Title: **H-EPLM Design Description**

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Issue	Date	Sheet	Description of Change	Release
1	24.07.01	all	First issue of document	
2 Draft	11.06.02	All	Second issue (draft) for review	
2	14.06.02	All	PDR issue of document	
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4	15.02.05		**Updates as agreed in CDR RIDs:**	
		S.5.7.1, Table 8	RID 11153: Corrected timing of V504 and V505 closing in Table 8 to be consistent with Table 7.	
		All	RID 11319: Lower level design review output to H-EPLM Design Description	
		S.14.2	RID 11331: Remaining open points:	
			RID 11446, Item 1, 3 and 5:	
		S.3.3.3 etc	1) Telescope contamination temperature corrected to 50°C	
		S.5.11.1	3) Number of telescope struts in Table 12 corrected to be 6	
		S.13.1	5) Number of absorbers in Table 29 clarified	
			Updates "normal work":	
		§2	Document issues and revisions updated	
		§5.1	Solar cell type updated	
		§5.2	Clearance to Fairing: Reference to approved RFD added	
		§5.7.1	Valve opening linked to HOT evacuation	
		§6.2.1	Figure 34 updated for TEL temperature	
		§6.5	New figures for beam entrance configuration added	
		§12.5	Reference to anti-shroud deleted	
		§13.2	External MLI description updated, several new figures	
		§13.14.3	Several updates reflecting design evolution	
		§14.2	Open Points list updated to reflect current status	
		§14.2	Sub-Co review status updated to reflect current status (changes not tracked by sidebars)	

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1 Introduction

1.1 Scope

This design report describes the design, function and performance of the HERSCHEL Extended Payload Module (H-EPLM).

The H-EPLM is based on the design heritage of the ISO (Infrared Space Observatory, successfully flown in 1995 – 98), and on various studies performed under ESA contract. During the Phase B activities main emphasis has been laid on the consolidation of the design, verification of system requirements and the definition of the baseline. Trade-offs were performed where necessary.

The description is based on the documents given in the list of applicable documents.

In summary this design description contains a comprehensive description of the H-EPLM baseline design. Detailed description of the cryogenic subsystem, thermal design and structural behaviour are given in the specific technical reports.

1.2 Scientific Mission

As part of the ESA Science Programme “Horizon 2000” Herschel / Planck is a major project combining two scientific missions:

the Herschel (Far Infra-Red and Sub-millimetre Telescope) mission, being the fourth Cornerstone, and

the Planck survey mission (Mapping of Cosmic Background Radiation Anisotropy) being the third Medium mission of the ESA Horizon 2000 Programme.

The two spacecraft will be launched together with an Ariane 5 ECA launch vehicle into an orbit around the second Lagrangian point (Liberation Point) L2 for individual astronomical observations.

Infrared observations in the wavelength range of about 60 to 670 microns by three scientific Instruments are the objective of the Herschel mission. This infrared region is widely inaccessible from ground. The three scientific instruments are:

- HIFI (Heterodyne Instrument for Herschel) is a heterodyne detector with several frequency bands
- PACS (Photo-conductor Array Camera and Spectrometer) is a grating instrument with photo conducting detectors in the short wavelength bands and bolometers in the long wavelengths
- SPIRE (Spectral and Photometric Imaging Receiver) relies on bolometers, but uses Fourier Transformation for the spectral resolution.

These Instruments complement each other in their spectral resolution.

1.3 Definition of the Herschel Extended Payload Module

The Herschel Payload Module (H-EPLM) accommodates for the Herschel mission, the focal plane units (FPU's) of the three scientific instruments:

- HIFI (Heterodyne Instrument for Herschel),
- PACS (Photo-conductor Array Camera and Spectrometer),
- SPIRE (Spectral and Photometric Imaging Receiver)

The H-EPLM also accommodates the following (warm) payload equipment:

- The Local Oscillator Unit (LOU) of the HIFI Instrument
- The waveguides from the LFU located in the Herschel SVM to the EPLM HIFI LOU

The H-EPLM provides interfaces to

- The SVM and the Herschel Telescope.

The H-EPLM consists of:

- The Optical Bench Assembly (OBA), accommodating the instrument Focal Plane Units (FPU) on the Optical Bench Plate (OBP) and providing the mechanical interface to the FPU's. Additionally, the OBA provides the thermal connections of the FPU's and the baffling.
- A superfluid helium cryostat designed to mechanically support and to maintain the FPU's and optical subsystem within the cryogenic environment as specified in the IID's Part B.
- The H-EPLM / Herschel telescope interface structure for mounting the telescope on top of the cryostat.
- The H-EPLM thermal control to maintain all equipment temperatures within their thermal design limits.
- H-EPLM harness, including the science instrument harness as defined from the requirements in the IID's Part B.
- The Cryo Control Unit monitoring the Cryo Control System and performing actuation of valves.
- The Herschel Solar Array/Sunshade (HSS) protecting the Cryostat against the sun irradiation and accommodating the Solar Array (SA)
- The SVM shield protecting the Cryostat against SVM thermal radiative flux.

The superfluid helium cryostat consists of:

- Structural and insulation components featuring an outer vessel, a tank suspension system to minimise heat conduction from outer vessel to the cryogenically cooled elements (OBA and associated FPU's) and the adequate shielding and thermal insulation to minimise the heat radiation from the outer vessel.
- A helium subsystem to provide the adequate cryogenic temperature environment to FPU's. This passive cooling system features a main He tank (HTT), containing superfluid helium, a passive phase separator and the cryogenic components to

operate it. It also features an additional helium tank (HOT) designed to provide the required autonomy of the cryogenic system on the launcher.

- A cryo cover which closes the cryostat on ground and preserves the sensitive optical components inside the cryostat from contamination during the first weeks in orbit.

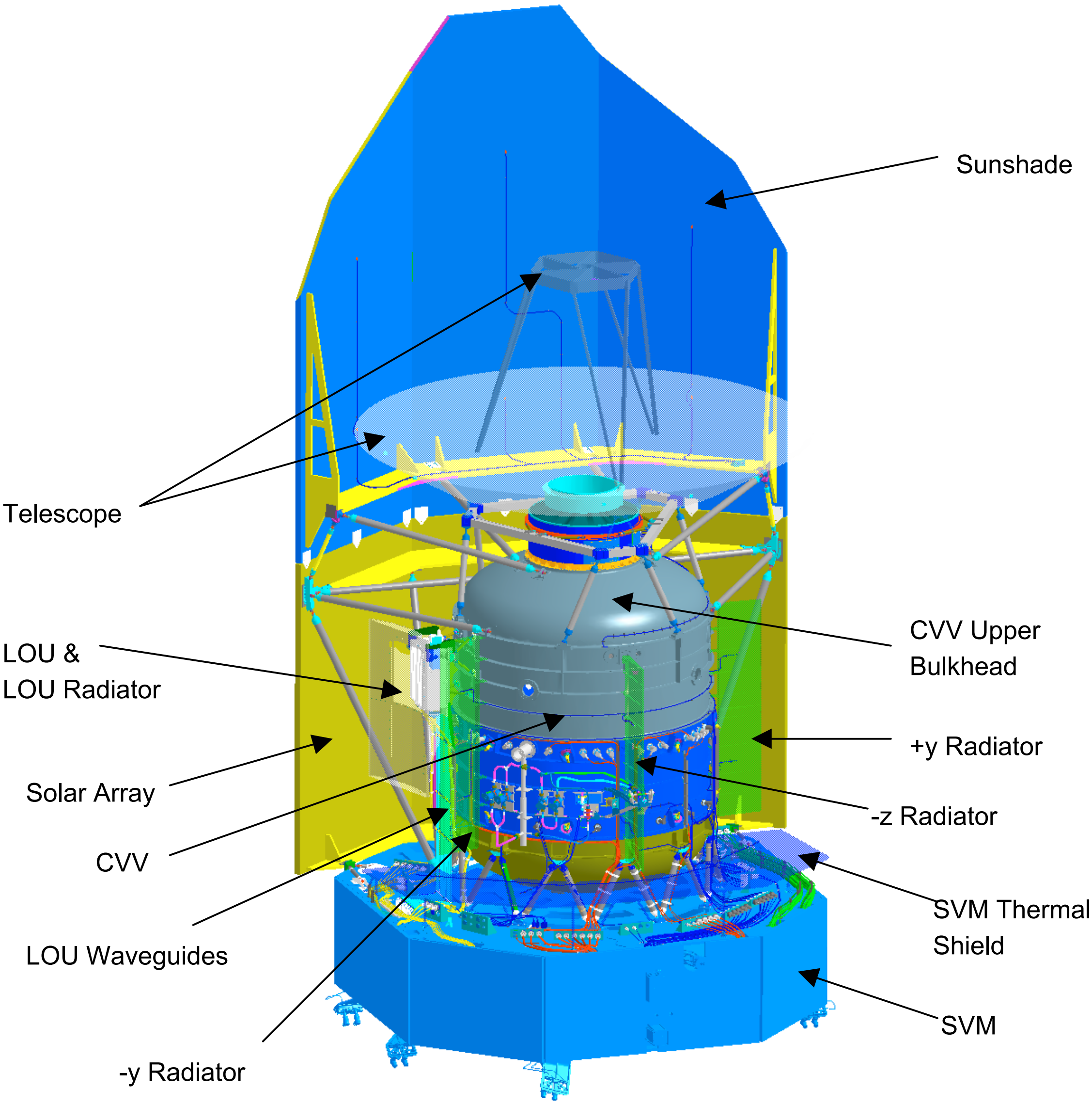


Figure 1: Herschel S/C (Extended Payload Module and SVM)

1.4 Model Philosophy

The Herschel program adopts a two model philosophy applying

- an EQM (Engineering Qualification Model)
- a PFM (Proto Flight Model)

The PFM will be launched into orbit after having run through the total qualification/acceptance sequence.

The EQM is derived from the existing ISO (the predecessor program of Herschel) - QM. It will be modified to allow advanced functional and EMC testing of the scientific instruments within the EQM cryostat. The EQM and its performance are described in Description of EQM, [RD1].

2 Documents and Abbreviations

2.1 Applicable Documents

[AD1] Herschel/Planck Instrument Interface Document, Part A, SCI-PT-IIDA-04624, Issue 3.3, 30.06.04

[AD2] Herschel/Planck Instrument Interface Document, Part B; Instrument “PACS”, SCI-PT-IIDB/PACS-02126, Issue 3,2, 02.03.2004

[AD3] Herschel/Planck Instrument Interface Document, Part B; Instrument “SPIRE”, SCI-PT-IIDB/SPIRE-02124, Issue 3.3, 21.06.2004

[AD4] Herschel/Planck Instrument Interface Document, Part B; Instrument “HIFI”, SCI-PT-IIDB/HIFI-02125, Issue 3,2, 05.03.2004

[AD5] H-EPLM Requirement Specification ;HP-ASPI-SP-0250; Issue 3.3, 20.10.2004

[AD6] Herschel EPLM Interface Specification; HP-2-ASPI-IS-0039; Issue 6.0, 07.10.2004

[AD7] H-EPLM Environmental and Test Requirements;HP-2-ASED-SP-0004; Issue 3.0, 16.07.2004

[AD8] General Design and Interface Requirements Specification, HP-1-ASPI-SP-0027, 5.0, 07.10.2004

[AD9] Environment & Test Requirements Specification, HP-1-ASPI-SP-0030, Issue 5.0, 07.10.2004

[AD10] EMC Requirements Specification, HP-1-ASPI-SP-0037, Issue 4.0

The IIDA and the IIDBs are applicable together with all agreed Change Requests.

2.2 Reference Documents

[RD1] Description of EQM, HP-2-ASED-RP-0028

[RD2] Documentation Identification Procedure, HP-2-ASED-PR-0001

[RD3] H-PLM Helium System Description, HP-2-ASED-RP-0034

[RD4] Herschel-Planck EMC Analyses, H-P-1-ASPI-AN-0202

[RD5] EMC Control and Verification Plan, HP-2-ASED-PL-0013

[RD6] HERSCHEL PLM Grounding Scheme", HP-2-ASED-DW-0001

[RD7] Alignment Method, Plan & Results, HP-2-ASED-TN-0097

[RD8] Herschel Straylight Calculation Results, HP-2-ASED-TN-0023

[RD9] Cryostat aperture size requirements including the effects of SPIRE HERSCHEL misalignments, SPIRE-RAL-NOT-001242, 18/04/02

[RD10] PACS stay out envelope, PACS-KT-ICD-0000W1, Sheet 8 of 9, Issue 27, 26/06/03

[RD11] ISO Payload Module Lessons Learned, ISO-GR-B1430.009

[RD12] Helium Subsystem Safety Analyses, HP-2-ASED-AN-0002

[RD13] Permeation Through CVV Sealings, HP-2-ASED-TN-0034

[RD14] Description of the PLM FM Cryo Control Instrumentation, HP-2-ASED-TN-0048

[RD15] Herschel Alignment Concept, HP-2-ASED-TN-0002

[RD16] Pitch and Roll Assessment, HP-2-ASED-TN-0080

[RD17] H-EPLM Electrical Interface Control Document PFM, HP-2-ASED-IC-0001

[RD18] H-EPLM Mechanical Interface Control Document PFM, HP-2-ASED-IC-0002

[RD19] Thermal analysis report, HP-2-ASED-RP-0011, issue 4, 15.04.04

[RD20] CRYO-HARNESS BRANCH CHARACTERISTICS, HP-2-ASED-TN-0085

[RD21] Cryo Harness Interconnection diagram - CCH, HP-2-ASED-ID-0088

[RD22] Cryo Harness Interconnection diagram - SIH HIFI, HP-2-ASED-ID-0090

[RD23] Cryo Harness Interconnection diagram - SIH SPIRE, HP-2-ASED-ID-0091

[RD24] Cryo Harness Interconnection diagram - SIH PACS, HP-2-ASED-ID-0089

[RD25] Herschel PLM EICD, HP-2-ASPI-ID-0621

[RD26] Herschel Electrical Interface Control Document (Telescope), HER.NT.0187.T.ASTR

[RD27] Hypotheses and Methods for Lifetime Calculation, HP-2-ASED-TN-0065

[RD28] Thermal Tests on H-EPLM Components and Samples, HP-2-ASED-RP-0095

[RD29] TSS Design Justification, HP-2-ASED-TN-0081

[RD30] Helium Control System Design, HP-2-ASED-TN-0013

[RD31] Stainless Steel Soldering Confidence Tests - Final Summary Report ´, HP-2-ASED-RP-0016

[RD32] Summary Report of performed ISO-NCR Reviews, HP-2-ASED-RP-0033

[RD33] FMECA, HP-2-ASED-RP-0031

[RD34] Qualification Program for EPLM Cryo Components, HP-2-ASED-PL-0024

[RD35] Critical Items List, HP-2-ASED-LI-0008

[RD36] Herschel CVV Interface Specification, HP-2-APCO-IS-0001

[RD37] Herschel CVV Structural Analysis Report, HP-2-APCO-TN-0001

[RD38] Herschel EPLM Structural Analysis Report, HP-2-ASED-TN-0049

[RD39] Herschel Stress Analysis Summary Report, HP-2-ASED-RP-0113

[RD40] Mechanical Qualification and Properties of Procurement Items, HP-2-ASED-RP-0112

[RD41] HEPLM FE Model Description - FE Model, HP-2-ASED-TN-025

[RD42] Handling and Transportation during Qualification Test Phase Technical Note, HP-2-ASED-TN-0024

[RD43] Facility and Transportation Plan, HP-2-ASED-PL-0014

[RD44] CVSE Set-up Description, HP-2-ASED-TN-0094

[RD45] Cryo Harness Description, HP-2-ASED-TN-0103

[RD46] H-EPLM Thermal Distortion Analysis - FE Model Description and Results, HP-2-ASED-TN-0046

[RD47] Evaluation of Calorimeter Tests for Herschel Internal MLI, HP-2-ASED-TN-0083

[RD48] J. Doenecke: Survey and Evaluation of Multilayer Insulation Heat Transfer Measurement, ICES July 1993

[RD49] Evaluation of LINDE/ESTEC-MLI Measurements and Transformation to the ISO Cryostat MLI Design, Doc. No.: ISO.TN-B1430.007, dated 12.07.88

[RD50] RfD / RfW Status List, HP-2-ASED-LI-0016

[RD51] Herschel Satellite AIT Plan, Part 1: EPLM & S/C Qualification Phase, HP-2-ASED-PL-0025

[RD52] Herschel Satellite AIT Plan, Part 2: EPLM & S/C Acceptance Phase, HP-2-ASED-PL-0026

[RD53] Barbecue Thermal Analyses, HP-2-ASED-TN-0112

[RD54] Thermal Hot Spots on Sunshade, HP-2-ASED-TN-0108

2.3 Abbreviations

The list of abbreviation is covered in the [RD2].

3 H-EPLM Major Requirements

3.1 System/Mission Requirements

In this section relevant design drivers are identified. Furthermore, key derived requirements are included.

3.1.1 H EPLM Overall Functional and Performance Requirements

The following functional and performance requirements apply:

- The H-EPLM shall provide a suitable environment for instrument operation as defined in the IIDBs, [AD2], [AD3] and [AD4]. Details are provided in the next section.
- Provide the optical interface between the FPU's, and the telescope.
- For the Herschel missions the spacecraft shall have a nominal lifetime of 3.5 years from launch till the end of the mission taking into account launch delay of 25 hours. This duration includes the transfer of 6 months to the L2 Lissajous orbit.
- The lifetime of items which degrade with time or usage shall be designed for 6 years
- To provide the low temperature environment for FPU's, a cryostat with an open He cooling system shall be implemented with a He II bath temperature of less than 1.7 K.
- The H-PLM environment together with the sun irradiance in L2 shall allow keeping the telescope in a temperature range of 70 K - 90 K.
- During operation conditions the sun aspect angle of ±30° around the y axis and ± 1° around x axis shall be possible

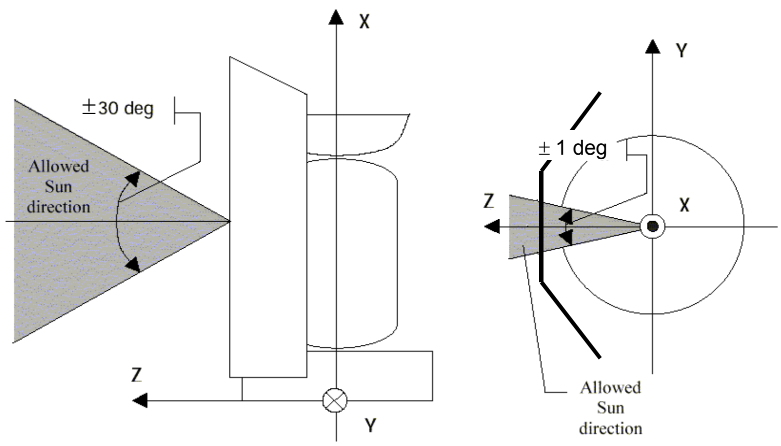


Figure 2: Solar Aspect Angels on H-EPLM at L2

3.1.2 Operational Requirements

The Herschel EPLM shall be designed to support all operations namely

- ground operations, as are AIT (Assembly, Integration, Test) and Launch campaign
- launch/flight operations

A reference to the basic launch/flight operations requirements applicable to the Herschel EPLM in the various operations phases are provided in the following subsections.

3.1.2.1 Ground Operations

A summary description of the AIT related ground operations is covered in Section 12.

3.1.2.2 Pre-launch/Launch Phase Operations

The pre-launch operations start six to eight weeks prior to launch. Activities in this phase encompass the final simulations and data flow tests, including the Dress Rehearsal and the final Mission Readiness Tests. The pre-launch phase ends at launcher lift-off. The launch phase encompasses the whole launcher flight from lift-off up to spacecraft separation from launcher.

The requirements applicable during the pre-launch and launch phase are covered in [AD5].

3.1.2.3 Initial Orbit Phase

The Initial Orbit Phase (IOP) operations will start after separation from the launcher with initial Sun acquisition and transition from battery to solar power.

All operations defined in the IOP timeline will be undertaken in order to:

- establish the spacecraft health post launch
- configure the spacecraft for subsequent IOP operations
- check-out the spacecraft subsystems
- acquire attitude
- perform the necessary attitude manoeuvres and orbit corrections.
- Start telescope decontamination heating phase

In addition, the standard monitoring and control activities will be performed. Following verification of the correctness of the orbit manoeuvre the IOP will end.

The requirements applicable during the initial orbit phase are covered in [AD5].

3.1.2.4 Commissioning Phase

After completion of the IOP when the spacecraft is in its transfer orbit towards L2, the commissioning phase will start. The activities in this phase include the complete check-out of spacecraft functions and verification of all subsystems performance. During this phase the commissioning of the Herschel payloads may be started.

The cryo cover opening will occur during the telescope cool-down after the end of telescope decontamination heating.

The requirements applicable during the Commissioning Phase are covered in [AD5].

3.1.2.5 Performance Verification and Routine Operations Phase

The performance verification phase starts after successful completion of commissioning activities.

After the Performance Verification Phase has been completed, the Routine Operations Phase will begin.

No specific additional requirements are applicable to the H-EPLM for these phases.

3.1.3 Physical Requirements

- The mass of the H-EPLM under ASED responsibility shall not exceed 1825 kg
- The nominal position of the H-EPLM Centre of Gravity (CoG) shall be located:
    - in the range of 0 to –40 mm on Y axis
    - in the range of 0 to + 70 mm on Z axis
- The H-EPLM shall fit under the Ariane 5 fairing as defined in [AD6]
- Provide an unvignetted field of view for the Telescope

3.1.4 Electrical (Harness / Waveguides/ Bus) Interfaces

The following electrical interfaces to the SVM exist:

- CCU interface to SVM (power, Mil-Std 1553 B bus and 4 Ariane-5 dry loop commands)
- E-PLM cryo control harness
- Telescope heater and thermistor harness
- Scientific Instrument harness (SIH) I/Fs between cold units and instrument warm boxes arranged in the SVM
- Waveguides between LOU and LSU in the SVM

3.1.5 Power

The HERSCHEL solar array shall deliver the electrical power for the Herschel spacecraft as defined in the following table:

- Minimum Begin Of Life power 1700 Watts
- Minimum End Of Life power 1400 Watts
  Nominal mission life time = 3.5 years
- Minimum End of Life power 1230 W (no margin)
  Extended mission life time = 6 years
  (reduction to 4.5 years under discussion)
- Voltage at the SVM I/F connector 30 Volts

The power values include a margin of 10% already.

3.1.6 Mechanical Requirements

The H-EPLM shall achieve the following natural frequency requirements:

- Lateral frequency (H-EPLM on SVM) > 13 Hz
- Longitudinal frequency (H-EPLM on SVM) > 34 Hz, with a target of 35 Hz

considering H-EPLM mounted on the SVM FEM.

Solar Array/Sunshade shall achieve the following frequency requirements in hard mounted conditions

- First lateral mode (in Y and Z) > 24 Hz
- First longitudinal mode (X) > 70 Hz.

The Telescope and mounting structure shall achieve in hard mounted conditions

- First mode > 36 Hz.

3.1.7 Thermal Environment

Ground and Pre-Launch Phase:

The He filled PLM is in a temperature controlled environment at 22±3°C [AD7].

Early Orbit Phase:

The thermal loads to be applied for the H-EPLM during the launch and early orbit phase are defined in detail in [AD7].

The solar aspect angle during launch can be derived from Figure 3 and shows two barbecue modes, one after fairing jettison and the other after upper stage separation from the launcher.

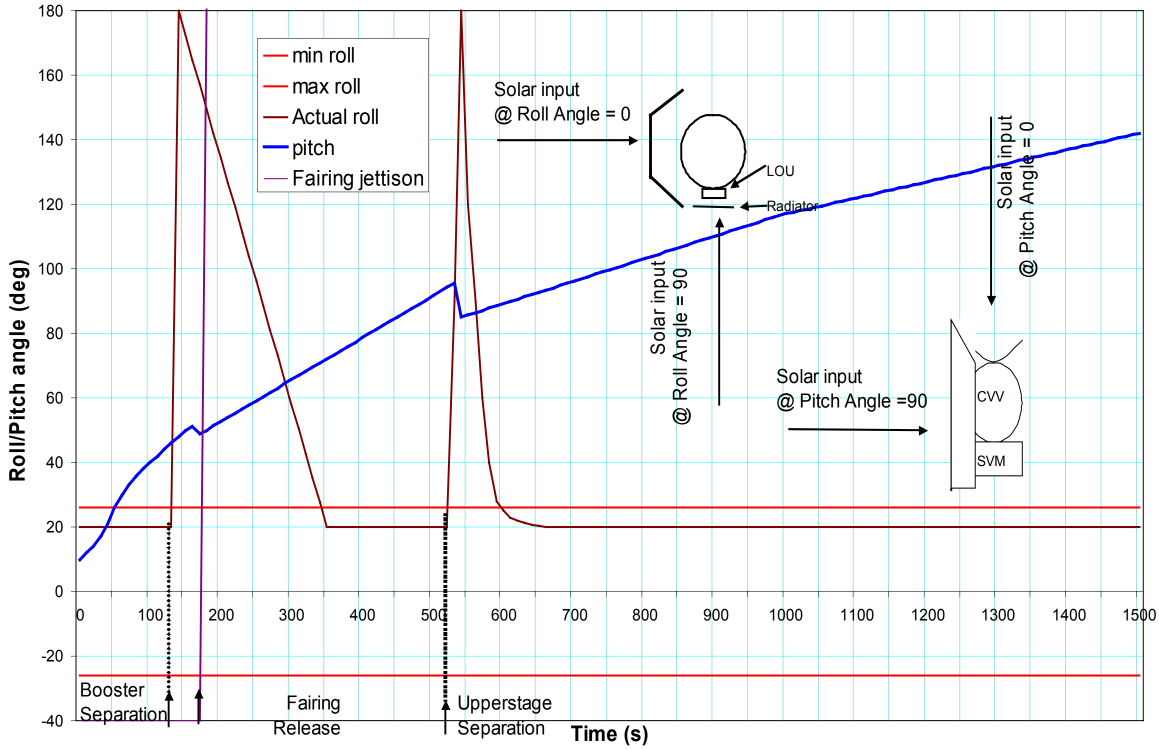


Figure 3: Roll and pitch angle evolution during launch

The applicable values of the solar constant for the early orbit phase (BOL) are:

- 1425 W/m² during Winter Solstice (WS)
- 1325 W/m² during Summer Solstice (SS)

Albedo is the fraction of incident solar radiation that is reflected from the earth back into space. A value of 0.3 $\pm$ 0.05 shall be used.

The Earth infrared radiation shall be assumed to be that of a black body with a characteristic temperature of 288 K. The average infrared radiation, emitted by Earth, is 230 W/m^2, with variations between 150 W/m² and 350 W/m².

Thermal Environment at L2

During on-orbit operation at L2 the extremes of solar constant are:

- 1405 W/m² during Winter Solstice (WS)
- 1287 W/m² during Summer Solstice (SS).

The temperature of the H-EPLM structure attachment points on the SVM is to be considered at 293 K and the temperature of the SVM top MLI to be at 230 K [AD7].

3.2 Margin Philosophy

Design margins are necessary to cope with the uncertainties during the design phase of the project and to provide a buffer for the operational phase of the satellite. The margins are controlled by ASED and not by the subsystem and unit supplier, to provide sufficient flexibility.

3.2.1 Mission Life Margin Requirements

The cryostat and its internal insulation shall meet the specified nominal lifetime and temperature requirements given in the IIDA. The amount of cryogen shall be sized accordingly and shall include a margin of 15 %.

3.2.2 Mass Margin

The maximum mass of the H-EPLM shall be computed using the following margins for H-EPLM elements

- 9% for elements which have passed PDR
- 5% for elements which have passed CDR
- 2 % for weighed elements.

3.2.3 Structural Design Margin Requirements

The structure design margin requirements are summarised in Table 1.

Item	Yield SF	Ultimate SF	Buckling SF
Conventional metallic material	1.1	1.5	2.0 [1])
Unconventional materials	1.4	2.0	2.0
Inserts and Joints	1.5	2.0	N/A

[1]) 1.5 in combination with non-linear buckling analysis

If the structural integrity can not be demonstrated by test for practical reasons, use of unconventional material is not allowed and an additional safety factor of 1.5 shall apply.

In case of protoflight approach, the various MOS shall be greater than 20% (not applicable for buckling)

Table 1: Structure Design Margin Requirements

3.3 Scientific Instruments Requirements

3.3.1 General

The HERSCHEL payload consists of three instruments. The HERSCHEL Payload Module will accommodate the cold HERSCHEL instruments, which are the:

- SPIRE FPU, Photometer and Spectrometer JFET units, inside the cryostat
- PACS FPU and HIFI FPU inside the cryostat
- HIFI LOU on the outside of the cryostat

The warm electronics of the instruments are arranged in the HERSCHEL SVM.

The spacecraft performances, capabilities and requirements imposed on the instruments are described in the IIDA [AD1]. Instrument requirements on the HERSCHEL spacecraft and the instrument capabilities and performances are described in the IIDBs ([AD2], [AD3] and [AD4]) of the SPIRE, PACS and HIFI instruments.

3.3.2 Mechanical/Configuration

3.3.2.1 Focal Plane Units (FPU's)

The Optical Bench Plate (OBP) accommodates three Focal Plane Units (FPUs) and two JFET boxes with a total mass of 176 kg. The required allocation on the OBP is specified in the IID-Bs, i.e. [AD2], [AD3] and [AD4].

The instrument fixations are specified in the IIDB's. The number of fixation points is for PACS 3, for HIFI 4 and for SPIRE 3. All related holes on the Optical Bench are fixed. There will be no provisions for compensation of thermal displacements on the EPLM side.

The detailed allocations for the instrument FPU masses and dimensions are specified in the IIDB's.

3.3.2.2 CVV Externally Mounted Units

The HIFI LOU has outer dimensions of 556 x 439.3 x 179 mm and an allocated mass of 31 kg. The nominal mass as per the IIDB is 42kg (excluding LOU radiator). The LOU interfaces with the spacecraft via a specific mounting structure, which shall also carry the LOU radiator. The LOU mounting structure forms part of the thermal path between LOU and LOU radiator.

The LOU radiator and its supports/thermal links will be provided by the instrument. The following physical data are the current baseline, i.e. dimensions: 1253 x 711.5 x 439.6mm and a mass of 6.0kg (allocated), 6.9kg (nominal).

Between the LOU and the LSU, which is allocated in the SVM, a waveguide connection exists. This waveguide assembly will be provided by ASED and consists of 14 lines. Due to thermal reasons it is made from stainless steel. The waveguides are mechanically fixed on the CVV and SVM via dedicated supports. The support design has to take into account the (different) thermal shrinkage of the waveguides and the CVV as well as the required thermal isolation of the waveguides from the CVV.

The LOU mounting structure provides an interface to two alignment cameras during on-ground testing.

3.3.2.3 SVM Mounted Units

The HERSCHEL S/C Prime is responsible for the mechanical requirements of warm instrument boxes.

3.3.3 Thermal Requirements

The instrument FPU's require three different temperature levels. A fourth temperature level is required for the SPIRE JFETs. The required operating temperatures per instrument are summarised in the following tables and are based on the IIDBs for PACS [AD2], SPIRE [AD3] and HIFI [AD4]. These temperatures shall be provided by the HERSCHEL cryostat cooling system.

The temperatures of the LOU, which is mounted outside on the CVV, are listed in Table 5. The LOU is thermally de-coupled from the CVV by GFRP struts. The thermal control of the LOU is performed via a dedicated radiator. The responsibility of the LOU thermal control has been passed to the instrument contractor.

Instrument Interface	Temp. Level	TMM Node	Operating		Heat Load
PACS			Min.[K]	Max.[K]	[mW]
Red Detector	L0	721	1.6	1.75	0.8
Blue Detector	L0	723	1.6	2.0	2.0
Cooler Pump	L0	761	1.6	10 5	500 (peak) 2
Cooler Evaporator	L0	762	1.6	1.85	15
Optics/Structure assy.	L1	781 782 783	2.0	5.0	30
HOB Interface	L2			12	0

Table 2: PACS Temperature Requirements

Instrument Interface	Temp. Level	TMM Node	Operating		Heat Load
SPIRE			Min.[K]	Max.[K]	[mW]
Detector Enclosure	L0	814	0	2.0 1.71 (goal)	4.0 1.0 (goal)
Cooler Pump	L0	815	0	10 2	500 (peak) 2
Cooler	L0	816	0	1.85	15

Instrument Interface	Temp. Level	TMM Node	Operating		Heat Load
SPIRE			Min.[K]	Max.[K]	[mW]
Evaporator				1.75 (goal)	15 (goal)
SPIRE OB units	L1	800 830	0	5.5 3.7 (goal)	15 13 (goal)
HOB Interface	L2			12 8 (goal)	0 0 (goal)
Instrument Shield	L2			16	0
PM-JFETs	L3	831		15	50
SM-JFET	L3	832		15	25

Table 3: SPIRE Temperature Requirements

Instrument Interface	Temp. Level	TMM Node	Operating		Heat Load
HIFI			Min.(K)	Max.(K)	[mW]
L0 boundary	L0	949	0	2	6.8
L1 boundary	L1	939	0	6	15.5
FPU structure	L2	910	0	20	22

Table 4: HIFI Temperature Requirements

Instrument Interface	Thermal node No.	Operating		Functional testing	Start-up	Switch-off
		Min.(K)	Max.(K)	Max.(K)	Max.(K)	Max.(K)
LOU	4200	90	150	298	80	303

Table 5: LOU Temperature requirements

The temperature stability requirement for LOU Waveguides is 0.3 mK per sec.

