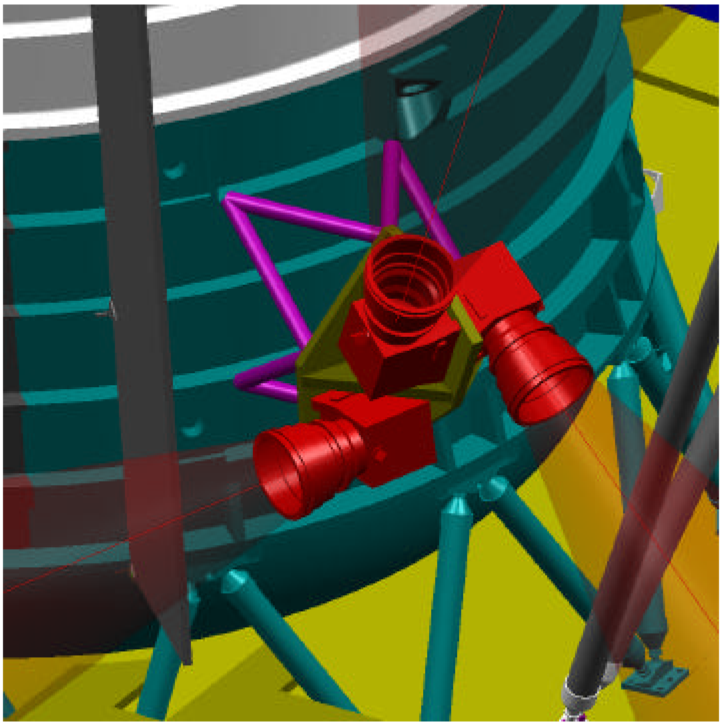


Figure 7.3.1-2 Possible Star tracker accommodation on CVV

A preliminary assessment of the impact of the conductive loads on the CVV lifetime is around 1 month. The radiative loads are less critical than in the previous configuration, because the STR assembly is implemented in front of the CVV MLI. This configuration is therefore the preferred one and will be investigated in more details for the PDR colocation.

7.4 Radiation analyses

7.4.1 Purpose

This analysis permits to evaluate the equivalent satellite shielding provided by the whole structure and appendages in terms of equivalent aluminium thickness.

The Subcontractors shall add the standard satellite shielding specifications provided in [AD1] Radiation Requirements (REF-ASPI-CN-11-E, issue 1, 19/10/1999) (cubical aluminum box of 0.8 mm for equipment inside the spacecraft and 0.1/1.6 mm for equipment outside) to its equipment radiation model in order to demonstrate the compatibility of the parts with Herschel mission.

This analysis shall demonstrate that shielding specified in [AD1] is verified for all Herschel equipment.

This analysis also provides an estimation of the cumulated dose at the center of each electronic equipment.

7.4.2 Radiation environment

The space radiation environment is consisted of trapped particles (electrons and protons), solar protons and cosmic rays. The mission dose depth curve is presented in Figure 7.4.2-1.

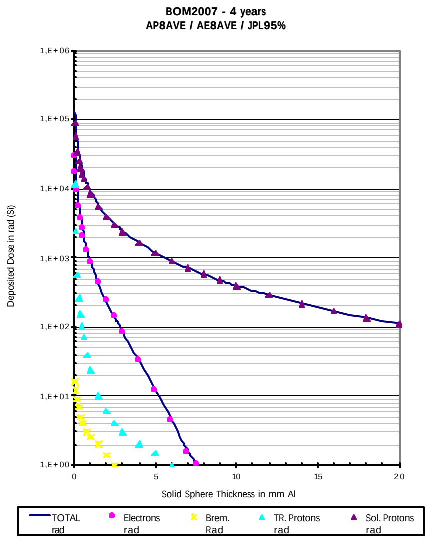


FIGURE 7.4.2-1 MISSION DOSE DEPTH CURVE

7.4.3 Herschel modeling

Herschel satellite is performed with CATIA CAD tool using the following CATIA files in HERSCHEL_AMT directory:

– HERSCHEL equipment: ME.HES.A11F.Z.010SA index F

– HERSCHEL structure: ME.HES.A120.Z.010SA index C

– Herschel propulsion: ME.HES.A17M.Z.010SA index A

– Herschel instrument: ME.HES.A200.Z.010SA index D.

The main structure thickness 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			

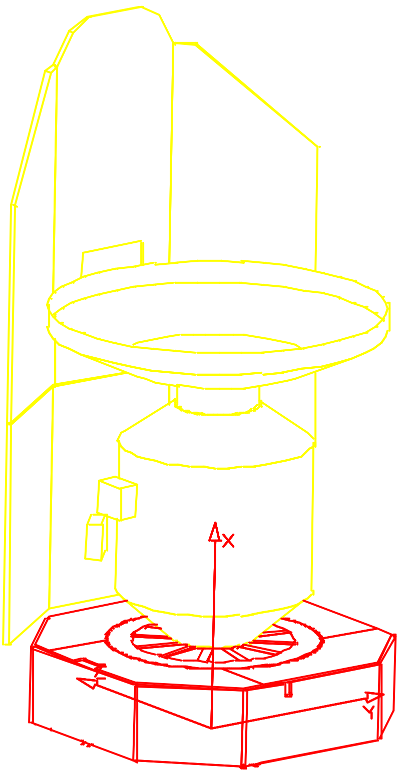


Figure 7.4.2-2 CATIA/NOVICE of Herschel satellite

7.4.4 Shielding analysis and Deposited dose calculations

Ray tracing analysis have 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 AD1 are verified.

For cumulated dose calculations (slant path), the target equipment is modeled as a 0.8mm thick aluminium 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
QRS	2.12	HSDPU	2.16
FSS ELEC.	1.77	HSFCU	2.31
CDMU	2.15	FHICU	2.34
PCDU	1.95	FHWEV	2.05
BATTERY	1.90	FHHRV	2.02
TRANSPONDER	2.16	FHFCU	2.19
EPC	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

7.4.5 Conclusion

This analysis provides an estimation of the dose levels within PLANCK equipments and shows that no major issues are expected. The radiation levels for EEE parts are low and, even including a margin of 2, will be lower thant 10 krad(Si) which is the hardness threshold required for EEE parts selection.

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 dimensionning case as far as units shielding efficiencies on either side are concerned.

7.6 ESD analyses

The ESD analyses are presented in document RD04.5. A summary of the analyses logic and main results is given in Section 8.6.

7.7 Disturbance torques on Herschel

This section summarises the disturbing torques applied on Herschel.

The external and internal torques are distinguished.

7.7.1 External disturbance torques on Herschel

As far as gravity gradient, geo-magnetic disturbance torque, and aerodynamic torques are concerned, two phases can be considered:

- after separation, at low altitude: these torques can be significant, but are negligible with respect to the torques provided by the thrusters
- during transfer orbit and at L2: Herschel will benefit particularly quiet dynamic conditions, these torques become insignificant compared to major sources detailed hereafter.

Solar pressure transverse to Sun Vector

This torque is significantly more important than any other one.

The Herschel solar pressure torque analysis (RD03.13) shows that the maximum expected torque is:

- 200 µN.m at BOL, around the Y-axis
- 180 µN.m at BOL, around the Y-axis.

This torque is due to the large surface exposed to Sun illumination and to the large lever arm (1.4 m) along the X-axis between the satellite centre of mass and the centre of pressure.

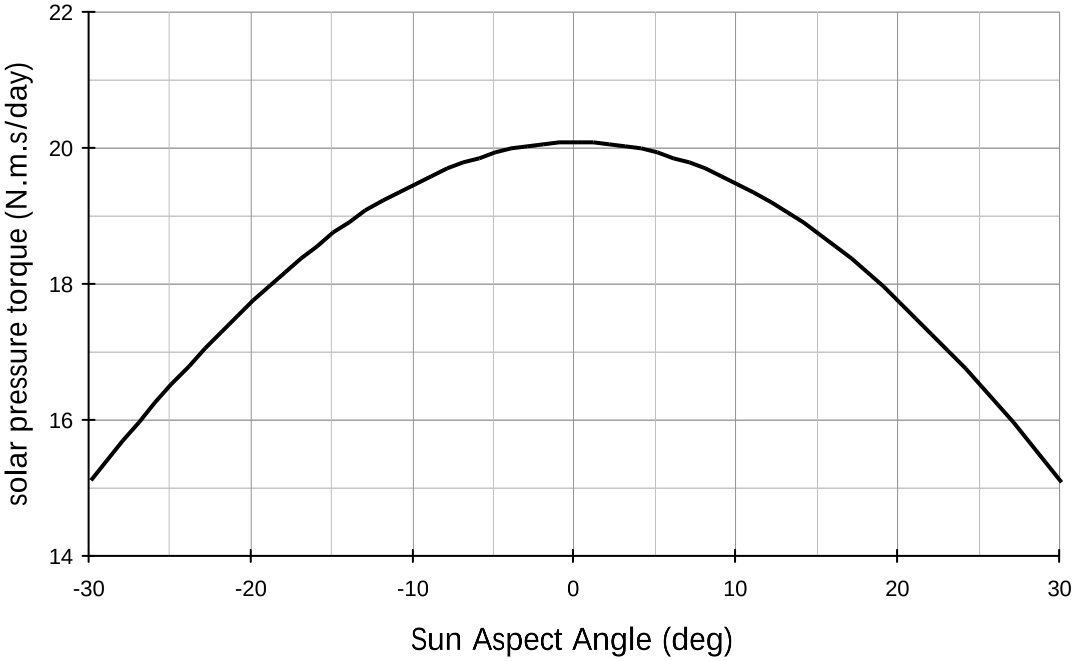
In order to account for variations of the centre of mass of Herschel and of the solar array shape and thermo-optical properties, a maximum torque of 230 µN.m is taken as a sizing case, and specified to the ACMS subsystem through the SVM specification.

In routine observations, the worst case occurs when the satellite remains in a constant attitude w.r.t. inertial space for a full observation period. Meanwhile the direction of the Sun in the satellite reference frame will be almost constant (the Sun angular rate will be ~ 1 deg/day). Consequently, the satellite will undergo a constant solar pressure torque (in inertial reference frame). Other types of pointing are more favourable for wheel off-loading because the angular momentum does not accumulate in a single direction. As wheel off-loading phases are not scheduled during observation phases, this is a driver to the sizing of the RWA angular momentum storage capability.

The accumulation of angular momentum during one day reaches at maximum:

- 230 µN.m × 1 day = **19.9 N.m.s.**

The following figure displays the solar pressure torque (in N.m.s per day) vs. the satellite SAA.



SOLAR PRESSURE TORQUE VS. SAA

Solar pressure windmill torque (along Sun Vector)

As shown in RD03.13, the maximum torque around Z is about 2 µN.m for a roll of ±1 deg.

In addition, an estimation of the torque due to a cell misalignment of 1 deg leads to another 2 µN.m.

The resulting torque is 4 µN.m, leading to a maximum accumulation of **0.4 N.m.s/day (max**).

Thruster misalignments

Thruster mispositioning and misalignments and deviations in the position of the satellite Centre of Mass (CoM) will result in perturbing torque during the orbit control mode and wheel off-loading phases.

As all contributions to the thruster torque are biases, the 3σ worst case torque has been derived by co-adding linearly the different independent contributions.

The following assumptions have been used for the analysis.

Thrust level	10N (per thruster)
Thrust fluctuations	5 %
CoM migration along X	75 mm
CoM migration along Y	5 mm
CoM migration along Z	5 mm
Thrust misalignment	1 deg (half cone)

ALL 3 σ ERRORS

The resulting worst case perturbing torques are displayed in the following table:

(Nm)	Control THR	ΔV THR
X	0.8	0.4
Y	1.2	0.9
Z	1.1	0.6

WORST CASE THRUSTER PERTURBING TORQUE

These values are to be compared to the available torque produced by the control thrusters, displayed in the following table:

AXIS	X	Y	Z
CONTROL TORQUE (Nm)	23.9	24.4	23.9

AVAILABLE THRUSTER CONTROL TORQUE

Providing a fair commandability (ratio of torque capacity to worst case perturbing torque > 20).

A 6 % use of thrusters in ON-modulation is therefore accounted. More precise figures will be given when the thrusters are selected and the ACMS algorithms developed. Worst case perturbing torques have been considered for the derivation of the fuel budget.

Helium exhaust

The torque due to the helium exhaust is specified in the SRS to be inferior to 1 µN.m, leading to an accumulated momentum of 0.09 Nms/day. Two main aspects can be highlighted:

- the torque induced by the helium exhaust by far inferior to the solar pressure torque (about 200 times lower).
- Astrium states a non compliance to this requirement (see RD01.2, page 217), since they evaluate this torque to be 150 µN.m

As mentioned in RD01.2, a recovery plan will be envisaged, to try to partially compensate the solar torque by the helium exhaust torque. In any case, the helium exhaust torque will remain inferior to the solar pressure torque, and the impact on the reaction wheel sizing should remain minor. Therefore, the current situation is not deemed critical.

7.7.2 Internal disturbance torques on Herschel

RWS Friction

The magnitude of the RWS friction torque is dependent on the wheel speed. During inertial pointing phases, when the pointing performance requirements must be met, the wheel speeds are almost constant (there are actually slowly drifting, due to the storage of the accumulated external solar pressure torque).

The magnitude of the RWS friction torque is maximum at maximum wheel speed and is evaluated to 0.02 Nm.

RWS resolution

The RWS command is coded on 8 bits, corresponding to an LSB of $1.6.10^{-3}$ Nm.

Rounding errors will therefore produce a uniform error in the range $\pm 8.10^{-4}$ Nm with a standard deviation 5.10^{-4} Nm. The frequency of this noise is that of the control law sampling, i.e. 4 Hz (TBC).

Microvibration

The Reaction wheel due to static and dynamic unbalances generate disturbance torque and force at harmonic frequencies of their rotation rate. These high frequency vibrations can be amplified by structure resonances and impact on the Relative Pointing Error. The following table summarises the RW microvibration main characteristics

Static unbalance	1.1 g.cm
Dynamic unbalance	20 g.cm2

These unbalances lead to a maximum 0.005 arcsec relative pointing error (at 1σ, corresponding to no structural amplification); thus proving margins wrt. the pointing budget.

Propellant and Helium sloshing

The sloshes are low frequency disturbances, with reduced disturbance torques and have, as based on ISO and other spacecraft experience a reduced impact on the pointing performances in scientific modes.

In Sun Acquisition Mode the rotational energy dissipation in the propellant has to be considered, this lead to a reduced disturbance torque (typically < 0.02 Nm), which is handled by a 3-axis attitude control.

8. PLANCK SYSTEM ANALYSES

8.1 Mechanical analyses

8.1.1 Introduction

The calculation detail is in the document RD04.1 " PDR PLANK Mechanical analysis 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 define and update subsystem (P-PLM and SVM) structural requirements
- to update and complete the mechanical environment specification for PLANCK equipment

PLANCK mathematical model has been prepared from SVM FE model delivery coming from ALENIA and P-PLM FE model coming from CONTRAVES.