For the HERSCHEL Telescope, the following requirements exist [AD1]:

- Telescope: 70 K to 90 K
- Telescope decontamination during early orbit phase: 50°C for a duration of 3 weeks

The required temperatures are achieved by specific thermal connections:

SPIRE:

SPIRE requires 4 separate Level 0 interfaces and two Level 1 interfaces:

Level 0

- two I/F for the ^{3}He cooler evaporator (i.e. one open and one rigid pod)
- one I/F for the ^{3}He cooler pump
- one I/F for the Spectrometer detector enclosure

Level 1

- Two strap I/F for the FPU structure

The attachment points of the pump and evaporator cooling straps need to be separated on the He II tank structure..

Further SPIRE consists of two JFET boxes, mounted on the optical bench next to the FPU. The JFET amplifiers are thermally insulated from the Herschel Optical Bench Plate.

PACS:

PACS requires 5 separate Level 0 interfaces and three Level 1 strap interfaces, i.e.:

Level 0

- two I/F for the ^{3}He cooler evaporator (the single provided flex link is connected to both, the open and the rigid pod)
- one I/F for the ^{3}He cooler pump
- one I/F for the Red Detector of the FPU
- one I/F for the Blue Detector of the FPU

Level 1

- for the FPU structure (photometer optics)
- for the FPU structure (collimator)
- for the FPU structure (spectrometer housing)

Also the PACS FPU is equipped with a ^{3}He sorption cooler which requires recycling every 48 hours. During Herschel cryostat warm-up or cool-down phases, the rate of temperature change shall not exceed 20 K/hour above 30 K.

HIFI:

HIFI requires one Level 0 and one Level 1 strap interface, i.e.:

Level 0

- for the internal FPU structure (detector)

Level 1

- For the FPU structure (housing)

Furthermore, the following temperature stability requirements apply for HIFI:

- Level 0: 6 mK/100sec
- Level 1: 6 mK/100sec

- Level 2: 15 mK/100sec

It has to be noted that the cryostat itself produces a very stable mass flow rate so that the temperature stability is practically only influenced by the instruments internal dissipation changes.

3.3.4 Electrical /EMC Requirements

Electrical Requirements

Specific requirements exist for the instrument, i.e.

SPIRE FPU/JFETs:

SPIRE requires a specific cable design consisting of 4 twisted triples, each triple being isolated.

PACS FPU:

PACS requires specific low capacitive lines for the FPU cryo read-out electronic, which are realised by so-called triax cables, i.e. a coax with a second outer shield.

HIFI FPU:

HIFI requires for the FPU measurement signals 4 coax lines with low attenuation which needs a specifically manufactured cryo compatible semi-rigid coax cable (copper plated stainless steel inner and outer conductor).

CVV Externally Mounted Units:

HIFI LOU:

See chapter 5.8. The LOU needs several low resistance/high current lines (50 mOhm /1.5 A) for its amplifiers which can only be realised with copper harness. In consequence, an respectively higher thermal load on the LOU from the SVM has to be taken into account.

EMC Requirements

A summary of the most relevant EMC requirements applicable to the HERSCHEL PLM equipment is listed below.

Requirement	Short Description
Harness Design	a) Harness of different categories to be separated incl. I/F connector b) Where possible separate bundles shall be used for redundant lines c) Twisted wires shall use adjacent pins on connectors/receptacles

In addition o the above requirements, there are some general design guidelines to follow in order to minimise electromagnetic emissions and harden susceptible functions against EMI, both with minor effort and impact on instruments and PLM budgets.

Guideline	Short Description
EMC Design Guidelines	a) Separate signal and primary power ground b) Adopt star point concept on S/C c) Use EMI filters d) Isolate detector housings and electronic boxes from electrical signals e) Use twisted shielded cables for the interconnect harness f) Use good and reliable bonding provisions g) Select power converter frequency outside detector bandwidth h) Synchronise power converters i) Local >10 Oe DC magnetic fields to be avoided or compensated and the use of soft magnetic materials shall be avoided as far as practicable

3.3.5 Alignment / Optical

3.3.5.1 Summary of Alignment Requirements

The below referenced requirements are extracted from [AD5].

Focus Alignment (HERS-1220)

The absolute in-orbit focus alignment distance between telescope focus and each scientific instrument shall be less than:

Instrument	Absolute alignment requirement
PACS	± 7.0mm
SPIRE	± 7.7mm
HIFI	± 8.5mm

Pupil Mismatch (HERS-1230)

The absolute in-orbit pupil lateral mismatch in telescope M2 plane shall be lower than:

Instrument	Absolute alignment requirement
PACS	± 7.0mm
SPIRE	± 9.5mm
HIFI	± 24mm

LOU w.r.t. to HIFI FPU Alignment Requirements

The alignment and stability requirements for the LOU w.r.t. the HIFI FPU have been taken from the document [AD4]

Alignment Requirements for LOU w.r.t. HIFI FPU (HERS-1250)

Δx	Δy	Δz	Rx	Ry	Rz
±0.75mm	±15mm	±0.75mm	±0.038deg	1)	±0.038deg

1) The rotation error Ry will cause a lateral misalignment in x direction of z*sin(Ry).
The Δx value includes already offsets due to any rotation Ry.

It is assumed that the HIFI and LOU internal alignment error does not contribute to this budget TBC by HIFI.

The LOU rotations Rx, Ry, Rz are about the cryostat window.

Stability Requirements for LOU w.r.t. HIFI FPU (HERS-1250)

Δx	Δy	Δz	Rx	Ry	Rz
±0.075mm/ 100 s	±0.003mm/ 100 s	±0.075mm/ 100 s	±0.003deg/ 100 s	±0.04deg/ 100 s	±0.003deg/ 100 s

The very high stability along the y axis should be regarded as a goal, which may be verified by analysis.

Requirements related to System Pointing Performance

The following requirements are derived from System Pointing Performance needs and include the contribution of Telescope (I/F w.r.t. CVV) and CVV.

PACS LOS Bias (HERS-0640)

The alignment bias of PACS Line of Sight with regard to the PLM-SVM interface frame shall be lower than ± 5arcmin (including ground and in-orbit effects)

Around-LOS Bias (HERS-0645)

The maximum around-LOS alignment bias of each instrument with regard to PLM-SVM interface shall not exceed 12arcmin (including on-ground positioning accuracy, thermoelastic behaviour)

SPIRE and HIFI LOS w.r.t. PACS LOS (HERS-0650)

SPIRE and HIFI in-orbit LOS shall be known with regard to PACS LOS with an accuracy better than ± 3.6 arcsec (TBC) (including on-ground alignment knowledge, in-orbit stability knowledge).

This requirement is related to the in-orbit knowledge accuracy of SPIRE (resp. HIFI) cubes w.r.t. the PACS FPU cube. It includes:

- On-ground relative position knowledge accuracy (y-z plane)
- In-orbit relative stability knowledge during cool-down (y-z plane)
- In-orbit thermoelastic behaviour (y-z plane)
- The relation between the yz instrument relative position knowledge and relative in-orbit LOS is the worst case focal length of the telescope.

Around LOS Knowledge (HERS 0660)

The around LOS alignment of each instrument with regard to the PLM-SVM interface frame shall be known with an accuracy better than ± 0.5arcmin at 68% confidence level (including on-ground alignment knowledge, in-orbit stability knowledge).

Instrument LOS w.r.t. CVV/STR Stability (HERS-0700 b)

During observation phase, the alignment stability of the instruments LOS w.r.t. the CVV/STR assembly interface plane shall be better than:

- • 0.4 arcsec peak/peak around y (0.25 arcsec goal) over 1 month
- • 0.2 arcsec peak/peak around z (0.1 arcsec goal) over 1 month
- • ± 0.1 arcsec on 1 minute (± 0.02 arcsec goal) around each axis

taking into account worst case sun aspect angle variation. The CVV/STR assembly is assumed to be perfect.

The stability analysis shall be budgeted according to contributions as specified.

Alignment Stability between CVV/STR I/F and SVM/PLM I/F between Lift-Off and Operational Mission (HERS-0702)

The alignment stability between the CVV/STR assembly interface plane and the SVM/PLM interface plane shall be better than 30 arcsec peak/peak around each axis. This includes all events between lift-off and operational mission (launch effects, cool-down effects,...).

Alignment Stability between CVV/STR I/F and SVM/PLM I/F during Observation Phase (HERS-0704)

During observation phase, the alignment stability between the CVV/STR assembly interface plane and the SVM/PLM interface plane shall be better than 6 arcsec peak/peak around each axis over one month taking into account worst case sun aspect angle variation and temperature gradient at SVM/PLM interface.

3.3.5.2 Optical Requirements

The optical interfaces are controlled via a set of mechanical interfaces defined w.r.t. H-EPLM co-ordinates. The focal plane units shall be mechanically mounted to the Herschel optical bench. This optical bench is aligned to the telescope in accordance with alignment requirements, identified in the previous section.

SPIRE FPU:

The cryostat and baffle structure shall be compatible with the SPIRE beam as defined in [RD9].

PACS FPU:

The cryostat and baffle structure shall be compatible with the PACS stay out envelope defined in [RD10].

HIFI FPU:

Optical Requirements:

The part of the telescope beam which HIFI uses the centre with extension to the –y-side. The following figure from the IID B shows the envelope at the cryostat opening (453 mm above focus = level of CVV aperture).

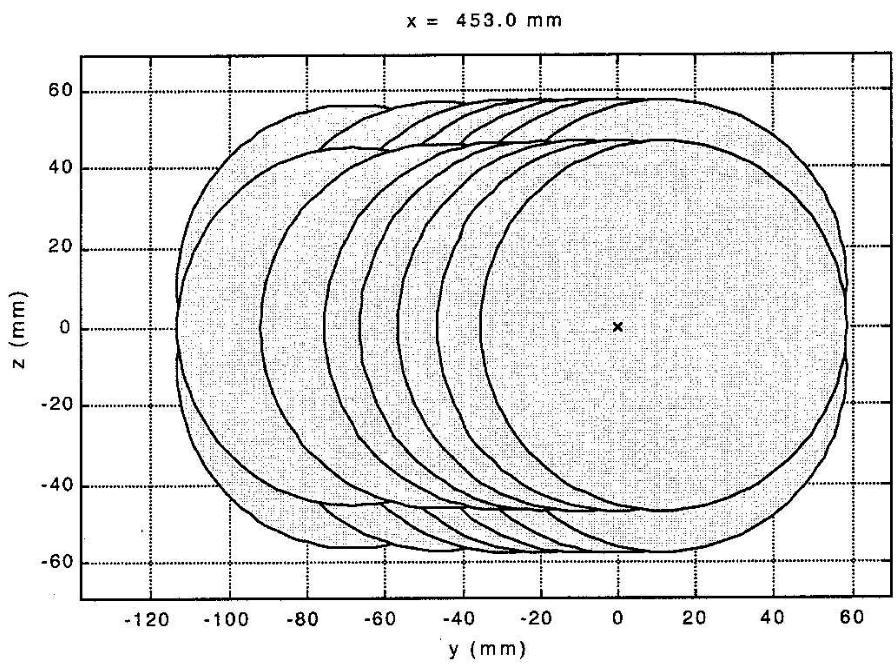


Figure 4: HIFI Beam Shape at the Height of the Cryostat Opening [AD4]

The HIFI FOV lies close to the centre of the telescope FOV. Therefore obstruction cannot occur here. The figure is shown as an example.

LOU Requirements:

Seven LOU beams shall enter the cryostat outer vessel along 7 parallel paths from the –y side. A 30 mm free diameter (at operational temperature) is required for each of the window diameters. The inter-beam spacing is defined as 50 mm (at operational temperature). The windows shall be tilted so that the angle of incidence and the exit angle shall be at least 2.0°. Surfaces surrounding the windows and filters must also be tilted to avoid standing waves.

The total transmission for the 7 LOU channels shall have a minimum transmission of 80 % at EOL.

3.3.6 Straylight

The requirements, as defined in the IID-A ([AD1]) and in [AD5], are described below:

For the spacecraft design w.r.t. straylight for the Herschel instruments an integrated approach has been selected. This means that the instrument optical layout is included in the system straylight analysis. This approach allows to directly provide the straylight level originated from the various sources at the detector level.

The system straylight requirements are given therefore directly as the straylight reaching the detector level. The system will provide the following maximum straylight over the full operational wavelength:

Scattered light (source outside the telescope FoV)

Taking into account the worst combination of the Moon and the Earth positions w.r.t. the LOS of the telescope with maximal:

- Sun - S/C - Earth angle of 37º
- Sun - S/C - Moon angle of 47º
- Sun - S/C - LOS angle of 60º to 120º (in x-z plane),º,
- Sun - S/C – LOS angle of ± 1° (about x = roll)

the straylight shall be: < < 1.0% of background radiation induced by self-emission of the telescope.

Sources inside FOV:

Over the entire FOV at angular distances 3' from the peak of the point-spread-function (PSF), the straylight will be: < 1∗10 -4 of PSF peak irradiance (in addition to level given by diffraction).

Self-emission

The straylight level, received at the defined detector element location of the PLM/Focal Plane Unit Straylight model by self emission (with “cold” stops in front of PACS and SPIRE instrument detectors), not including the self emission of the telescope reflectors alone, should be < 10% of the background induced by self-emission of the telescope reflectors.

4 ISO Heritage

The Herschel PLM design is based on the heritage of ISO (Infrared Space Observatory, successfully flown in 1995 – 98). Thus Herschel benefits from commonalties as the design principle, e.g. CVV, tank suspensions, thermal shields, from the tank material selection, from the He-System Components and from the established GSE. Also the established operational procedures and the ISO Verification and Test Concept have been used for the development of the corresponding Herschel documentation.

The essential experiences gained during the development and testing of ISO have been compiled in the document: ISO Payload Module – Lessons Learned, [RD9]. This document highlights the issues of the ISO-PLM program where during development and qualification unexpected problems occurred. In detail specific attention has been paid to:

- Vibration behaviour and floppy tank
- LHe-valves
- Ventline pressure drop
- Thermoacoustic oscillations
- Cryo-Harness interconnection technology
- Insufficient tank straps pretension during tests
- Cryo-cover windows coating
- Contamination by GSE

During Phase B all the above mentioned topics have been carefully analysed respectively were taken into account for the Herschel design development and hardware procurement activities. Various Technical Notes were published analysing the a.m. problems, e.g. [RD30] discussing the ventline pressure drop, the TAO problem; a comprehensive cryo-harness interconnection technology confidence program has been performed as outlined, for instance, in the [RD31].

Due to the availability of the complete ISO documentation dedicated reviews have been performed with the aim to transfer and to use ISO know-how for the Herschel design development in Phase B.

A review of ISO NCR´s from all major ISO components respectively subsystems, refer to [RD32], followed by a review of RFD´s and RFW´s were performed and the outcome has been taken into account for the establishing of the corresponding Herschel procurement specifications.

Another important aspect in case of using ISO experience for Herschel is the involvement of former ISO personnel. This could be realised for nearly all project-disciplines like engineering, AIT and PA.

Furthermore, also the involvement of ISO experienced companies provides a certain continuity with respect to transfer of the ISO heritage and know-how to Herschel, i.e. besides Astrium, APCO, GORE, Eurocopter, Linde, REMBE, Stoehr, Phoenix and others.

Since many of the cryogenic components, already developed and qualified for ISO, will be reused for Herschel, e.g. DLCM´s, Liquid Level Probes, PPS, temperature sensors, Liquid Helium valves,…, a significant risk reduction benefit with respect to development and qualification is obvious for the Herschel program.

Figure 5: ISO

5 H-EPLM Design

5.1 Overall Configuration

The Herschel S/C consists of the Service Module (SVM) and the Extended Payload Module (H-EPLM). Major components of the EPLM are the scientific instruments (HIFI, SPIRE, and PACS), the telescope, the cryostat and extensions like the Herschel Solar Array Sunshade (HSS). Figure 6 shows the components outside the cryostat, whereas Figure 7 shows the cryostat internal components.

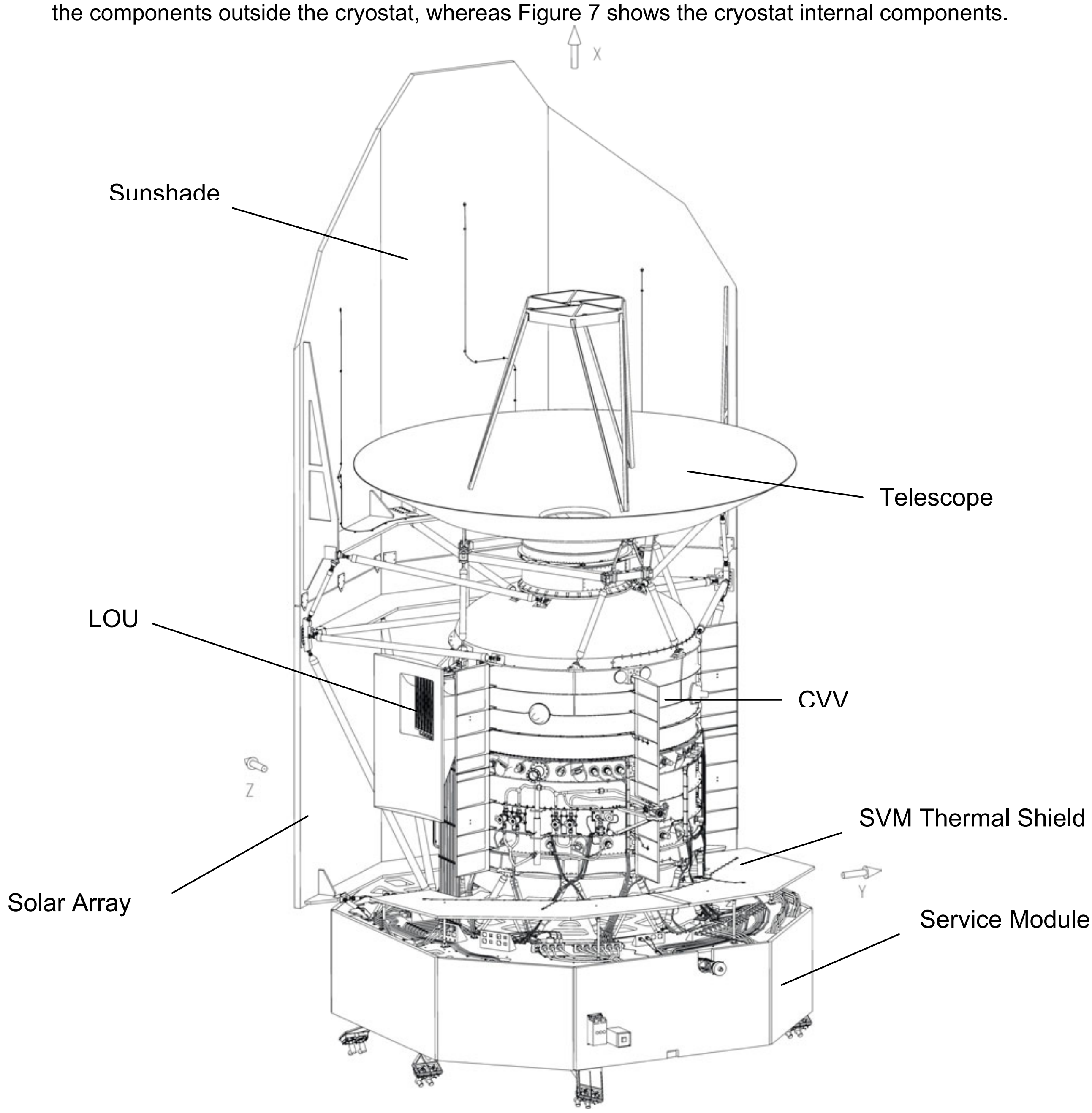


Figure 6: Herschel Spacecraft

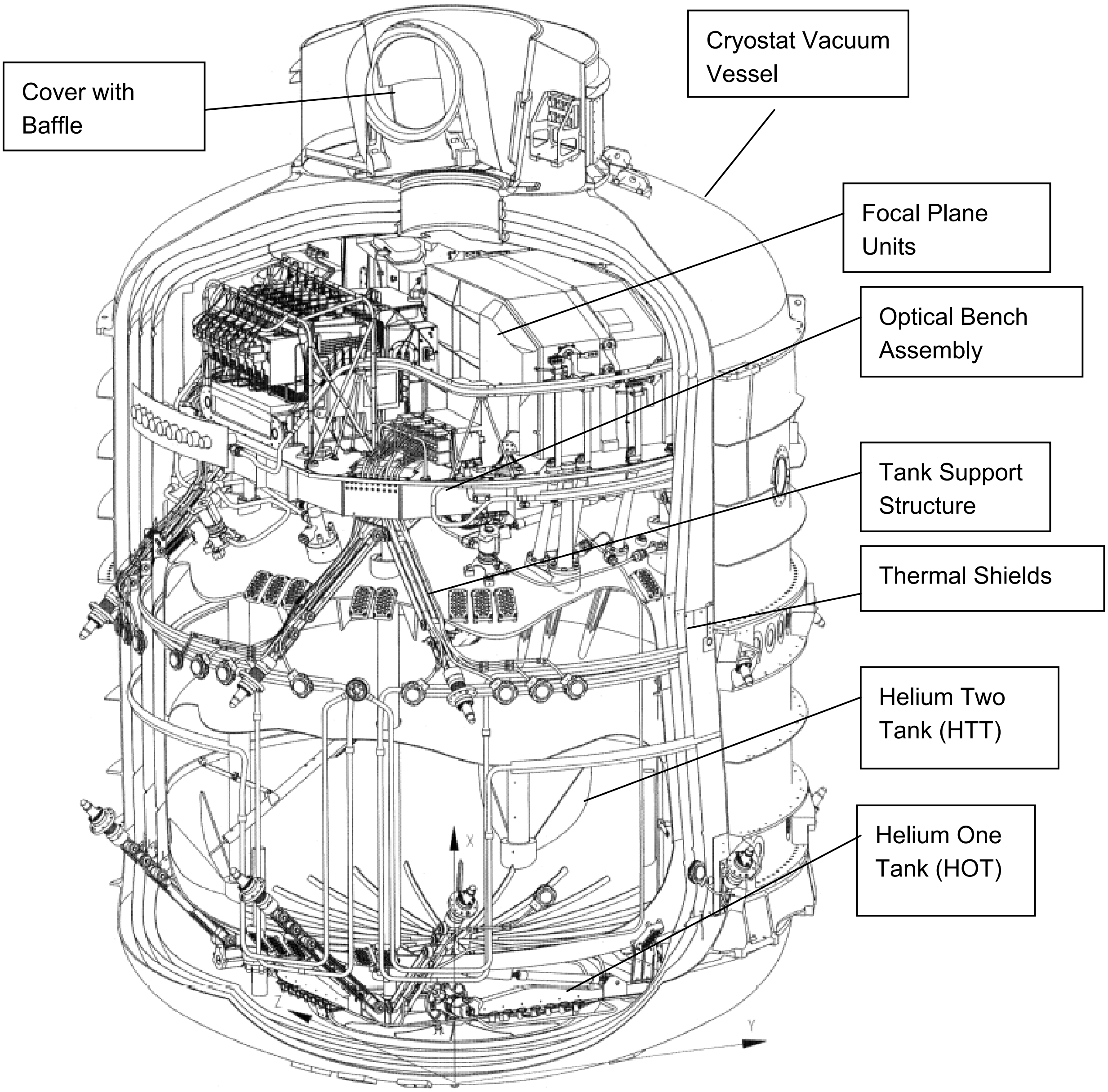


Figure 7: Cryostat cross section

The overall configuration is driven by the allowable volume under the Ariane-5 fairing, the diameter of the telescope (3.5 m diameter), the need to protect the cryostat and the telescope from sun light and the required location for the centre of gravity. As a compromise to all these aspects, the centre of the cryostat is 60 mm shifted in –z direction wrt. launcher symmetry axis.

The primary function of the EPLM is to provide the cryogenic environment required by the instruments. The cryogenic temperatures for the instruments are achieved using a classical – ISO like– cryostat as shown in Figure 8. The in orbit cooling medium is superfluid liquid helium (He II) stored in the Helium Two Tank (HTT).

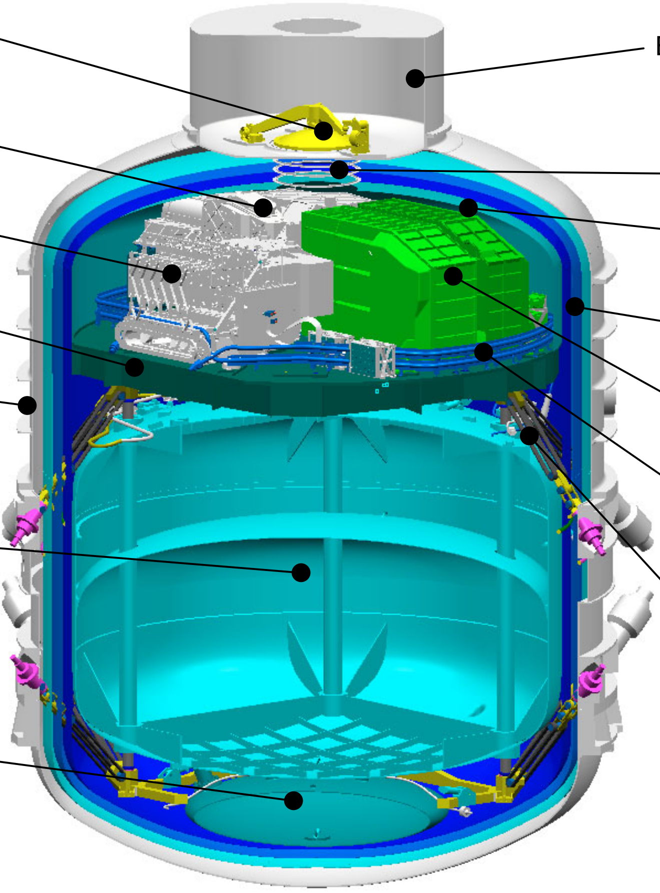


Figure 8: Cross section of the cryostat, indicating the names of the components

The HTT is designed for a maximum volume of 2367 litre inside the boundary conditions of the cryostat together with the instrument and optical bench configuration. It will be filled with 337kg of helium to achieve a minimal lifetime of 3.5 years. The HTT also provides several interfaces to the helium control elements and thermal interfaces to the focal plane units. The mass is mainly driven by the structural and the internal and external pressure loads coming from the cryostat safety elements.

The optical bench assembly provides all the mechanical interfaces to the focal plane units. Its design is driven by stiffness requirements.

For operations in orbit several heat sinks for dissipated energies from the focal plane instruments to the cryostat are required. The provided thermal links for these purposes are defined in four levels:

- Level 0: 10 direct thermal conductance links from an instrument I/F to the superfluid helium in the HTT (PACS 5, SPIRE 4, HIFI 1)
- Level 1: a thermal contact from an instrument I/F to the evaporated helium gas coming out of the PPS at the HTT in the sequence first PACS (3), than SPIRE (2) and HIFI (1).
- Level 2: the optical bench carrying the FPU's is thermally connected to the helium gas leaving the heat exchangers from Level 1.

- Level 3: The helium gas leaving the optical bench is thermally connected to two JFET boxes from SPIRE before entering the vapour cooled radiation shields.

For instrument testing on ground and the phase on the launcher the heat load on the HTT has to be minimized. This is performed by evaporating helium out of the helium one tank (HOT) through the venting system (heat exchangers) of the HTT by switching of valves.

HTT, HOT and OBA are mechanically supported by the Spatial Framework (SFW). It consists of a lower and an upper part. The upper part carries the OBA, the lower part the HOT; the HTT is clamped between the upper and lower part. The thermal function is to isolate the HTT from the heat coming from the Tank Support Suspension (TSS) and the dissipation by the instruments on the OBA. Therefore items, connecting the frame with the HTT are made from carbon fibre reinforced plastic. The axial loads are taken by 8 bones and the lateral force by 8 struts. The mechanical needs and the requirement to maintain the ISO heritage, mainly for the Tank Support Suspension (TSS) drive the SFW geometry and properties.

The TSS consists of 16 chains, each chain is built up of 4 loops. The chains function under tension only, and are pre-loaded to cover with sufficient margin the launch loads and provide the required alignment in orbit. To minimise the thermal conductivity the 2 innermost loops made of CFRP and the others from GFRP. The TSS provides additionally the I/F for the three thermal shields. The chain design is identical to the ISO design, except the cross section.

The function of the thermal shields is to minimise the radiation from the “warm” CVV to the “cold” inner parts. The shields are covered with MLI and cooled by the vent line. The inner shield is also used for the thermal fixation of the harness.

The primary function of the Cryostat Vacuum Vessel (CVV) is to provide vacuum environment for the whole inner parts on ground and during launch. The vacuum is needed for thermal insulation of the cryo system. In addition the CVV has a load carrying function for the telescope, the LOU and the HSS. These parts are connected via struts with the CVV. Directly mounted on the CVV are the harness and parts of the cryo system. The CVV has also to provide the feed through for the harness connectors. In orbit the CVV temperature shall be minimised. The expected temperature is about 70 K. Therefore the parts facing the “hot” HSS are covered with MLI and the parts pointing to the deep space are black. To increase the area of the black surface the three radiators are mounted on the CVV. An aperture for the telescope beam is located in the top part of the CVV. The cover closes this aperture during ground activities and LEOP.

On the top the CVV has an opening of diameter of 288 mm for the optical path from the telescope to the instruments. On ground the cryo cover closes this path. For all ground operations the cryo cover must be leak tight to maintain the vacuum in the CVV. For ground testing the cryo cover inner mirrors can be cooled with liquid Helium/Nitrogen.

To minimise the stray light the cryostat baffle is placed between CVV and telescope. This baffle is also structurally connected to the telescopes mounting structure (TMS) via 6 glass fibre struts.

The TMS is designed to carry the telescope and to provide a stiff and extremely plane I/F to the telescope. The TMS consists out of a frame and 6 load carrying struts. The strut design takes care, that the deformation due to the CVV shrinkage in orbit (8 mm in diameter) will not cause telescope deformations (Wave front error). Thermal insulation between the telescope and the CVV is required to limit the impact on the PLM life time during the decontamination phase of the telescope, where the telescope is heated up to 50^{o} Celsius. Therefore the struts are made from T300 carbon fibre reinforced plastics. The telescope frame is made from M55j, which has a CTE of almost zero.

The HIFI instrument on the OBA has a RF link to the LOU, which is mounted on the - y side of the CVV. To satisfy the HIFI needs the CVV has 7 windows of a diameter of 34mm and 2 additional alignment windows with a diameter of 24mm. The LOU shall have a temperature of 120 K and is thermally de-coupled from the CVV by GFRP struts. HIFI will provide a radiator, which controls the LOU temperature.

The RF waves are transferred by wave guide to the LFU in the Herschel Service Module.

To protect the CVV and the telescope from sunlight the Herschel Solar Array/Sunshade (HSS) is used. It shall shadow the PLM for pitch angles of +- 30 degree and roll angles of +- 1 degree. The lower part of the HSS is the solar generator of the Herschel S/C. GAGET2 solar cells with external Si-diode are used to fulfil the power requirements. The upper part is called sunshade and is covered with OSR to minimise the temperature of the sunshade and consequently minimise the telescope temperature. The HSS is mounted by glass fibre struts on the CVV and connected by carbon fibre struts on the SVM. The backside of the HSS is covered with MLI to minimise the radiation to the CVV.

The whole cryostat is mounted on the SVM via glass fibre struts. In order to maximise the life time and consequently to minimise the thermal conductance while fulfilling the overall stiffness requirements a configuration of 24 struts was found to be optimal.

Also on the SVM mounted is the SVM shield, which serves as baffle protecting the black parts of the CVV from the radiation of the “hot “ SVM. To minimises the shield temperature (about 120 K the side pointing to the SVM is covered with gold plated Kapton foil. The other side is covered with a single Kapton foil. The minimum temperature is reached by tilting the shield by 5 degree to the deep space (V groove effect). The thermal conductance to the SVM is minimised by using glass fibre struts.

Another link of the SVM to the PLM is the cryo harness. Starting from the connector brackets on SVM top platform the harness is routed on the CVV. The instrument and cryo control harness is routed through the vacuum tight feed through in the CVV to the instruments on the Optical Bench.

The figures following are showing the essential system dimensions.