8.1.2 Analysis of PLANCK satellite dynamic behaviour

8.1.2.1 Subsystem mechanical performances

8.1.2.1.1 PLANCK Service Module

General

The Service Module (SVM) finite element model has been defined by CASA and checked by ALENIA.

(PLANCK SVM configuration is the FEM model sent 25/02/2002 by mail: "planck-full2.dat").

The references (location and name) of received FEM are in the following archive directory: Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/SVM/ planck-full2.dat

This model has been modified. The modification are the following:

- 3 layers for the cone. (G969/M18 35°/-35°/+35°). This modification was introduced because the cone stiffness in the model was too high. This definition is in line the one presented at structure PDR.
- RBE2 instead of RBE3 at the BEU and PAU I/F. This modification was introduced because the RBE3 don't represent the equipment stiffness on the panel.
- Mass from BEU and PAU have been adjusted as follows (mass max, ref: RD04.11):
    - PAU 11.95 Kg
    - BEU 46.88 Kg

This mathematical model has sufficient detail for the stiffness simulation in the dynamic analyses.

SVM FE model description

The model description is in the document RD06.2. " Planck SVM FEM Description". The Solar panels are included in the FEM by ALENIA (without description documentation).

The main characteristic are the following:

- SVM cone:
  - Honeycomb: height H/C=15 mm: core Hexcel 3/16-5056P-.001 [4-28]
  - **Three layers** composite face sheet: resin epoxy G969/M18 35°/-35°/+35**° thickness for each sheet: t= 3 x 0.19 mm.**

Local reinforcements have been implemented on the cone in the interface areas around the GFRP struts fixations. These reinforcements consist in increasing the stiffness of the upper interface ring of the cone. The total number of the plies of the composite face sheet has been increased, the honeycomb properties remaining unchanged. The core thickness of the upper reinforced ring is about 12 mm.

- SVM upper/lower closure platform**:**
  - Honeycomb: total height H=20 mm: core 4-20: 3/16-5056P-.0007
  - Four plies composite face sheet: resin epoxy G801/M18 45°/0°/-90°/-45° thickness for each sheet t= 4 x 0.1 mm.
- SVM lateral panels:
  - Honeycomb: height H/C=35 mm: core 4-20: 3/16-5056P-.0007
  - Aluminium face sheet: skin AA 7075 T6 Total thickness for each sheet: t= 0.3 mm.
- SVM shear webs:
  - Honeycomb: height H/C=15 mm: core 4-28 3/16-5056P-.001
  - Four plies composite face sheet: resin epoxy G969/M18 60°/-60°/-60°/60° thickness for each sheet: t= 4 x 0.19 mm.
- RCS panel

  The mechanical characteristics of the RCS panel are:
  - Honeycomb: height H/C = 20mm: core 4-20: 3/16-5056P-.0007

  Three plies composite face sheet resin epoxy G801/M18 45°/0°/-45° thickness t for each face sheet = 3 x 0.1 mm.
- P-PLM sub platform

  The mechanical characteristics of the P-PLM sub-platform are**:**
  - Honeycomb: height H/C = 20mm core 4-20: 3/16-5056P-.0007.

  Aluminium face sheet: skin A1 7075 T6.

  Total thickness for each sheet: t= 0.3 mm.

PLANCK SVM model characteristics

The main characteristics of the model are:

- Number of Nodes: 10747 and Element: 11673 (64482 d.o.f)
- SVM FEM mass is: 1311.2 Kg.

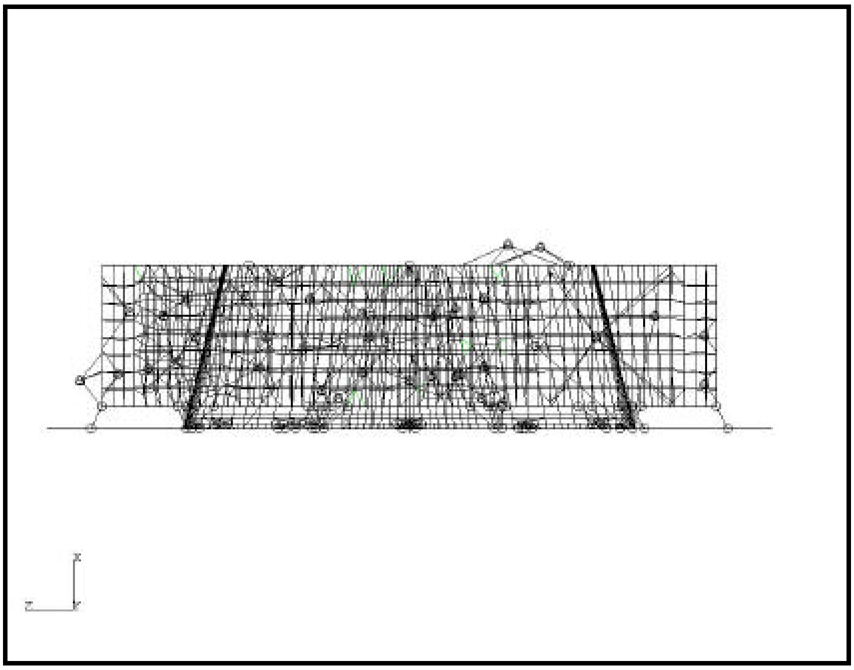


FIGURE 8.1.2-1 Y VIEW OF PLANCK SVM MATHEMATICAL MODEL

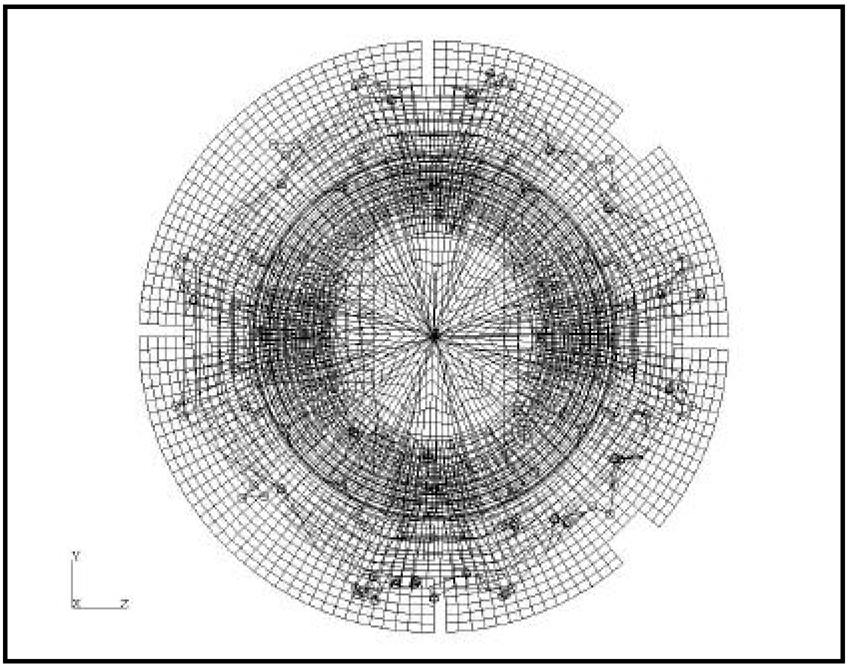


FIGURE 8.1.2-2 X VIEW OF PLANCK SVM MATHEMATICAL MODEL

PLANCK SVM Dynamic performances

PLANCK SVM dynamic global (global box modes, global lateral and longitudinal ones) and local stiffness (panels ...) are obtained from a modal analysis performed with a rigid PLANCK PLM mass equals to 336Kg and located at the centre of gravity of the Payload (boundary conditions of the dynamic SVM specifications, the location of the PLM Cog is 1035 mm above the PLM/SVM interface).

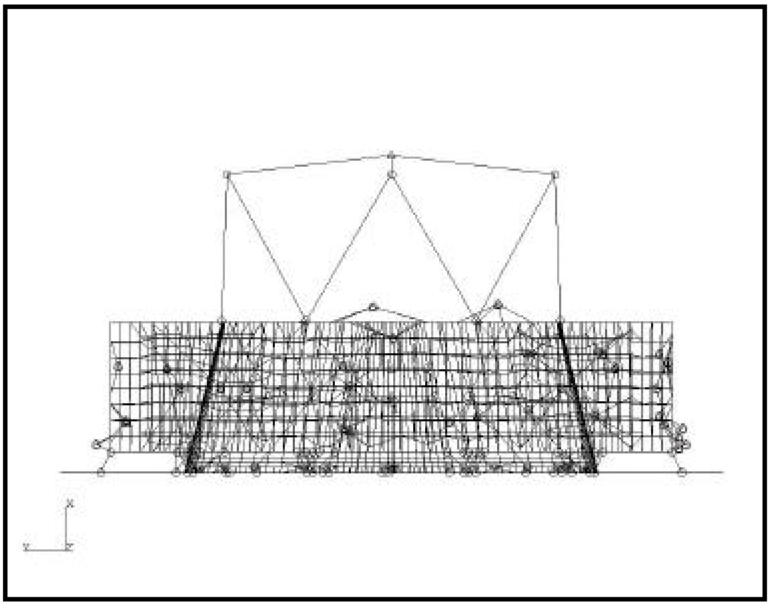


FIGURE 8.1.2-3 PLANCK SERVICE MODULE MATHEMATICAL MODEL WITH RIGID PAYLOAD

The main modal results coming from the modal analysis of PLANCK SVM are summarised in the following table. The boundary conditions used in this analyses are simply boundary conditions applied at the S/C interface.

MODE FREQUENCY	EFFECTIVE MASSES (Kg)			
(Hz)	Mx	My	Mz	MODE DESCRIPTION
24.3	14.8	/	/	Inner SA (X Axis)
31.9	56	/	3.4	PLANCK subplatform (bending mode X Axis)
48.2	58	/	44	Local box mode Side Z+/Bending mode of lateral panel
49	50.3		7.9	Local box mode Side Y+Z-
51.3	3.8	90	194	First lateral global box Z mode/Bending mode lateral panel Z+Y-
54.2	6.5	34.7	66.3	Fuel Tank mode
54.8	7.3	241	64	First lateral global box Y mode
55.6	/	98.8	15.7	Fuel Tank mode
61.	10	305	3.75	First lateral global SVM Y mode
62.2	63	/	152	First lateral global SVM Z mode
86.2	153	8	54.8	SVM longitudinal X mode

TABLE 8.1.2-1 PLANCK SVM MODAL RESULTS

Comments

These results have allowed to define SVM dynamic requirements given in Chapter 8.1.1.4.

First PLANCK SVM global box modes are close to 50 Hz in lateral. Below 50 Hz, only local box mode and lateral panels, solar arrays and sub platform bending modes are identified.

First PLANCK SVM global mode (participation of cone stiffness) are computed around 60 Hz in lateral and 86 Hz in longitudinal direction. Fuel tank modes appear within the frequency range [50 Hz-60Hz].

8.1.2.1.2 PLANCK Payload Module

General

The PLANCK PLM finite element model implemented in the satellite system FEM model has been built by CONTRAVES. (PLANCK PLM configuration is the FEM model sent 02/04/2002 by mail: "CSAG_FEM_020402.zip").

The references (location and name) of received FEM are in the following archive directory: Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/PLM/ CSAG_FEM_020402.zip.

This mathematical model has sufficient detail for the stiffness simulation in the dynamic analyses.

PLANCK PLM model characteristics

PLANCK PLM FEM has 18049 Elements
15290 Nodes
91740 degrees of freedom

PLANCK PLM FEM mass is 349.1 Kg

Planck payload structure is defined from the two following structural parts. PLANCK PLM FE model is presented through next figures.

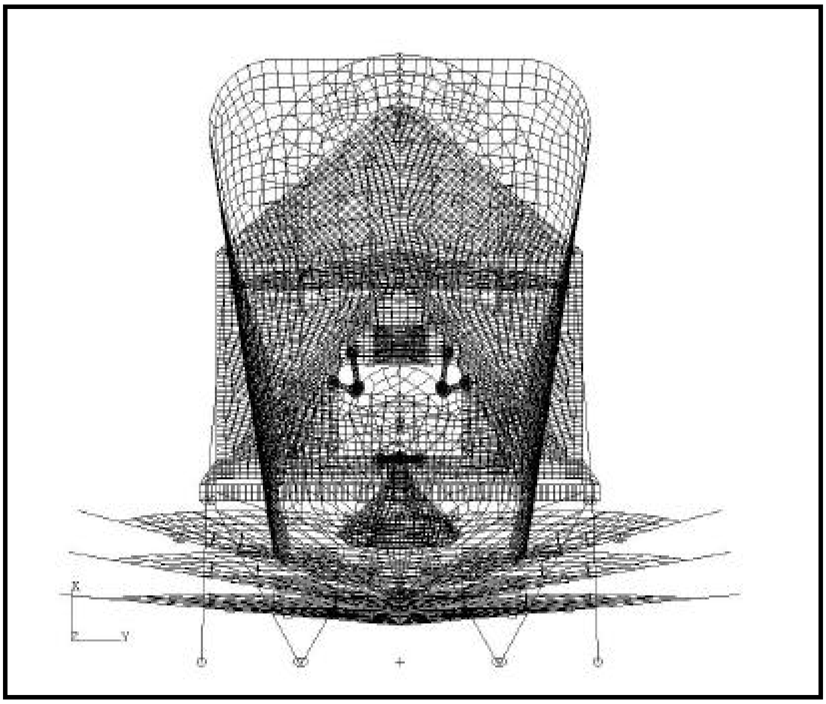


FIGURE 8.1.2-4 PLANCK PLM (Z VIEW)

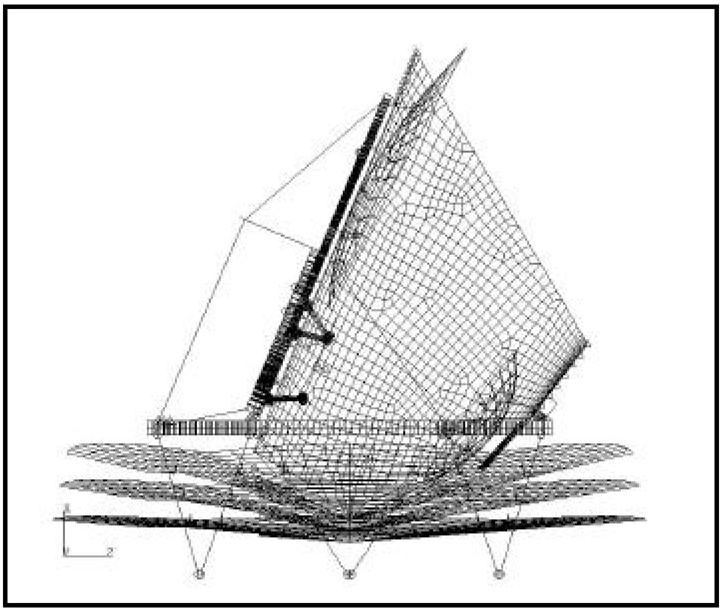


FIGURE 8.1.2-5 PLANCK PLM (Y VIEW)

PLANCK Payload module is defined from the following substructures:

- PLANCK Telescope
- PLANCK Cryo structure.

These substructures are described hereafter:

- **PLANCK telescope.**

PLANCK telescope structure is presented in the following figure.

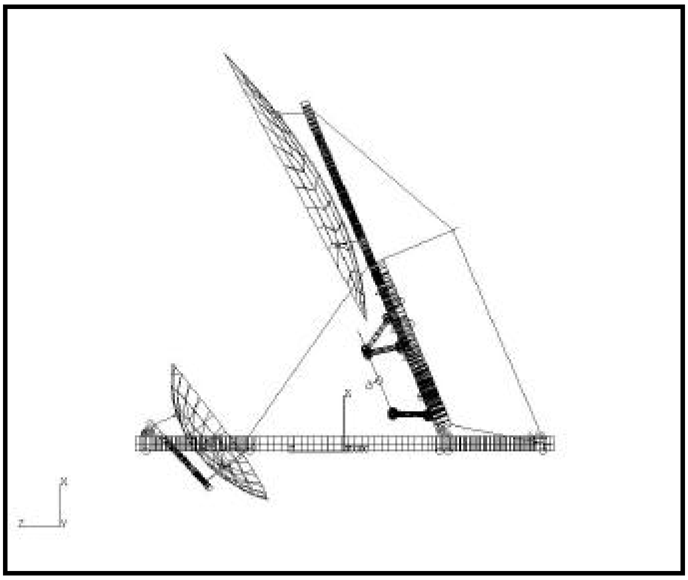


FIGURE 8.1.2-6 PLANCK TELESCOPE

The mechanical properties of PLANCK telescope structure are:

- CFRP interface ring: Rectangular section 88mm X 88 mm X 1.8 mm (16 plies 0.1125 mm thickness)
- PR support: Plate with CFRP face sheet (thickness =0.9 mm, 8 plies 0.1125mm thickness) and a core thickness =50 mm.

The concentrated mass associated to FPU instrument is connected to an Aluminium plate which is supported by 3 couples of CFRP bars. The FPU struts support are modelled with PCOMP elements (5 plies of 0.5mm thickness).

- **PLANCK Cryo substructure.**

PLANCK Cryo structure is presented in the following figure.

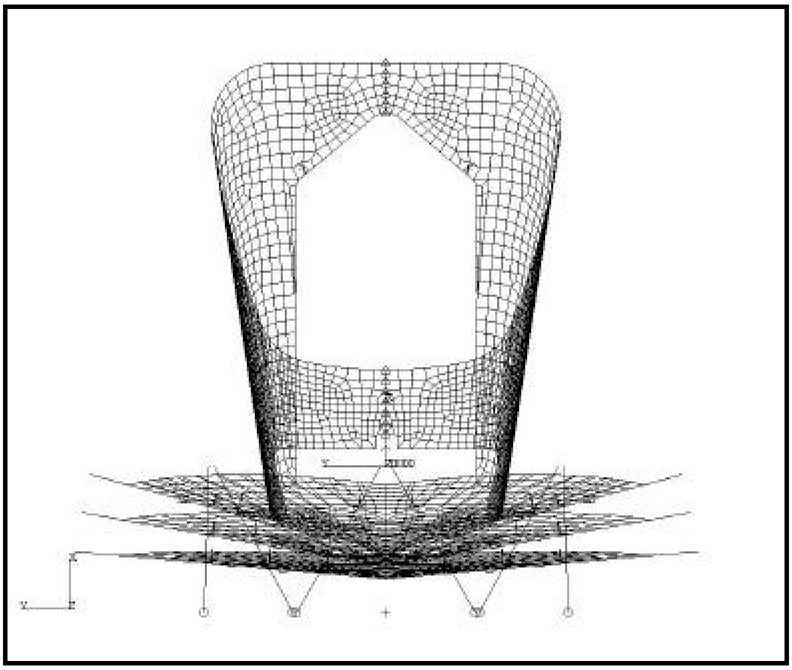


FIGURE 8.1.2-7 PLANCK CRYO-STRUCTURE

The main mechanical characteristics of the PLANCK cryo substructure are:

- Grooves: Plate with Aluminium face sheet thickness =0.3 mm and NIDA ALU thickness =20 mm
- Baffle: NIDA Alu (thickness 20mm with Aluminium face sheet thickness=0.3 mm
- Struts support: GFRP circular section 50mm diameter with a thickness =2.7 mm.

PLANCK PLM Dynamic performances

- **PLANCK PLM dynamic behaviour (with Telescope).**

The PLANCK PLM structure has been determined in order to evaluate the stiffness of the complete PLM without SVM structure. The PLM structure is considered with simply supported boundary conditions introduced at each interface point with service module. PLANCK PLM main modes are listed in the next table.

Frequency (Hz)	Mx [Kg]	My [Kg]	Mz [Kg]	Mode description
18.1	0.0	146.5	0.0	First Y lateral mode
24.6	10.0	0.0	45.8	Coupled Z-X global mode
27.0	0.0	0.0	142.9	First Z lateral mode
29.6	0.0	124.6	0.0	Second Y lateral mode
30.8	0.6	0.0	74.5	Second Z lateral mode
44.5	58.0	0.8	12.0	First longitudinal mode
59.6	51.8	0.0	0.2	Second longitudinal mode

TABLE 8.1.2-2 PLANCK-PAYLOAD MODULE MAIN MODES

Comments

PLANCK PLM main modes are identified around 18 Hz in lateral direction Y and around 27 Hz in lateral Z direction. In the longitudinal direction two modes are clearly identified around 44 Hz and 59 Hz and concern mainly the Telescope. Telescope modes are mainly longitudinal modes with low lateral coupling.

PLANCK PLM modes with low effective mass are associated to light structures like grooves and baffle. The main modes of these structures are identified as defined hereafter:

- Grooves main mode: between 17 Hz and 27 Hz
- Baffle main mode: between 24 Hz and 45 Hz.

No particular modal coupling between subsystem is shown on the proposed PLANCK PLM design.

PLANCK Telescope dynamic behaviour

The PLANCK Telescope structure has been determined in order to verify the stiffness requirements specified for sizing the Telescope structure The telescope structure is considered with supported boundary conditions (Uz=Utheta=0 in a local cylindrical coordinate system, avec Z local = X satellite) introduced at each of six interface points with GFRP struts support and 1 point being fixed on 1 2 3 degrees of freedom). PLANCK Telescope (FPU+PR) main modes are presented hereafter.

FREQUENCY [Hz]	MASS Mx [Kg]	MASS My [Kg]	MASS Mz [Kg]	MODE SHAPE DESCRIPTION
39.8	/	68.5	/	First global lateral Y mode
48.2	92.4	/	16.4	First global axial X mode
54.6	/	/	59	First global lateral Z mode

TABLE 8.1.2-3 PLANCK TELESCOPE MAIN MODES

Comments

PLANCK Telescope Lateral main modes are located around 40 Hz for the Y axis and above 54 Hz for the lateral Z axis. The frequency of these modes are correctly located compared to the frequencies of the P PLM which are at 18 Hz (Y axis) and 26 Hz (Z axis). Lateral PLANCK PLM modes and lateral Telescope modes are correctly de-coupled.

PLANCK Telescope longitudinal mode located around 48 Hz is de-coupled from the lateral ones. This de coupling should ensure a good dynamic behaviour of the PLANCK PLM and Telescope.

8.1.2.1.3 PLANCK satellite mathematical model

The mathematical model of the whole PLANCK satellite is assembled using the models of the various subsystems defined previously in this chapter: PayLoad Module (PLM) and ServiCe Module (SVM). (see FEM description in the precedent chapters).

PLANCK model characteristics

- Number of physical nodes: 26067.
- Number of elements: 29734.
- Total number of degrees of freedom: 156402.

The references (location and name) of NASTRAN files used for the following analyses are defined in the next table.

Modal analysis	Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/MODAL/ *modal_planck.dat*
Sine analysis	Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/SINUS/ *sinus_planck.dat*

Mass budget

The following table presents the mass budget of PLANCK satellite.

SUBSYSTEM	MASS IN THE MODEL]Kg]
P-PLM	349.1
SVM	1311.2
Total mass	**1660.3**

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           1.660340E+03     -2.540953E-18 -6.602098E-03 -2.204916E-02
        Y           1.660340E+03      8.415546E-01 -1.904378E-16 -2.204916E-02
        Z           1.660340E+03      8.415546E-01 -6.602098E-03 -4.600463E-17

                                    I(S) [INERTIA MATRIX]
                        *  2.387475E+03 -1.705498E+00  2.209285E+01 *
                        * -1.705498E+00  2.220988E+03 -3.348433E+01 *
                        *  2.209285E+01 -3.348433E+01  2.074419E+03 *

                                    I(Q)[MAIN INERTIA VALUES]
                        *  2.228219E+03                             *
                        *               2.389029E+03                *
                        *                             2.065635E+03 *