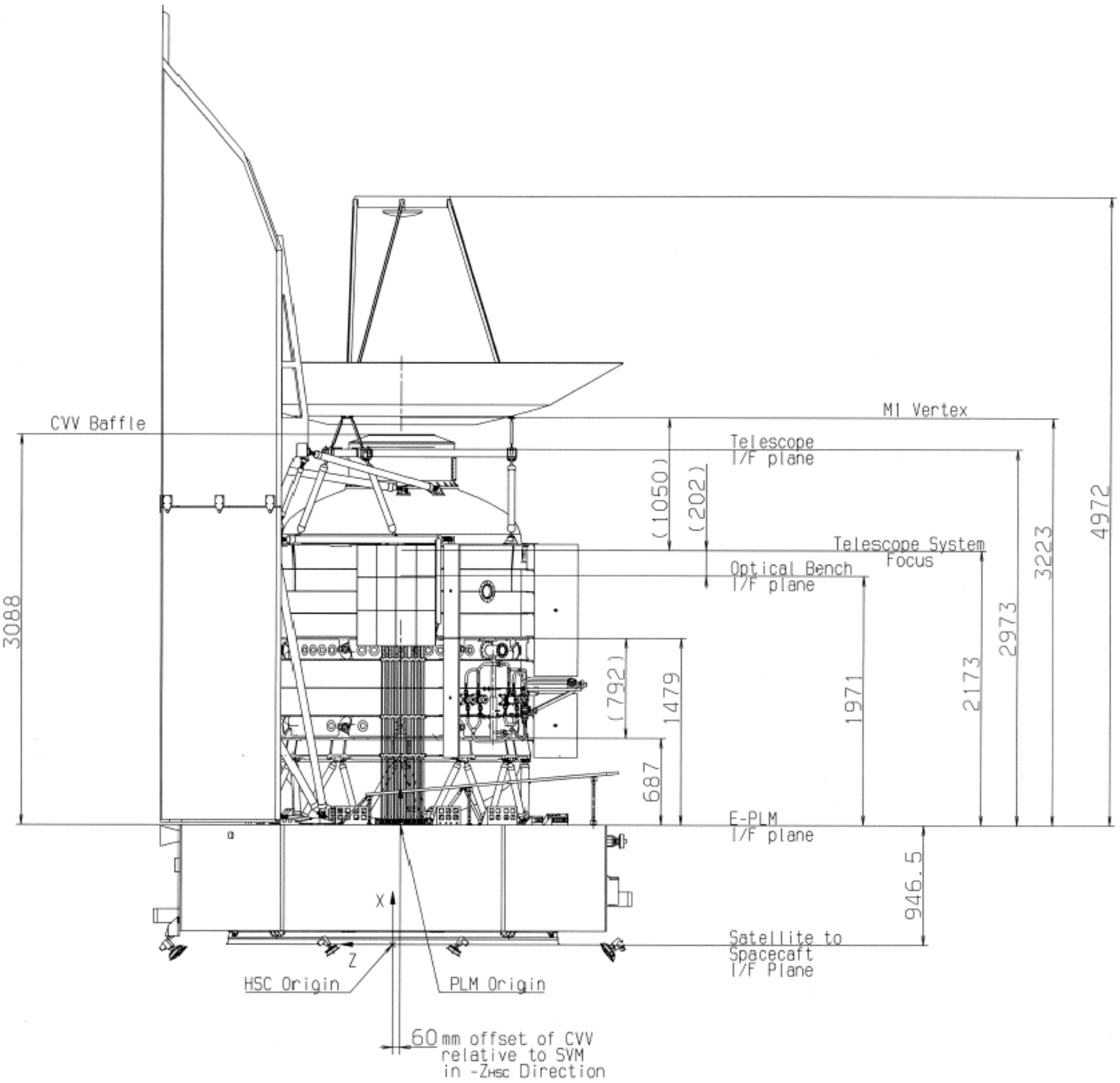


Figure 9: Herschel S/C view from -y

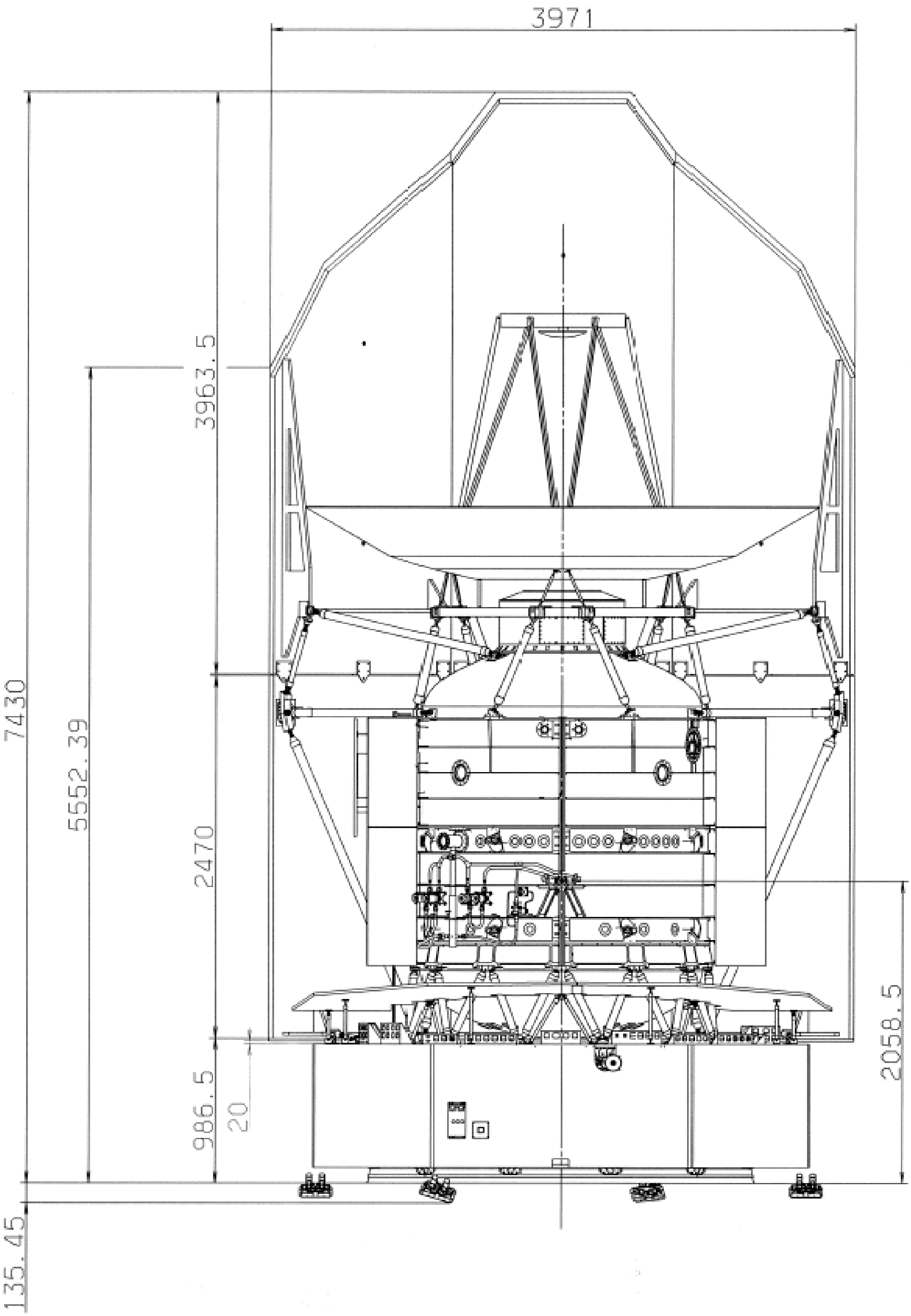


Figure 10: Herschel S/V view from -z

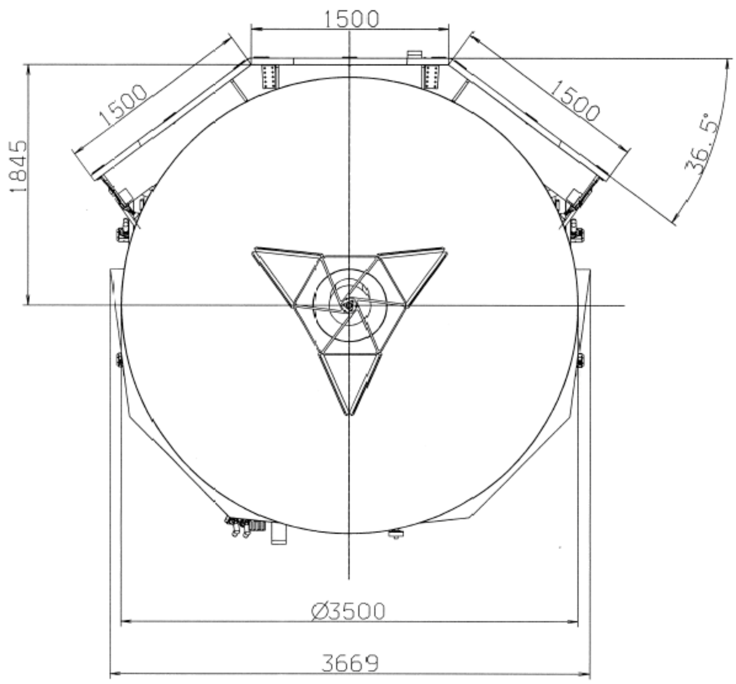


Figure 11: Herschel S/C, view from +x

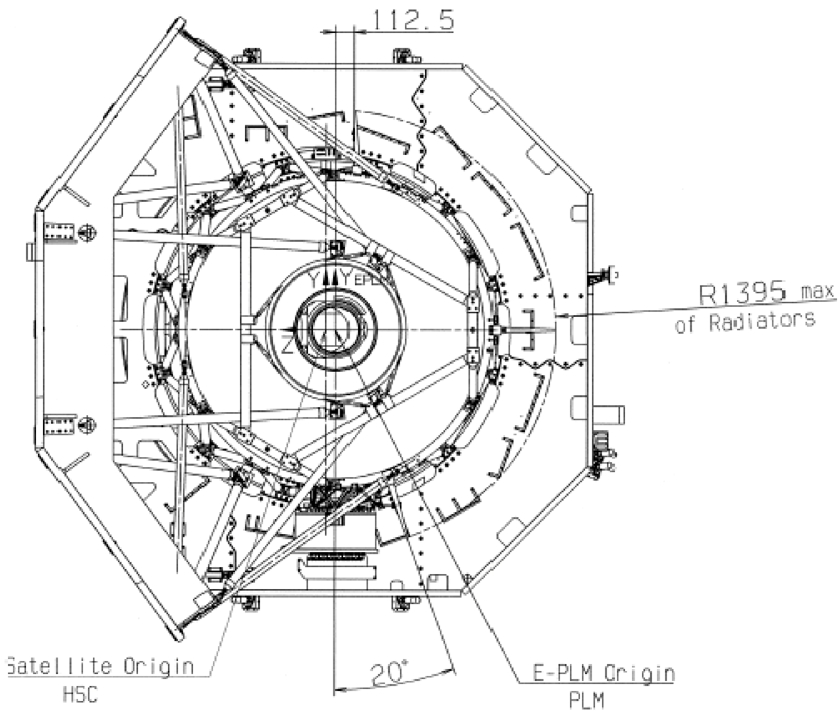


Figure 12: PLM View from –x w/o telescope

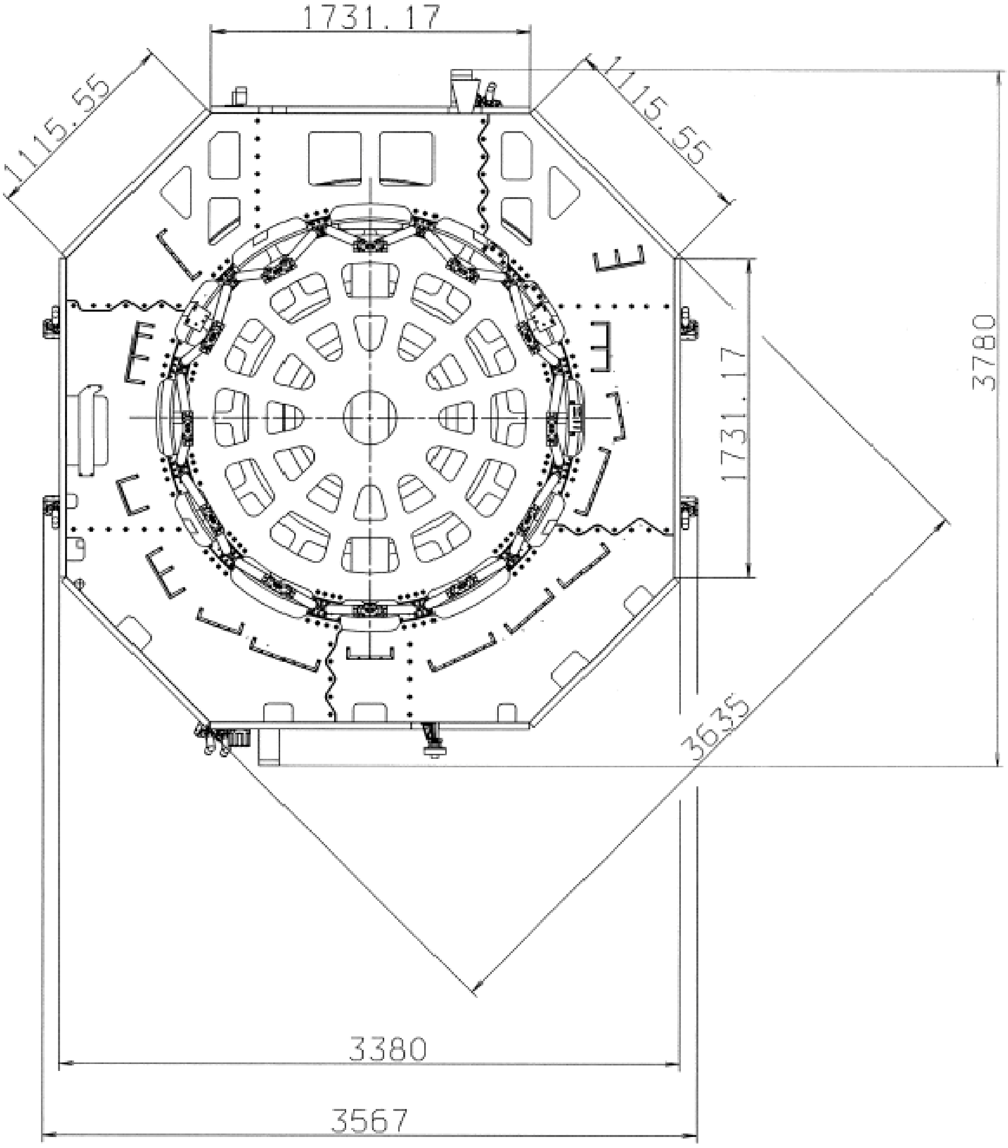


Figure 13: View to SVM from +x w/o EPLM, but including PLM/SVM IF struts

5.2 Envelope and Internal Clearance to Fairing

The Figure 14 shows that the envelope of the fairing, as defined in [AD6], is penetrated by the HSS. The reason for the penetration is the new shape of the HSS caused by the 100mm elongation of the HTT and the introduction of the new requirement HERS-0092. HP-2-ASED-RD-0021 (1/-) was raised by ASED and approved by ASP in CCB#77 to cover this deviation.

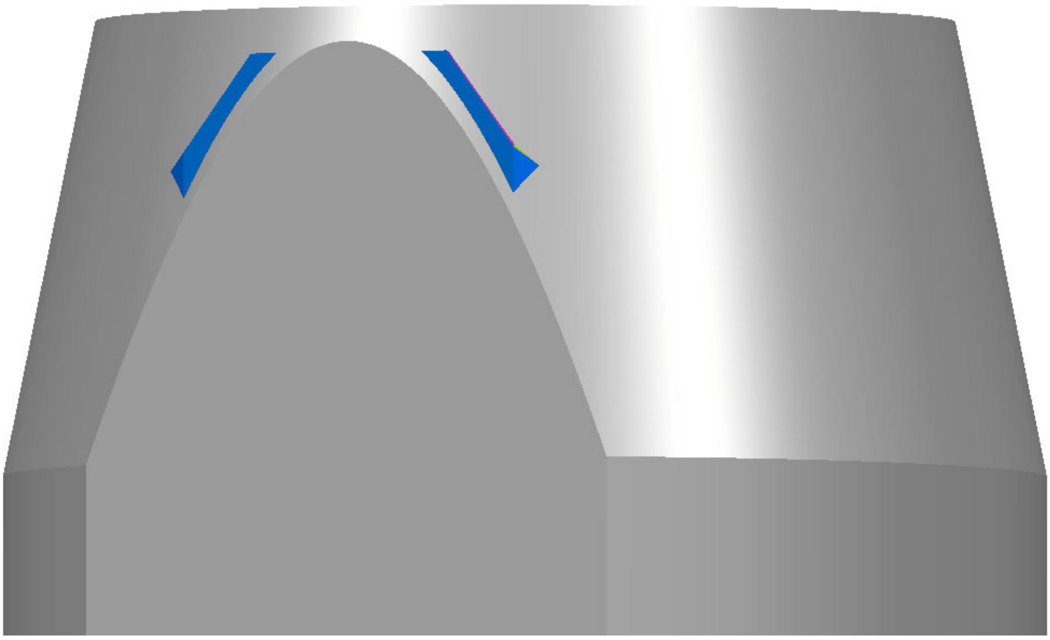


Figure 14: Penetration of the EPLM wrt. fairing envelope, as defined in [AD6]

5.3 Instrument Accommodation

The accommodation areas of the scientific instruments HIFI, PACS and SPIRE are as follows:

Instrument unit	**Location**
HIFI FPU	Optical Bench Plate (OBP)
LOU and waveguides	Outer CVV, -Yside
LOU windows (7 channels + 2 alignment windows)	Outer CVV –Y side
PACS FPU	Optical Bench Plate (OBP)
SPIRE FPU, incl. JFET boxes	Optical Bench Plate (OBP)

The Optical Bench Assembly (OBA) provides the mechanical mounting interface for the FPUs as well as the interfaces for the instrument cooling. The mechanical fixation to the Optical Bench Plate (OBP) is achieved by bolts.

5.3.1 Optical Bench Assembly

The Optical Bench Assembly (OBA) provides through the Optical Bench Plate (OBP) itself a solid and alignment stable support of the Scientific Instruments (PACS, HIFI, SPIRE FPU, SPIRE-JFETs) within the Herschel cryogenic environment.

The OBP shall be a light aluminium plate, which is supported at four I/F points and provides I/F for the instruments and associated parts of instrument harness.

Figure 15 and Figure 16 show a top and side view of the Optical Bench Assembly.

The FPUs are mounted by conventional bolts as defined in.

For HIFI and PACS the mounting accuracy and position stability is assured by dowel pins in the instrument feet, to avoid any slippage due to mechanical loads. The mounting accuracy < 0.1 mm is achieved by precisely positioning the holes for the dowel pins. Therefore, no lateral adjustment possibility is foreseen.

All related holes on the OBP are fixed, there will be no provisions for compensation of thermal displacements from OBP side.

Concerning axial positioning wrt telescope focus, only PACS is critical. Therefore, in this case shimming will be applied, if necessary. Since the PACS FPU has to be thermally insulated from the OBP, the thermal washers will also serve as alignment shims.

The OBA provides the interfaces to the instrument cooling with the following thermal I/F links:

- Level 0 FPU's to the HTT
- Level 1 FPU's to Optical Bench Helium Cooling Loop L1 (thermally isolated from OBP)
- Level 2 OBP temperature
- Level 3 JFET's to OBHCL 3

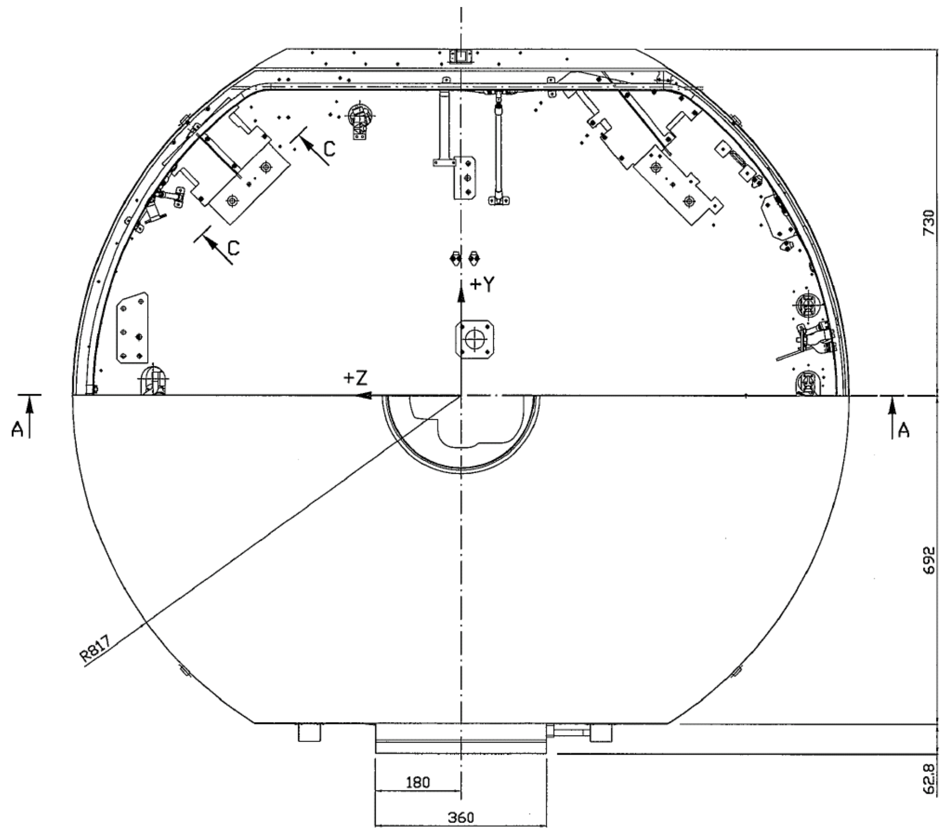


Figure 15: Dimensions of the Herschel Optical Bench Plate with Instrument Shield (top view)

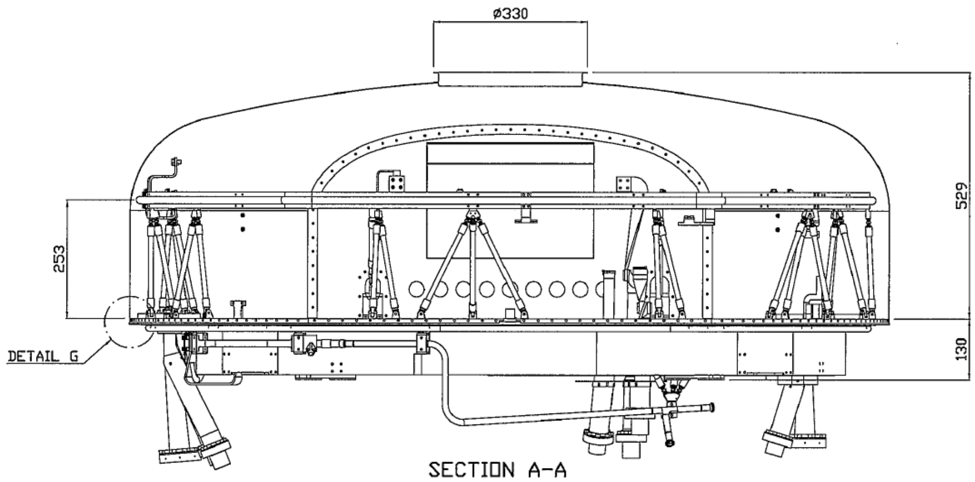


Figure 16: Herschel Optical Bench Assembly: Side view

The following figures provide different views of the OBP with instruments.

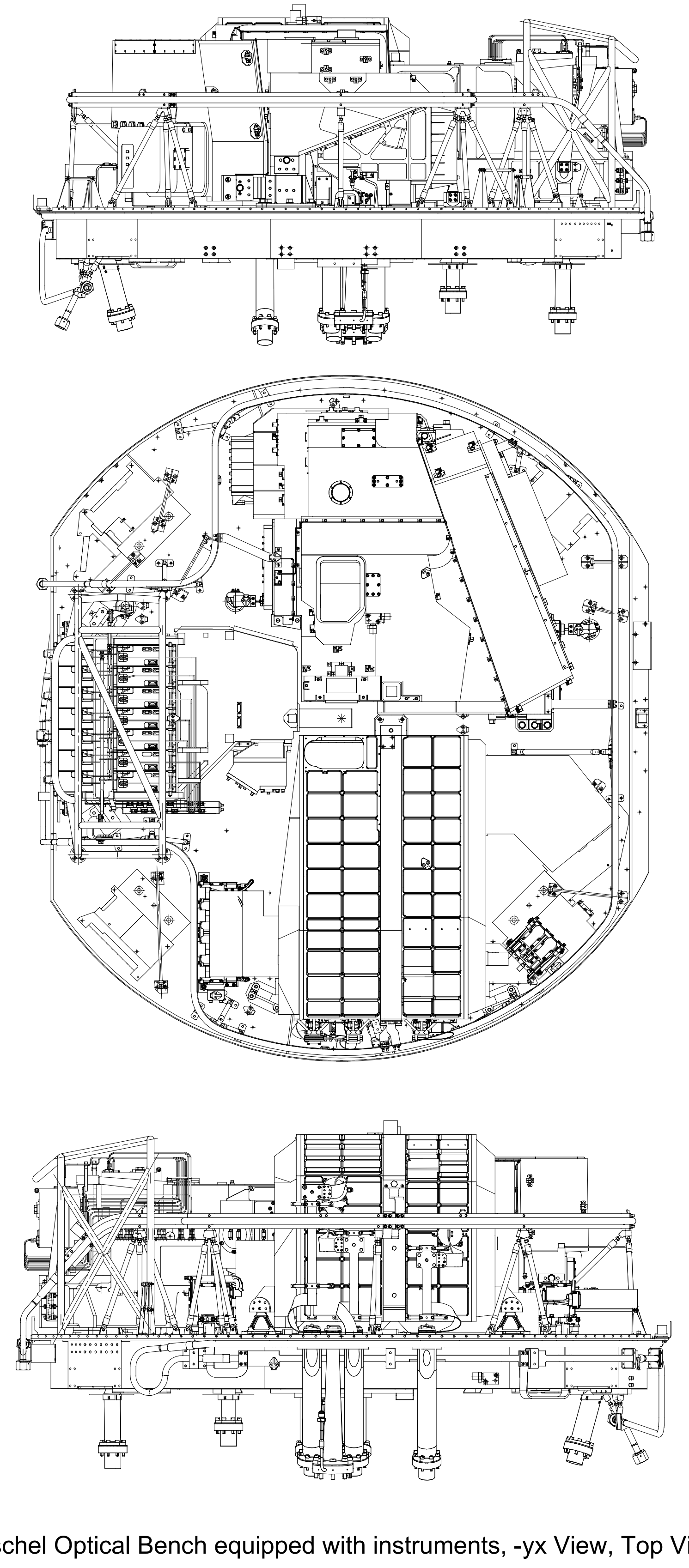


Figure 17: Herschel Optical Bench equipped with instruments, -yx View, Top View and yx View

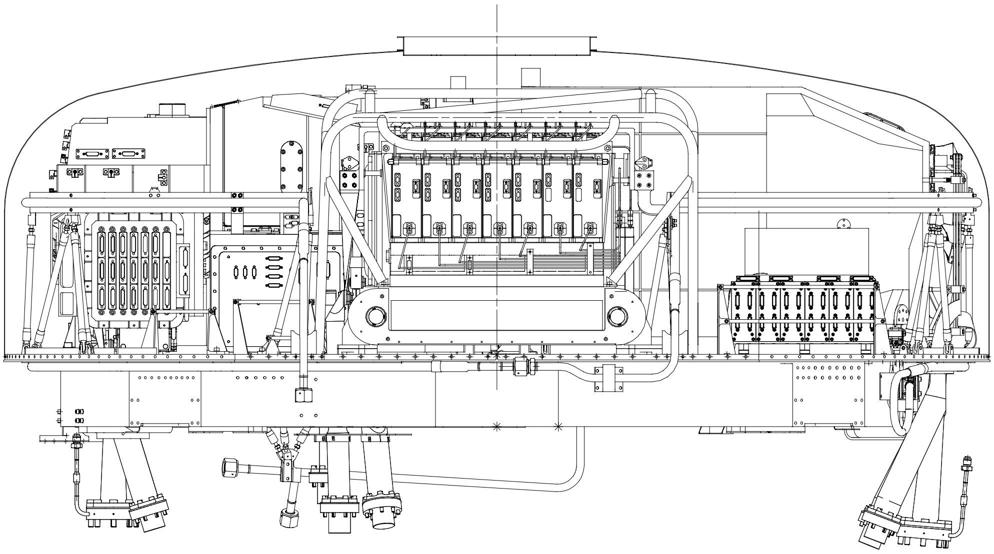


Figure 18: Herschel Optical Bench including instrument shield and baffle equipped with instruments, -zx View

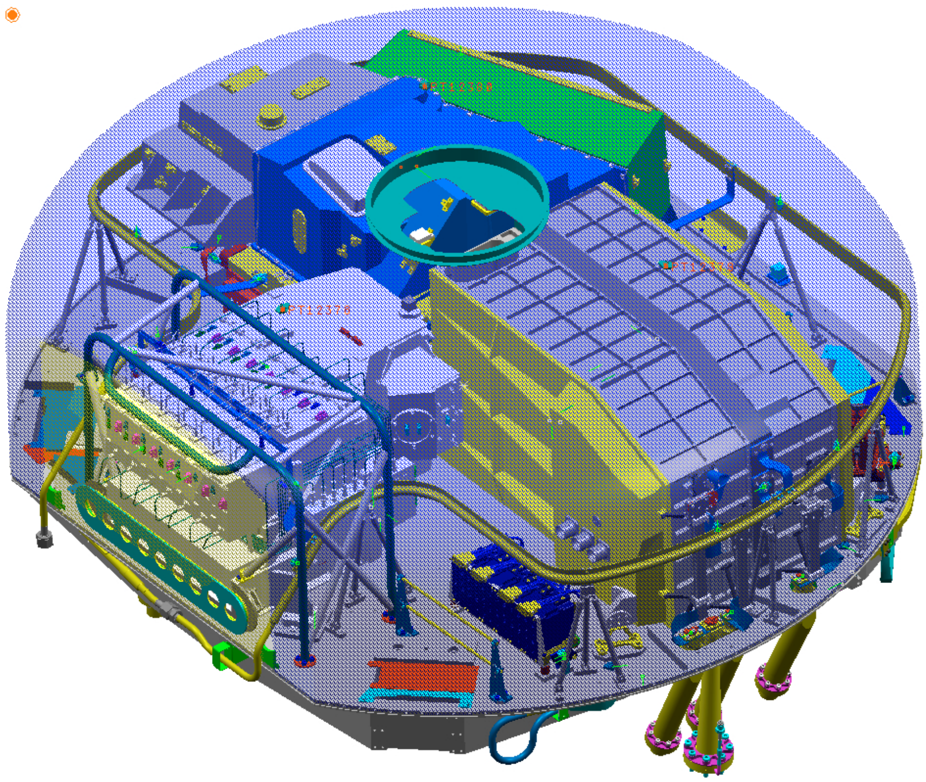


Figure 19: Herschel Optical Bench Assembly, Isometric view with transparent instrument shield and baffle, equipped with instruments (HIFI front left, SPIRE front right, PACS in the back)

The holes at extreme left and right are optical windows used for alignment monitoring. The corresponding CVV windows will be closed when not needed.

5.3.2 Units mounted outside the cryostat

One unit of the instruments is mounted on the outer side of the CVV, i.e. LOU of HIFI

The LOU mounting structure to the Herschel satellite consists of a GFRP strut system and a mounting base plate which provides

- mechanical support
- shrinkage-free stable alignment, i.e. thermally stable LOU interface position
- thermal insulation from CVV

The design of the LOU mounting structure and the routing of the LOU waveguides to the SVM is shown in the following figures.