                                     Q [MAIN EIGEN VECTORS]
                        * -1.868225E-02  9.975058E-01  6.806786E-02 *
                        * -9.774948E-01 -3.914465E-03 -2.109234E-01 *
                        * -2.101308E-01 -7.047650E-02  9.751298E-01 *
```

The FEM mass budget covers the baseline (1537 Kg; X cog 0.856 m) (see RD02.3).

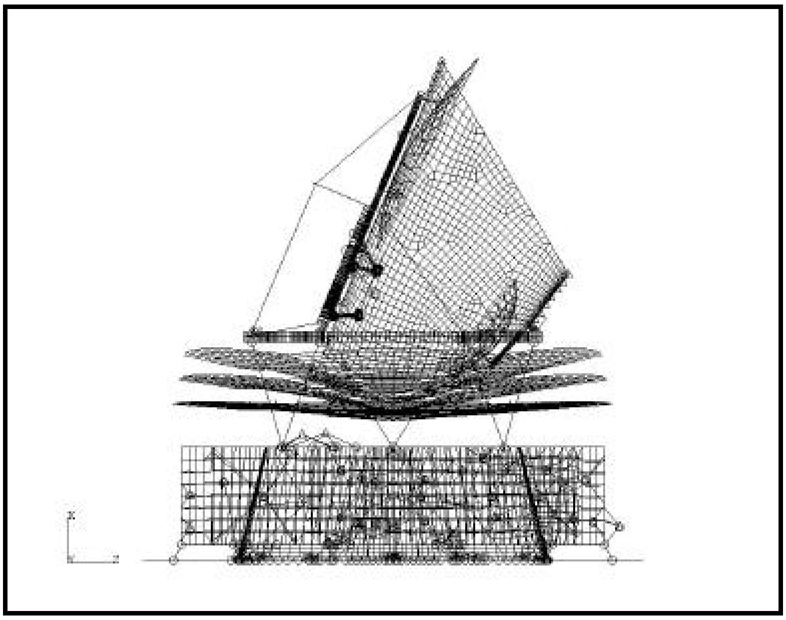


FIGURE 8.1.2-8 Y VIEW OF PLANCK SATELLITE

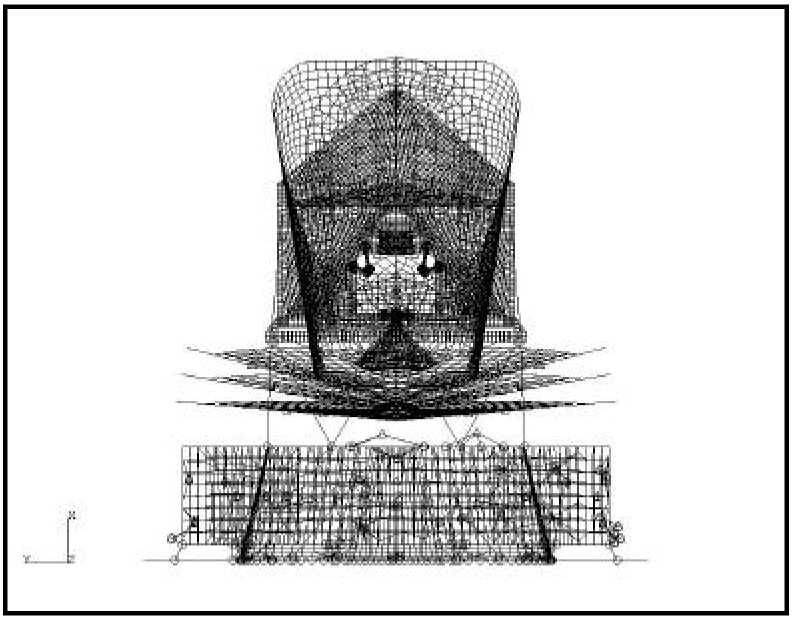


FIGURE 8.1.2-9 Z VIEW OF PLANCK SATELLITE

8.1.2.2 Overall system mechanical analyses

8.1.2.2.1 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 PLANCK 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.

8.1.2.2.2 PLANCK Satellite overall dynamic analyses

The dynamic analysis is performed up to 100Hz which corresponds to the frequency bandwidth of the sine vibration tests.

The boundary conditions applied at the interface of the spacecraft are simply supported boundary condition (123 degrees of freedom are clamped).

Modal analysis

PLANCK satellite main modes are listed in next table.

Mode Frequency	Effective Masses [Kg]			
(Hz)	**Mx**	**My**	**Mz**	**Mode description**
17.2	/	154.6	/	First lateral P-PLM Y mode
23.3	/	/	45	Baffle + grooves - mode
24.1	12	/	79	Baffle + grooves 2/3 + PLM Z mode
26.2	/	/	93	First lateral P-PLM Z mode
29.7	1.7	142.6	/	Second lateral Y mode
29.8	66.5	6	4.7	Sub platform X mode (BEU side)
30.6	/	/	59.8	PPLM Z mode
32.8	30.6	/	/	Sub platform X mode (Control box side Z+)
33.1	/	19.5	1.2	Helium tanks mode Y
33.2	/	1.8	54.4	Helium tanks mode Z
43.7	50.6	1.6	8.6	Telescope axial X mode + groove 3 - mode
48	63.8	/	31.7	Local axial SVM box mode (side Z+) + Fuel tanks
50.8	2.1	32.1	36.0	Local axial SVM box mode + Fuel tanks
50.9	5.0	35.6	115.2	Local axial SVM box mode + Fuel tanks
54.3	2.4	246.7	5.9	SVM global box Y mode + Fuel tanks
58.3	/	7.4	74	SVM local lateral Z mode (lateral panels)
58.7	97.7	4.8	5.6	SVM local axial X mode
61.2	48.7	171.9	27.8	SVM global Y mode
62	54	72	39.8	Global coupled XYZ mode + lateral panels
86.2	48.4	/	2.4	SVM axial X mode

TABLE 8.1.2-4 PLANCK SATELLITE MODAL ANALYSIS RESULTS

Comments

PLANCK satellite main modes

PLANCK satellite lateral main modes (P-PLM modes) have been computed at 17.2 Hz in lateral Y and 26.2 Hz in lateral Z. The first longitudinal mode computed around 29Hz is the subplatform bending mode with low effective mass (66Kg). This mode has not to be taken into account because it will be modified in the next design optimisation (new frequency subplatform specification will be increase above 80 Hz due to high local displacement of BEU). Indeed, strength problem have been identified (negative safety margin coming from CASA results) and consequently the sub platform will be stiffened.

The longitudinal mode with the maximal effective mass (less than 10 % of the satellite mass) is located at the frequency of 58.7 Hz.

Compared to the Launcher frequency requirements, the frequencies of PLANCK satellite main modes fulfil the following relations:

- First longitudinal mode = 58.7 Hz > 31Hz (margin >> 20 %)
- First lateral mode = 17.2 Hz > 9 Hz (margin >> 20 %).

PLANCK secondary main modes

Other PLANCK modes with effective mass less than 5 % of the total mass are located within the frequency bandwidth 0-60 Hz:

- 18.6 Hz-26.6 Hz Grooves bending modes
- 24Hz - 50 Hz Baffle bending modes
- 40Hz –50Hz telescope modes.

No significant modal coupling is identified between PLANCK substructures.

Evolution between model and baseline design

Taking also into account a cone configuration with 4 layers M40 (thickness 0.135mm each) , PLANCK SVM Y lateral main mode are above 17 Hz, 24 Hz for the Z lateral axis and the longitudinal subplatform one is above 29 Hz.

The dynamic behaviour with a cone configuration with 4 layers and 3 layers are very close.

So, the analyses with 3 layers are coherent with the baseline design.

Dynamic Sine Response analyses

- **Methodology.**

The dynamic response analysis is performed using the qualification levels specified by ARIANE5 user's manual.

***Longitudinal axis:** ±1.25g from 5Hz to 100 Hz.

***Lateral axis:** ±1g from 5Hz to 25 Hz
±0.8g from 25Hz to 100 Hz.

These qualification levels are applied at the base of the spacecraft. No notching is considered at this step of the analysis. The reduced damping factor considered in this analysis is 2 % for each mode which is usually consistent with most of the experimental tests.

- **Notching on main modes.**

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 (6g longitudinal and 2g 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.

ITEM	ARIANE V QSL [g]	QUASI STATIC LAUNCHER INTERFACE LOADS	DYNAMIC LAUNCHER INTERFACE LOADS	FREQUENCY [Hz]	FLIGHT NOTCHING LEVEL	QUALIF NOTCHING LEVEL
Fx [N]	6	99600	38780	61.8	1g	1.25g
Fy [N]	2	33200	48460	54.1	0.411g	0.548g
Fz [N]	2	33200	30490	50.7	0.6g	0.8g
My [N.m]	2	27938	60000	23.2	0.373g	0.466g
Mz [N.m]	2	27937	87360	17.1	0.256g	0.32g

TABLE 8.1.2-5 PREDICTED PLANCK NOTCHING LEVELS

For the primary main modes, the predicted qualification notching levels are:

- longitudinal direction: 1.25g (no reduction of the IF level)
- lateral Y direction: 0.32g at 17.1 Hz
- lateral Z direction: 0.466g at 23.2 Hz.

8.1.3 Inputs to support subsystem spec

Dynamic loads and mechanical environments of structures and instruments have to be evaluated and specified through EVTR and GDIR specifications. The following chapter give a descriptions of these loads, environment and the mechanical requirements applicable to subsystems.

- **Design limit loads.**

The main Design limit loads extracted from the dynamic response analysis are presented in next tables. Notching on primary main modes are taken into account in these loads.

PLANCK TELESCOPE REFLECTORS

Design Limit loads

	DESIGN LIMIT LOADS			
Instrument	**^ mounting plane [g]**	**// mounting plane [g]**	**Frequency (Hz)**	**Load Direction**
Primary mirror	±8 ±10	±28 ±2	43.8 24.1	X Z
Secondary mirror	±16 ±27	±12 ±5	55.6 58.3	X X

TABLE 8.1.3-1 DESIGN LIMIT LOADS FOR TELESCOPE REFLECTORS

Comments

These design limit loads are consistent with the SR and PR mirror specification which specify 30g spherical at qualification.

Design limit loads

For instruments, the design limit loads are presented in the next table.

	DESIGN LIMIT LOADS			
Instrument	**^ to mounting plane [g]**	**// to mounting plane [g]**	**Frequency (Hz)**	**Load Direction**
PAU	±22	±17	29.7	X
BEU	±40 ±4.5	±8 ±12.5	29.7 58.4	X Z
FPU	±7 ±10	±30 ±5	58.9 26.3	X Z
JFET	±25 ±13	±2.5 ±14	58.8 43.8	X X

TABLE 8.1.3-2 TELESCOPE INSTRUMENT DESIGN LIMIT LOADS

Comments

The 30 g level along X axis for the FPU is of the same order of magnitude as the FPU QSL specified for the SRR (that is to say: 24*1.25 = 30g). However, with the previous design (which was globally stiffer than the current one at satellite level), this level was generated by a longitudinal mode at 81Hz, whereas the current level is generated by a global (SVM + PPLM) longitudinal mode at 58.7 Hz, that induces a coupled "PR support panel/FPU support" deformation. The FPU participates mainly to this mode.

Moreover, in order to take into account this difference between the FPU FEM and the current design, an additional safety coefficient of 1.2 is applied on the QSL.

For the BEU, a study has been performed in order to find a solution to reduce the very high levels (40 g at 29.8 Hz (subplatform mode), thus a displacement of 11.1 mm).

A solution will be to add 2 oblique carbon tube of 70 mm diameter that join the inferior part of the cone to the subplatform at BEU interface level. The accelerations are decreasing around 20 g (design) with displacements lower than 1mm out of plane, at a frequency around 80 Hz.

This solution seems to be the interesting to reach acceptable levels on BEU, and the feasability of this design modification is being studied.

	DESIGN LIMIT LOADS			
Instrument	**^ to panel [g]**	**// to panel [g]**	**Frequency (Hz)**	**Load Direction**
SCC panel	±25	±20	51	Z

TABLE 8.1.3-3 SCC PANEL DESIGN LIMIT LOADS

Comments

The maximal out of plane loads have been computed at the frequency of the longitudinal main mode of PLANCK satellite. It will be possible to reduce these loads taking into account extra notching which could be possible at high frequencies.

SVM EQUIPMENT

Design limit loads

For SVM equipment, design limit loads have been computed and presented hereafter in the next tables.

	DESIGN LIMIT LOADS			
Equipment	**^ to panel [g]**	**// to panel [g]**	**Frequency (Hz)**	**Load Direction**
SVM lateral Panels	±25	±20	51	X
Fuel tank	±14.5	±10	75	Z

TABLE 8.1.3-4 DESIGN LIMIT LOADS (TANKS AND EQUIPMENT LATERAL PANELS)

For SVM panel, design limit loads have been computed and presented hereafter in the next tables.

Design limit loads	**^ to panel [g]**	**// to panel [g]**	**X sat =// to panel [g]**	**Load Direction**
SVM lateral Panels	±25	±6	±20	X

TABLE 8.1.3-5 DESIGN LIMIT LOADS (LATERAL PANELS)

Comments

For SVM lateral panels, the design limit loads have not increased sine SRR phase. For fuel tanks, the design load levels are qualification levels for qualification testing.

Global SVM interface loads

For computing SVM/PLM interface forces, Global SVM load cases have been defined and are presented in the next table.

LOAD CASE	X AXIS	Y AXIS	Z AXIS
1	±14g	/	±4.5g
2	/	±9.5g	/
3	±2 g	/	±9.5g

TABLE 8.1.3-7 SVM GLOBAL INTERFACE LOADS

These loads have to be applied to the whole Telescope structure only (the resultant force is applied to centre of gravity). These global Quasi static loads coming from telescope behaviour only (V-groove masses being de-coupled at high frequencies), generate equivalent sizing forces is the struts at the interface points with SVM.

8.1.3.1 PLANCK Random vibration analyses

Methodology

The methodology for computing random acceleration levels on P-PLM equipment are based on two technical approach which give estimated levels from the weight of the equipment (HERSCHEL approach with ESA formulae) and from experimental results (second approach with XMM experimental random curve) provided by ESA. The final random results presented in the PLANCK technical document RD04.8 " Planck Random Environment Analysis" are defined from equipment location consideration on the panels.

P-PLM random vibration specification

The following levels presented in the next table are the random vibration levels specified for P-PLM equipment (FPU, JFET, BEU, PR, SR). These levels define a random spectrum with an horizontal maximal level:

- 20-100Hz: +3dB/Oct
- 100Hz-300Hz: PSDmax [g²/Hz]
- 300Hz-2000Hz: -5dB/Oct.

Maximal PSD values (PSD max) of qualification random spectrum are defined in the following tables.

P-PLM EQUIPMENT	MASS [Kg]	IN PLANE ACC [g²/Hz]	OUT OF PLANE ACC [g²/Hz]
FPU	52	0.1	0.2
JFET	2.3	0.2	0.4
PAU	3	0.15	0.3
BEU	**30**	**0.15**	**0.3**

TABLE 8.1.3-8 PLANCK PLM EQUIPMENT RANDOM VIBRATION SPECIFICATION (QUALIFICATION LEVELS)

NOTE: BEU and PAU random vibration levels take into account a reduction of the Payload sub platform area .using a large cut out part in the middle of PLM sub platform.

PLANCK SVM equipment random vibration specification

The random qualification levels for PLANCK equipment located inside SVM are presented in the next table. These following Random vibration levels are the specified random vibration levels for SVM instruments.

ITEM	MASS [Kg]	MOUNTED PANEL	PANEL MASS/SURF [Kg/m²]	OUT OF PLANE LEVEL [g²/Hz]	IN PLANE LEVEL [g²/Hz]
SCC	50.3	[-Z;+Y]	48.7	0.2	0.1
SCC	50.3	[-Z;-Y]	48.7	0.2	0.1
4K CAU	5.6	[+Y]	32.5	0.3	0.15
4K CEU	7.5			0.3	0.15
4K CCU	16.5			0.3	0.15
Battery	6.8	[+Z;-Y]	55	0.2	0.1
PCDU	18.2			0.2	0.1
AOCS IF/Unit	8.69			0.2	0.1
CDMU-A	13.33			0.2	0.1
DCCU	31.55	[+Y;+Z]	38	0.2	0.1
REBA	8			0.2	0.1
QRS	1.43	[-Y]	16	0.6	0.3
X/B transponders	3.46			0.6	0.3
TWTA	0.75			0.6	0.3
EPC	1.4			0.6	0.3
Diplexer	0.3			0.6	0.3
REU	33.5	[+Z]	52.7	0.2	0.1
DPU	13.6			0.2	0.1
STR Mapper Elec				0.2	0.1
SCCE/+HP	18.8	[-Z]	21	0.3	0.15
BEU	33.5	Platf [+X]	>40	0.3	0.15
PAU	9.5	Side –Z		0.3	0.15
Control box	20.9	Platf [+X]	30	0.3	0.15

TABLE 8.1.3-9 QUALIFICATION RANDOM LEVELS FOR PLANCK SVM EQUIPMENT

These levels have been included in IIDA (ref AD04.1).

These random loads will be confirmed after the vibroacoustic analysis with the S/C FEM.

8.1.3.2 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 17 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”.

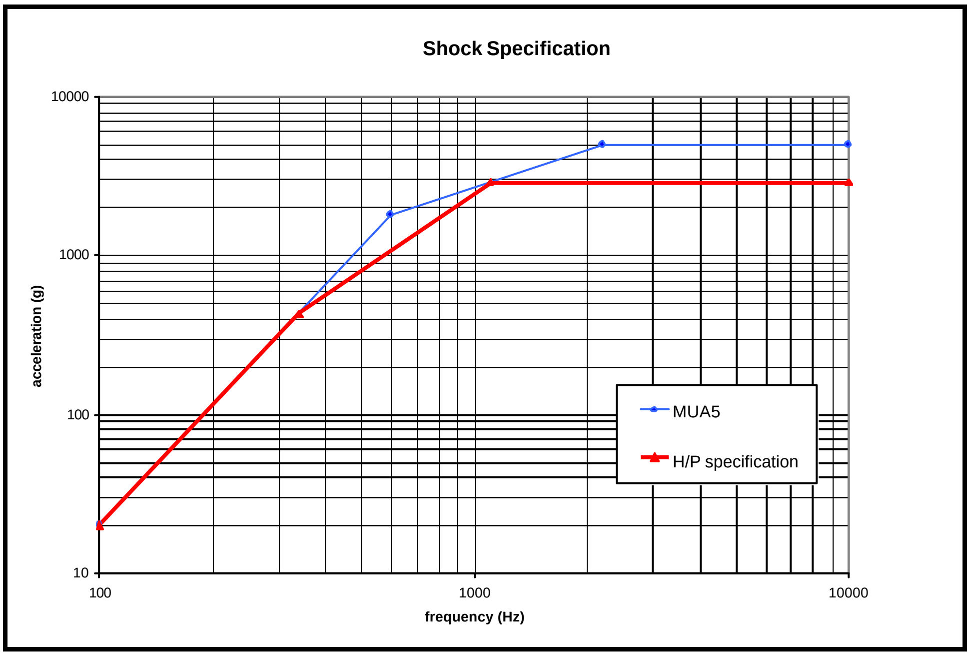


FIGURE 8.1.3-1 HERSCHEL/PLANCK SHOCK SPECIFICATIONS AT SPACECRAFT INTERFACE

The interface shock response spectrum is defined by the following shock acceleration levels (see Table 8.1.3-10).

FREQUENCY [Hz]	SHOCK ACCELERATION [g]
100	20
600	1000
10000	3600

TABLE 8.1.3-10 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 8.1.3-11 P-PLM INTERFACE SHOCK RESPONSE SPECTRUM (SRS P-PLM) (QUALIFICATION LEVEL)

BEU Shock specification

P-PLM EQUIPMENT	Shock Specification
BEU	SRS P-PLM

TABLE 8.1.3-12 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

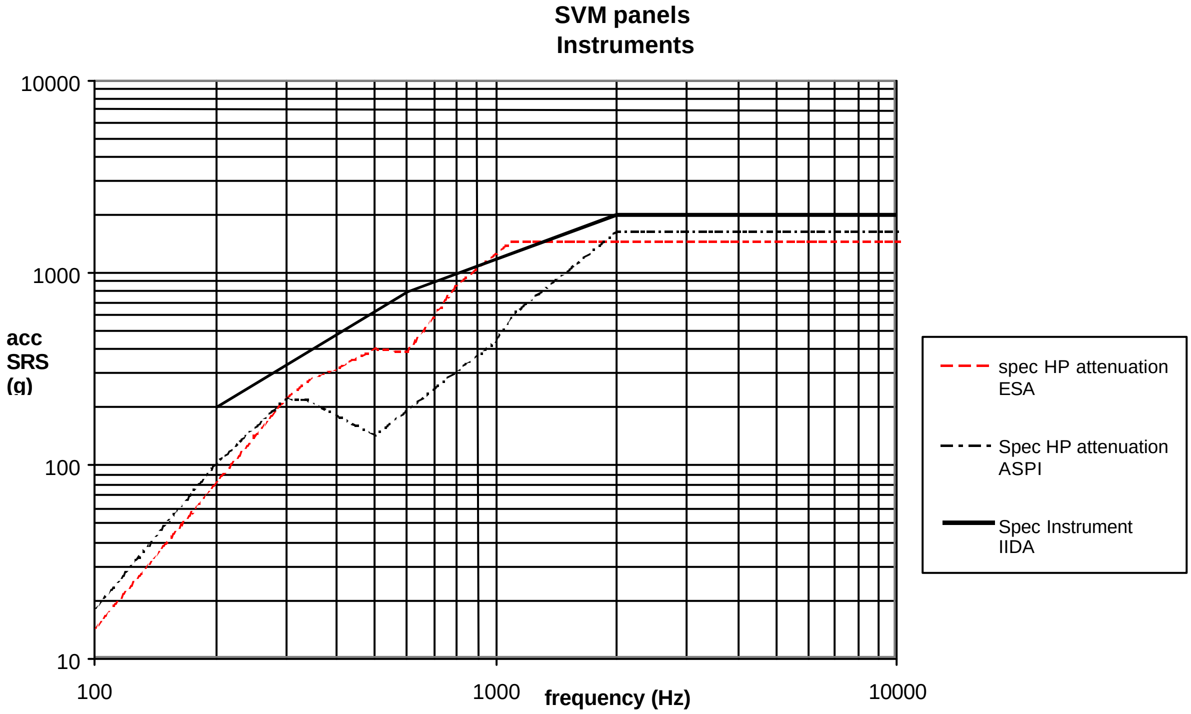
TABLE 8.1.3-13 PLANCK PLM STRUCTURE SHOCK SPECIFICATION

PLANCK 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
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 8.1.3-14 SHOCK RESPONSE SPECTRUM SB 2 (QUALIFICATION LEVELS)



The IID-A specification is closed to the calculated ones. So, the IID-A specification stays recommended.

8.1.4 Inputs to PLANCK SVM structural requirements specification

The mechanical design of PLANCK SVM has to be defined from mechanical environment and stiffness requirement to fulfil the Launcher frequency specification. These mechanical has been defined with the latest PLANCK SVM mass configuration and mechanical design**.**

PLANCK SVM Dynamic requirement specification

In order to avoid modal coupling between substructure, SVM dynamic requirements have been defined and concerns the frequency location of:

- Global SVM modes with rigid Payload:

  In relation with the global stiffness of central tube, the global SVM modes with rigid Payload have to be defined to reach and fulfil the Launcher frequency requirements with PLANCK Payload modelled as a rigid mass:

  - PLANCK axial main mode with effective mass > 10% of total mass > 60 Hz
  - PLANCK lateral main mode with effective mass > 10% of total mass > 35 Hz

- SVM global Box modes:

  SVM global Box modes have to be de-coupled to PLANCK main modes. These technical considerations and the mechanical design lead to the following frequency requirements:

  - Frequency of SVM longitudinal global box mode > 45 Hz (with effective mass > 5 % of SVM mass)
  - Frequency of SVM lateral global box mode > 50 Hz (with effective mass > 10 % of SVM mass).

– Tank support modes:

  To avoid modal coupling between SVM modes located around 50 Hz and fuel tank main modes, the frequency requirements:

  - Frequency of PLANCK fuel tank longitudinal X main mode > 145 Hz TBC
  - Frequency of PLANCK fuel tank lateral main mode > 80 Hz.

– SVM Lateral panels

  The lateral panel frequency requirements have been defined from the lateral behaviour of PLANCK satellite for de-coupling out of plane modes of panels to satellite main modes. With a target of 70Hz, the main lateral panel frequency requirement is:

  - Frequency of out of plane lateral panel > 50 Hz.

PLANCK SVM Stiffness requirement specification

– Global lateral stiffness (central tube)

  A global lateral and longitudinal stiffness is specified to ensure a satisfactory global dynamic behaviour of PLANCK satellite with respect to the Launcher frequency specifications. The lateral and longitudinal stiffness requirements specified for central tube are:

  - 2 E 8 N/m > $K_{lateral}$ (Y) > 1.5 E8 N/m
  - 2 E 8 N/m > $K_{lateral}$ (Z) > 1.5 E8 N/m
  - 3.7 E 8 N/m > $K_{longitudinal}$(X) > 3.1 E8 N/m.

– Local interface stiffness (interface SVM/P-PLM)

  Local stiffness at SVM interface points with GFRP strut support are given by the central tube. For communality reasons, local stiffness are similar to HERSCHEL SVM but these local interface stiffness are not needed.

– Local interface stiffness (interface SVM/fuel tank)

  To avoid a significant frequency decrease coming from local SVM stiffness, local interface points between fuel tank and SVM have been estimated and derived as a local stiffness requirement.

PLANCK SVM interface specification

The global dynamic behaviour of PLANCK satellite generate forces (during sine test) at SVM/ GFRP struts interface points. These dynamic local loads depend on the frequency location of subsystem modes (P-PLM and SVM). These loads are specified for local and global SVM interface sizing.

8.1.5 Inputs to P-PLM structural requirements specification

The objectives of the P-PLM structural requirements are to ensure a satisfactory global satellite dynamic behaviour and to define the main global H-PLM dynamic loads for PLANCK Payload Module sizing.

P-PLM frequency performance

– Frequency of the P-PLM longitudinal (X)mode > 44 Hz

– Frequency of the P-PLM lateral Y mode > 18 Hz

– Frequency of the P-PLM lateral Z mode > 26 Hz.

PLANCK Telescope stiffness specification:

– Frequency of PLANCK Telescope longitudinal (X) mode > 48 Hz

– Frequency of PLANCK Telescope lateral (Y) mode > 39 Hz.

– Frequency of PLANCK Telescope lateral (Z) mode > 55 Hz.

TELESCOPE Quasi static loads

Telescope quasi static loads have been defined and specified defined for interface and global sizing of the struts. These loads are presented in the following table. These loads are design loads and have been evaluated from the computed interface forces.

LOAD CASE	X AXIS	Y AXIS	Z AXIS
1	±17.5g		±4g
2		±15g	
3	±12.5g		±17.5g

TABLE 8.1.5-2 TELESCOPE QUASI STATIC LOADS (DESIGN LOADS)

NOTE: All ARIANE V quasi static loads are not covered by these P-PLM loads. The ARIANE V should be taken into account.

Baffle Quasi static loads

Baffle quasi static loads have been defined and specified defined for Telescope interface and link sizing These loads are presented in the following table. These loads are design loads and have been evaluated from the computed interface forces.

Load Case	X Axis	Y Axis	Z Axis
1	±19g		±10g
2		±13g	
3	±10g		±18g

TABLE 8.1.5-3 BAFFLE QUASI STATIC LOADS (DESIGN)

NOTE: All ARIANE V quasi static loads are not covered by these P-PLM loads. The ARIANE V should be taken into account.

PLANCK SVM Interface specification

The global dynamic behaviour of PLANCK satellite generates forces (during sine test) at SVM/ GFRP struts interface points. These dynamic local loads depend on the frequency location of subsystem modes. These loads are specified for local SVM interface sizing.

The loads are computed for the 6 interface points (2 sizing cases are presented)

F Radial [N]	F Tangential [N]	F Longitudinal [N]	Moment Mr (N.m)	Moment M_{tan} (N.m)	Moment M_z (N.m)
±1200	±1600	±8700	±25	±90	±2
±700	±9700	±13600	±120	±45	±25

8.1.6 Planck Thermoelastic analysis

8.1.6.1 Reference file:

SVM ALENIA received file: (dated 12/04/02)
Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/THERMO/svm_p.zip
Model description: see document RD06.3 " Stability Analysis Report"

PLM contraves receive file:

The PLM model used to perform the thermoelastic analysis is the same as the modal one (see § 8.1.2.1.2). The main change is the removal of the RBE2 replaced by RBE3.

Planck spacecraft thermoelastique FEM:
Fuego:/data/planck_struc/ARCHIVE_PDR/ANALYSES_PDR/MODELES/THERMO/thermo.dat

The mathematical model of the whole PLANCK satellite is assembled using the models of the various subsystems defined previously in this chapter: payload module (PLM) and service module (SVM).

8.1.6.2 Introduction

Planck thermoelastic analysis could not be performed because the thermoelastic FE Model did not meet the mechanical mathematical model specifications relative to the thermoelastic FE Models. (ref: "Mechanical Mathematical Model Specification" n° HP-ASPI-SP-0014 is 1).

The specifications are the following:

– A zero stress test must be applied on the finite elements model with the following hypotheses:
    - unit with isostatic boundary conditions
    - coefficient of thermoelastic expansion set to 20 $10^{-6°}$ C^{-1} (only for this test) on all material of the model
    - homogeneous increase of temperature of +100°C applied to the whole model.

The maximum Von Mises stress ,σ_{max}, and the maximum rotations, θ_{max}, due to the temperature increase must satisfy:

– $\theta_{max} < 1.10^{-7}$ rad

– $\sigma_{max} < 10^{3}$ Pa.

8.1.6.3 Model Check

In the following table are reported the maximum Von Mises stresses induced by the isotermal load subdivided per substructures or model items.

MODEL ITEM	MAXIMUM s_{VM} [Pa]	LOCATION (grid)
PLM Small Mirror Support/Frame Attachment	1.34E8	74023
PLM Small Mirror Support	1.03E8	71037
PLM Small Mirror Support connection bars	8.71E7	75511
PLM Rear Plate/Frame connection (fittings)	3.40E7	73130
PLM Rear Plate (FPU supports region)	3.03E7	66448
PLM FPU Supports	1.82E7	90394
PLM Frame	1.30E7	75510
PLM Plane (normal to Rear Plate)	9.05E6	70034
STRUTS	4.98E6	49011
PLM Waffle	2.37E6	203105
PLM Rear Small Plate	1.70E6	93023
PLM V1 (lower)/Blade	1.64E6	30140
SVM Cone	1.55E6	5211
SVM Payload Subplatform	1.11E6	5233
SVM Internal Bars	1.01E6	5233
SVM Lower Closure Panels	9.43E5	10773
SVM Cone Closure Panel	8.78E5	6868
PLM Small Mirror (near joints)	6.53E5	92054
SVM Upper Closure Panels	5.58E5	9387
PLM V2 (mid)	5.36E5	33204
PLM V3 (upper)	5.03E5	37320
SVM Lateral Panels (near shear pan. connect.)	2.94E5	4001
SVM Shear Panels	2.77E5	11501
PLM Large Mirror	1.65E5	91103
PLM FPU	2.13E2	90010

TABLE 8.1.6-1 ISOTHERMAL EXPANSION CHECK INDUCED STRESSES PER ITEM.

In the following table are presented the maximum rotations of the representative grid points, the rotations are referred to the NASTRAN 0 basic coordinate system.

LOCATION	GRID POINT	ROTATION [rad]			
		MAGNITUDE	X	Y	Z