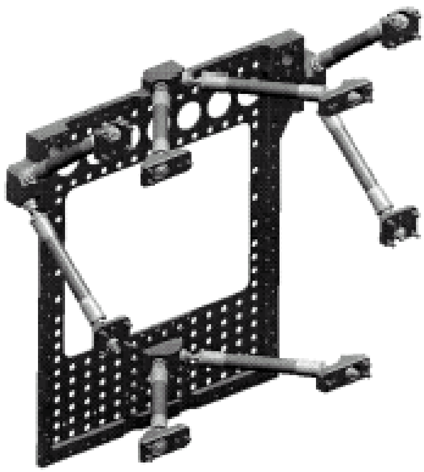


Figure 20: LOU Mounting Structure

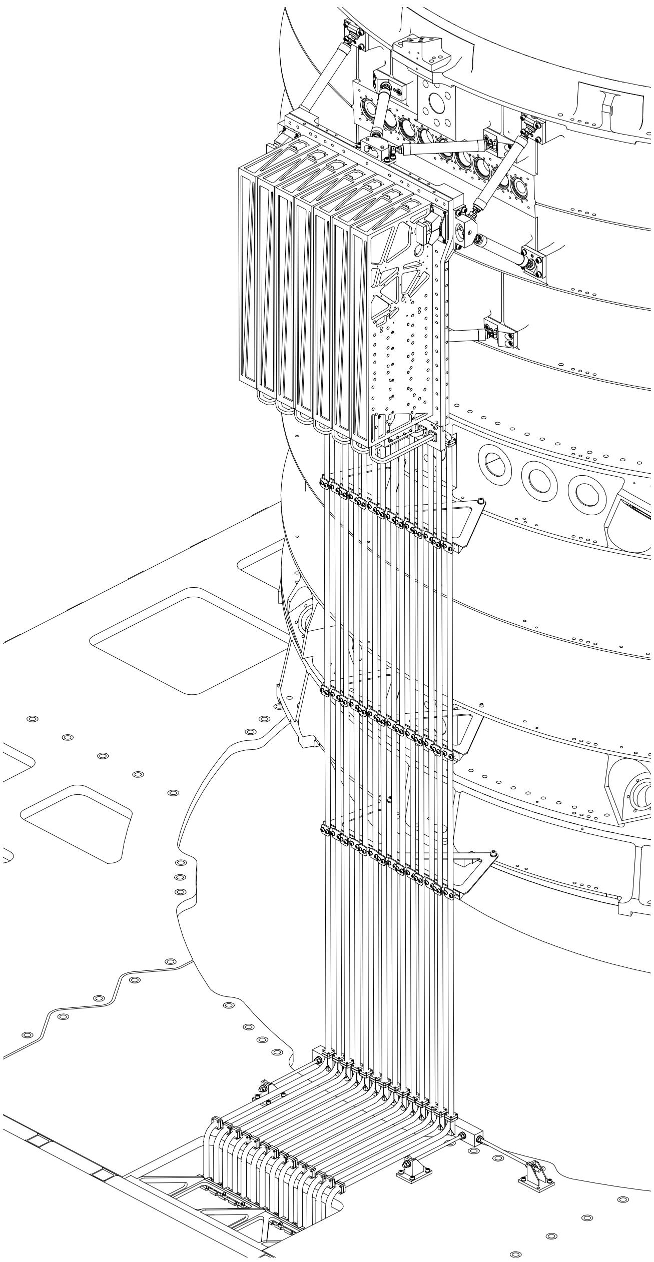


Figure 21: LOU and Waveguides Assembly interfaces on the Herschel Satellite

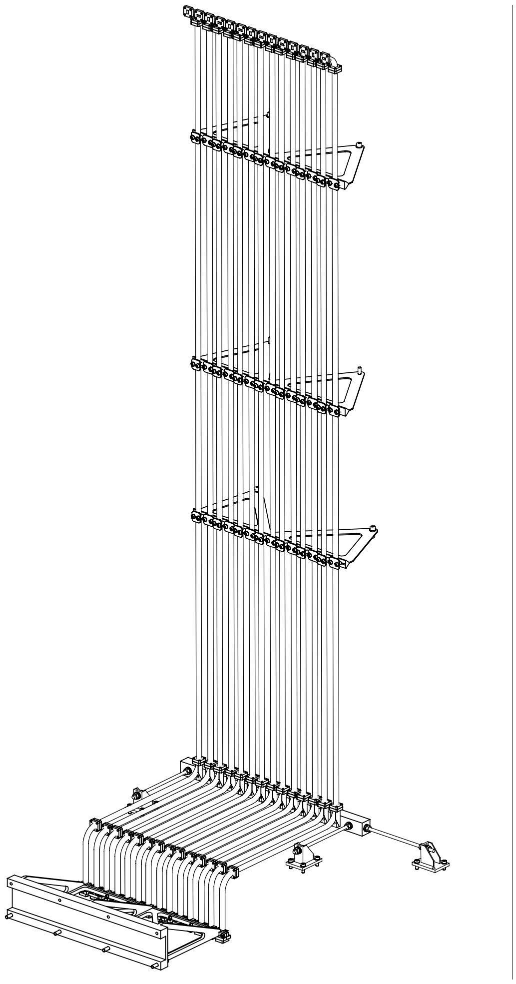


Figure 22: Waveguides Assembly Interfaces to Herschel Spacecraft (CVV and SVM now shown)

5.4 Telescope Accommodation

The Herschel telescope is mounted on top of the CVV via the Telescope Mounting Structure (TMS).

The TMS consists of six struts connecting CVV and a hexagonal interface frame providing axial positional stability and stiffness (CVV struts). Additional six struts connect the hexagonal telescope mounting frame and the upper rim of the cryostat baffle (CB), thus providing lateral positional stability and stiffness. The telescope interface frame accommodates at its +Y side bracketry for the telescope heater and sensor lines. Figure 24 shows the structural layout of the TMS.

The CVV struts (CFRP T300 struts) also provide sufficient thermal insulation to limit the heat flow from the telescope to the CVV. The CVV struts are designed such that a radial shrinkage of the CVV of 4 mm is possible without distorting the interface frame and its interface to the telescope. To avoid distortion of the telescope, the interface frame has to guarantee an interface planarity of 80 μm. The upper frame TMS allows radial shrinkage of the CVV interface and limits the distortion effects to the telescope.

Figure 24 shows the telescope dimensions and the telescope interface struts to be mounted to the upper side of the interface frame.

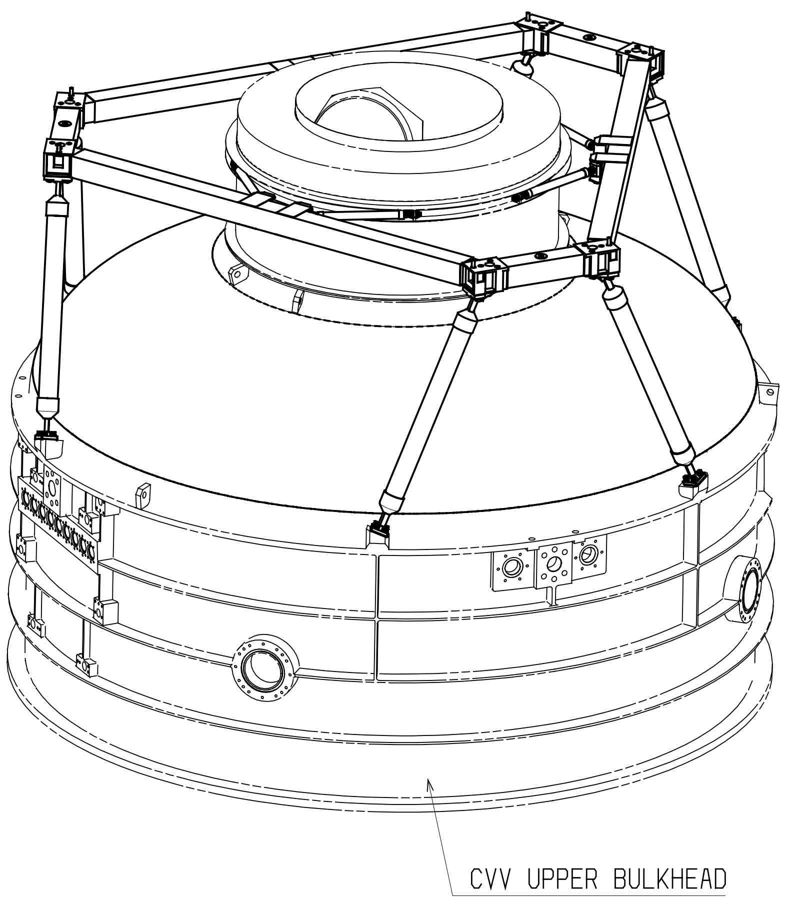


Figure 23: Herschel Telescope CVV fixation structure mounted onto CVV.

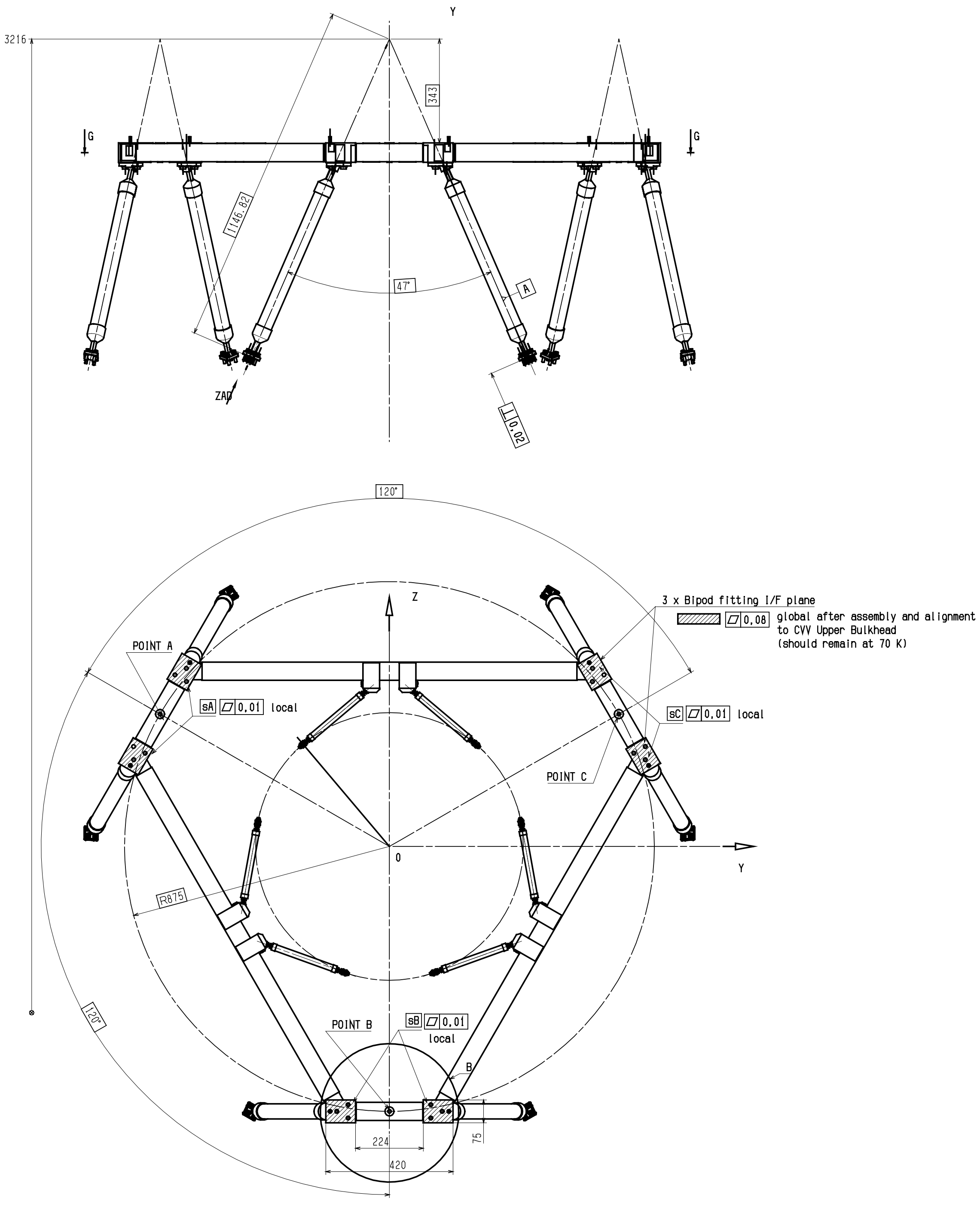


Figure 24: Herschel Telescope Structure layout

5.5 Description of the Helium Control System

The Herschel Helium Control System consists of all components which are in contact with cryogenic fluids (superfluid and normal boiling Helium). Therefore the Helium Control System comprises the following components:

- Main superfluid Tank (He II Tank, HTT)
- Auxiliary Tank (He I Tank, HOT)
- Cryostat Internal Piping System
- Cryostat External Piping System
- Cryostat Internal Cryo Components
- Cryostat External Cryo Components
- Cryo Cover
- Cryogenic Vacuum Servicing Equipment (CVSE)

Remark: In addition to the above mentioned components the cryostat is equipped with various sensors for monitoring the thermal behaviour of the Cryostat. The instrumentation is described in Chapter 13.1.

The description of the Cryogenic Ground Support equipment is not scope of this document. To the extent possible the ISO CVSE will be used for Herschel after refurbishment.

The Herschel Helium Control System, which is shown in Figure 25, is derived from the ISO Helium Control System. Differences result from different mission requirements and in consideration of 'ISO Lessons learned' (see [RD9]). Various concepts of the He Control System have been analysed. Details of the assessment and the trade-offs are given in [RD30].

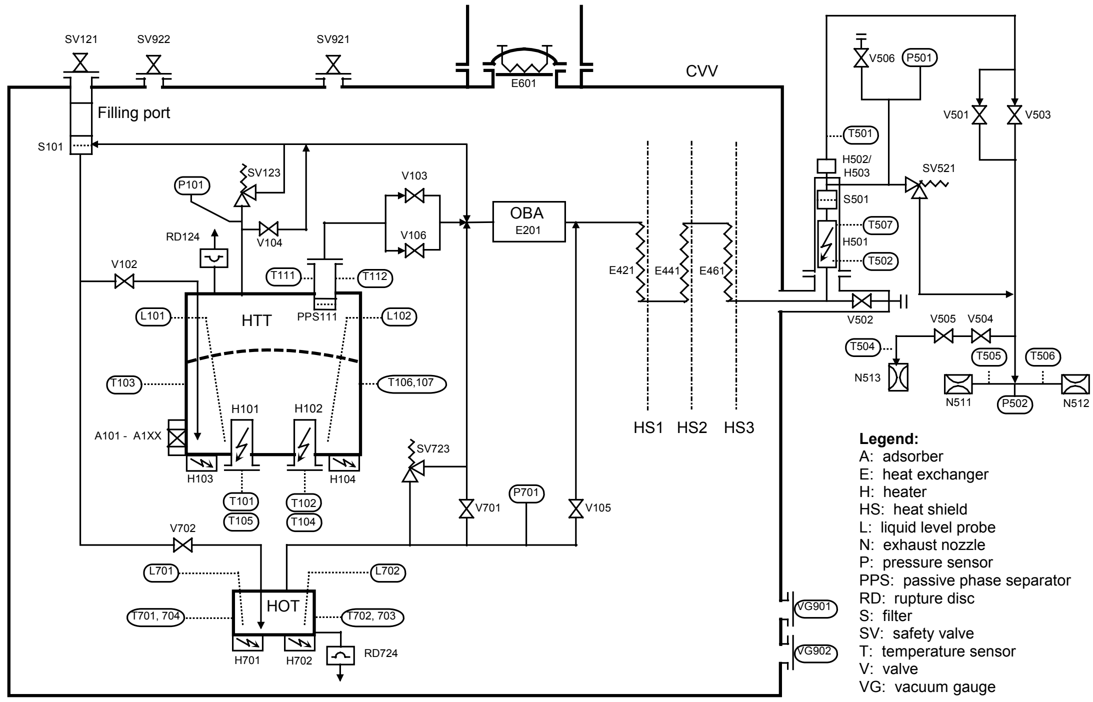


Figure 25: Helium subsystem flow diagram

Main part of the Helium System is the HTT, which contains 2367l of superfluid Helium. To separate the fluid and gas phase a Passive Phase Separator (PPS111) is mounted on top of the tank. For pre-launch operations an auxiliary tank with a volume of 80l is mounted at the bottom side of the cryostat. To fulfil the safety requirements both Helium tanks are equipped with safety valves (SV123 and SV723) and Burst Discs (RD124 and RD724). Both tanks can be filled via the Filling Port and by switching of the Liquid Helium Valves. The FPUs, Optical Bench and Radiation Shields will be cooled by the venting Helium gas. To prevent icing caused by the venting Helium gas prior to launch a Heater device (H501) is part of the external ventline. The Helium can be vented through two different nozzle systems (N511/N512 and N513). During LEOP the nozzle with the large diameter (N513) will be used together with the nozzles with the smaller diameter (N511/N512). For nominal in-orbit operations N513 will be closed and only the nozzles with the smaller diameter (N511/N512) are used. For a depletion of the Helium tanks both tanks are equipped with electrical heaters (H103, H104 and H701, H702). The filling level of both Helium tanks can be measured by either liquid level probes (4.2K condition) or Direct Liquid Measurement devices (only HTT and 1.7K condition).

The cryostat design is based upon the ISO cryostat design. Nevertheless several differences have to be considered for the design of the Herschel PLM. The main differences between ISO and Herschel are given in Table 6. Implications of the differences and potential problems are addressed in [RD3].

Item	ISO	Herschel

Item	ISO	Herschel
Lifetime	18 months	42 months
CVV Temperature	120K	70K
Experiment Operational temperatures	1.7-1.9K	1.65-1.7K
Orbit	Ellipt. Earth orbit, 1000/70000km	L2, 1.5 Mio km from earth
Auxiliary Tank Position and Volume	Above HTT, 60l	Below HTT, 80l
Main Tank Geometry and Volume	Torus, 2250 litre	Cylinder, 2367 litre
Launcher	Ariane 4	Ariane 5
Mass Flow Rates	4.3mg/s	1.9 to 2.2 mg/s
Delta p requirements	For auxiliary tank evacuation	For main tank temp. adjustment
Heat Shield temperatures Inner Heat Shield Middle Heat Shield Outer Heat Shield	Ground /Orbit 34 / 30 K 110 / 45 K 210 / 80 K	Ground / Orbit 90 / 32 K 150 / 41 K 210 / 55 K
Pre-Launch Operations	PAD operations	No PAD operations
Model Philosophy	QFM	PFM
Cover Design	3 active cooled therm. shields	active cooled therm. shield
Launch Configuration	Single config.	Double config.
Cleanliness Requirements	Identical	Identical
Safety regulations	Ariane 4	Ariane 5
Pre-Launch Operations	Ariane 4	Ariane 5
In orbit commissioning Phase	days	Weeks
Cruising phase	No	6 months (TBC)
Optical Bench and experiments position	Inside torus	On top of Tank II

Table 6: Differences between ISO and Herschel

Most of the cryo components have been used in ISO. Small modifications are necessary to deal with the Herschel specific constraints. A major improvement compared to ISO is the implementation of Helicoflex® sealings instead of Kapton sealings.

In the Helium System Description /HP-ASED-RP-0034/ special consideration is given to the following aspects:

- Description of cryo components, instrumentation and thermal interfaces
- Fluid Dynamics: Thermo-Acoustic Oscillations, Pressure Drop Analysis
- Operations: safety, cryogenic activities during: AIT, ground operations, pre-launch operations, LEOP

- Critical areas: heat load verification, instrument failure cases, helium leaks, momentum of vent gas, film flow, He II Tank temperature adjustment and stability

Cryostat Components

The Cryo Components are defined in Section 12.1.

All Cryo Components will undergo a qualification program to cover all potential development deviations, as process, manufacturing, operation or material changes, introduced by the manufacturer in the last 10 years, compared to the 'original' ISO cryo components. The qualification and acceptance requirements are listed in the 'Qualification Program for EPLM Cryo Components' (see [RD34]) and are defined in the individual Cryo Component Procurement Specifications. A successful qualification review will release the manufacturing of the FM/FS. The FM/FS components shall be acceptance tested.

5.6 Cryo Instrumentation

Please refer to Description of PLM FM Cryo Control Instrumentation, [RD14].

5.7 Herschel PLM Operations

5.7.1 *Mission Phases*

All mission phases and Herschel PLM relevant requirements are described in Section 3.1.2. The PLM operations activities during the pre-launch/launch phases are covered in the AIV Section 12.

An overview on the specific sequence of Cryo Control Unit (CCU) events during the LEOP phase is given in the Table 7 below.

Table 7: Sequence of CCU Events during LEOP

	After Launch				
Event	**Days**	**Hours**	**Operation Description**	**Initiation**	**Remarks**
1. Open Valves V 501 and V 503	L0 (lift-off)+tbd min.	0	V501 and V 503 will be opened by related current pulses from the CCU	AR 5, dry loop CMD´s (“switch closure”)	After external pressure has decreased below 50mbar (tbc), for HOT evacuation during launcher ascent

Event	After Launch		Operation Description	Initiation	Remarks
	Days	Hours			
2. Open Valves V 103 and V 106	L0+tbd min.	0	V 103 and V106 will be opened by related current pulses from the CCU	AR 5, dry loop CMD´s ("switch closure")	Just before entering µG environment.
3. Monitoring of EPLM Status	L0+tbd	TBD	Acquisition of selectable monitoring tables	By related TC from CDMU	The monitoring function can be triggered whenever housekeeping status information from the cryo system is needed.
4. DLCM-Operation	L0+tbd	TBD	Injection of about 20 W over 200 sec. into the HTT.	By related TC from CDMU	According cryo system operational needs. About once per 6 month over the mission expected.
5. Close Valves V504 and V505	3 to 4 weeks (tbc)		Valve actuation by related current pulses from CCU	By related TC from CDMU	TC to be given according to temperature and He mass-flow.

Afterwards only Events 3 and 4 will occur during nominal mission operation.

In the following the further H-PLM specific operations activities are summarised:

- Telescope Heating

A telescope heating system is included for in-orbit contamination release from optical surfaces and for bake-out of the telescope. During the early orbit contamination release phase the telescope will be heated up to at least 313 K for a maximum duration of three weeks.

- Opening of cryostat cover

When Herschel EPLM is considered to be sufficiently outgassed and the telescope has reached a temperature of < 90K, the cover shall be opened by telecommanding the 2 NED's (Non Explosive Devices).

The following table summarises the further Herschel PLM activities during until routine operations.

Table 8: Herschel PLM and PLM relevant activities during the post launch Mission Phases

Phase	Duration [tbd]	Activities
Initial Orbit Phase	From T0 to T0+3 to 4 weeks (tbc)	- Close Valves V504 and V505 - Switch on telescope heating
Commissioning Phase	From T0+2d to T0+1month	- P/F checkout

Phase	Duration [tbd]	Activities
		- P/L switch-on and checkout - End of telescope heating (T0+3w) - Telescope cool-down - Cryo-cover opening
Performance and Verification Phase	From T0+1m to T0+3m	- End of telescope cool-down - P/L performance verification and calibration

5.7.2 Herschel PLM Routine Operations

The Herschel PLM is operated via the SVM subsystems. The Cryostat Control Unit (CCU) will provide operational access to the cryostat instrumentation as well as to the telescope and PLM temperature sensors. The CCU will be operated by the CDMU via a MIL-STD 1553 B bus interface and is powered via a LCL by the PCDU. Through its user interface the unit:

- monitors the cryostat status by acquisition of the pressure and temperature sensor readings,
- operates and monitors the helium content measurement system and
- operates the cryogenic-valves and acquires their status indicators.

Operational access to the CCU will be implemented via the CCU / SVM interface consisting of:

- the two interfaces (CCU A/B) to the electrical power subsystem (EPS) via dedicated power-lines controlled by the PCDU.
- the two interfaces (CCU A/B) to the data handling subsystem (CDMS) via the redundant (Bus A/B) Mil Std 1553 B bus controlled by the CDMU.
- the four discrete He valve interfaces controlled by the launch vehicle during the ascent.

Cryo System Monitoring

The cryo system monitoring will cover the acquisition of the readout of the cryo system temperature, pressure and He valves status sensors. The monitoring data are collected and prepared for further processing and ground transmission within the OBDH.

Temperature measurement: Temperature measurement will be accomplished by measuring the voltage drop over a temperature sensor caused by an imposed constant current. The sensor interface will be implemented as a 4-wire interface consisting of two voltage sense lines and two lines for the exciting current.

Pressure measurement: Pressure measurement will be accomplished by measuring the differential voltage of a resistive bridge with one pressure sensitive sensor. The bridge will be supplied with an imposed constant current. The sensor interface will be implemented as a 4-wire interface consisting of two voltage sense lines and two lines for the exciting current.

<u>He valve status</u>: The He valve position is indicated by a reed contact which is closed when the valve is open. The status of the He valve will be acquired by a standard relay status (RSS) interface.

<u>Direct liquid content measurement (DLCM)</u>

The liquid helium content of the Helium II tank will be determined by measuring the temperature increase of the liquid helium caused by a constantly monitored injection of an exactly defined heat pulse. The DLCM will be initiated by a command from the CDMU, which contains a parameter for the selection of the time duration of the measurement. During the DLCM the nominal cyclic monitoring will be suspended. The DLCM temperature sensors (T 102/T 105 and T 101/T 104) in nominal mode will be part of the cyclic cryo system monitoring.

<u>H-PLM Commanding</u>

The CCU will receive, decode, process, and execute the commands generated by the CDMU and distributed via the Mil Std 1553 B bus. The following Mil Std 1553 B bus command types will be processed by the CCU:

- valve commands (including arming) used to switch the He valves into open or closed position
- DLCM commands (including arming) used to initiate the direct liquid content measurement function
- monitoring commands used to
  - initiate monitoring function (table acquisition selected by CMD parameter) or
  - to modify the acquisition tables content

5.7.3 Instrument Operations: Observation Timelines

In the following a observation timeline of 6 x 48h which includes transient operation of and switching between 5 different instrument modes is provided. The transient temperature and heat flow results are based on the following instrument timeline (see [RD19]):

• Start conditions (steady state):	Instruments average dissipation
• PACS Photometer Mode (incl. sorption cooler cycle)	48 h
• SPIRE	48 h
• HIFI	48 h
• SPIRE	48 h
• PACS Spectrometer Mode (no sorption cooler cycle)	24 h
• HIFI	48 h
• PACS Spectrometer Mode (no sorption cooler cycle)	24 h

5.7.4 Operational Constraints

At this stage the following operational constraints originating from the H-EPLM have been identified:

- During the direct liquid content measurement (DLCM) all instruments need to be switched off to ensure constant dissipation and a precise temperature measurement

5.7.5 Operational Modes

The following Herschel operational modes have been summarised.

- Science Observation Modes

The PLM will support the payload operational modes identified in the Table 9. The standby mode assumes that the instruments are not fully powered and provide no thermal dissipation in the focal plane.

Table 9: Herschel Payload Operational Modes

MODE	HIFI	PACS	SPIRE
#1	Prime	Standby	Standby
#2S	Standby	Prime (Spectrometer)	Standby
#2P	Standby	Prime (Photometer)	Standby
#3S	Standby	Standby	Prime (Photometer)
#3P	Standby	Standby	Prime (Spectrometer)
#4	Standby	Prime (Photometer)	Parallel (Photometer)

In order to support the scientific observation a number of different pointing modes will be supported by Herschel, e.g. raster pointing and line scanning.

- Lines of Sight Calibration Mode

This mode will be used to measure the relative angles between the lines of sight of the instruments and the axes of the primary attitude. Extensive initial calibrations shall take place during the Performance Verification phase. In addition the validity of these initial calibrations will be checked periodically by a single calibration.

- Survival Mode

The purpose of the survival mode is to maintain a safe attitude for the spacecraft and the instruments after a major on-board failure or a violation of the attitude constraints. While in Survival Mode, the on-board schedule is discontinued. Major on-board failures are defined as any hazard, which affects the mission objectives, the mission lifetime or the mission safety.

- Autonomy Mode

During all mission phases, the spacecraft will be capable of operating nominally without ground contact for a period of at least 48 hours without interrupting the planned operations. The Autonomy Mode is the normal mode of operation during the routine phase.

5.7.6 Autonomy and Fault Management

The mission profile and operational concept requests a high degree of on-board autonomy.

The Herschel PLM Helium system and the cryo control unit (CCU) are a passive system. Therefore, the potential source of errors is limited, but consequently no specific fault management is foreseen on the PLM itself.

5.8 Electrical Design

The electrical design of the E-PLM is driven by its physical configuration. In particular the accommodation of the instrument cold units located on the optical bench within the Cryo Vacuum Vessel (CVV) and the related instrument warm units sitting within the service module necessitate a special cryo harness for their proper interconnection.

The Scientific Instrument Harness (SIH), especially designed for minimizing thermal losses, which have adverse effects on the cryostat lifetime, connect the payload instruments warm units with their related cold units. In addition, the faint measurement signals, generated by the detectors within the cold Focal Plane Units, have to be protected against any electromagnetic interference on their way via the SIH to the warm units by application of adequate signal grouping and proper shielding.

The Cryostat Control Unit (CCU) provides operational access to the cryo system. For that purpose the payload module is equipped with the Cryostat Control Instrumentation (CCI), a set of monitoring and control devices (e.g. temperature sensors, pressure sensors, liquid He valves etc.) which are operated by the CCU via the Cryostat Control Harness (CCH).In addition, the CCH provides also the electrical interconnection for those CCI devices (e.g. on the telescope and the CVV cover) which will be operated directly from the SVM or the EGSE during ground testing.

The HSS, consisting of the Sunshade (SSD) and the Solar Array (SA), protects the payload module from the sun irradiation. Mounted on the outer surface of the three equally dimensioned panels of the sunshield, the Solar Generator (SG) provides the spacecraft with the electrical energy required to keep the S/C alive and operating during it's mission in space.

Appropriate design requirements and design control will ensure that no EPLM electrical device will disturb the functional performance of any other equipment on the EPLM due to electromagnetic interference caused by exceeding their specified values of conducted or radiated electromagnetic emissions or susceptibilities. Furthermore electromagnetic compatibility of the EPLM with the SVM and the launcher will be provided by the above mentioned measures and will be verified by adequate testing.

The E-PLM electrical design consequently includes the following components:

- The Cryo Harness Subsystem consisting of :
  - The Cryostat Control Harness (CCH), including the Telescope Harness
  - The Scientific Instrument Harness (SIH), for the HIFI , PACS and SPIRE instruments
- The Cryostat Control system consisting of :
  - The Cryostat Control Unit (CCU)
  - The Cryostat Control Instrumentation (CCI)
- The Photo Voltaic Assembly (PVA) mounted on the solar array panels of the HSS

The Cryo Control Harness (CCH) is subdivided into a CVV internal, CVV external and SVM part. The CCH distributes the power and sensor signals between the SVM (CCU, PCDU and CDMU) and the cryostat instrumentation located on the telescope, SSD, CVV (ext.) and CVV (int.).The part of the CCH required for the operation (by the EGSE) of the cryo control instrumentation during ground testing and the pre-launch phase only, ends at the SVM interface connector bracket.

The Scientific Instrument Harness (SIH), also subdivided into a CVV internal, CVV external and SVM part, provides the electrical inter-connections between mounted instrument warm units and the HIFI, PACS and SPIRE cold units (FPU's) located on the optical bench assembly within the cryostat.

In addition the electrical inter-connections between the SVM mounted HIFI warm unit and the HIFI LOU, mounted externally on the CVV, is part of the SIH.

The schematic of the Harness Segments and major Harness Interfaces are shown below.

The Cryo Harness is divided in three main segments, as defined below.

	Cryo Control Harness (CCH) (for the cryo control instrumentation wiring to the SVM warm units)	**Scientific Instrument Harness (SIH)** (for the HIFI, PACS and SPIRE instruments)
CVV Internal	**CVV int. CCH** Between the CVV internal and the CVV feed through connectors.	**CVV int. SIH** Between the CVV internal instrument FPU's and the CVV feed through connectors.
CVV External	**CVV ext. CCH** Between the CVV external cryo control instrumentation respectively the CVV feed through connectors and the SVM interface connector bracket.	**CVV int. SIH** Between the CVV external HIFI LOU respectively the CVV feed through connectors and the SVM interface connector bracket
SVM	**SVM CCH** Between the SVM interface connector bracket and SVM warm units (CCU, PCDU and CDMU).	**SVM SIH** Between the SVM interface connector bracket and SVM instrument warm units of HIFI, PACS and SPIRE.

Table 10: Cryo Harness main segments

The Cryo Harness is further subdivided into individual harness bundles to respect the EMC class and redundancy requirements as well as to consider the S/S and AIV constraints during integration.

A comprehensive description of the Cryostat Control Unit (CCU), the Photo Voltaic Assembly (PVA) and the Cryo Harness is given in the component design description of section 12.

In summary the electrical system design provides:

- the necessary instrumentation for the in-flight monitoring and control of the cryogenic system
- the additional instrumentation for the monitoring and control of the cryogenic system during ground operation and testing
- the electrical interconnection between the instrument warm and cold units via the SIH
- the electrical interconnection between the SVM and the CCI on the telescope, the SSH, the CVV and the cryo cover via the CCH
- the electrical interconnection between the EGSE and the CCI on the telescope, the CVV and the cryo cover via the CCH
- the electrical interconnection between the CCU and the CCI on the SSD and the CVV (inside and outside) via the CCH
- the electronic unit for cryostat in-flight monitoring and operations
- the interfaces to the electrical ground support equipment (EGSE)
- the interface to Ariane 5 dry-loop interconnections via the umbilical
- the electrical power generation for the complete spacecraft
- the electrical interconnection between the solar generator and the SVM

An overview of the EPLM electrical system design, showing its components and their functional relationship, is given in schematic below (Figure 26).

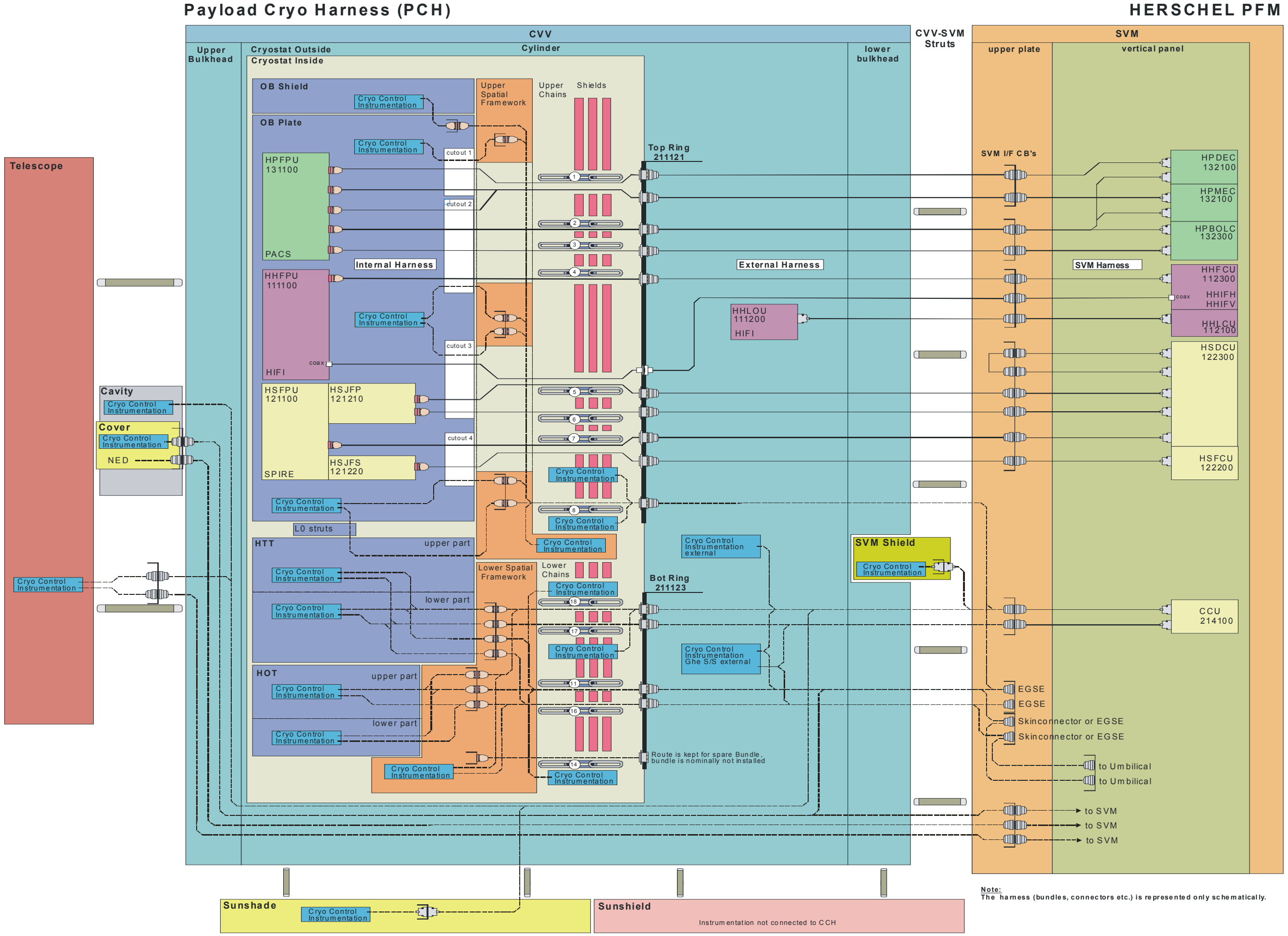


Figure 26: Overview of the EPLM Electrical System Design

5.9 EMC Concept

5.9.1 General

The EPLM design shall ensure electromagnetic compatibility between all equipment of the payload as well as compatibility of the complete integrated payload with the service module.

Both goals can be fulfilled for a PLM adequately designed for EMC

1. under consideration of the specific behaviour and characteristic of the equipment and in particular the restrictions imposed due to the requirements on the thermal design and the lifetime
2. in accordance with the applicable EMC requirements.

The payload overall interfaces and, in particular, their characteristics are defined and controlled in the applicable Instrument Interface Documents (IIDs) and the approach to guarantee and confirm overall EPLM EMC is described in [RD5].

5.9.2 Grounding and Bonding

The amount of negative potential that could be charged in L2 on isolated structures and on dielectric materials depends on the material characteristics, its geometry and location and on the charge exchange rate due to photoemission effect. In order to limit the amount of differential charging, we apply the same rules as are usually applied for a spacecraft operating in GSO:

- All electrical conductive structures (incl. e.g. CFRP, metalised tapes, OSRs conductive parts will be bonded to the satellite grounding reference, that is, no insulated electrically conductive part will exist.
- Dielectric surfaces will be minimised in thickness and exposed area in order to minimise the up-charging potential.
- The outer surface of the CVV has been black anodised. Although this is not usual for outer surfaces in the plasma environment, it is regarded acceptable (see the analysis in HP-2-ASED-RD-0009) because
  - external charge will not degrade the structure of the CVV, and
  - the instruments are OFF during transfer to L2

The proposed grounding scheme for minimization of pick-up noise as well as minimization of emission is the distributed Star point Grounding Concept as reflected in [RD6]. In general the principle is based on the use of single ended or differential driver interfaces in combination with differential receivers or opto-coupled interfaces. As a feature derived from ISO, there is no dedicated ground connection for the cryostat foreseen, i.e.: Grounding of the cryostat will be accomplished by overall shields between the cryostat and the SVM, i.e. by cable bundles overall shield and coaxial outer conductors only.

5.9.3 Harness Design Rules

The harness shall be designed to minimise emission of- and susceptibility to radiated electromagnetic fields and to minimise emission of- and susceptibility to conducted noise, once on the wires and shields. Therefore the following harness design rules exist:

- shielding effectiveness (SE) of shield to be maximized under consideration of the thermal constraints
- harness routing to be accomplished as close as possible to the structure for the minimization of structure loops
- intermediate grounding of the cable overall shields is favourable
- wire twisting to be applied
- wire pairs shall be impedance balanced (same cable lengths and type)
- cable lengths to be minimized

5.9.4 Payload EMC

The EMC related design and characteristics of the 3 scientific instruments as well as the influence of the cryostat and the harness has been assessed in the ASPI analysis document [RD4]. This document justifies also the adequacy of the existing CE/CS and RE/RS requirements in order to confirm the payload compatibility.

5.10 Mechanical Design

In this section the approach of the design development/analysis is described. Detailed design features are included in section 12 of this document. Detailed analysis results are part of the Structural Analysis Report ([RD38]) and the Stress Analysis Summary Report ([RD39]). Key test results of components are covered in the report: Mechanical Qualification and Properties of Procurement Items [RD40]. This section concentrates on

- Key mechanical design drivers
- structural analysis approach,
- basic analysis results

The mechanical verification approach is part of the AIV section.

5.10.1 Mechanical Design Drivers

The key drivers for the mechanical design are:

1. Launch environment including load and stiffness requirements,

2. Pressure loads on the HTT, HOT, CVV resulting from cryo system safety requirements,
3. Optimization of thermal behaviour.

The general design concept of the ISO cryostat is maintained. This means the TSS design and the basic dimensions, as the CVV diameter distance of the TSS chains of 891 mm remain unchanged.

The HTT design is driven by the pressure, resulting safety aspects of the cryo system. The driving cases are the latest opening of the burst disk at 3.06 and the external delta pressure of 1.05 bar, due to the potential failure of the CVV. The outer dimensions are defined by the overall dimensions of the CVV. The internal pillars are taking the axial load of the TSS pre-tension and the launch loads. The internal bulkhead is needed to increase the helium gas natural frequency.

The Optical Bench design is driven by the frequency requirement in order to avoid a coupling to the first global frequency of 34 Hz. The height of the plate the orientation of the ribs has been optimised.

The HSS design is mainly resulting from the shading function in orbit. Much effort has been spend to find a compromise between the maximum thermal insulation to the HSS to the CVV without getting a too low HSS frequency. Within several iterations a frequency of 24 Hz lateral for the HSS was defined as minimum acceptable HSS frequency to get an acceptable dynamic behaviour of the EPLM.

5.10.2 Summary of Mechanical Design

The structural analysis approach has changed from a top down to a bottom up analysis. This means:

1. Since PDR the structural mathematical model is completely revised. The initially ASED models of components are replaced by subcontractors mathematical models (with only few exceptions). Details can be found in [RD41]
2. The ASED stress analysis is replaced by the stress analysis made by the subcontractors. The summary of these analyses can be found [RD39].

With the CDR mathematical model the complete set of analysis has been repeated. The following shows an overview of the basic results and the documentation:

Analysis	Documentation	Major Results	Remark
Natural Frequency	See [RD43]	Frequency requirements are met. Frequencies of major modes are slightly higher. No significant change of dynamic behaviour	The frequency and stiffness requirements for the procurement items have been correctly implemented.
Responses Analysis	See [RD43] (primary results)	Results are compliant with the defined loads	

Analysis	Documentation	Major Results	Remark
	See [RD38] (comparison with specifications of components)	in the procurement specifications	
Static Analysis	See [RD38]	Results are compliant with the defined loads in the procurement specifications	
Distortion Analysis	See [RD45]	Results given as input to [RD15]	
Herschel Stress Analysis: Summary Report	See [RD39]	Margins are positive with the exception of local areas of the HSS	

Table 11: Structural Analysis Documentation Overview

All dynamic analysis has been performed using the SVM mathematical model, which means, that the documented dynamic properties are properties of the whole Herschel S/C.

5.10.3 Analysis Results

The EPLM design meets the mechanical requirements of the EPLM.

Nevertheless attention should be kept on the following mechanical behaviour.

- Potentially a notch of the second bending mode (26.5 Hz) is needed to avoid overtesting of HOT in lateral direction (7.5 g design load)
- The cross coupling in lateral direction during vibration tests in axial direction is significant (e.g. close the axial global mode at 37 Hz)
- High loads in the struts 6 and 7 in the orbital thermal distortion cases.

5.11 Thermal Design

The Herschel EPLM thermal design shall be able to provide the required instrument interface temperatures for at least 3.5 years mission lifetime and to provide a cold environment for the Telescope that must be lower than 90 K. The central part of the Herschel EPLM is the CVV which is mounted on the SVM. Externally the CVV carries the Telescope, the Herschel Solar Array and

Sunshade (HSS), as well as the LOU and the Star tracker. The CVV interior contains the Helium cooling system and the Optical Bench with the three instruments.

5.11.1 CVV External Thermal Control System

The basic task of the CVV external Thermal Control System is to minimise the temperature of the Cryostat Vacuum Vessel (CVV) and to provide a cold environment for the Telescope and the Local Oscillator Unit (LOU). The LOU has an own radiator to reject its dissipation to space. The overall thermal control configuration is shown in Figure 27.

The -z side of the CVV is black anodised, whereas the +z side is covered with MLI. The performance value of the black anodising is given in [RD28].

<u>Support Struts and Solar Array with Sunshade</u>

The CVV is thermally isolated mounted on top of the warmer SVM via 24 GFRP (S-glass) struts. The Herschel Solar Array and Sunshade (HSS) protect the CVV, the Telescope and the LOU from solar radiation. The front of the Sunshade is covered with OSRs to minimize the Sunshade temperature and consequently also the Telescope temperature. The front side of the Solar Panels is covered with solar cells to provide the electrical power. The HSS is attached to both the CVV with 8 GFRP struts and to the SVM with 4 CFRP struts (M55J) and 3 titanium tubes. The LOU together with its radiator is located at the –Y side of the CVV by means of 8 GFRP struts. The Telescope needs to be thermally isolated from the CVV especially during the decontamination phase where the Telescope shall be heated to 50°C for 3 weeks. 6 CFRP (T300) and 6 GFRP serve as thermal decoupling of the Telescope on the +X side of the CVV. A compilation of all support structures is given in Table 12. All struts are filled with polyurethane foam to suppress radiative heat exchange inside the tubes.

Assembly	attached to	Support Structure
CVV	SVM	24 GFRP (S-glass) struts
HSS	CVV	8 GFRP (S-glass) struts
HSS	SVM	4 CFRP (M55J) struts 3 Titanium tubes
Telescope	CVV	6 CFRP (T300) struts 6 GFRP (E-glass) struts
LOU	CVV	8 GFRP (E-glass) struts
LOU Waveguides	CVV	3 GFRP bracktes
LOU Harness	CVV	4 GFRP bracktes
SVM Thermal Shield	SVM	14 GFRP (E-glass) struts

Table 12: Herschel EPLM Support Structures

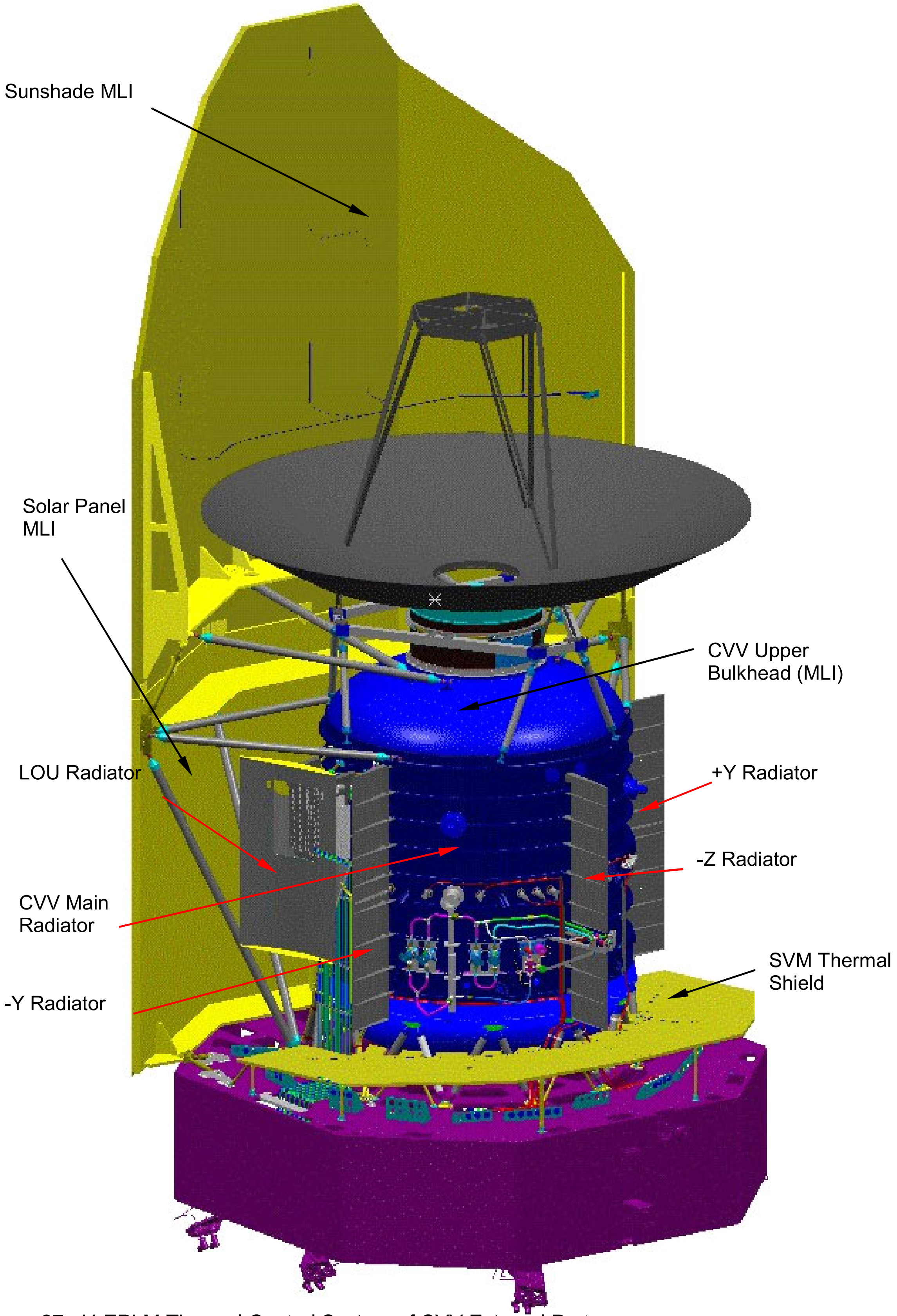


Figure 27: H-EPLM Thermal Control System of CVV External Part

CVV Radiators

To minimize the heat radiation from the warm HSS MLI to the CVV, the +Z half and the ±X side of the CVV is covered with MLI, the remaining area of the CVV serves as radiator. The area of this main radiator is about 4.5 m². To shadow the main radiator area from the warmer HSS MLI and to increase the radiator area, the CVV is equipped with three additional radiators made of Al 6063. These radiators are mounted on the -Z and ±Y sides of the CVV and provide a radiative area of about 1.7 m² in total. All radiator surfaces are black anodized to achieve an emissivity of about 0.8 at operational temperature [RD25].

External MLI and SVM Thermal Shield (V-Groove)

Except the CVV and LOU radiators, the LOU waveguides and part of the SVM/CVV struts, all EPLM surface is covered with MLI. All external MLI surface is of low IR emissivity and high specularity to reject parasitic heat to space via multiple reflections. Furthermore, a thermal shield is mounted on the SVM to shadow the CVV radiators and the Telescope rear side from the warm SVM top MLI and from the SVM side panels. This shield is tilted by about 5° and called the SVM Thermal Shield. The +X side of this shield is covered witha single foil and the –X side is covered with one Al-coated Kapton foil. Thus, the SVM Thermal Shield reflects also heat to space by multiple reflections (V-groove effect). Together with to the CVV radiators, the V-groove effects are mandatory to achieve a low CVV temperature of about 70 K.

CVV External Harness

The Scientific Harness (SIH) linked to the warm SVM is one of the main contributors to the CVV external heat load. The cross-sections and dissipation for the CVV external harness (between SVM and CVV) are summarized in Table 1 together with the Cryostat Control Harness (CCH) data. Copper is avoided as far as possible. Only the heaters for Telescope decontamination, LOU temperature stabilization and helium ventline heating (required for rapid depletion on ground) use copper harness. For EMC reasons all harness branches need overall shields. To minimize parasitic heat flows, those shields are manufactured out of Manganin wires with 0.05 mm diameter.

External Harness	Aver. Dissip.*	Stainl. Steel	Brass	Cu	SiO_2	Manganin	Teflon
(SIH)	mW/m	mm^2	mm^2	mm^2	mm^2	mm^2	mm^2
PACS FPU	2.9	37.536	5.131	-	-	17.52	367
SPIRE FPU	1.96	9.646	6.019	-	-	12.1	107
SPIRE JFETs	0.104	37.28	3.97	-	-	32.26	353
HIFI FPU	7.0	30.73	6.014	-	21 **	8.64	121
HIFI LOU	29	7.72	0.914	75.12	-	24.31	107
Telesc. Heater	0	0.384	-	8.0	-	3.24	11
CCH	~0	6.15	7.08	2.4	-	16.79	84

*) valid for 293 K, dissipation at lower temperature expected to be lower
**) dielectric material for HIFI coax cables

Table 13: Harness Dissipation and Cross-Section outside the CVV

The Scientific Harness and the Cryostat Control Harness are routed to the CVV connector brackets inside C-shaped aluminium profiles. The profiles are isolated from the CVV structure with Vespel washers, except the uppermost (+X) washer, which is made out of stainless steel for EMC reasons.

5.11.2 CVV Internal Helium Cooling System

Instrument Thermal Interfaces to Helium Cooling System

The Helium Cooling System provides four different temperature levels for instrument cooling:

The superfluid helium tank provides the lowest cooling temperature level at 1.65 K. This is called the “Level 0” interface. The evaporated helium leaves the tank in a ventline that is connected to the focal plane interfaces of the instruments. This part of the ventline is thermally decoupled from the Optical Bench Plate (OBP) by means of CFRP struts and represents the "Level 1" cooling interface at (3-6) K. The adjacent part of the ventline downstream is thermally well connected to the OBP and provides the "Level 2" cooling interface at (8-12) K, see Figure 28. Before the remaining ventline is then connected to the three thermal shields, a "Level 3" cooling interface has been introduced to cool the SPIRE JFETs to a temperature of about 15 K.

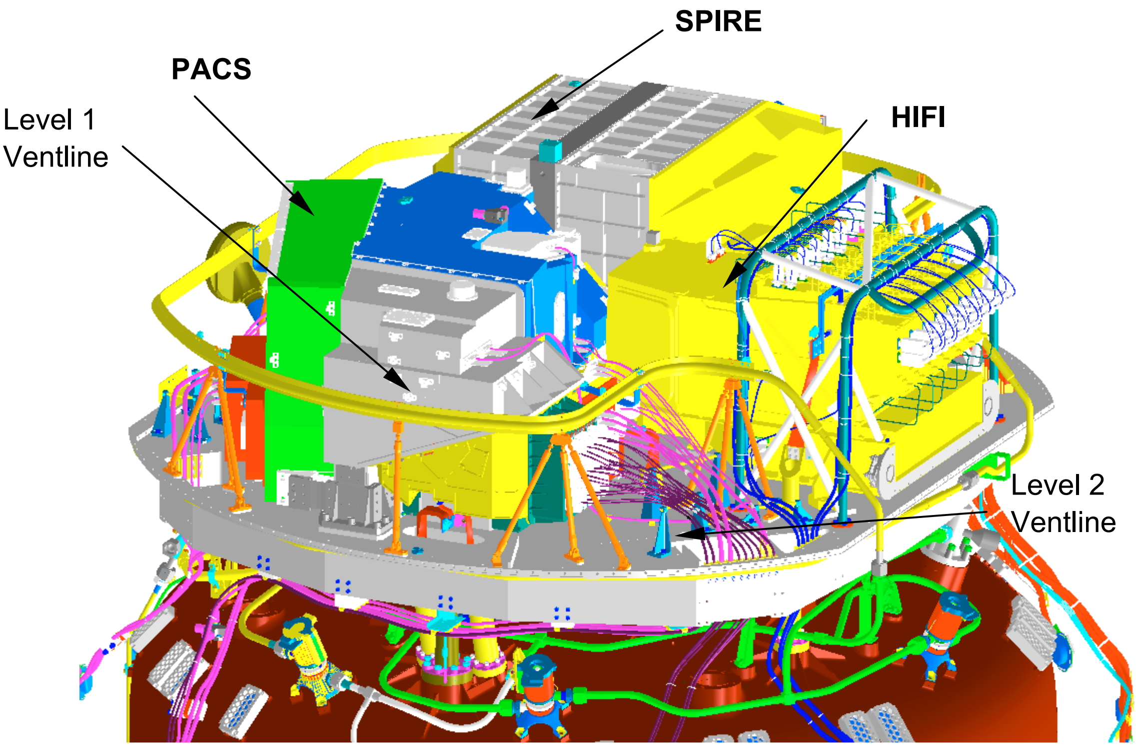


Figure 28: Level 1 and Level 2 Ventline Design

The PACS Focal Plane Unit (FPU) structure is thermally decoupled from the OBP via CFRP T300 feet and is cooled via three copper cooling straps connected to the Level 1 ventline. The SPIRE FPU structure is also thermally decoupled from the OBP and is cooled via two copper cooling straps connected to the Level 1 ventline downstream after the PACS straps. The HIFI FPU structure is directly mounted, i.e. thermally well connected to the OBP which itself is cooled via the Level 2 ventline. The HIFI FPU requires also an interface to the Level 1 temperature that is provided by a cooling strap attached to the ventline downstream after the SPIRE Level 1 interface.

The SPIRE instrument requires 3 separate Level 0 interfaces: for the 3He cooler evaporator, for the 3He cooler pump and for the detector enclosure structure. PACS requires 4 separate Level 0 interfaces: for the 3He cooler evaporator, for the 3He cooler pump, for the "Red Detector" and for the "Blue Detector". HIFI requires one Level 0 interface only.

All rigid parts of the L0-cooling links consist of tubular circular bars made of aluminium Al 1050 with about 70 W/mK at 1.7 K. They have identical flanges that are mounted to the helium tank wall via 8 x M5 screws in order to achieve adequate thermal contact couplings. The flexible parts consist of packages of thin copper foils adapted to the appropriate instrument L0 interfaces. Each copper foil package is pressure welded at its ends.

During the C/D phase it turned out that for the 3He cooler evaporator for PACS and SPIRE the conductance to the Level 0 need to be improved significantly. Seeing that the finally required thermal conductance to the helium cannot be provided by a design with the tank wall thermal resistance in between, additional “open pods” have been introduced for these interfaces in parallel to the already existing solid pods. The “open pods” are made out of Al 6063 and are connected to flanged openings located on the HTT in the vicinity of the solid ones. An elongated end of the flexible copper part interconnects both ends. These hollow pods will be filled with superfluid helium in orbit (without gravity) and on ground by tilting.

Tank Suspension System

The tank suspension principle of using CFRP and GFRP straps is taken from the ISO heritage. The detailed design for Herschel is shown in Figure 30. The material selection is based on a trade-off considering the thermal and mechanical properties versus temperature [RD29]. For the trade-off also the cryostat thermal behaviour on ground played an important role. In this case the CVV is at room temperature (293 K) and the thermal shields are much warmer than in orbit. Finally, the two innermost straps are made out of CFRP T300 and for the remaining two straps GFRP (S-glass) is used.

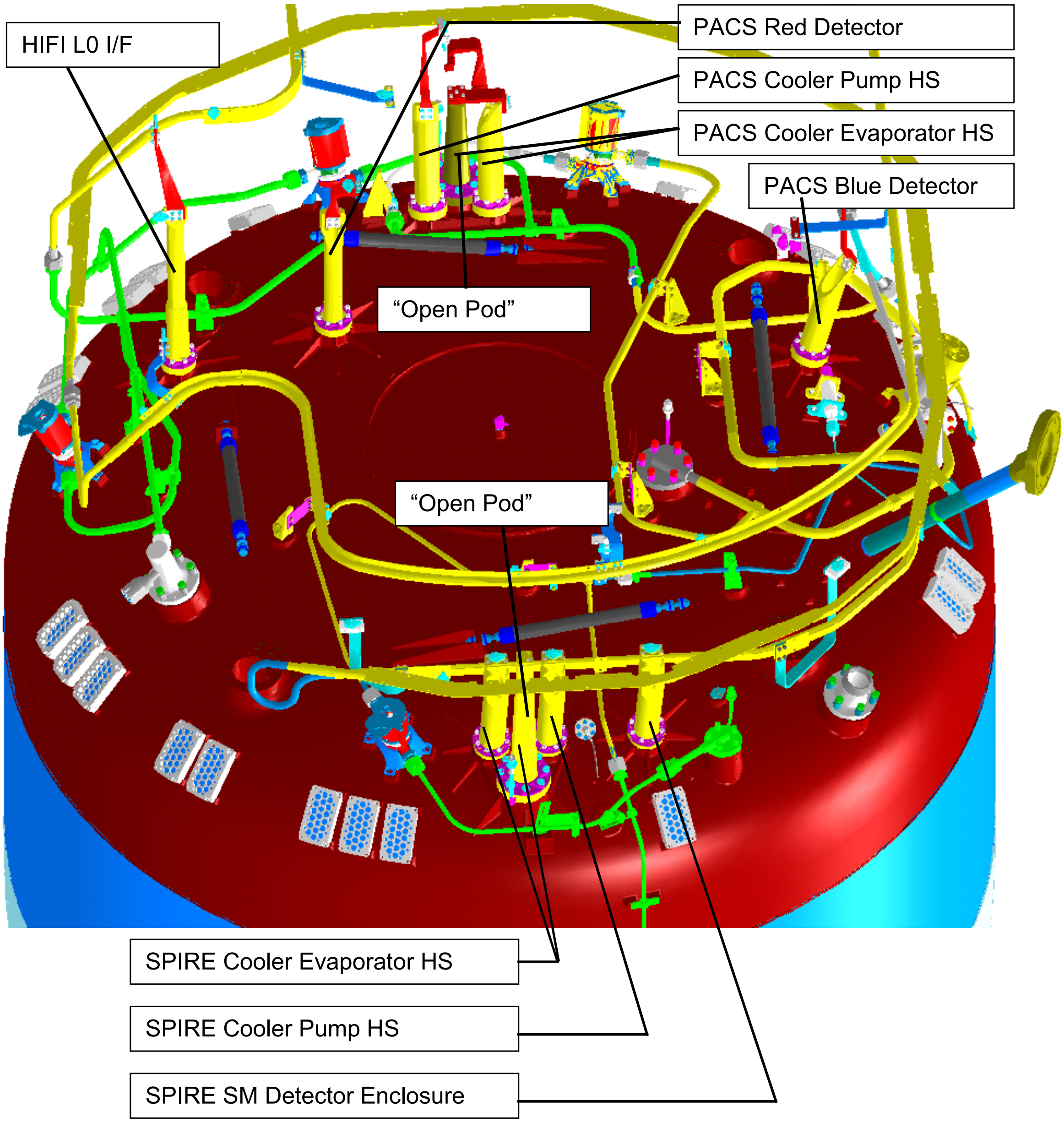


Figure 29: Instrument Thermal Links to HTT (Level 0)

Vapour-cooled Thermal Shields and MLI

To minimize the thermal leak to the helium tank, three helium vapour-cooled shields made of aluminium Al 6061 are arranged between the warm CVV structure (70 K) and the helium tank (1.65 K). The shields are attached to the Tank Support Suspension straps and intercept the incoming heat from the straps. The beam entrance baffle and the LOU entrance baffle are thermally connected to the intermediate Thermal Shield (TS 2), see also Figure 30. The inner sides of the shields are polished to achieve an emissivity of about 0.03. The thermal shield outer sides are covered with crinkled, non-spacered MLI.

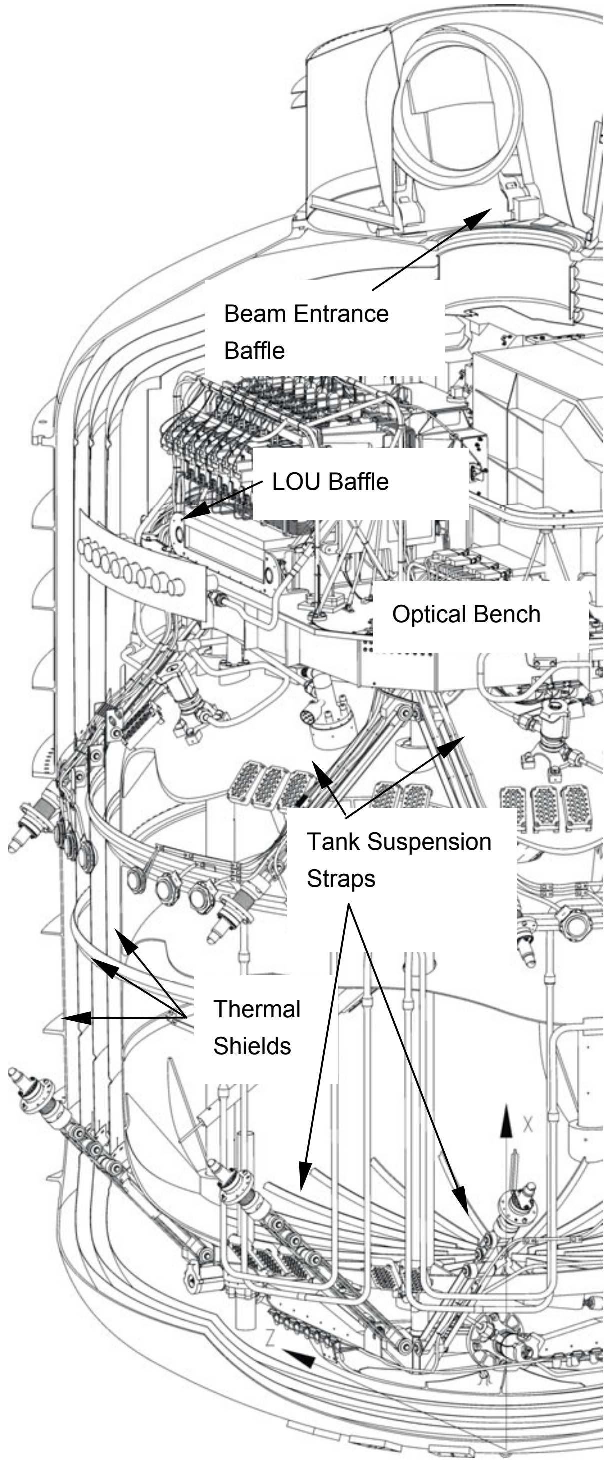


Figure 30: Thermal Shields and Tank Suspension

Thermal Design of CVV Internal Harness

The Scientific Harness (SIH) is the main contributor to the CVV internal heat load. Therefore, it was mandatory to avoid the use of high conductive copper wires but use brass and stainless steel wires only. Also for the HIFI coax cables a design solution could be found without using copper. The cross-sections and dissipation for the CVV internal harness is summarised in Table 14 together with the Cryostat Control Harness (CCH) data. To reduce the heat load to the Optical Bench all FPU harness is thermally anchored at the innermost Thermal Shield (TS 1). Furthermore, all FPU harness is thermally anchored on the Optical Bench Plate (OBP) to reduce parasitic heat conduction to the FPUs themselves. Since the SPIRE JFETs are thermally connected to Level 3 and isolated from the OBP (Level 2), this harness need not to be anchored at the TS 1 and must not be anchored at the OBP. The JFET harness brackets at the OBP are therefore isolated with Vespel washers.