Payload Subplatform	8027	3. 843 E-3	3. 844 E-3	-4.749 E-6	8.213 E-6
	8445	3. 844 E-3	3. 844 E-3	4.765 E-7	6.302 E-6
Thrusters	10087	3. 840 E-3	3.840 E-3	8.934 E-6	-7.004 E-6
	10222	3. 845 E-3	3.845 E-3	9.043 E-6	8.675 E-6
	10362	3. 851 E-3	3.852 E-3	-1.885 E-5	-1.009 E-5
	10463	3. 843 E-3	3.843 E-3	-8.890 E-6	9.445 E-6
	10518	3. 836 E-3	3.836 E-3	-1.877 E-5	2.631 E-5
	10655	3.850 E-3	3.850 E-3	4.704 E-6	1.911 E-5
	13062	3. 844 E-3	3.844 E-3	-1.371 E-5	1.003 E-5
FPU	90404	3. 873 E-3	3.872 E-3	-3.419 E-5	-3.786 E-6

TABLE 8.1.6-2 INDUCED GRID POINT ROTATIONS

– The maximum Von Mises stress ,σ_{max}, is equal to 134 Mpa (> 10^{-3} Mpa).

– Absolute maximum Grid rotations referred to NASTRAN 0 basic coordinate system are:

- X axis = 4.945 E-2 rad >1.10^{-7} rad
- Y axis = -3.939 E-3 rad >1.10^{-7} rad
- Z axis = 1.619 E-2 rad >1.10^{-7} rad.

– Thrusters relative maximum Grid rotations referred to FPU are:

- X axis = 3.600 E-5 rad >1.10^{-7} rad
- Y axis = -4.323 E-5 rad >1.10^{-7} rad
- Z axis = -3.010 E-5 rad >1.10^{-7} rad.

Model Checks don't meet the ASPI requirements. The model is not representative for thermoelastic analyses, thus thermoelastic analyses can't be performed.

However, the model will be used for calculation of the forces in the interface struts between PLM and SVM.

8.1.6.4 Thermoelastic I/F SVM/PLM loads

Interface loads between SVM and PPLM (at the GFRP struts/cone interface) have been computed in order to obtain an order of magnitude of these efforts (see RD04.11). The results are summarised hereafter. The maximum load computed on the 6 interface points is given in the cylindrical coordinate system whose origin is at the centre of the PPLM/SVM interface.

Axis	Radial	Tangential	longitudinal
Max load on one I/F point	558 N	222 N	208 N

Those loads are largely covered by dynamic loads (see RD04.1).

We remind the maximum design loads given in RD04.1: 13606 N out of plane and 9774 N in plane (reference plane is the interface plane).

As a consequence, thermoelastic load cases should not be sizing for the PPLM interface brackets.

8.2 Micro Vibration analyses

Reference files:

[1] Fuego/data/Planck_struc/ARCHIVE_PDR/MICROVIB/Force_cooler_X.dat.

[2] Fuego /data/Planck_struc/ARCHIVE_PDR/MICROVIB/Force_cooler_Z.dat.

[3] Fuego /data/Planck_struc/ARCHIVE_PDR/MICROVIB/ dep_punch_planck.m: matlab file for punch post-processing.

Software version:

- Nastran 70.0
- Postrait 2002
- Matlab6.

8.2.1 Introduction

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) minimizes 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 aim of this first analysis is to determine the level of acceleration due to the 4K compressor perturbation calculated at the 6 nodes located at the interface of the bipods and P-PLM (Figure 8.2.2-2) as well as at the center of gravity of the FPU for information.

8.2.2 Study logic

8.2.2.1 Model

The model used for this analysis is presented in Section 8.1.2.1.3.

The compressor is represented by a rigid body connecting together its 4 interface points enabling introduction of interface disturbances (Figure 8.2.2-1).

The disturbance is modeled as a force in the Spacecraft Z-direction (axis of the 4K cooler) applied to the Center of Gravity of the compressor. Its fundamental frequency is at 40 Hz, however it may vary from 35 to 45 Hz depending on the cooler velocity. In the course of this study, harmonics up to 200 Hz have been considered. Each of them with an amplitude of 40 mN (conservative approach).

For information, results are also provided assuming a disturbance force in the spacecraft X-direction of amplitude 40 mN (perpendicular to the axis of the 4K cooler and parallel to the Y+ panel).

The FPU is represented by a point mass connected to the structure with a rigid body element. The HFI and LFI levels are not detailed. Outputs of the computations are presented at the 6 nodes located at the interface of the bipods and P-PLM (Figure 8.2.2-2) as well as at the FPU node for information (located at the CoG of the FPU). The FPU local coordinate system, in which all results are provided, is shown in Figure 8.2.2-2.

The Nastran model was designed for sinus analysis, therefore the model is representative of the Planck dynamic behavior up to 140 Hz. Results at higher frequencies must be considered with caution. For instance, some equipment are model as point mass connected to a panel by mean of a rigid element. This assumption is valid only if the equipment is 'rigid' in the frequency band of the analysis. Since the specification on the equipment rigidity is set at 140 Hz, the model may not be very accurate above this frequency.

8.2.2.2 Nastran Analysis

The Nastran analysis is a forced response computed by modal superposition between 0 and 200 Hz. The perturbation is a force of 40 mN applied at the center of gravity of the 4K cooler compressor in the spacecraft Z-direction. The analysis is based on a free-free modal analysis (including modes from 0 to 250 Hz) normalized to the generalized mass of the Planck spacecraft. Structural damping is set to 0.5 % (conservative).

The output of the analysis includes the acceleration (due to the disturbance described above) computed t the 6 nodes located at the interface of the bipods and the P-PLM (Figure 8.2.2-2) as well as at the CoG of the FPU for information. [1, 2].

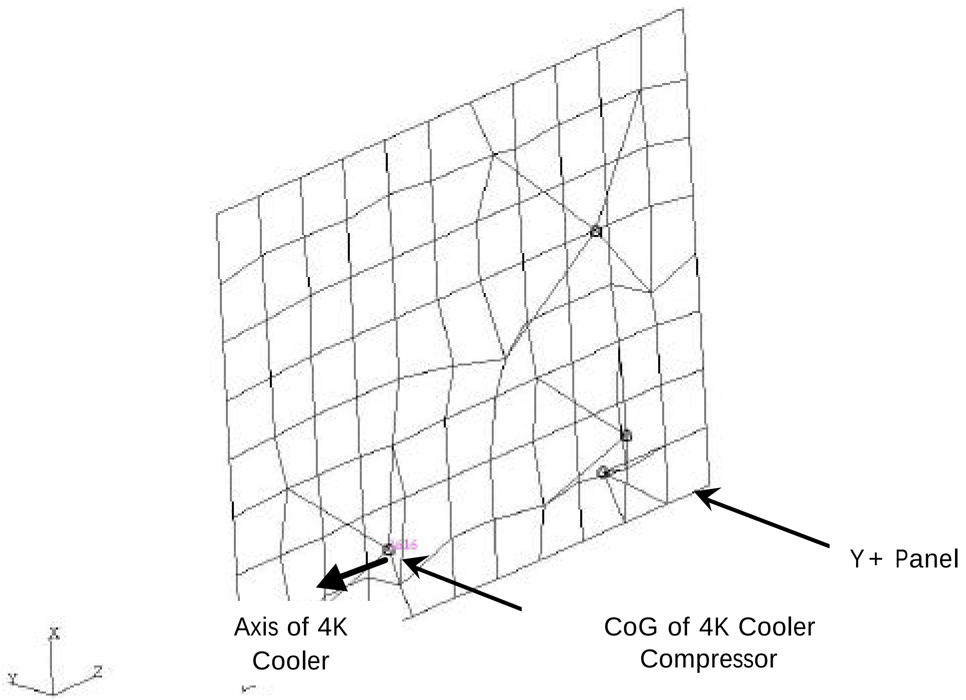


FIGURE 8.2.2-1 MODEL OF 4K COOLER COMPRESSOR MOUNTED ON Y+ PANEL

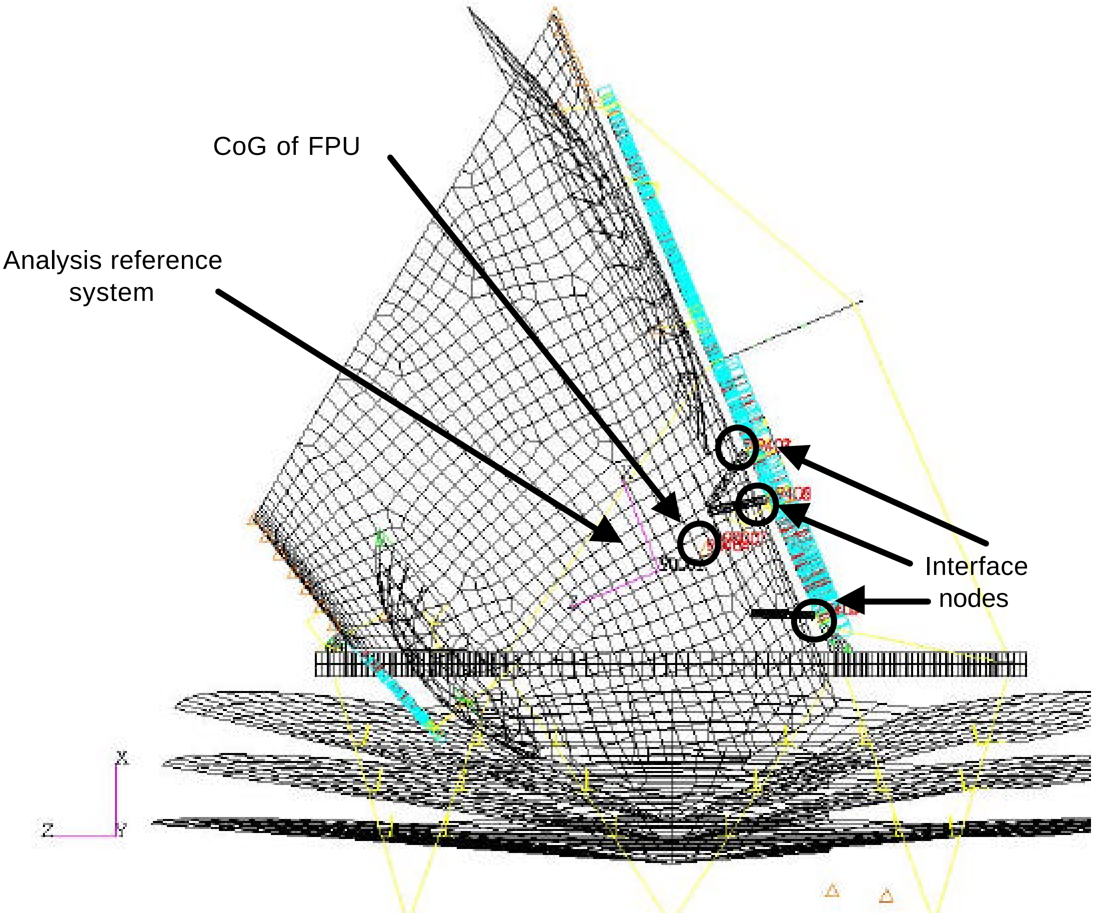


FIGURE 8.2.2-2 FPU MODEL

8.2.2.3 Specifications

Since the interface at which microvibration levels are defined is internal to the instrument, it was decided to derive computational results at 6 points defining the interface of the bipods and the P-PLM as well as the CoG of the FPU for information (Figure 8.2.2-2).

The specification is defined as follows:

- acceleration < 1 mg RMS in all the +/- 10 % bandwidth around the fundamental (35-45 Hz) and harmonics of the 4K compressor up to 200 Hz.

The Nastran Punch file (including the acceleration at the 6 +1 (CoG) nodes as discussed above) is transformed in a matlab variable using Postrait 2002. A matlab file [3] is then used to compute the results presented in Section 8.2.3 In the text below, the example of the response in the X-direction at the CoG of the FPU is provided.

- For each direction and each of the 7 points, the acceleration is computed by modal superposition using Nastran in between 0 and 200 Hz (L_X(f)). A constant perturbation force of 40 mN is assumed on the entire frequency band. This force is applied at the center of gravity of the 4K cooler compressor in the spacecraft Z-direction.

- The RMS value of the acceleration is computed for each direction and for each of the 7 nodes ($LRMS\_X(f) = \frac{L\_X(f)}{\sqrt{2}}$, with L_X(f) the peak level response).
- Since only the harmonic itself contributes to the response in each +/- 10 % bandwidth around the harmonics, the RMS value computed in these bands is (for each of the 7 nodes in all three directions) $L\_RMS\_X(H, fun) = L\_RMS\_X(H * fun)$, with H the harmonic order (1 to 5) and fun the fundamental frequency of the compressor (varying from 35 to 45 Hz).
- For each harmonic, the maximum over the fundamental frequency is computed: $L\_RMS\_X\_\max(H) = Max_{fun}(L\_RMS\_X(H, fun))$. This results is provided in the tables below (Hi (mg)).
- The RMS value of the acceleration is then defined as the quadratic sum over the harmonics: $LRMS\_tot(fun) = \sqrt{\sum_H LRMS\_X(H, fun)^2}$. This result is also provided in the tables below (see **Total 1 (mg)**).
- **For information a very conservative approach is also provided**. The total acceleration is the quadratic average of the maximum acceleration at each harmonic: $LRMS\_tot = \sqrt{\sum_H LRMS\_X(H)\_\max^2}$. This results covers possible shifts of resonant frequencies. This result is also provided in the tables below (see **Total 2 (mg)**).

8.2.3 Results

The specification (1 mg) is defined for frequencies below 200Hz, therefore only the first 5 harmonics (H1 to H5) were considered.

Results derived in Section 1.2 are presented in Tables 8.2.3-1 to 8.2.3-4 below. They are expressed in the FPU local coordinate system (see Figure 8.2.2-2).

When the disturbance force is applied in the spacecraft Z-direction (nominal case), the maximum acceleration is reached on node 5 with an amplitude of **0.31 mg, see Table 8.2.3-3** (below the specification of 1 mg). The FPU is also sensitive to a disturbance force applied in the spacecraft X-direction since the maximum acceleration is reached on node 5 in the Z-direction with an amplitude of **0.29 mg.**

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total 1 (mg)	Total 2 (mg)
Node 1	0.02	0.05	**0.06**	**0.21**	0.22	0.22	**0.32**
Node 2	0.02	0.05	**0.06**	**0.21**	**0.23**	**0.23**	**0.32**
Node 3	0.02	**0.06**	0.05	0.15	0.15	0.17	0.23
Node 4	0.02	0.04	**0.06**	0.18	0.18	0.19	0.26
Node 5	0.02	0.04	**0.06**	0.15	0.15	0.16	0.23
Node 6	0.02	**0.06**	0.05	0.13	0.13	0.14	0.20
FPU CoG	0.02	0.02	0.02	0.02	0.02	0.04	0.05
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-1 DISTURBANCE IN THE ZSAT-DIRECTION RESPONSE IN THE XLOC DIRECTION

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total (mg)	Total 2 (mg)
Node 1	0.01	0.13	**0.27**	0.04	0.03	**0.27**	0.30
Node 2	0.01	0.13	**0.27**	0.04	0.06	**0.27**	**0.31**
Node 3	0.01	0.13	**0.27**	0.04	0.03	**0.27**	0.30
Node 4	0.02	0.13	0.23	**0.09**	0.11	0.23	0.30
Node 5	0.02	0.13	0.23	**0.09**	**0.13**	0.23	0.30
Node 6	0.01	0.13	**0.27**	0.05	0.06	**0.27**	**0.31**
FPU CoG	0.05	0.03	0.08	0.01	0.01	0.08	0.1
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-2 DISTURBANCE IN THE ZSAT -DIRECTION RESPONSE IN THE YLOC DIRECTION

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total (mg)	Total 2 (mg)
Node 1	0.02	0.10	0.08	0.21	**0.29**	0.29	0.38
Node 2	0.02	0.15	0.10	0.11	0.22	0.22	0.31
Node 3	0.02	0.13	0.08	0.19	0.19	0.23	0.31
Node 4	0.02	0.08	0.12	0.20	0.20	0.25	0.35
Node 5	0.02	0.10	**0.17**	**0.25**	0.25	**0.31**	**0.44**
Node 6	0.02	**0.16**	0.07	0.09	0.09	0.18	0.22
FPU CoG	0.02	0.05	0.08	0.03	0.04	0.08	0.11
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-3 DISTURBANCE IN THE ZSAT -DIRECTION RESPONSE IN THE ZLOC DIRECTION

The disturbance is modeled as **a force in the X-direction** (perpendicular to the axis of the 4K cooler). The same disturbance characteristics are kept and the same computations are run.

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total (mg)	Total 2 (mg)
Node 1	0.15	0.10	0.03	0.13	**0.12**	0.16	**0.25**
Node 2	0.14	0.10	**0.04**	0.13	**0.12**	0.16	**0.25**
Node 3	**0.16**	0.09	0.03	0.12	0.08	**0.17**	0.24
Node 4	0.14	**0.11**	0.03	**0.14**	0.07	0.15	0.24
Node 5	0.14	**0.11**	0.03	**0.14**	0.06	0.15	0.23
Node 6	0.15	0.09	0.03	0.13	0.07	0.16	0.23
FPU CoG	**0.16**	0.03	0.01	0.03	0.03	**0.17**	0.17
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-4 DISTURBANCE IN THE XSAT -DIRECTION RESPONSE IN THE X DIRECTION

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total (mg)	Total 2 (mg)
Node 1	0.03	0.03	0.07	0.05	0.02	0.07	0.10
Node 2	0.03	0.03	0.07	0.05	0.03	0.08	0.10
Node 3	0.03	0.03	0.07	0.05	0.02	0.07	0.10
Node 4	0.03	0.03	0.07	**0.12**	**0.12**	0.12	0.18
Node 5	0.03	0.03	0.07	**0.12**	**0.12**	**0.13**	**0.19**
Node 6	0.03	0.03	0.07	0.04	0.04	0.08	0.10
FPU CoG	**0.09**	0.03	0.02	0.02	0.02	0.09	0.10
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-5 DISTURBANCE IN THE XSAT -DIRECTION RESPONSE IN THE Y DIRECTION

	H 1 (mg)	H 2 (mg)	H 3 (mg)	H 4 (mg)	H 5* (mg)	Total (mg)	Total 2 (mg)
Node 1	0.14	0.09	0.06	0.23	0.23	0.23	0.37
Node 2	**0.16**	0.05	0.08	0.23	0.23	0.25	0.38
Node 3	0.13	0.07	0.06	0.10	0.10	0.14	0.22
Node 4	0.03	0.26	0.05	**0.29**	**0.29**	**0.29**	0.49
Node 5	0.04	**0.27**	**0.09**	**0.29**	**0.29**	**0.29**	**0.50**
Node 6	0.12	0.04	0.06	0.10	0.10	0.13	0.20
FPU CoG	0.09	0.14	0.04	0.08	0.08	0.14	0.20
Specification	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1**	**1**

TABLE 8.2.3-6 DISTURBANCE IN THE XSAT -DIRECTION RESPONSE IN THE Z DIRECTION

* Note that for these harmonics, the various bandwidth considered for the calculation may be higher than 200Hz.

8.2.4 Conclusions

This analysis shows that the acceleration computed at the center of gravity of the FPU as well as at the 6 nodes located at the interface of the bipods and P-PLM are within the specifications. Tables 8.2.4-1 and 8.2.4-2 present a synthesis of the results.

	NODE 1	NODE 2	NODE 3	NODE 4	NODE 5	NODE 6	FPU COG
Total 1 X (mg/Margin)	0.22	**0.23**	0.17	0.19	0.16	0.14	0.04
Total 1 Y (mg/Margin)	**0.27**	**0.27**	**0.27**	0.23	0.23	0.27	0.08
Total 1 Z (mg/Margin)	0.29	0.22	0.23	0.25	**0.31**	0.18	0.08
Specification	**1**	**1**	**1**	**1**	**1**	**1**	**N/A**

TABLE 8.2.4-1 DISTURBANCE IN THE ZSAT DIRECTION

	NODE 1	NODE 2	NODE 3	NODE 4	NODE 5	NODE 6	FPU COG
Total 1 X (mg/Margin)	0.16	0.16	**0.17**	0.15	0.15	0.16	**0.17**
Total 1 Y (mg/Margin)	0.07	0.08	0.07	0.12	**0.13**	0.08	0.09
Total 1 Z (mg/Margin)	0.23	0.25	0.14	0.29	**0.29**	0.13	0.14
Specification	**1**	**1**	**1**	**1**	**1**	**1**	**N/A**

TABLE 8.2.4-2 DISTURBANCE IN THE XSAT DIRECTION

– The maximum ratio is 3.2 occurring in the Z-direction at interface node 5 (FPU local reference system, see Figure 8.2.2-2). For information considering a disturbance in the spacecraft X direction; the minimum margin would 3.4 occurring in the Z-direction at interface node 5 (FPU local reference system, see Figure 8.2.2-2).

For information Acceleration levels at the Center of Gravity of the FPU are close to those computed at the 6 interface nodes of the bipods with the P-PLM.

The FPU is also sensitive to a disturbance applied in the Spacecraft X-direction.

The analysis is conservative:

- the assumed disturbance is 40mN on the entire frequency band, which is the upper limit of the induced force,
- Structural damping is set o 0.05 %.

8.3 Thermal analyses

The thermal analyses at system level are gathered in the Thermal Analyses Report (RD04.2). In this chapter, we only summarise the main results related to some critical items:

- the thermal interface specifications of the Planck Sorption Cooler subsystem
- temperature results obtained on the Planck BEU/DAE control box.

8.3.1 Sorption Cooler Compressors thermal interfaces

All SVM thermal analyses have been performed using a simplified TMM of the Sorption Cooler (delivered by JPL, see RD01.1). This TMM was mandatory to evaluate with as much accuracy as possible the thermal dissipation as well as the induced temperature fluctuation of this equipment.

This model is made of:

- 6 thermal nodes for each inner beds (elements alternatively heated and cooled for adsorption/release of the Hydrogen working fluid)
- 6 thermal nodes for each outer shells (components in contact with the spacecraft, i.e. the heat pipes network).

Each inner bed is conductively connected to its associated outer shell by a variable conductance simulating the behaviour of the thermal switch between them. The outer shells are thermally linked to the heat pipes through a contact conductance, which value is provided by the Thermal Control subsystem responsible (Alenia) given the fixation layout as well as the type of thermal filler used. Finally, specific heat and internal dissipation are associated to each of the above thermal nodes to match with the electrical input power on one side, and physical behaviour of the system on the other side (heat generated by adsorption/desorption phenomena are taken into account).

At system level, we have used the simplified TMM to deduce and establish un-ambiguous thermal interfaces specifications towards LFI/JPL instrument team. All the results presented hereafter have been obtained coupling the above TMM to a single boundary node at 260 K (heat sink).

Interface Thermal Fluxes

One important point is that the peak thermal dissipation on the spacecraft depends on the thermal contact between the outer shells and the heat pipes. We have shown on the next figures the evolution of the total Sorption Compressor and single element peak dissipation, with contact conductance data ranging from 500 W/Km² (degraded contact) up to 10000 W/Km² (maximum contact achievable with solid interfiller with high overall contact pressure). The curves are related to 520 W input power, which correspond to a 470 W nominal consumption on which is applied 10 % system margin.

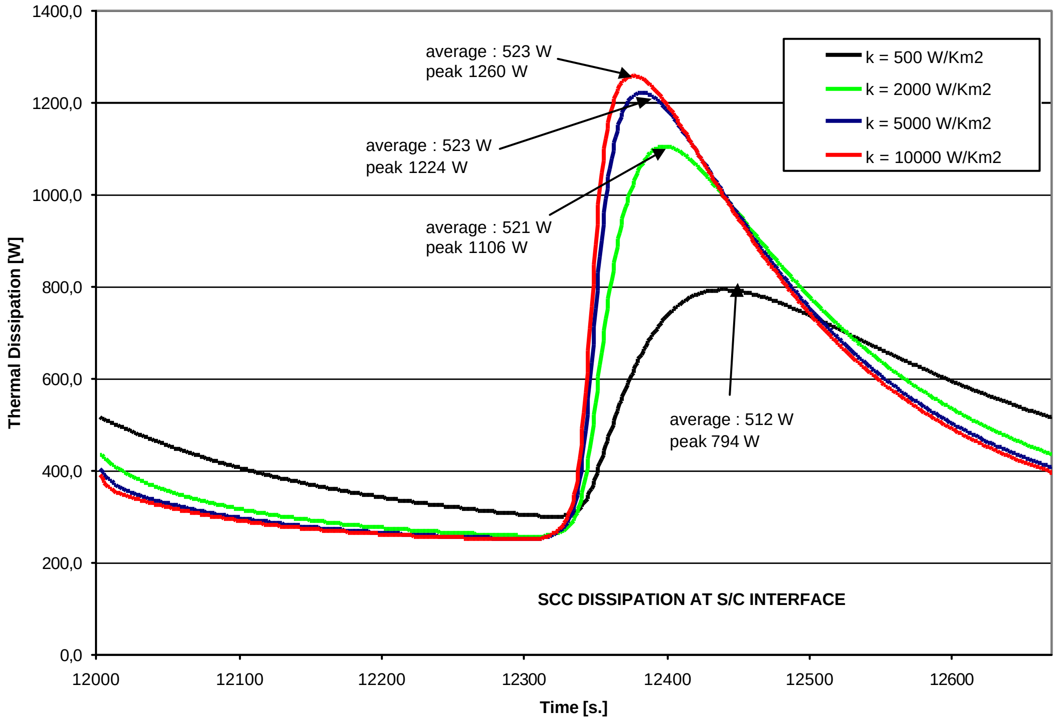


FIGURE 8.3.1-1 TOTAL SCC DISSIPATION AT S/C INTERFACE VS. CONTACT CONDUCTANCE

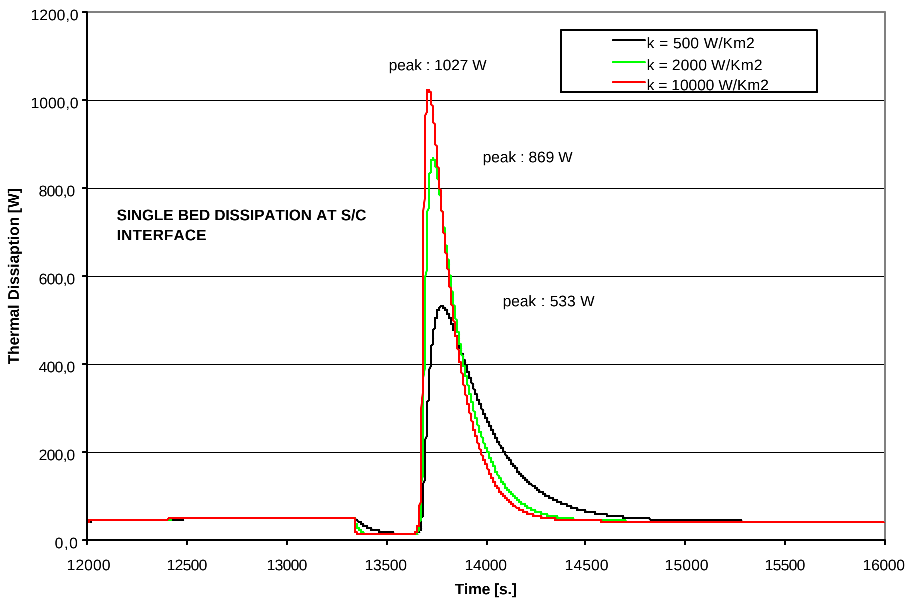


FIGURE 8.3.1-2 DISSIPATION UNDER A SINGLE ELEMENT VS. CONTACT CONDUCTANCE

The data reported on the previous issue of the Sorption Cooler ICD (annex of LFI IID-B Issue. 2.0) were 520 W average dissipation, and 1250 W total peak dissipation. In the present issue (AD04.6), the input electrical power has been reduced to 470 W maximum. We have therefore carried out the same exercise as described above, and deduced a maximum total peak dissipation of 1200 W. We have besides added a precision concerning the way JPL shall respect these requirements. It is asked to check the heat dissipation requirement with a maximum value of 10000 W/Km² for contact conductance, which ensure that the SCS will never exceed the specified data. Furthermore, the single element maximum allowable peak dissipation (1020 W) is now requested in order to stay below the power density sustainable by commercial heat pipes (~ 6 W/cm²).

Interface temperatures

The thermal interfaces of the SCC have been defined in agreement with all parties (ESA, ALCATEL, ALENIA and JPL) at spacecraft side of the interface outer shell/pipes. The temperature requirement at this interface is a [260 K, 280 K] range during adsorption phases.

If the thermal contact between the outer shells and the spacecraft is low, this will of course lead to a raise of the temperature of all the inner elements. If the outer shells temperature is higher than 282 K during adsorption, the straight impact is that the SCS cannot provide the requested temperature level inside the FPU. It has been therefore agreed with JPL to add a temperature gradient requirement between the outer shells and the spacecraft during the absorbing phase of each element. This gradient shall be lower than 2 K, which means a minimum value of the thermal conductance to be fulfilled.

The next table compiles the impact of the contact conductance on the temperature gradient. The specific data of 2000 W/Km² is the one used by the TCS responsible (ALENIA) for the thermal analyses. It is estimated conservative (actual data higher than 2000 W/Km² given the fixation layout). Alenia has carried out the same analyses with the overall SVM TMM, including the SCC reduced model. Results are gathered in Table 8.3.1-1.

Contact conductance (W/Km²)	ΔT SCC/Spacecraft (boundary node)	ΔT SCC/Spacecraft (ALENIA PDR results)
10000	0.2 K	
2000	1.4 K	~ 0.5 K
500	5.5 K	4 K

TABLE 8.3.1-1 SPACECRAFT/SCC THERMAL CONTACT INFLUENCE ON PERFORMANCES

From above results, it is mandatory to provide a high thermal contact between the Sorption Cooler Outer Shells and the heat pipes they are mounted on. The baseline solution allows fulfilling this requirement thanks to a very dense fixation layout.

Interface temperature fluctuations level

The JPL temperature fluctuation level requirements are still not accepted because non-achievable by the spacecraft. A sensitivity analyses has been performed in order to estimate the impact of the thermal conductance SCC/heat pipes already discussed above, on the level of the temperature oscillations under the elements.

For this computation, we have used the whole SVM TMM, provided by Alenia in February 2002 (Issue 0). The TMM has been updated in order to reflect the baseline heat pipes configuration, as described in the SVM design report (RD01.1). The computation is related to 520 W input power, which is the nominal value on which is applied the 10 % system margin mandatory to anticipate potential increase of the actual electrical consumption (therefore thermal dissipation).

REMARK: The data presented in table are not correct in term of absolute levels (Alenia has updated and refined the SVM TMM), but the results can be compared between each other.

K contact SCC / Heat Pipes (W/Km²)	500	ALS Nominal Data 2000	Maximum Data 10000	
T inner bed max	227 °C	225 °C	225 °C	
T outer shell max	59 °C	28,5 °C	16 °C	
T outer shell during adsorption	8 °C	5,5 °C	4,8 °C	
T I/F heat pipes max during adsorption	3,4 °C	4,3 °C	4,6 °C	**spec = [-13 °C , 7 °C]**
I/F heat pipes temperature stability under absorbing beds	± 0,35 °C	± 0,5 °C	± 0,6 °C	**spec max : ± 0,5 °C**

TABLE 8.3.1-2 SPACECRAFT/SCC THERMAL CONTACT IMPACT ON SCC TEMPERATURE FLUCTUATION (RTMM)

The above results are corroborated by Alenia outputs obtained with the overall SVM TMM developed for PDR analyses (see Table 8.3.1-3).

Contact conductance	500 W/Km²	2000 W/Km²	Requirements
T outer shell max (no T margin)	50° C	18° C	
T outer shell max during adsorption (no T margin)	2° C	- 1° C	[-11° C , 9° C]
T I/F pipes max during adsorption (no T margin)	-2° C	- 0.5° C	[-13° C , 7° C]
Temperature stability under adsorbing beds (no margin)	± 1.4° C	± 2.8° C	spec max: ± 0.5°C

TABLE 8.3.1-3 SPACECRAFT/SCC THERMAL CONTACT IMPACT ON SCC TEMPERATURE FLUCTUATION (SVM TMM)

Reducing the contact conductance do not allow to meet the requirements, with the major drawback of increasing the outer shell temperature during adsorption (temperature margin reduction).

8.3.2 LFI BEU/DAE warm unit

Thermal analysis results performed by ALENIA at SVM level show non-compliance of the BEU/DAE temperature with the specification as reported in the Instruments Interface documentation (AD04.5 and AD04.6). The hot case computed (w/o margin) temperature is 32.8° C for a design requirement at 28° C (57 W dissipation).