Internal Harness (SIH)	Average Dissip. *	Stainl. Steel	Brass	SiO_2	Teflon
	mW/m	mm^2	mm^2	mm^2	mm^2
PACS FPU	4.32	37.594	5.1	-	367
SPIRE FPU	1.186	11.068	6.216	-	107
SPIRE JFETs	0.041	47.646	1.441	-	412
HIFI FPU	4.55	30.805	6.014	21 **	123
CCH	~0	4.888	3.068	-	59

*) valid for 77 K, dissipation at lower temperature expected to be lower

**) dielectric material for HIFI coax cables

Table 14: Harness Dissipation and Cross-Section inside CVV

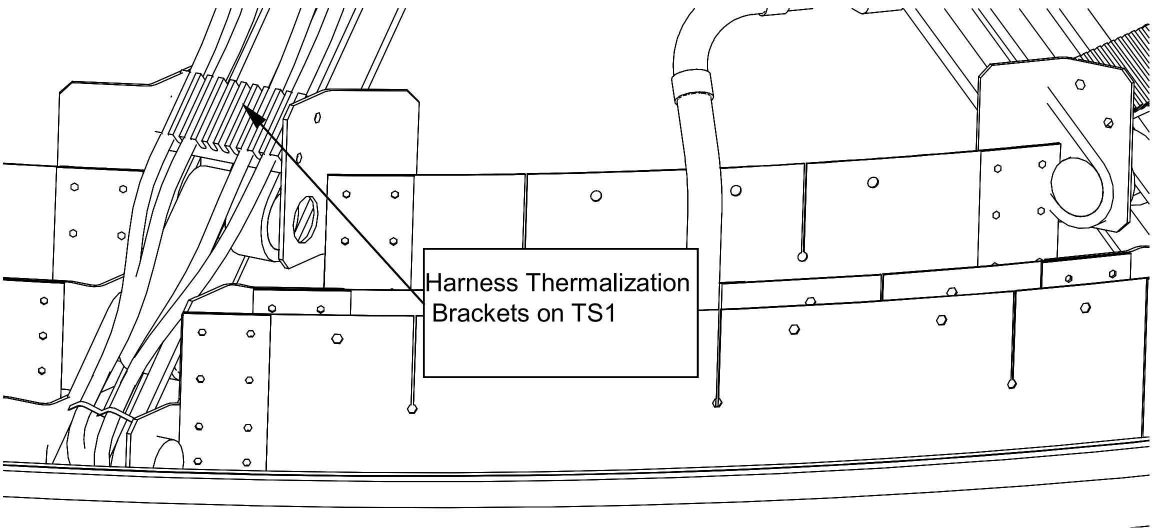


Figure 31: Harness Thermalization on Thermal Shield 1

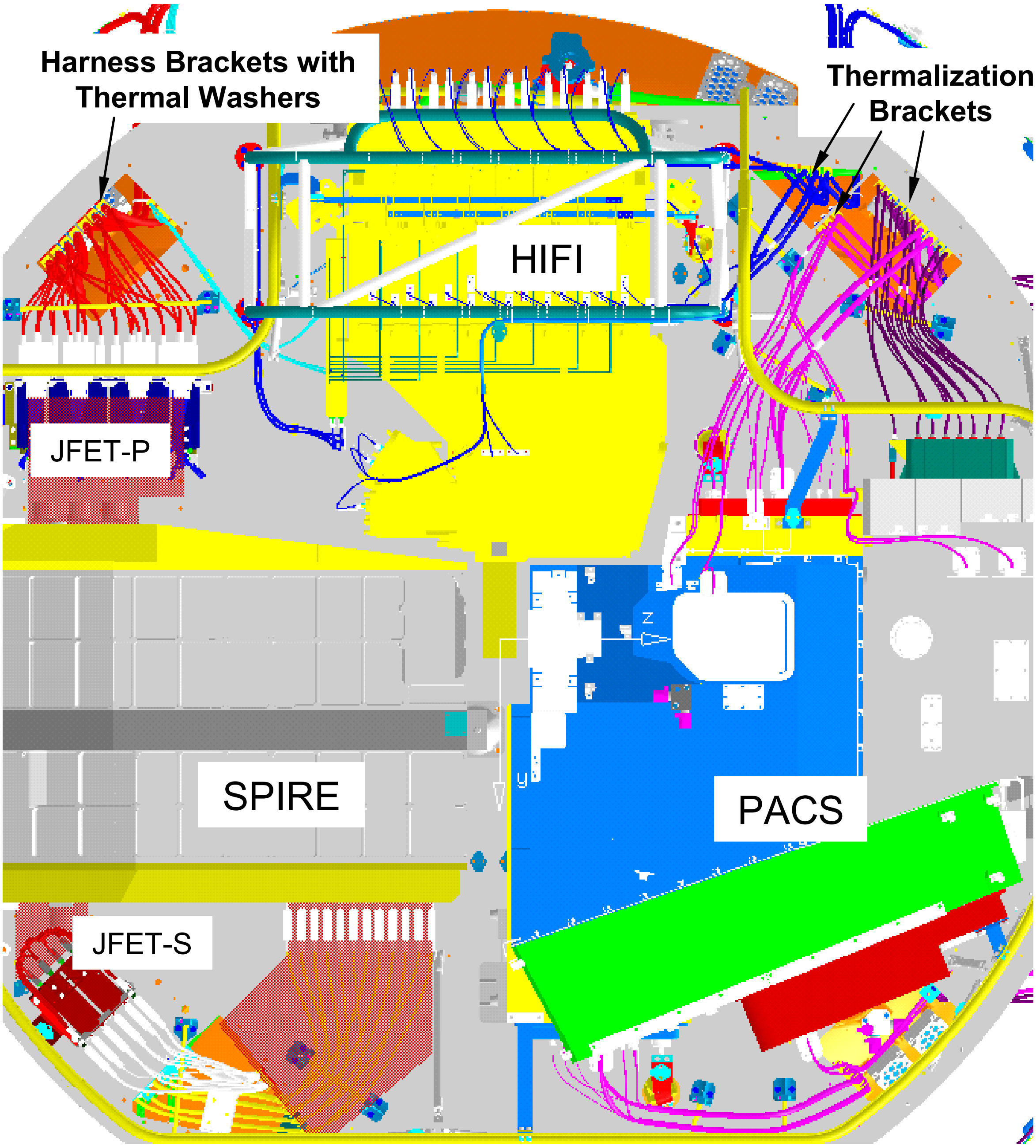


Figure 32: Harness Thermalization on OBP

5.12 The Major Changes Since PDR

5.12.1 The Major Changes of the Overall Configuration

L0 thermal links requirements and design

- Introduction of open tank with open pods.

L3 thermal links to JFETs

- JFETs are isolated from OB plate and are connected to the extension of the ventline.

Cryo Cover Mirrors

- Cooled mirrors have been introduced to simulate the thermal background of the telescope for ground testing. Cooling is performed by Liquid Helium or Liquid Nitrogen.

Extension of HTT by 100mm

- To increase the lifetime of the Herschel mission the HTT has been extended by 100mm which allows to increase the He mass by approx. 8%. This extension has a design impact on the following items:
  - HTT
  - Thermal shields and MLI
  - CVV
  - HSS
  - External MLI

Shape of HSS

- The elongation of the HTT and the requirement HERS-0092 has necessitated a new shape of the sun shade.

SPIRE Over-shields and Faraday interconnection method

- New requirements for CVV internal double shielding and the Faraday interconnection method have been introduced and implemented in the harness design.

5.12.2 The Major Changes of the Cryogenic System

Helium control system

- The position of the pressure sensor P502 has been changed to the inlet to the nozzles N511/512 in order to measure directly the inlet pressure of these nozzles. Together with temperature information on the external vent line this should be a better possibility to determine the in orbit mass flow.

- The temperature sensor type inside the vent line heater H501 has been changed from one thermocouple to two Pt1000, because of redundancy and the possibility of measurements over long distances/ several interconnections (launcher umbilical).
- Several components (SV123/723, H501, Filling Port assembly, PPS) are now equipped with flanges, avoiding welding during integration (inside clean room), allowing easy exchange with spare parts.

Thermal interfaces to the FPU

- Due to increased requirements on the Level 0 thermal conduction two additional connections to the helium inside the HTT have been introduced (open Pods).
- The other Level 0 I/Fs to the HTT have now tank internal Pods extensions in order to improve FPU ground testing flexibility.

Helium Two Tank

- Tank volume increased to 2367 l

6 Performance and Budgets

6.1 Operational Lifetime

The lifetime has been calculated according to [RD25] leading to the following results:

Lifetime calculated with IID-A [AD1] heat load allocations:

Best case Lifetime:	4.47 years
Nominal Lifetime:	4.06 years
Worst case Lifetime:	**3.72 years** (contractual)

Lifetime calculated with Instrument Reduced TMM‘s (IID-B´s, [AD2], [AD3] and [AD4]):

Best case Lifetime:	4.73 years
Nominal Lifetime:	4.32 years
Worst case lifetime:	3.98 years

6.2 Thermal Performance

Status description as per CDR, see [RD19].

6.2.1 Heat Flow Charts

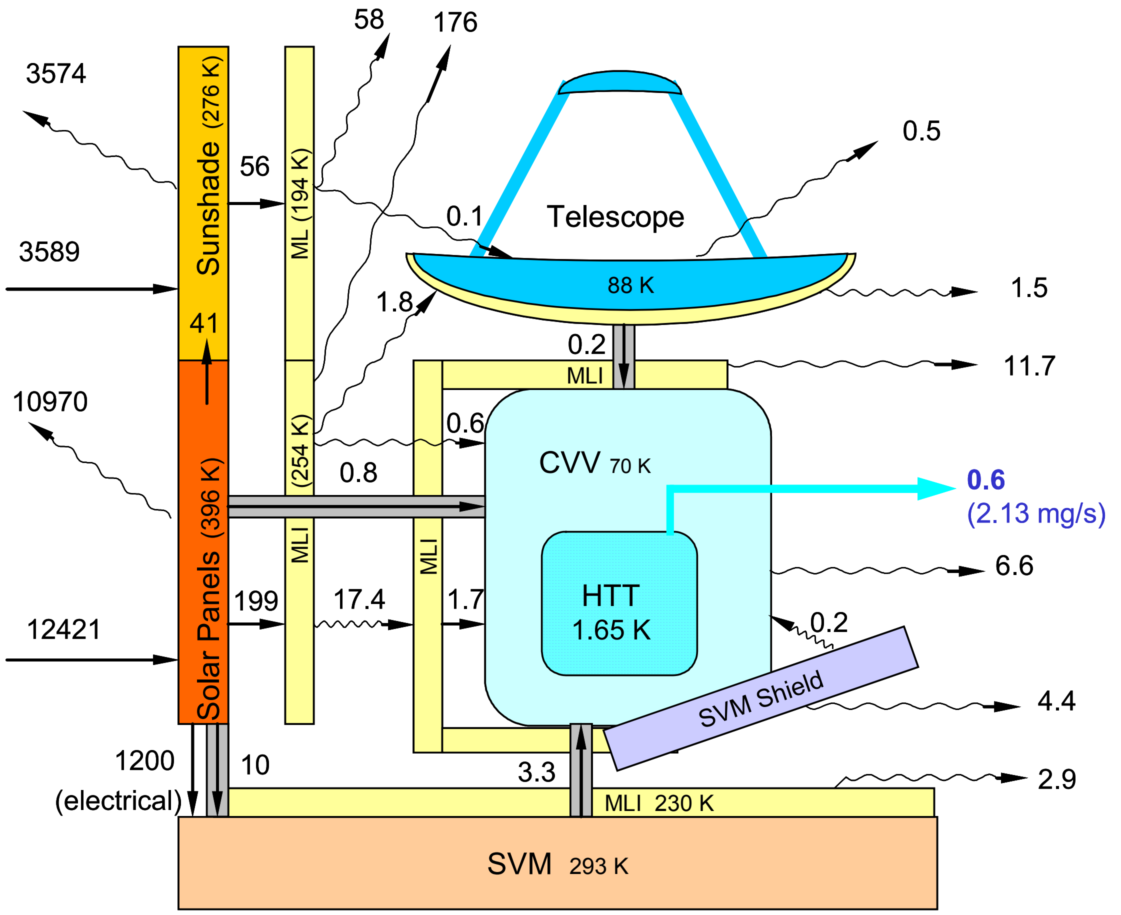


Figure 33: CVV External Heat Flow Chart (in [W]) for Hot Case Environment at L2 Orbit

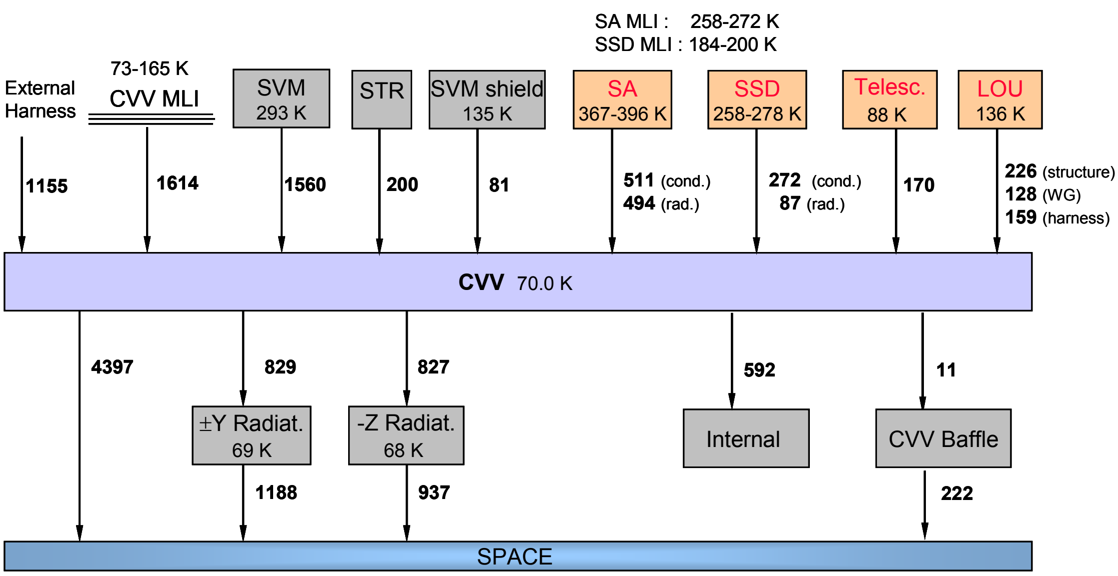
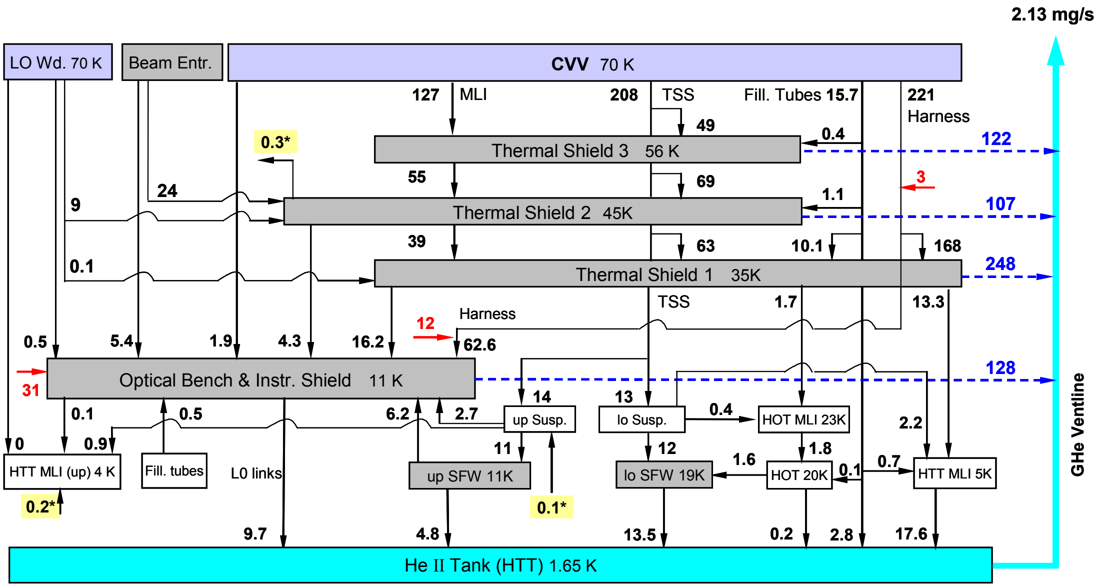
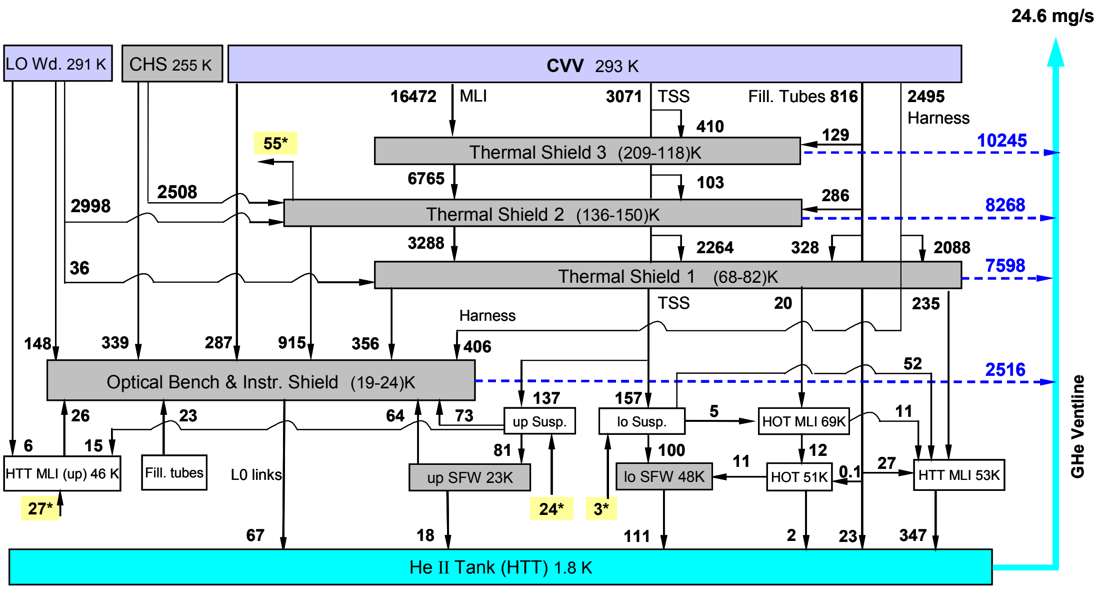


Figure 34: CVV Heat Flow Chart (in [mW]) for Hot Case Environment at L2 Orbit



Only main paths are shown. All values are in [mW]

Figure 35: HPLM internal Heat Flow Chart for Average Instrument Dissipation and Hot Case Environment at L2 Orbit



Only main paths are shown. All values are in [mW]

Figure 36: CVV Heat Flow Chart for On-Ground Environment

6.2.2 EPLM Temperatures

Item	Node	T, cold case [K]		T, hot case [K]	
SA MLI, center panel	[7100]	253	+19 / -32	270	+20 / -34
SA MLI side panel	[7101]	241	+18 / -30	258	+19 / -32
SSD MLI, center panel	[7160]	157	+11 / -18	196	+15 / -25
SSD MLI side panel	[7161]	148	+10 / -16	184	+14 / -23
Telescope	[8000]	78.3	+4 / -6	87.8	+5 / -6
LOU support plate	[4200]	132	± 2	136	± 3
Solar Array, center panel	[7000]	371		396	± 5
Solar Array, side panel	[7001]	352		376	± 5
SSD (OSR's), center panel	[7060]	219		276	± 11
SSD (OSR's), side panel	[7061]	205		258	± 11
SVM Thermal Shield	[6204]	122		135	± 3

Table 15: EPLM Temperatures with uncertainties in L2 Orbit

In case the solar cells are in shunt mode and all absorbed solar energy is dumped in the Solar Array, the temperature of the center panel increases to 409 K (136°C).

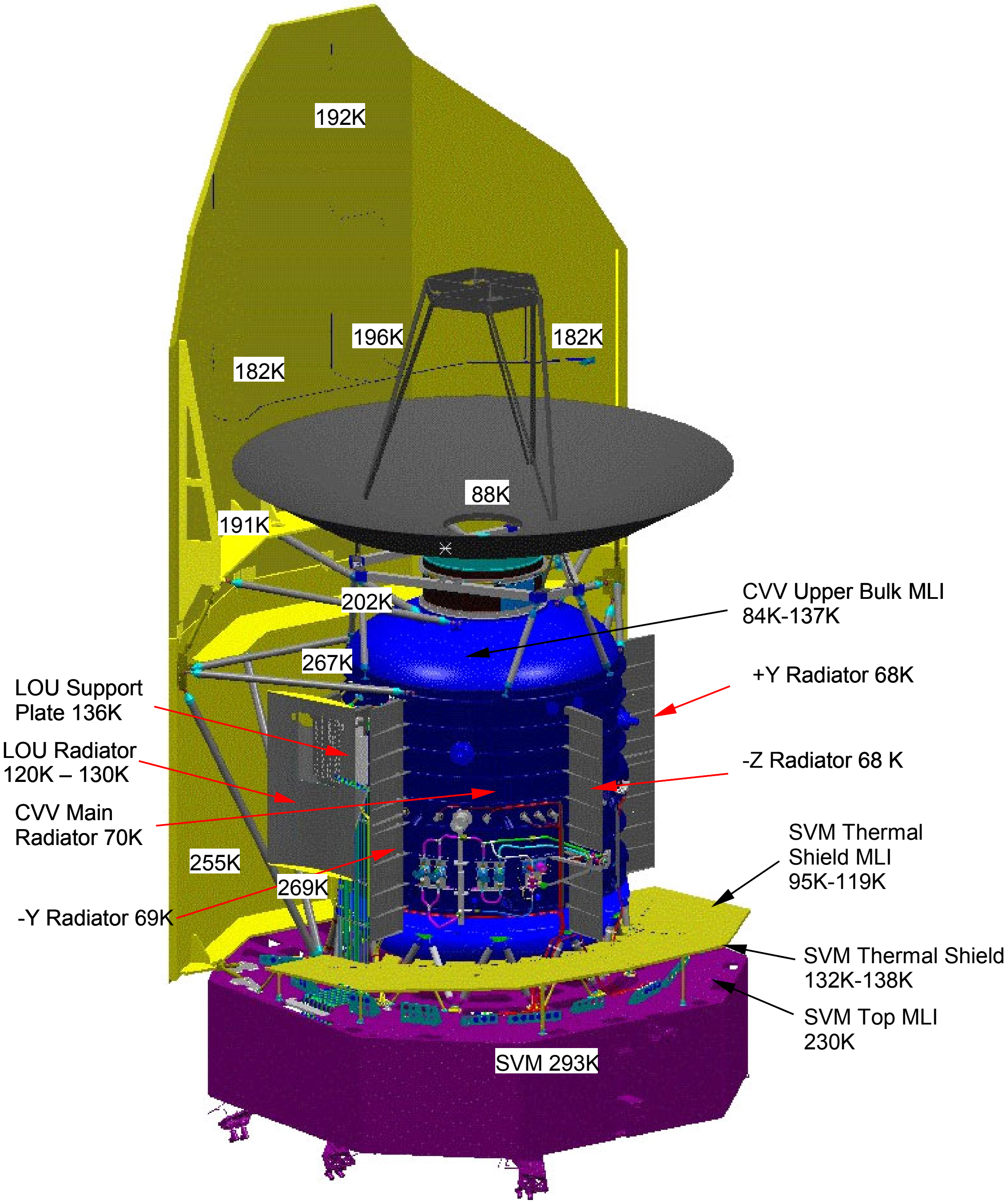


Figure 37: H-EPLM Temperature Distribution for Hot Case Environment at L2

6.2.3 Instrument Interface Temperatures

	Interface	I/F Requirement		Node	Analysis Results	
		Heat Load	Temperature		2.1 mg/s	2.2 mg/s
Level 0	PACS Red Detector	0.8 mW	1.6 K … 1.75 K	721	1.68 K ±0.06K	1.68 K ±0.06K
	PACS Blue Detector	2.0 mW	1.6 K … 2 K	723	1.73 K ±0.06K	1.73 K ±0.06K
	PACS Cooler Pump	2.0 mW	1.6 K … 5 K	761	1.73 K ±0.06K	1.73 K ±0.06K
		500 (peak) mW	1.6 K … 10 K		12.0 K ±0.06K	12.0 K ±0.06K
	PACS Cooler Evapor.	15 mW	1.6 K … 1.85 K	762	1.796 K ±0.06K	1.796 K ±0.06K
	SPIRE Detector	4 mW	< 2 K	814	1.74 K ±0.06K	1.74 K ±0.06K
		1 mW (goal)	< 1.71 K (goal)		(1.68 K ±0.06K)	(1.68 K ±0.06K)
	SPIRE Cooler Pump	2 mW	< 2 K	815	1.69 K ±0.06K	1.69 K ±0.06K
		500 mW (peak)	< 10 K (peak)		9.77 K ±0.06K	9.77 K ±0.06K
	SPIRE Cooler Evap.	15 mW	< 1.85 K	816	1.70 K ±0.06K	1.70 K ±0.06K
		15 mW (goal)	< 1.75 K (goal)			
	HIFI Detector	6.8 mW	< 2 K	949	1.96 K ±0.06K	1.96 K ±0.06K
Level 1	PACS FPU	30 mW	2 K … 5 K	781	3.60 K ±0.18K	3.55 K ±0.18K
				782	4.34 K ±0.18K	4.24 K ±0.18K
				783	4.57 K ±0.18K	4.43 K ±0.18K
	SPIRE FPU	15 mW	< 5.5 K	800	4.43 K ±0.35K	4.22 K ±0.35K
		13 mW (goal)	< 3.7 K (goal)			
	HIFI L1	15.5 mW	< 6 K	939	5.77 K ±0.32K	5.37 K ±0.32K
Level 2	OBP near PACS	0 mW	< 12 K	371	11.8 K ±0.5K	10.9 K ±0.5K
	OBP near SPIRE	0 mW	< 12 K	381	11.4 K ±0.5K	10.6 K ±0.5K
		0 mW (goal)	< 8K (goal)			
	Instr. Shield / SPIRE	0 mW	< 16 K	315	11.5 K ±0.5K	10.6 K ±0.5K
	HIFI FPU	22 mW	< 20 K	919	13.3 K ±0.5K	12.4 K ±0.5K
Level 3	SPIRE PM-JFET	50 mW	< 15 K	831	16.1 K ±0.5K	15.1 K ±0.5K
	SPIRE SM-JFET	25 mW	< 15 K	832	14.6 K ±0.5K	13.7 K ±0.5K
LOU	LOU (HIFI)	7000 mW	90 K …150 K	4200	(132-136) K* ±3K	

*) cold-hot case environment at L2

Table 16: Calculated Instrument Temperatures for IID-B Allocations, Hot Case Conditions at L2

6.3 Structure

6.3.1 Mass, COG and MOI

The following table summarises the mass of the H-EPLM (status as per CDR).

Item Description	Nominal Mass kg	Mass with Margin kg
Sum H-EPLM dry	1383,51	1475,98
He 2 Tank filling 98 %, 2367 ltr.	336	336
Unfilled, with Instruments and Telescope	1907,63	2000,68
Filled, with Instruments and Telescope	2243,63	2336,68
Filled, without Instruments, without Telescope	1719,51	1811,98
Required Mass		1825

Table 17: H-EPLM mass budget

The position of the centre of gravity and the moment of inertia are summarised in Table 18.

CoG [mm] at H-EPLM wet (with He II) given in S/C coordinate system:			
	Mass (w/o contingency): 2227,9 kg	**Mass (with contingency): 2335,3 kg**	**Requirement**
COG_x	2673,9	2667,1	-
COG_y	-30,9	-29,8	0 -> -40 mm
COG_z	49,5	58,6	< 70 mm

CoG [mm] at H-EPLM dry (w/o He II) given in S/C coordinate system		
	Mass (w/o contingency): 1892 kg	**Mass (with contingency): 1999.4 kg**
COG_x	2782,8	2769,0
COG_y	-36,7	-35,1
COG_z	69,8	79,3

MoI [kg m²] at H-EPLM wet (with He II) - with contingency (based on mass of : 2335.3 kg)			
MOI_xx =	2183.9	MOI_xy =	-12.7
MOI_yy =	4102.1	MOI_xz =	386.4
MOI_zz =	3940.5	MOI_yz =	4.8

Table 18: H-EPLM CoG and MoI

6.3.2 Frequencies

The actual frequencies and frequency requirements are summarised in [RD38].

Item	Requirement in [AD1]	CDR Status Design	Remark
HSS hard mounted lateral	24 Hz	24.7Hz 28.8 Hz	The “critical” bending mode is the second mode with 26 Hz.
axial	70 Hz	70.7 Hz	Axial modes are split into different modes with axial effective masses.
Telescope including mounting structure	36 Hz	37.4 Hz	
Herschel S/C axial	34 Hz (target 35 Hz)	37.0 Hz	
Herschel S/C lateral	13 Hz	14.2 Hz	

Table 19: Comparison of analysed frequencies with the requirements

6.3.3 Margins of Safety

The actual margins of safety are reported in [RD38].

6.4 Power

The results of the PVA reference design performance prediction are summarized in the Table 20 below.

CASE	Performance	Solar Aspect Angle: 0 deg.				Solar Aspect Angle: 30 deg.			
		Center Panel	Side Panels	Total Power	Requirement	Center Panel	Side Panels	Total Power	Requirement
BOL, WS, LEOP 1424 W/m², non-op.	**Power/W** **Temp./°C**	- 137	- 115						
BOL, SS, LEOP 1328 W/m², operating	**Power/W** **Temp./°C**	643 122	562 100	**1767**	**1700**				
BOL, WS, LEOP 1424 W/m², operating	**Power/W** **Temp./°C**	732 128	640 105	**2012**					
EOL (3.5y), SS, L 2 1287 W/m², operating	**Power/W** **Temp./°C**	590 119	526 97	**1642**		516 106	460 86	**1436**	**1400**

CASE	Performance	Solar Aspect Angle: 0 deg.				Solar Aspect Angle: 30 deg.			
		Center Panel	Side Panels	Total Power	Requirement	Center Panel	Side Panels	Total Power	Requirement
EOL (3.5y), WS, L 2 1424 W/m², operating	**Power/W** **Temp./°C**	626 129	564 107	**1754**		569 115	513 95	**1595**	
EOL (6.0y), SS, L 2 1287 W/m², operating	**Power/W** **Temp./°C**	531 122	929 100	**1460**		480 108	847 88	**1327**	**1230**

Table 20: PVA performance prediction

6.5 Field of View

The overall configuration of the beam entrance is shown in Figure 38. The following figures (Figure 39 and Figure 40) indicate the field of view of the instrument and the clearance to the different structural items.

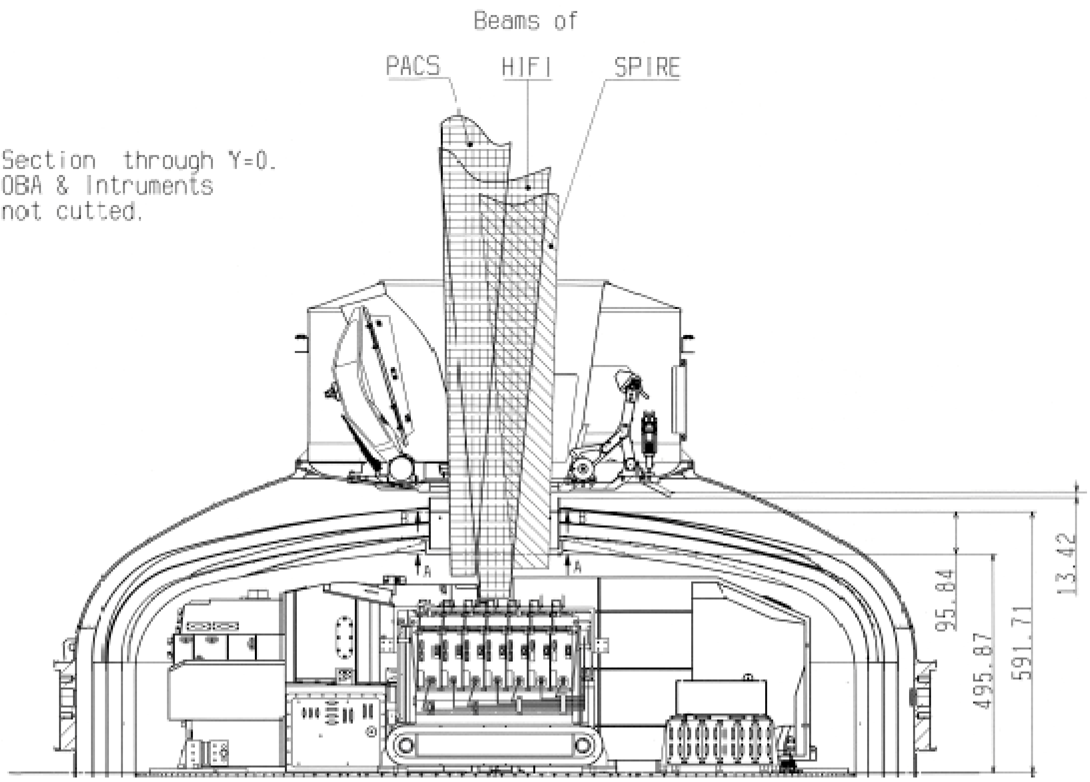


Figure 38: Overall configuration of beam entrance

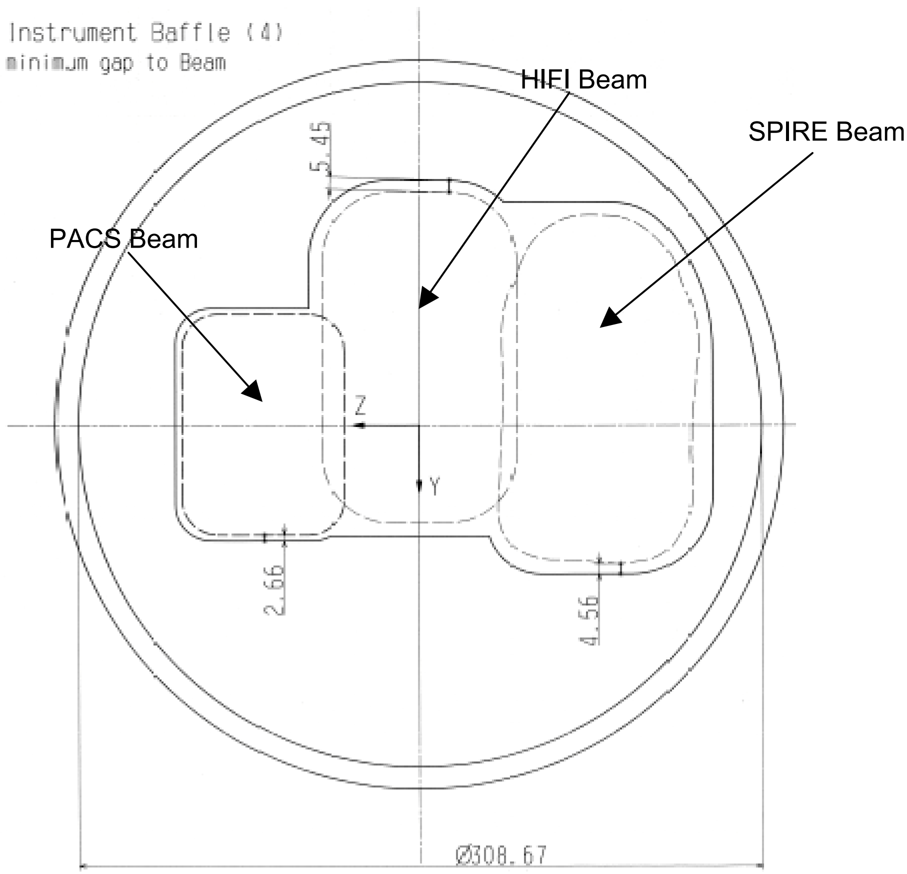


Figure 39: Instrument Beam at Instrument Shield Aperture (x=495.86 from focal plane)

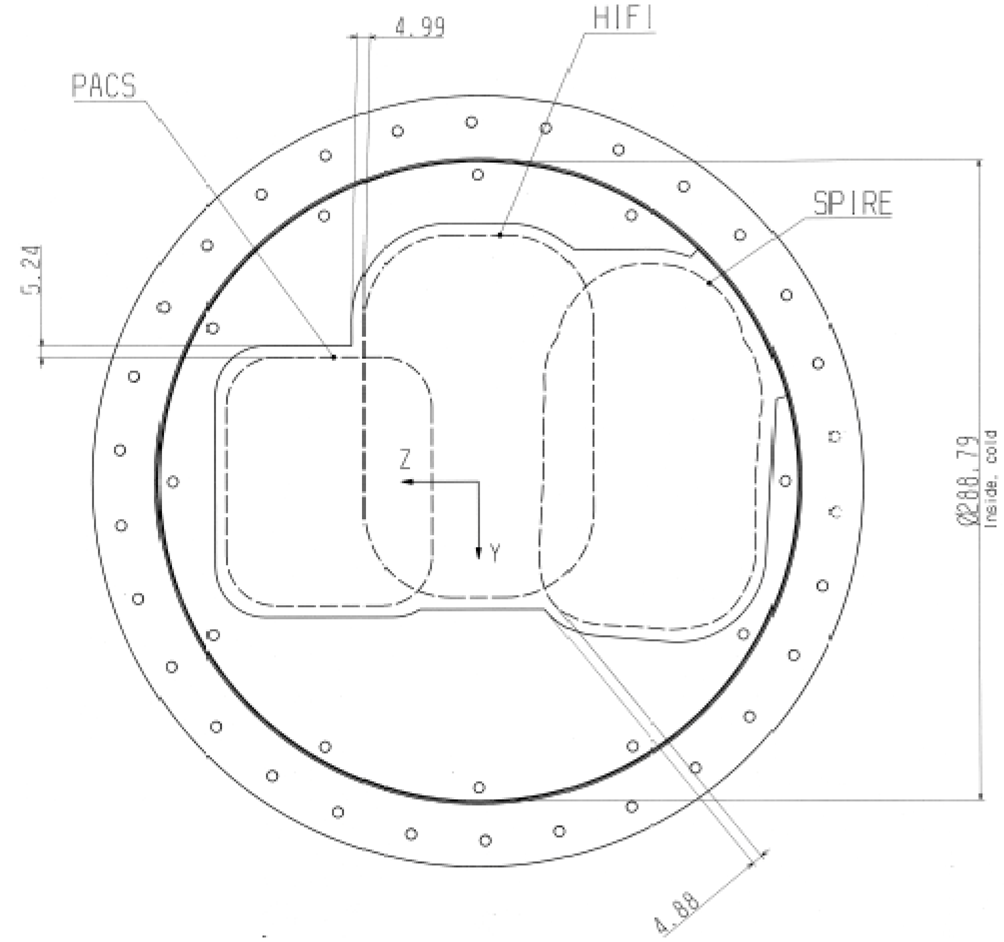


Figure 40: Instrument Beams at TS2 entrance baffle Aperture (591.7mm from focal plane)

6.6 Alignment

The following tables summarise the achievable alignment results. The values are compared to the requirements (all values are±).

6.6.1 Instruments w.r.t. Telescope

The table below summarises the alignment errors for each instrument in axial and lateral directions.

Table 21: Alignment Budget: Instrument w.r.t. Telescope

	Focus Alignment (x mm)			Pupil Mismatch (lateral mm)		
	PACS	SPIRE	HIFI	PACS	SPIRE	HIFI
Achievable Value	5.1	5.0	7.4	3.7	4.1	16.3

Requirement	7.0	7.7	8.5	7.0	9.5	24.0

6.6.2 LOU w.r.t. HIFI FPU

The table below provides the alignment errors for the alignment of the LOU to the HIFI FPU.

Table 22: Alignment Budget: LOU w.r.t. HIFI FPU

	Δx (mm)	Δy (mm)	Δz (mm)	Rx (arcsec)	Ry (arcsec)	Rz (arcsec)
Achievable Value	0.64	0.83	0.62	90.9	Incl. in x	98.5
Requirement	0.75	15.0	0.75	137	Incl. in x	137

The following table provides the achievable stability values of the LOU w.r.t. HIFI.

Table 23: Alignment Stability Budget: LOU w.r.t. HIFI FPU

	Δx (mm)	Δy (mm)	Δz (mm)	Rx (arcsec)	Ry (arcsec)	Rz (arcsec)
Achievable Value 1)	0.0074	0.00001	0.0038	0.070	0.16	0.10
Requirement	0.075	0.003 2)	0.075	10.8	144	10.8

1) Calculated for LC1-LC2 steady state analysis, expect for Δy where transient calculation has been performed
2) Within 100sec. The very high stability along the y axis should be regarded as a goal (according to HIFI IID-B, [AD3])
It is expected that the **goal** value of 0.003mm/100sec. can be achieved because the temperature change of the LOU baseplate takes about 2 days.

6.6.3 Line of Sight Stability

The line of sight stability requirements and achievable values are summarised in

Table 24: Line of sight stability requirements and achievable values

	Requirement	Achievable Value	Remark
PACS LOS w.r.t. PLM SVM I/F	5 arcmin	111.1 arcsec	Bias
Around LOS Instrument w.r.t. PLM /SVM I/F	12 arcmin	51.5 arcsec	Bias

	Requirement	Achievable Value	Remark
Around LOS Instrument w.r.t. PLM /SVM I/F	0.5 arcmin	21.1 arcsec	Knowledge 1б value
SPIRE & HIFI LOS w.r.t. PACS LOS	3.6 arcsec	8.4 arcsec (HIFI) 1) 6.8 arcsec (SPIRE)	Knowledge
LOS stability w.r.t. CVV/STR I/F plane	0.4 arcsec, y, 1month pp 0.2 arcsec, z, 1month pp ±0.1 arcsec, all, 1min	Ry= 0.26 arcsec Rz= 0.026 arcsec R ≤ 0.00005 arcsec	0.25 arcsec goal 0.1 arcsec goal ±0.02 arcsec goal
CVV/STR I/F plane w.r.t. SVM /PLM I/F plane Stability	30 arcsec , each axis pp	Rx= 2.2 arcsec Ry= 86.3 arcsec 2) Rz= 1.6 arcsec	Incl. all effects between lift-off and operational mission
CVV/STR I/F plane w.r.t. SVM /PLM I/F plane Stability	6 arcsec, each axis, 1month	Rx= 0.45 arcsec Ry= 0.62 arcsec Rz= 0.85 arcsec	During observation phase

1. Requirement of 3.6 arcsec not achievable, but improvement seems possible (see [RD7], RFD to be issued, see [RD50])
2. Requirement of 30 arcsec not achievable for Ry, RFD to be issued, see [RD50].

6.7 Straylight

a) Thermal self emission

The following table provides the calculated thermal self-emissions onto PACS and SPIRE detectors in relation to the self emission of M1 plus M2, as reference the 'standard telescope' with total emissivity of 0.03 and temperature 70 K is used. This self emission of M1 plus M2 is set to 100 (used as normalisation). So the specification is violated, if the sums exceed 10 for thermal self emission. The detailed results are covered in [RD8] .

Table 25: Sum of Self Emission onto PACS and SPIRE detector

PACS DETECTOR		SPIRE DETECTOR	
pessimistic	optimistic	pessimistic	optimistic
28.6	12.2	14.0	7.7

b) Straylight from infield sources:

The requirement is met.

c) Straylight from out-of-field sources:

The specification is violated, if the sums exceed 1 for external sources (the value of 100 is the normalised value of thermal emission of both reflectors as in a).

Table 26: Scatter paths onto PACS and SPIRE detector

Emitting object	PACS DETECTOR	SPIRE DETECTOR
moon at 13 degrees, cone baffle	8.69E-04	5.00E-04
earth at 23 degrees, cone baffle	4.09E-03	1.81E-03

For these scatter paths the requirement is met with large margin.

Table 27: Worst case radiances for specific directions of the moon, from which pure specular radiation onto detectors can occur

	Moon bright zone (400 K)		Moon dark zone (100 K)	
	80 μ	670 μ	80 μ	670 μ
Path 1 for SPIRE	13.0	4.0	1.45	0.92
Path 2 for SPIRE	13.0	4.0	1.45	0.92
Path 3 for SPIRE	16.4	5.1	1.84	1.16

Note: calculated for SPIRE Detector. The situation for PACS will be similar. Data are calculated only for the 3 most intense paths out of about 22 up to now.

Thus, the specification of 1% is violated for these specific locations of the moon.

6.8 Shading Function of HSS

The HSS fulfils the required shading function. The various cases are discussed in [RD16].

The HSS shading function for nominal operations is shown in Figure 41. The critical area is the pitch angle of -30°. The sub-reflector and the main reflector are just shaded by the HSS. A further rotation of the spacecraft is not possible without illuminating the sub-reflector and, or the main reflector. The values are derived using the envelope of the Telescope, as provided by ASEF. The half sun diameter of 0.25° and 2.5° for diffraction are considered. The figure shows clearly, that for smaller pitch angles a roll of 5° respectively 6.25° is possible. The interference of the HSS with the faring does not allow an increase HSS, hence does limit the pitch angle. For positive pitch angles the -x side of the SVM shield is illuminated by the sun.

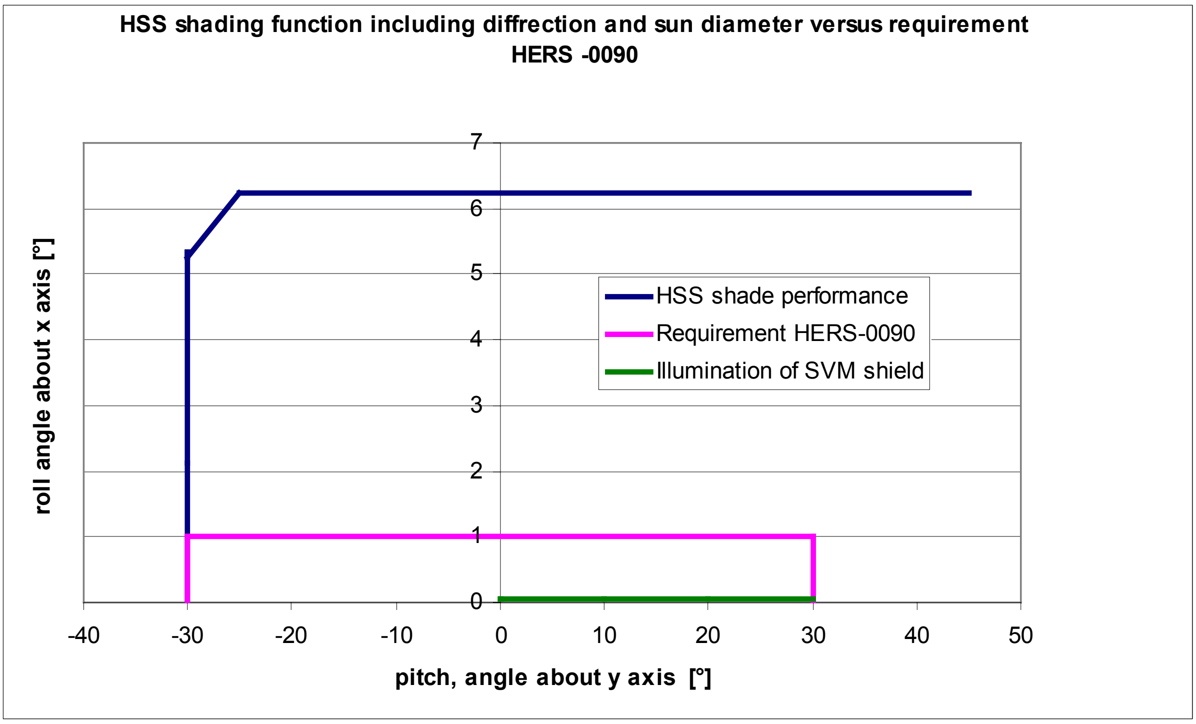


Figure 41: Shading of function for nominal operations (according to [AD5], HERS-0090)

6.9 Cleanliness

The Cleanliness Team established a bottom up contamination budget. A summary of the results is listed in the tables below. The figures are worst case calculations plus a margin. Cleaning operations in Europe and in Kourou become necessary and are included in these figures. They can be interpreted as contamination goals in order to meet the EOL requirements.

Particulate contamination budget

PARTICULATE in ppm	PLM inside CVV	FPU and Optical Bench	S/C outside	TELESCOPE	HIFI-LOU Optical Windows
Level at delivery to Astrium	200	300	(400) 4)	300	100
AIT, incl. cleaning steps up to encapsulation	500	200	2500 6)	1890 1)	200 7)
From encapsulation to separation	0	0	2300 3)	2300 3)	230 8)

PARTICULATE in ppm	PLM inside CVV	FPU and Optical Bench	S/C outside	TELESCOPE	HIFI-LOU Optical Windows
In orbit (redistribution, µ meteorides) 3)	50	50	10	10	10
Total EOL	**750**	**550**	**4810**	**4500**	**540**
Requirements from instrumenters	1200	1200	n. a. 2)	4500 5)	1200
Remaining margin	450	650	n. a.	0	660

1) No cleaning foreseen, but protection with cover during majority of AIT sequence
2) No requirement, requirements outside S/C only for telescope and LOU windows
3) Values provided by Alcatel
4) Not relevant for EOL value because of several cleaning steps
5) This value is an average of the requirement for M1 and M2
6) Value at fairing encapsulation

7) Protected- with a cover during majority of AIT sequence, windows are cleanable.
8) Because of the limited view factor compared to the telescope, the venting under the fairing and the vertical orientation of the windows, it is assumed that not more than 10 % of the 2300 ppm growth for S/C outside during launch is applicable to the windows.

Molecular contamination budget

MOLECULAR in 10-7 g/cm2	PLM inside CVV	FPU and Optical Bench	S/C outside	TELESCOPE	HIFI-LOU Optical Windows
Level at delivery to Astrium	2	30	2	2	2
AIT, incl. cleaning steps up to encapsulation	4	1	25	4	4
Contamination from CVV internal outgassing	n. a.	25	n. a.	n. a.	0
Water ice from air permeation through seals	1	12 1) (40)	n. a.	n. a.	0
From encapsulation to separation	0	0	8 3)	8 3)	8
In orbit (outgassing,	2	2	200	26	tbd 2)

MOLECULAR in 10-7 g/cm2	PLM inside CVV	FPU and Optical Bench	S/C outside	TELESCOPE	HIFI-LOU Optical Windows
thruster plume) 3)					
Total EOL	**9**	**70**	**235**	**40**	**tbd**
Requirement	60	60	n. a. 4)	40	85
Remaining margin	51	-10 5)	n. a.	0	tbd

1) Acc. to issue 3 of [RD13], taking into account 575 days of cold condition of the cryostat until launch (40 is valid for HIFI housing only).
2) To be calculated by Alcatel. For the optical windows the back scattering effects will be limited by the LOU- and CVV-radiators.
3) Values provided by Alcatel
4) No requirement, requirements outside S/C only for telescope and LOU windows
5) A lower contamination level at delivery to Astrium would allow to achieve positive margin

7 External Interfaces

7.1 External Mechanical Interfaces

The Herschel E-PLM has external mechanical interfaces towards the service module, the telescope and the LOU as part of the instrument HIFI. The external mechanical interfaces are defined in [RD18].

There are three major load carrying plus a number of other mechanical interfaces towards the service module, i.e.

1. the PLM/SVM interface struts, carrying the complete PLM with CVV, telescope, instruments and all its other attachments, also including part of the HSS. The 24 PLM/SVM interface struts are mounted on the SVM cone via 12 interface brackets, linking two struts each.
2. the HSS has direct interfaces with the SVM via the main axial load carrying CFRP struts linking the SA upper edge with the SVM cone. The interface consists of two strut brackets, which are mounted on the SVM cone upper interface ring. The lateral loads are transferred form the HSS to the SVM by three small struts.
3. the SVM Thermal Shield in mounted on the SVM upper platform and cone via the SVM Thermal Shield struts.
4. interfaces with the warm electronic units on the SVM, i.e. harness and waveguides
5. brackets supporting harness and waveguides
6. MLI interfaces

The telescope is mounted on the CVV via the Telescope Mounting Structure (TMS). The three telescope bipods are interfacing with the TMS frame upper edge.

The LOU as external part of the HIFI instrument is mounted on the -Y side of the CVV via the LOU support structure. The LOU instrument and radiator are mounted on the LOU support plate.

7.2 External Thermal Interfaces

The external thermal interfaces are covered in [RD17].

7.3 External Electrical Interfaces

The electrical interfaces of the HERSCHEL **E**xtended **P**ay**l**oad **M**odule are defined in [RD17]. The ICD is the generic information source for all electrical interfaces including the 3 instruments and the CCS (Cryostat Control System).

The characteristics of the cryoharness and the connector interfaces are described in [RD20] and in the cryo harness interconnection diagrams ([RD21], [RD22], [RD23] and [RD24]).

The external electrical interfaces, as described in the referenced documentation above is compliant to [AD6], [RD25] and [RD26].

8 Cleanliness

The applicable cleanliness requirements for the Herschel satellite system are defined in the Herschel / PLANK Cleanliness Requirements Specification, H-P-1-ASPI-SP-0035.

Since the particle and molecular contamination requirements in the first issue of a.m. specification were not accepted by ESA, a working group called "Cleanliness Team" was established, which was led by ESA, supported by specialists from Alcatel and EADS Astrium GmbH.

The purpose of the Cleanliness team was to derive correct cleanliness operations on ground, to assure the cleanliness requirements for instruments at end of life under worst case conditions and to agree a cleanliness specification and apportionment.

The outcome of this working group is summarised in the Cleanliness Team Report H-P-1-ASPI-RP-314. The specification H-P-1-ASPI-SP-0035 has been updated accordingly.

8.1 Basic Cleanliness Definitions for the Herschel H-PLM

There are three distinctly different areas where cleanliness has to be well defined with separate requirements:

- The internal space of the He subsystem, with leak rates as performance drivers
- The vacuum space of the cryostat, performance drivers are the thermal insulation properties and the optical performance of the instruments
- The outside of the H-EPLM incl. the telescope, LOU and HIFI Optical Windows, together with transport conditions and test chamber environments.

8.2 Cleanliness critical areas

8.2.1 He Subsystem

Cleanliness is important for the inside of He tubing and He tanks, the surfaces of which usually come into contact with liquid He. The overall performance of the cryostat depends on proper filling with He and establishing a predetermined stable gas flow from the system. Both items are influenced by the level of cleanliness inside.

8.2.2 Cryostat Vacuum Vessel (CVV)

The CVV not only provides thermal insulation under atmospheric conditions but also contains the experiments, which are susceptible against molecular and particulate contamination.

8.2.3 S/C Outside incl. Telescope

Cleanliness sensitive elements at the S/C outside are the telescope mirrors, the LOU Optical Windows in the CVV and the LOU, due to its openings towards the windows. The baseline for the telescope mirrors, optical windows and LOU is to avoid a cleaning by protecting them with appropriate covers during most of the AIT activities.

8.3 Particle Contamination

8.3.1 He Subsystem

Requirements and procedures for the cleaning of the cryo components were adapted from the ISO cleaning procedures. Any shortcuts in this area would lead to incalculable risks for the He SS performance.

Additional effort may be warranted in the area of particles introduced by He filling operations. Filters will be used in the He filling flow as close as possible to the He filling port.

Special cleaning procedures will be applied for the He dewars and all filling lines.. A set of clean dewars shall be provided for He filling operations and always the same dewars of this set shall be used during the Herschel programme.

8.3.2 Cryostat Insulation Vacuum

ISO Experience:

Protection of the experiments against contamination by particles was the main driver for extensive use of the class 100 cleanroom during ISO Integration. A detailed justification is given in ISO document ISO AS 1300 TN 0429 (ISO Cleanliness Policy) which has been considered during the Cleanliness Team meetings and for the establishment of the Herschel EPLM Contamination Control Plan.

It is assumed that particle contamination plays only a minor role for the cryostat's thermal insulation. The utilized MLI foils are rather insensitive to particles. Care has to be taken, however, that the MLI blankets do not become the source of particles. Spacers will be handled in such a way as to avoid particles release. Assembly of the MLIs to a class 100 environment was required and the particle emission properties have to be analysed or measured.

The accumulated particle density is proportional to the time, a surface is exposed to a contaminated environment. For HERSCHEL, the integration period is planned for 139 working days during 7 months. Refurbishment after qualification takes another 64 working days during 3.5 months. The contamination levels at delivery to Astrium, which can be controlled during incoming inspection, added by the contamination budget of AIT activities, including all precaution/cleaning planned, will result in an EOL obscuration factor of < 750 ppm (incl. margin) for all surfaces inside CVV.

8.3.3 S/C Outside

Particle contamination of the outside will be mainly accumulated during AIT and lift off phase. Special cleaning procedures before launch for certain surface areas such as the LOU optical windows in the CVV have to be considered. As a first approach, conditions in a class 100 000 cleanroom will provide a suitable environment, if all critical areas are protected. Additional efforts for selected areas will be discussed. For the lift off phase the particle fall out is specified to be max. 2300 ppm, ref. H-P-1-ASPI-SP-0035. Cleanliness of test setups will be commensurate with the above outlined cleanroom category.

Cleanliness of transportation containers are considered with a particle fall out of max. 25 ppm per transport.

8.4 Molecular Contamination

8.4.1 He Subsystem

With the possible exception of the phase separator, no adverse effects of molecular contamination inside the He SS are known. Naturally, the contamination must be limited more or less to surface layers, any macroscopic amount of contaminants can block filters or orifices or result in stuck valves. The use of proper cryogenic procedures usually is sufficient to prevent the accumulation of such amounts. Any pumping operations on the system will only be performed with oil-free pumps or properly trapped pumps in combination with fast closing safety valves. Any molecular contamination will freeze to the walls until the lifetime of the system reaches its end. Only after warm-up of the respective surfaces the contaminants will be released and most likely redistributed to colder surfaces in the vicinity.

8.4.2 Cryostat Insulation Vacuum

A potential source for contamination in the CVV is the pump oil. An oil free turbo pump alone is no guarantee for an oil free vacuum, oil vapour from the roughing pump still can be transported into the vacuum space, especially under transient conditions like power breakdown. The cryo pumping action of a cold He reservoir is strong enough to condense oil vapour through a well functioning turbo pump. All such effects typically lead to a visible oil film on all internal surfaces. MLI foils can adhere to each other and loose their insulating properties. Such catastrophic contamination must be avoided by the following measures:

- an automatically actuated shut-off valve at the vacuum port of the cryostat
- either suitable cold traps or a strict policy of never pumping on a cold cryostat. The latter alternative can become a problem if a small leak develops (transportation)!

Outgassing of internal components, in particular from composites, is another major source of molecular contamination. About 50 kg organic material will be inside the CVV including surfaces with water films which need to be baked out. A budget for all materials used inside the CVV has been established and is included in the Cleanliness Team Report. ISO experience resulted in two necessary procedures: Non-metallic components had to be vacuum pre-baked individually and the overall assembled H-PLM had to be baked in system configuration.. Particular problems were encountered in heating all CVV internal parts of the H-PLM to a uniform temperature. A bake out of about 100 h at 80°C under vacuum has been taken into account for above mentioned H-PLM budgets.

Permeation through the synthetic (Viton) CVV seals is another source of molecular contamination. An estimation of the amount and the effect of the permeation are provided in [RD13].

A temperature cycle from cold to warm will evaporate all volatiles which have been condensed before. A sufficient time for re-evacuating the system will be foreseen in such a case to remove the molecules out of the CVV.

In space, the thrusters can generate a considerable cloud of exhaust products, which would be drawn to cold surfaces like instrument optics and the cold telescope mirrors.. It might be considered, to keep the telescope warm until all manoeuvring is completed. At least the cover of the CVV has to be kept closed until most of the thruster activation has been completed.

All operational procedures in orbit must be scrutinized for compatibility with the cleanliness requirements!.

8.4.3 S/C Outside

Molecular contamination of the outside at launch will be commensurate with atmospheric conditions and temperature.

9 Alignment

This chapter provides an overview about the Herschel alignment concept. A more detailed description is given in [RD7].

Proper function of the three Herschel scientific instruments HIFI, PACS and SPIRE requires their precise alignment to the Herschel telescope focus. During the integration, however, the telescope is the last optical subsystem to be mounted upon and outside the cryostat if the cover has been already closed. Additionally the LOU has to be aligned w.r.t. HIFI FPU.

As a consequence the instruments have to be aligned to an optical reference system without the telescope. When as the last step the telescope is integrated it will be aligned to the same reference.

The most critical part of the alignment is the alignment of the LOU w.r.t. the HIFI FPU and the verification of the CVV shrinkage inside the TV chamber.

During the on-ground alignment two constraints must be taken into account:

- The alignment requirements are valid for in-orbit conditions
- The alignment requirements are specified for operational conditions, whereas the alignment can only be performed at ambient conditions.

The following environmental conditions will change between on-ground alignment and in-orbit operation:

- Gravity from 1g to zero g
- Atmospheric pressure from 1bar to 0bar
- Outer CVV temperature

These effects must be determined and have to be pre-compensated by a corresponding offset on-ground. The experience gained with the theoretical determination of these offsets and its confirmation during testing with the EQM and the “STM” will be applied for the PFM.

Effects due to temperature and pressure change can be confirmed during on-ground testing, however, the gravity release effect can only be determined theoretically. Restrictions must also be made for the testing of the temperature change (on-ground→in-orbit): The shrinkage of the CVV will be verified during TB/TV testing with the HIFI Alignment Camera. The expected CVV temperature during TB/TV testing is approx. 80-90K. In orbit the expected CVV temperature is expected to be approx. 70K. For the last 10 to 20K temperature range the shrinkage will be verified by extrapolation.

An alignment check shall be performed after the evacuation in order to quantify changes due to evacuation. Further alignment checks will be performed after cool down during the re-adjustment of the tank straps (the re-adjustment of the tank strap will move the OB) and before and after environmental testing.

The alignment method which will be applied for the Herschel PLM is described in [RD7]. However, in this chapter a small overview will be given.

During the Herschel integration the telescope is the last subsystem which will be mounted outside and upon the cryostat. At this integration stage the cryostat cover is already closed and therefore the optical reference from the instruments can no longer be seen. Consequently the instruments must be aligned to a common intermediate optical reference to which the telescope is aligned later on. The main integration and alignment steps are as follows:

1. Mounting of a reference cube at the optical bench.
2. Integration of the OB into the cryostat.
3. Adjustment of the OB w.r.t. the LOU windows 1)
4. Integration of the three instruments onto the optical bench. Each instrument is equipped with an alignment cube to represent its internal alignment.
5. Alignment measurement of the instruments w.r.t. the OB reference cube to know the actual orientation (position and angle) or directly to the CVV cube (step 6).
6. Alignment measurement of OB reference cube w.r.t. a reference cube mounted outside the CVV. If necessary correction of OB via the tank straps.
7. Closing the CVV upper part
8. LOU integration and alignment measurement w.r.t. the HIFI FPU via two additional alignment windows using theodolite . If necessary adjustment of LOU w.r.t. HIFI using the LOU mounting struts.
9. Closing the CVV cover
10. Evacuation and cool-down.
11. Alignment control and re-adjustment of the tank straps.
12. Telescope integration.
13. Alignment measurement of the telescope reference cube w.r.t. the CVV cube. If necessary adjustment.
14. Environmental testing (TB/TV, Vibration, Acoustic Noise).
15. Alignment check before and after environmental testing.

1) The LOU must be aligned w.r.t. the HIFI FPU via the seven LOU windows. It is not possible to align the windows w.r.t. CVV. Therefore, the OB (HIFI) must be aligned w.r.t. the LOU windows.

The complete integration, alignment and test logic flow is shown in the Satellite AIT Plan.

Alignment of the Herschel PLM will be performed in various steps and can be divided in the following three main areas.

9.1 STM Alignment

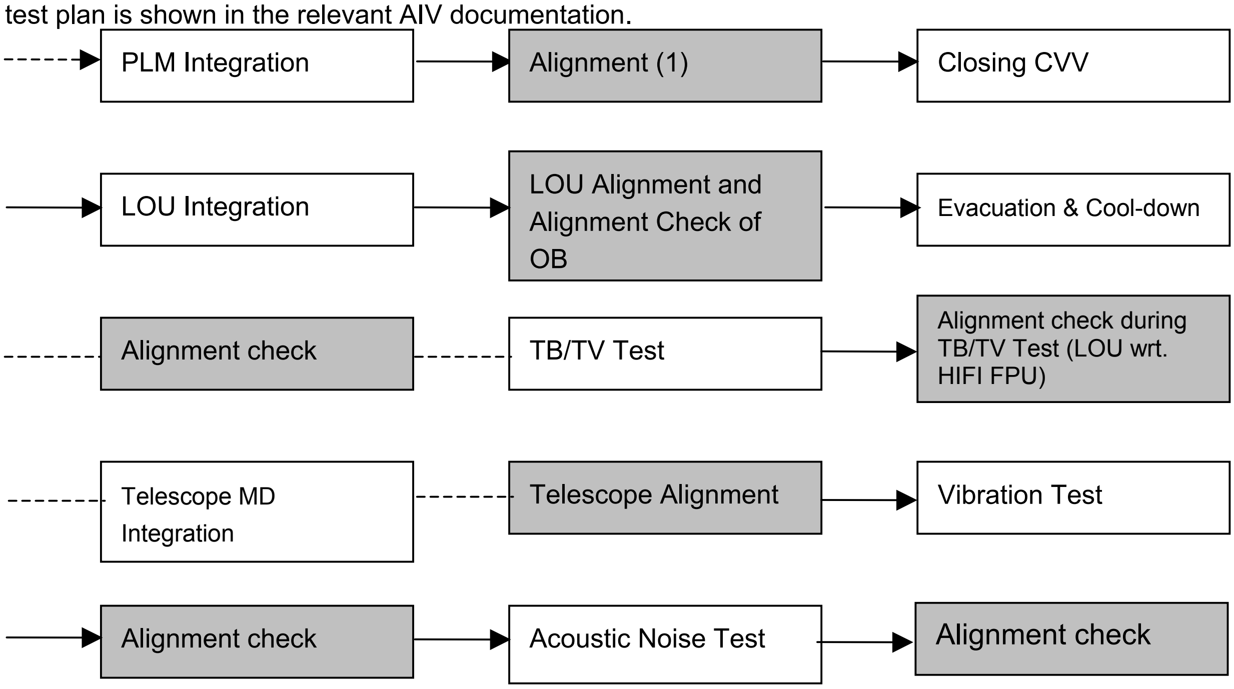
The STM serves for the qualification of the structure. Therefore the alignment shall be checked before and after the environmental testing. Furthermore, the effect on alignment due to outer CVV temperature change shall be verified with the STM inside the TV chamber. For this test the Instrument and LOU MTDs will be used, equipped with alignment references at the same place as the Instrument FMs.