The BEU/DAE temperature requirement is linked to the maximum design temperature of specific components, which are the Back End Modules (BEM's). So far, the BEU/DAE supplier (Laben) has conceded no relaxation of the demand. We have therefore included the simplified TMM of the unit (provided by Laben) into the overall S/C TMM, in order to compute with better accuracy the unit temperature. The relevant analyses are described in the Thermal Analyses Report (RD04.2). The main results are gathered in the next table.

BEU/DAE Interface temperature	ALENIA PDR baseline configuration	S/C TMM 1 thermal node for BEU	S/C TMM + BEU RTMM
Temperature w/o margin	**33° C**	**25.5° C**	**25.8° C**

The results show that there is no difference in the computation of the BEU/DAE control box interface temperature using a single thermal node or a reduced TMM. This consequently confirms Alenia results for the PDR baseline configuration. The temperature difference between ALENIA TMM and S/C TMM is due the updating of the P-PLM sub-platform, which is no more a full plate for mass reduction purpose.

Adding 7°C margin on the computed temperature, the best the TCS can provide to the BEU/DAE control box is an interface temperature of 40° C.

REMARK: The margin includes additional temperature gradient between the BEU and the sub-platform, due to a mounting onto a shim (not taken into account in SVM analyses).

Let's note that it brings the BEM's temperature at a maximum of 44° C only, according to Laben detailed thermal analyses. There would be a possibility to decrease this level adding some radiative area located around the BEU. The drawback is an increase of the heat loads onto the first V-groove shield, which is not acceptable at the moment. Let's note also that Laben computations do not take into account the conductive losses from the BEM's to the wave-guides. It is mandatory that Laben perform refined local analyses to consider these "cooling" loads. The last point to be checked by Laben is the real thermal needs of the BEM's, which temperature should stay under 45°C margin included.

8.4 Radiation analyses

8.4.1 Purpose

This analysis permits to evaluate the equivalent satellite shielding provided by the whole structure and appendages in terms of equivalent aluminium thickness.

The Subcontractors shall add the standard satellite shielding specifications provided in [AD1] Radiation Requirements (REF-ASPI-CN-11-E, issue 1, 19/10/1999) (cubical aluminum box of 0.8 mm for equipment inside the spacecraft and 0.1/1.6 mm for equipment outside) to its equipment radiation model in order to demonstrate the compatibility of the parts with Planck mission.

This analysis shall demonstrate that shielding specified in [AD1] is verified for all Planck equipment.

This analysis also provides an estimation of the cumulated dose at the center of each electronic equipment.

8.4.2 Radiation environment

The space radiation environment is presented in paragraph 7.4.2.

8.4.3 Planck modeling

Planck satellite is performed with CATIA CAD tool using the following CATIA files in PLANCK_AMT directory:

- Planck equipment: ME.PLS.A11F.Z.010SA Index C
- Planck structure: ME.PLS.A120.Z.010SA Index C
- Planck propulsion: ME.PLS.A17M.Z.010SA Index A
- Planck instrument: ME.PLS.A200.Z.010SA Index D
- Planck Solar Array: ME.PLS.A16G.Z.010SA Index B.

The main structure thickness 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

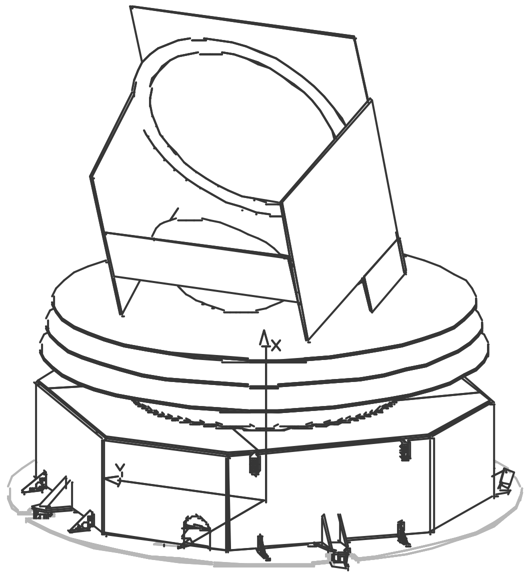


FIGURE 8.4.3-1 CATIA/NOVICE OF PLANCK SATELLITE

8.4.4 Shielding analysis and Deposited dose calculations

Ray tracing analysis have 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 Planck equipment, standard satellite shielding specifications in AD01 are verified.

For cumulated dose calculations (slant path), the target equipment is modeled as a 0.8mm thick aluminium 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
QRS	1.21	PAU	2.34
STARM. 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
TRANSPONDER	2.11	4K CEU	1.91
EPC	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

8.4.5 Conclusion

This analysis provides an estimation of the dose levels within Planck equipments and shows that no major issues are expected. The radiation levels for EEE parts are low and , even including a margin of 2, will be lower thant 10 krad(Si) which is the hardness threshold required for EEE parts selection.

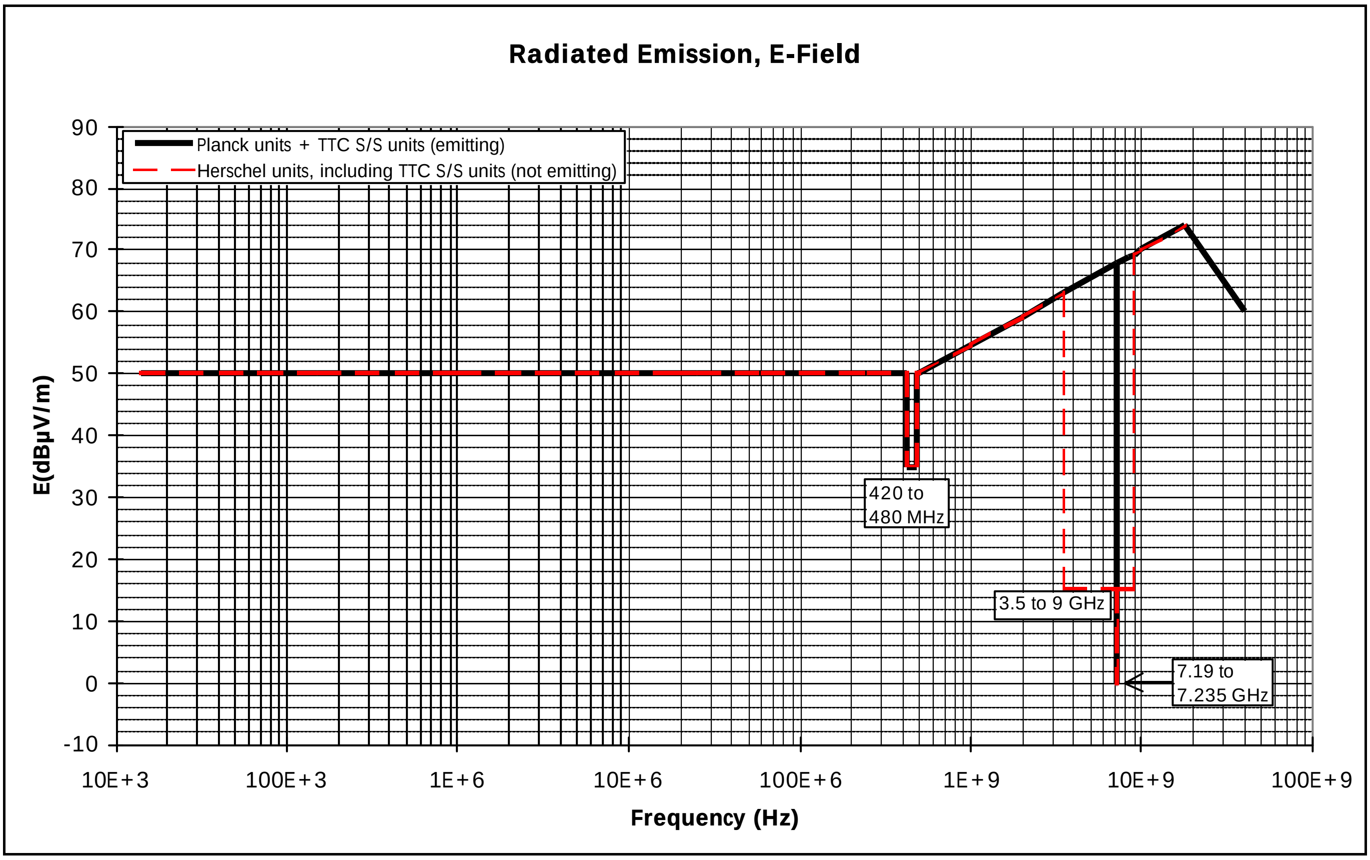
8.5 EMC analyses

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 that has been presented since the proposal 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).



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.

8.6 ESD analyses

The ESD analyses are presented in document RD04.5.

The various electrostatic environments met by Herschel and Planck satellites 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. 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, will be applied.

The ESD analysis document describes and justifies the rules used to minimize 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.

Planck satellite charging analysis is performed with the help of NASCAP software. Due to uncertainties of modelling and unknown input data, the results shall be considered preliminary. Nevertheless, if an anti-static paint is used on the PPLM baffle, the satellite charging shall be moderate.

8.7 Disturbance torques ON PLANCK

This section summarises the disturbing torques applied on Planck.

The external and internal torques are distinguished.

8.7.1 External disturbance torques on Planck

As far as gravity gradient, geo-magnetic disturbance torque, and aerodynamic torques are concerned, two phases can be considered:

- after separation, at low altitude: these toques can be significant, but are negligible with respect to the torques provided by the thrusters
- during transfer orbit and at L2: Herschel will benefit particularly quiet dynamic conditions, these torques become insignificant compared to major sources detailed hereafter.

Solar pressure transverse to Sun Vector

The Solar Pressure torque is rather reduced due to the Sun Pointing attitude and the well centred attitude.

Sun exposed Surface	13.85 m^2
Force = P × S × (Ca+2.Cs+4/3.Cd) typical SA coefficients: Ca=0.70, Cd=0.24, Cs=0.06	75 µN
Lever Arm = 30 mm (CoG shift from X axis) + sin(10°)*height of CoG	< 200 mm
Maximal Transverse torque	< 15 µNm

As the satellite is spinning the disturbance torque (30 mm × 75 µN = 2.25 µN.m) produced by the CoG shift from X axis will be averaged out on one rotation. The maximum temporary accumulation of momentum is torque/spin rate < 22 µN.m.s, which is negligible compared to the angular momentum due to the spin rate (about 200 Nms).

On the contrary, the lever arm due to the Sun aspect angle (SAA) creates an inertial torque that reaches 10 µN.m when the SAA is maximum (10°). Since this torque is contained in YZ plane, it creates a drift of the angular momentum, at the rate of:

- 10 µN.m / 200 N.m.s = 5 × 10-8 rad/s.

NOTE: The 10 µN is the component of the solar force in the Solar Array plane: 4.6 µPa × 13.85 m² × (Ca+Cd) × sin10° × cos10° (due to the directly absorbed solar flux, and the absorbed part of the diffuse reflection).

After an observation period of one hour, the angular momentum drift reaches 0.6 arcmin, contributing to 40 % of the relative pointing error.

Solar pressure windmill torque (along Sun Vector)

There may also be a constant windmill torque induced by asymmetrical optical properties of the SVM -X surface. For example, the Solar Array may be described as a patchwork of facets which are not perfectly aligned.

For the torque calculation, the assumption is made that each cell can have a misalignment of 1 degree, corresponding to an average flatness deviation of 1 mm for a 40 mm × 80 mm cell.

If all cells are all oriented with the worst orientation, i.e. all generating a torque around X in the same direction, each Solar Array elementary surface creates a density of lateral force of P = 2.2×10^{-8} N/m².

The induced torque around X is then:

- Tx = (2π/3) × R³ × P = 4.3×10^{-7} N.m

R being the radius of the Solar Array (2.1 m)

After an observation period of one hour, the maximum spin-up (or spin-down) produced by this torque is 8×10^{-6} rpm, contributing for 8% to the rate stability requirement (10^{-4} rpm over one hour).

Helium exhaust

The helium flow is described in HFI IID-B:

- 5 µmol/s of Helium 3
- 20 µmol/s of Helium 4.

The helium mass flow is then:

- 5 × 3 + 20 × 4 = **95 µg/s**.

A T-shape exhaust is accommodated on the –Y+Z panel, behind the DCCU. The two end branches of the T are nominally oriented parallel to the YZ plane.

The exhaust velocity of helium is given by HFI as the velocity of sound at 300 K, i.e. 1050 m/s. Assuming a hemispherical distribution of helium at the exhaust, the efficiency of the thrust is 1/2.

Each exhaust branch produces then nominally the following force:

- ½ × ½ × 1050 m/s × 95 µg/s = **25 µN.**

The SVM interface specification requires the SVM to be compatible with the following forces and torques, in order to be compatible with the rate stability requirement (10^{-4} rpm over one hour).

- **Force < 2 µN (maximum on any axis)**
- **Torque < 4 µN.m (maximum on any axis).**

This implies a maximum asymmetry of ±4 % in the two branches of the exhaust, since 2 µN = 25 µN × (54 % - 46 %). The 2 µN maximum force is reported in the IID-A.

Since the flow is very stable, the transverse forces and torques average out over one rotation, and the longitudinal force creates an orbit disturbance which is negligible with respect to the solar force (75 µN).

Thruster misalignments and repeatability

The following contributors are accounted:

Thrust level	10N (per thruster)
Thrust fluctuations	5 %
CoM migration along X	45 mm
CoM migration along Y	2 mm
CoM migration along Z	2 mm
Thrust misalignment	1 deg (half cone)

ALL 3 s ERRORS

This leads a maximum torque of 2.0 N.m, which is far below the control capacity (from 14 to 21 N.m according to thruster pair).

If the chosen thrusters are eventually 20-N, the ratio between the disturbance and the nominal force does not change.

A 6 % use of thrusters in ON-modulation is therefore accounted. More precise figures will be given when the thrusters are selected and the ACMS algorithms developed.

1-N thrusters are used in pulse mode only, and do not involve the use of other thrusters. They do not lead then to overconsumption.

8.7.2 Internal disturbance torques on Planck

Propellant sloshing

As the spacecraft is Spun around its maximum inertia axis, the fluids dynamics has a stabilisation effect on the spacecraft when no manoeuvres are performed.

However, the propellant moves between the tanks due to their difference of temperatures. This causes a variation of the inertia tensor, and then of the direction of the principal axis of inertia. This effect is described and quantified in RD03.18 (Impact of propellant tank temperatures on wobble angles).

Helium motion

The helium being gaseous, its effect is negligible with respect to propellant.