The main tasks are as follows:

- Qualification of the structure
  (Alignment measurement before and after the environmental tests)
- Verification of CVV shrinkage due to the temperature change w.r.t. outer CVV temperature inside TV chamber using the HIFI Alignment Camera

- Confirmation of the mathematical model

The actual test sequence is as follows (only alignment related steps have been shown). The complete test plan is shown in the relevant AIV documentation.



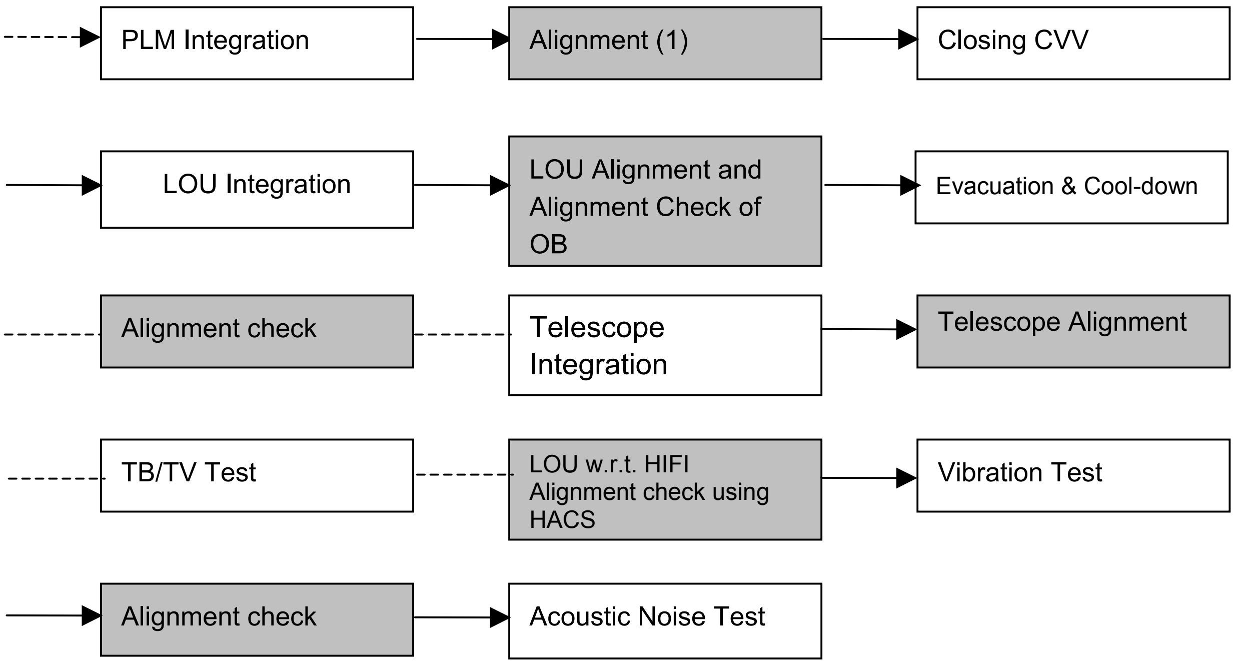
1) Only OB and FPUs

Figure 42: STM Alignment Sequence

The most critical alignment of LOU w.r.t. the HIFI FPU will be monitored inside the TV chamber at nearly operational conditions. For this purpose two alignment cameras are mounted temporarily on the LOU allowing to monitor simultaneously tilt and offsets (two cameras are needed to determine the rotation about the y axis).

9.2 PFM Alignment

For the PFM a validated and accepted alignment procedure is already approved with the EQM and the STM. With the PFM the acceptance tests will be performed according to the following schema (only alignment relevant part). The complete test plan is shown in the relevant AIV documentation:



1) Only OB and FPUs

Figure 43: PFM Alignment Sequence

To ensure that the alignment requirements are achieved at nearly operational conditions two alignment check s are planned during TB/TV testing. With both tests the shrinking of the CVV will be confirmed and therefore the confidence of the FEM increased.

The following tests are planned with the PFM during TB/TV testing:

- Verification of LOU w.r.t. HIFI FPU alignment using the HIFI Alignment Camera System (HACS).
- Verification of the Telescope cool-down behaviour w.r.t. the CVV.
  This will be achieved by measuring the displacement between the Telescope M1 and the LOU using Videogrammetry method at ambient and after cool-down.

On ESA request a measurement between Telescope and CVV has been implemented in order to verify the Telescope cool-down behaviour w.r.t. the CVV inside the TV chamber. No direct method of measuring the Telescope w.r.t. the Instruments (inside the CVV) is possible. Therefore a measurement of Telescope w.r.t. LOU is planned and agreed with ESA. For this measurement videogrammetry will be used.

A set of (two) cameras is located inside the TV chamber. Targets are placed on the Telescope (rim of M1) and the LOU. The satellite will be rotated about the z axis and the targets will be seen under different angles. The target position can be located via triangulation. Two measurements will be performed, one at ambient and the second after cool-down. The difference of both measurements is the movement of the Telescope w.r.t. the LOU due to cool-down.

Please note, that this test is not an end to end test, because the telescope is aligned to the instruments. But it can be compared to FEM results and increase the confidence of this model.

Measurements using Videogrammetry can only be performed with the PFM because the Telescope TM is not suitable (stability) for this measurement and the LOU is not visible for the videogrammetry camera due to a cooled shroud in the front of the CVV.

10 Straylight

The following major components contribute to the straylight budget:

- Telescope
- FPUs
- Baffles
- HSS.
- Dark gaps and spaces between individual structures

The straylight analysis has been performed using ASAP models of the components mentioned above.

For the telescope the detection of specular straylight paths (different from the desired one via M1 and M2 only) are very important. Here the rectangular legs of the telescope hexapod act as small plane reflecting mirrors opening side paths towards the sky with significant straylight contributions from Moon, Earth and bright stars from few specific directions.. Such side paths could only be avoided/reduced, if

- the legs are made rough (instead of smooth), however, emissivity is then increased
- the legs have a round cross section instead of a rectangular one.

One of both possibilities would be sufficient. However, the rectangular legs were favoured, since there are more specular paths from the round legs.

The space between the hole within the primary mirror and the cryostat requires most attention, since an interface harmonisation was necessary there (keyword M1-baffle). The design follows the rules:

- keep warm bodies far off the experiment beam
- avoid zigzag reflections with directions roughly parallel to the x-axis

Zigzag reflections near the y/z-plane are not as critical as they are not likely to reach the experiments.

Of course, the other components around the baffle set constraints, mainly the cryo-cover and the accessories necessary for its operation. The CVV opening has a diameter of 288 mm, compromising between the thermal/mechanical/optical needs. The lower radius of the M1-baffle is driven by mechanical constraints.

The opening near the primary reflector is mainly determined by the inner free diameter and other structural constraints. The telescope manufacturer stated a maximum possible inner diameter of 500 mm for the ASEF part of the M1-baffle. This lead to the decision to have the M1-baffle split into a circular part with 500 mm diameter connected to M1 itself and a conical part with 500 mm upper and about 362 mm lower diameter connected to the CVV, with a gap in between, which is necessary for vibration clearance, manufacturing tolerances, telescope adjustment and thermal movements.

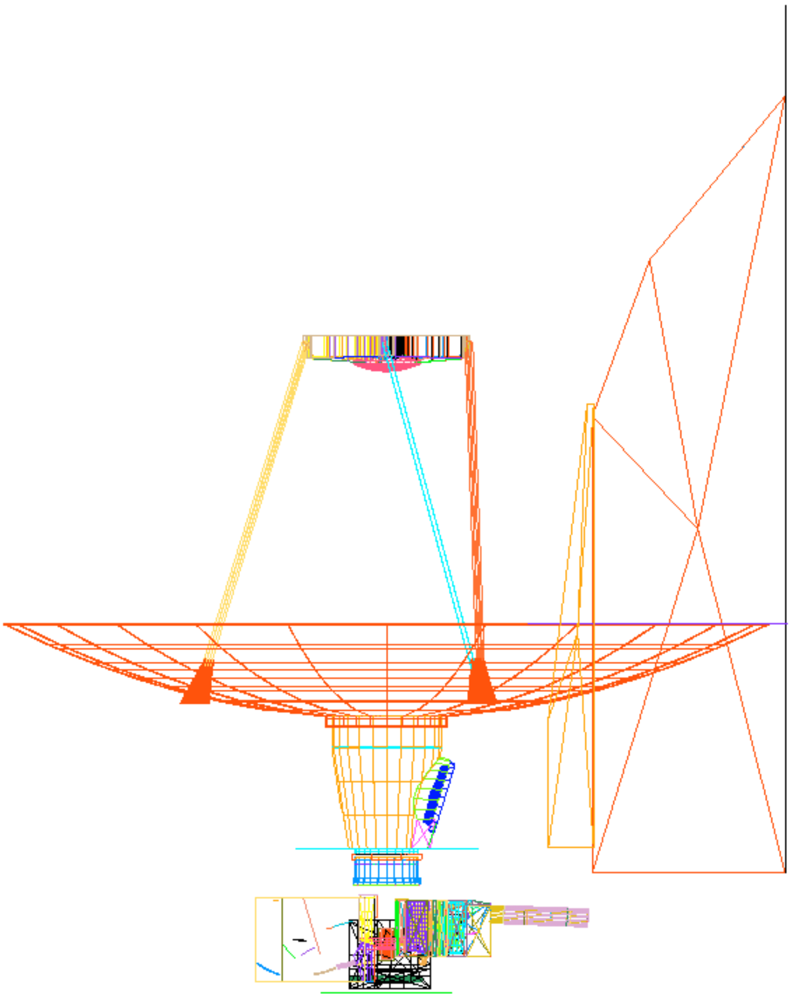


Figure 44: ASAP straylight model illustration

Several design options are driven by thermal optimization, most important are

- the thermal shield 2 baffle cylinder is black
- there is an aperture introduced within that cylinder, its upper side is black.

11 Reliability and Safety

11.1.1 Objectives

The objective of the following chapters is to introduce the Herschel reliability and safety concepts, which are currently implemented in the E-PLM design. The reliability and safety aspects as introduced hereafter are considering the design, experiences and lessons-learned from the ISO program.

11.1.2 Reliability and Fault Tolerance

For the Cryo-Control-Unit CCU design a reliability block diagram was established to demonstrate that the redundancy requirements are met.

The CCU design consists of two hot redundant branches, both providing identical functions, with a metallic separation between them. Redundant temperature sensors connected to the CCU will be arranged thermal symmetrically but at different locations in the CVV. Therefore, the spatial temperature resolution across the cryostat is more comprehensive, using the complete set of all redundant temperature sensors, than for a set derived from one single branch only. Nevertheless, the function with respect to the operation is guaranteed with only one branch of the CCU.

FMECA

Failure mode, effect and criticality analysis has been performed for the E-PLM, considering the subcontractor analyses and including all internal and external interfaces, to assure that timely and adequate provisions are implemented in the unit design specifications, operational plans and procedures.

- FMECA Methodology

The FMECA methodology in the following will be concentrated to the most important aspects, the single point failure identification and to the redundancy concept as already implemented in the E-PLM system design.

– Single Point Failure Identification

  The identification and elimination of single point failures are the prime objective of the FMECA effort.

The following main potential single point failures of the Cryostat CVV and Helium S/S are:

- internal leakage by valves
- external leakage of valves, tanks and pipe work
- unwanted opening of valves
- unwanted closing of valves
- loss of Phase Separator function
- loss of cryo-cover hold down function

A complete overview about all currently detected SPF´s is given in [RD33].

- Redundancy Concept

Redundancy and cross strapping is incorporated within the design to improve the reliability. Technical reliability requirements are incorporated into the S/S, unit and/or support specifications.

In the E-PLM design all ground operation valves of the CVV He system are in a single non-redundant configuration, whereas the flight operation valves are all redundant. Adequate handling procedures will support all ground operations, which will be applied by properly trained personnel. Furthermore, all necessary system parameters can be monitored with the Cryo SCOE EGSE respectively via the safety venting system so that a false valve position will be detected immediately during ground operation.

The cover actuator is equipped with non-explosive devices (NED) spool initiators, and redundant opening drive and kick springs.

The equipment and components including the test measurement equipment applied inside the CVV, e.g. the DCLM, heaters, thermistors, pressure sensors and accelerometers, are designed in a redundant configuration following the redundancy concept as applied for ISO.

11.1.3 Safety

Objectives

The object of safety assurance is to draw attention to hazards, to initiate safety provisions and to demonstrate that an appropriate safety program is implemented in accordance with ASPI Safety Requirements H-P-ASPI-SP-0029 respectively ECSS-Q-40A, the CSG Safety Regulations and the ARIANE 5 User Manual.

There are two major goals regarding safety, to prevent personnel injury and to prevent damage to flight hardware, equipment, facilities and environment.

Hazard Analysis (HA)

A HA has been prepared on EPLM level and on the associated ground support equipment, considering especially ground operations, launch preparation activities and the launch itself. The objective is to identify inherent hazards, which may result in loss of life, personal injury or damage to other equipment.

Adequate procedures will be used to control potential hazardous events, e.g. external leakage / burst of an item. They will define safety requirements and operational constraints, by tests (leakage tests, proof pressure tests, static load tests) and by the design, through materials selection and appropriate safety factors taking into account the maximum possible static and dynamic loads.

Safety Testing

The implementation of adequate validation tests on safety critical items to demonstrate the margin of safety or degree of hazard where this is appropriate is ongoing respectively have been already performed for some structural components like SFW and TSS.

Ground and flight testing of safety critical items will be assessed for adequacy of hazard control prior to test and monitored for correct implementation during test. Safety critical items control and monitoring is implemented in [RD34].

Safety assessments will be conducted together with regular progress meetings.

E-PLM Safety Concept

For Herschel EPLM structural elements the following safety factors have been implemented through the individual procurement specifications:

	Yield	Ultimate	Buckling
Conventional Materials	1.1	1,5	2,0
Unconventional Materials	1,4	2,0	2,0
Inserts and Joints	1,5	2,0	N/A

The above mentioned safety factors were applied to design limit loads.

The implementation of the safety factors have been analytically verified by a positive margin of safety as summarized in [RD39].

Helium Safety Philosophy

The philosophy of the helium safety system, a discussion of the failure scenarios, the assumptions for the consequences, the calculations for the resulting gas flows and the comparison with the capabilities of the safety devices is presented in the Helium Subsystem Safety Analysis [RD12].

Due to the amount of stored energy the Herschel cryostat is a pressure vessel and the general rules for pressure vessel design have to be followed and the safety regulations at launch site have to be considered. The application of these rules leads to a safety concept, which is based on the “leak before burst” criterion. Herschel is based on the following safety philosophy:

- Two failure tolerant
- Three independent paths for overpressure relief
- Passive safety system for all operation modes (no active controls or monitoring is required at any time)
- Use of rupture discs with the reversed buckling membrane principle as the ultimate safety device. Systems using only this type of rupture discs as second and final control device are considered as two fault tolerant.

The impact of the cold leaking helium gas will be controlled by dedicated hazard control procedures and the operational procedures, which have to be established during phase C/D.

Helium itself is a non-toxic gas. The hazards to be expected are personal injuries from frostbites (cold surfaces, cold gas plumes), asphyxiation due to in sufficient oxygen in the remaining air loss of orientation due to dense fog generation and impacts of cold damaged structures..

The failures and their impact will be assorted in three categories as shown in Table 28.

Category / Hazard Classification	Failure case	Expected mass flow rates (see chapter 7) (at 5 K)	Venting via	Release pressure
Small failure / Negligible	small He leak small CVV leak	1 g/s	Vent line	
			SV521	0.4+0.06 set pressure (1.46 bara)
Medium failure / Critical	medium He leak medium CVV leak	184 g/s	Safety valves	
			SV123/723	1.6 ± 0.16 bara
			SV121	0.45 ± 0.15 bar set pressure
Largest credible failure / Catastrophic	Loss of insulation vacuum	3.53 kg/s	Rupture discs and safety valves	
			RD124/724	2.8 ± 0.26 bar set pressure
			SV921+ SV922	0.4 ± 0.05 bar set pressure

Table 28: Failure Categories

During all potential failure modes, and especially in the case of a loss of insulation vacuum (during on ground operation), the endangerment of personnel caused by a burst of the HTT or the HOT and hence a burst of the vacuum vessel is prevented by the rupture discs RD 124 / 724 flanged directly onto the individual tanks and the corresponding safety relief valves SV 922/SV 921 at the vacuum vessel.

The rupture discs RD 124 / 724 open far below the burst pressure of the He tanks and the cross section of the safety relief valves SV 921/SV 922 is sufficient to vent the He mass flow produced during the loss of insulation vacuum. Unintentional opening of the rupture discs will be prevented by appropriate pressure staging.

All cryo-vacuum servicing equipment being connected to the cryostat will be designed such that it will not produce any overpressure in excess of the set values of SV 123, SV 723 or SV 921 / SV 922.

The CVV , HTT and HOT , cryo lines etc. will be tested to the pressure of the save opening of the relevant safety devices.

Potential Failure Effects

A failure in the cryostat subsystem can lead to pressure increases in an uncontrolled and dangerous way by evaporating LHe and/or expanding GHe within a closed volume of the He S/S.

The following separate volumes are currently identified:

- The He II and I tanks failure mode rupture appears by handling error, i.e. unintentional closure or blockage of valves
- Internal piping failure modes appear by handling errors as above and/or blockage of the system or valve filter and/or nozzles.

All other additional separable volumes cannot cause any hazard and will not be discussed here.

The following potential failure modes are currently identified for the cryostat:

- Unintentional closure of the He II or He I tank - In this case the pressure of the He-bath would increase due to external heat input until SV 123 opens and GHe will be released via the filling port and SV 121 or via the vent line and SV 521 to the atmosphere.
- Unintentional closure of the vent system - In this case cold GHe is entrapped in the piping and vent system and will expand due to external heat input. This GHe will be released via the vent line and SV521 or via the filling port and SV 121 to the atmosphere.
- Unintentional warm-up of the He-bath by electric heaters - Such a handling error results in an increase of the He vent rate. Venting via SV521 or in case of a heating with closed valves this low mass flow rate can be vented via the vent respectively filling line after SV 123 (723) opening.
- Air-Leak - Any air from a small leak for instance a not tight o-ring, which does not cause a vacuum breakdown, will be pumped away by the cold helium tanks by condensation. An overpressure inside the CVV can be achieved during warm-up and will be released by SV 921 / SV 922.
- He-Leak - A larger He -leak, e.g. by a leaky or broken joint in the Helium vent system or in one of the FPU's He3 sorption coolers, will strongly increase the heat input to the He tanks by the high heat conduction of the He gas. In that case, the tank pressure will increase until SV 123 / 723 opens and the mass flow will be released mainly via the filling line and SV 121 and partly via the vent line and SV 521 to the atmosphere.
- Loss of insulation vacuum - in this <u>worst case failure mode,</u> air will penetrate through a leak into the CVV and will condense on the walls of the He tanks. Due to the large enthalpy of air, the heat input to the He II tank and hence the evaporation rate can become very high.

The following leaks in the vacuum vessel can be considered as credible:

- rupture of an optical window (diameter 34 mm) ,
- burst of an electrical feed through glass isolation (diameter approx. 32 mm),

In case of a destruction of an optical window with a diameter of 34 mm (the maximum credible air - leak) approx. 0.,175 kg/s air will enter the CVV vacuum. The incoming air will condense immediately on the He II tank resulting in a steep increase of the tank pressure.. This will activate the opening of the rupture disc, and a large GHe mass flow rate has to be released from the tank in order to ensure that the pressure in the tank does not increase after opening of the rupture disc.

. The GHe mass flow in the CVV will be released then via SV 921 / 922 to the atmosphere.

The Herschel helium system has been analysed with respect to safety, refer to [RD12]. It is demonstrated that the safety philosophy of two fault tolerance has been implemented by adequate safety devices for all credible failures under all circumstances. It has been shown, that the mass flow rates produced in the considered failure cases can safely be vented via the Herschel safety devices.

12 AIV

12.1 Verification Approach

To meet project objectives relating to using ISO heritage, cost saving and schedule reasons the verification approach of H-EPLM includes some specific particulars. The Herschel project is based on a reduced PFM model philosophy where a dedicated structure and thermal model on PLM level is deleted.

The consequence of this single model philosophy is that the structural and thermal qualification of the Herschel E-PLM, respectively of the Herschel satellite, will be done with the EPLM PFM. In order not to overload the flight units, the duration of the qualification will be shared between unit level and module/system level tests.

Thus this PFM approach implies no unacceptable risks for the Herschel program, the verification approach is based on:

- The basic design of the PLM rely on the ISO design, respectively the ISO lessons learned
- Re-use, as far as possible, of modified ISO components or use of components, based on ISO design
- Implementation of the ISO heritage in the AIT sequence (see chapter 4)
- Components will undergo a qualification program, even if they are based on approved design
- Early qualification or delta qualification on unit level

The risk mitigation by early testing of components is described below for each of the subsystems.

The H-EPLM AIT program is divided into three main phases. The PLM electrical qualification will be done using the modified ISO QM as cryostat providing the necessary cryogenic environment for the instrument testing. The structural and thermal qualification will be done with the EPLM PFM, respectively on satellite level (for the structural qualification). After exchange of the instrument MTD's with the FM's, the final acceptance will take place on Herschel satellite level.

The details of the verification program are given in the Herschel EPLM Verification Program Plan.

12.2 Basic Integration Rules

Mechanical and electrical assembly and integration will be performed according to formal step-by-step procedures only. All activities will be given there in correct timely order.

All integration activities on the PFM cryostat will be performed in cleanroom class 100 environment up to and including final closure of the cryostat and evacuation.

The handling and integration activities of PFM hardware will be carried out using dedicated MGSE. It will be done by trained authorised personnel only with the necessary experience.

12.2.1 Pre-Integration Inspection and H/W Release

Before starting any integration activity an incoming inspection will be performed on each delivered item to control the quality of the hardware to be integrated.

As a minimum, the following controls/measurements will be performed:

- control of data package according to the shipping list
- completeness of H/W according to shipment documentation
- visual inspection (no obvious damage or degradation)
- cleanliness inspection
- conformity of identification markings and serial numbers to the configuration status
- fit check (if possible)
- functional health checks (where appropriate)

Release of hardware for integration will be controlled. Parts required for a particular integration activity will be kited to reflect the requirements of the governing integration procedure and the parts lists prior to the need date.

12.2.2 Hardware “as built status” List

Through an official record (ABCL) the hardware “as built status” will be traced during the AIT activities.

The list will include:

- name of hardware
- identity tag number
- drawing references
- integrated hardware part identification and serial number
- integration date

12.2.3 Handling

All handling activities of module and system hardware, in the various integration and test facilities will only be carried out using the dedicated MGSE and by trained personnel having the necessary experience.

12.2.4 Harness and Waveguides Integration

Harness and waveguides will be handled and installed only by experienced and authorised personnel.

All electrical interfaces will be protected by connector savers during integration, so mating/disconnecting will be made by breaking non flight hardware interfaces. Through an official record, all flight connector mating/ disconnecting steps will be traced during the AIT activities. This record shall state:

- unit and harness connectors identification: reference and type

- mating/ disconnecting date for:
  - harness connector to saver
  - unit connector to saver
  - harness connector to unit connector
    (tighten of fixing screws)

Electrical integration of harness will be completed by execution of detailed functional checks/tests. Adequate caps will protect open ends of the waveguides.

12.2.5 Electronic Units Integration

The general approach is a sequential assembling and testing. Each unit shall be reasonable functionally tested within existing constraints as far as possible before further units are added. The philosophy shall allow the identification of problems as clear and early as possible.

After unit mechanical integration and fixing bolt torque, a bonding measurement (or isolation as required) between unit housing and structure reference grounding point will be performed.

Electrical integration of units and subsystems will be completed by execution of detailed functional checks and tests.

In particular, prior to cryostat final closure and evacuation a health check of the inner scientific instrument harness will be performed with corresponding unit testers.

The system integration (electrical connection of SVM to PLM) will be performed according to the same principles:

- electrical interface verification completed by functional checks during and after final connection as explained hereafter.

12.2.6 Electrical Interface Checks

Electrical checks will be automated as far as practicable. This will ensure systematic control of all interfaces of a unit to be integrated. Before and after connection of a harness to its dedicated unit connector, all electrical S/C interfaces (e.g. power, data handling, grounding and shielding) will be tested using an Integration Data Acquisition System. The following checks will be performed to verify the electrical interface compatibility, to avoid any degradation of units:

- grounding plan verification through grounding measurements at unit and harness connector level
- safety verification of output signals by measurement at emitter unit level in unloaded configuration before harness connection. Such a verification will be restricted to high level signals (power supply – high level commands) and to signals for which a specific measurement is required due to the risk encountered by receiver units
- harness verification by performing the same kind of measurements at harness connector level before connection to the receiver unit

- signal characteristics measurement in loaded configuration (harness connected at emitter and receiver unit level) through break-out boxes and T-adapters

After removal of breakout boxes and T-adapters, final connection of each harness connector and tightening of fixation screws (plus marking where required) will be performed.

The instrument internal electrical interfaces (e.g. from warm units to FPU) will be checked I a two approach:

- verification of the database used by IDAS by testing the instrument test harness with IDAS
- verification of the FM harness with the verified IDAS

12.2.7 Functional Checks

Electrical integration of units, instruments and subsystems will be completed by execution of functional tests. Test equipment and procedures will be reused as elements of subsequent SFT. The environmental test will be accomplished by short functional test at ambient, He-I, or He-II conditions.

Functional checks of integrated units before continuing the next unit integration operations. These kind of functional checks are restricted to the minimum and allow to only verifying that the unit can be powered, commanded, and monitored.

12.2.8 Alignments

For a comprehensive description of the alignment, please refer to Chapter 9.

12.2.9 Cryo Operations

In order to allow instrument testing in the required thermal environment, the cryostat will be cooled down and the tanks filled with LHe. Instrument cool down requirements will be respected.

12.2.9.1 Cooldown & Filling

The cooldown and filling will be performed according dedicated procedures, based on existing and verified ISO documents and Herschel EQM PLM documents and using a CVSE based on the refurbished ISO CVSE units. Constraints to be regarded during cooldown and filling are described in the He S/S specification, [RD3].
Cooldown and filling will start after successfully performed evacuation and leak test of the internal Helium S/S to the cryostat isolation vacuum and isolation vacuum to ambient. After filling of the HTT with LHe-I, a cold leak test will be performed.
Similar procedures will be used for filling the HOT with He-I. Cooldown and filling will be performed with x-axis in vertical direction only. The principal set-up for cooldown and filling operations is described in detail in the CVSE Set-up Description [RD44] and shown in the following figure.

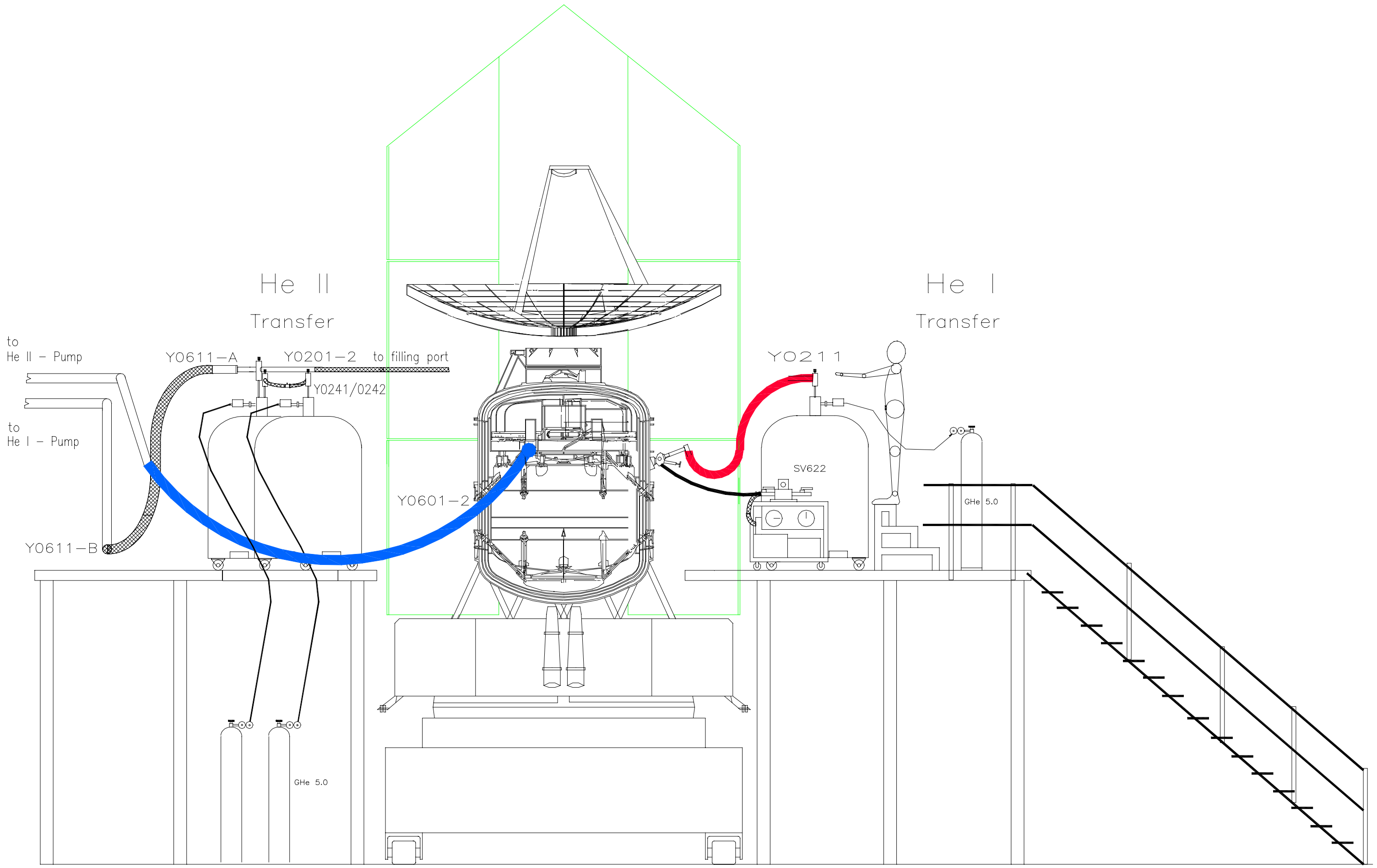


Figure 45: Set-up for cooldown, helium filling (He-I) and He-II production operation

12.2.9.2 Helium II Production and Top-Up

The Helium II production and top up will be performed according dedicated procedures also based on verified ISO and Herschel EQM PLM documents and using a CVSE, based on refurbished ISO CVSE units.
He-II production and top up will be performed with x-axis in vertical direction only.
Specific constraints, e.g. thermal gradient limits for instruments are described in the He-S/S Description [RD3] and will be strictly observed.
Principal test set-up is operations is described in detail in the CVSE Setup description [RD44] and shown in Figure 45 above.

12.2.9.3 Depletion and Warm Up

Depletion and warm-up activities will be performed according dedicated procedures also based on verified ISO and Herschel EQM PLM documents and using the CVSE.

In the nominal AIT sequence there will be only one depletion and warm-up after finalising satellite qualification test phase.

During the PFM integration and test sequence no depletion and warm up is foreseen.

12.2.10 Handling and Transportation

Detailed requirements regarding handling and transportation activities of the PLM and the satellite shall be covered in dedicated handling and transportation procedures.

An overview of the necessary handling and transportation activities is given in the Facility and Transportation Plan ([RD43]), which includes a description of the major facilities and GSE needed and the major transportation steps.

If the satellite in cold conditions needs be transported in its container (with x-axis horizontally), then the He-II tank will be filled to no more than about 50% for that purpose.

The Transportation Stimuli & Monitoring Unit (TSMU) will be attached to the transportation container and activated during transportation.

12.3 AIT Logic Flow

For illustration of how the different models come together during AIT sequence a simplified PLM and Satellite PFM/STM and PFM AIT flow is shown in the following figure, together with reference to the respective part of the AIT plan.

The details of the AIT activities are described in the two AIT plans. Part 1, [RD51], describes the PLM PFM integration, EPLM and S/C STM AIT sequence. Part 2, [RD52], describes the FM instrument integration and the EPLM & S/C FM acceptance test phase. The chapters 12.4 to 12.8 provide an overview of both plans.

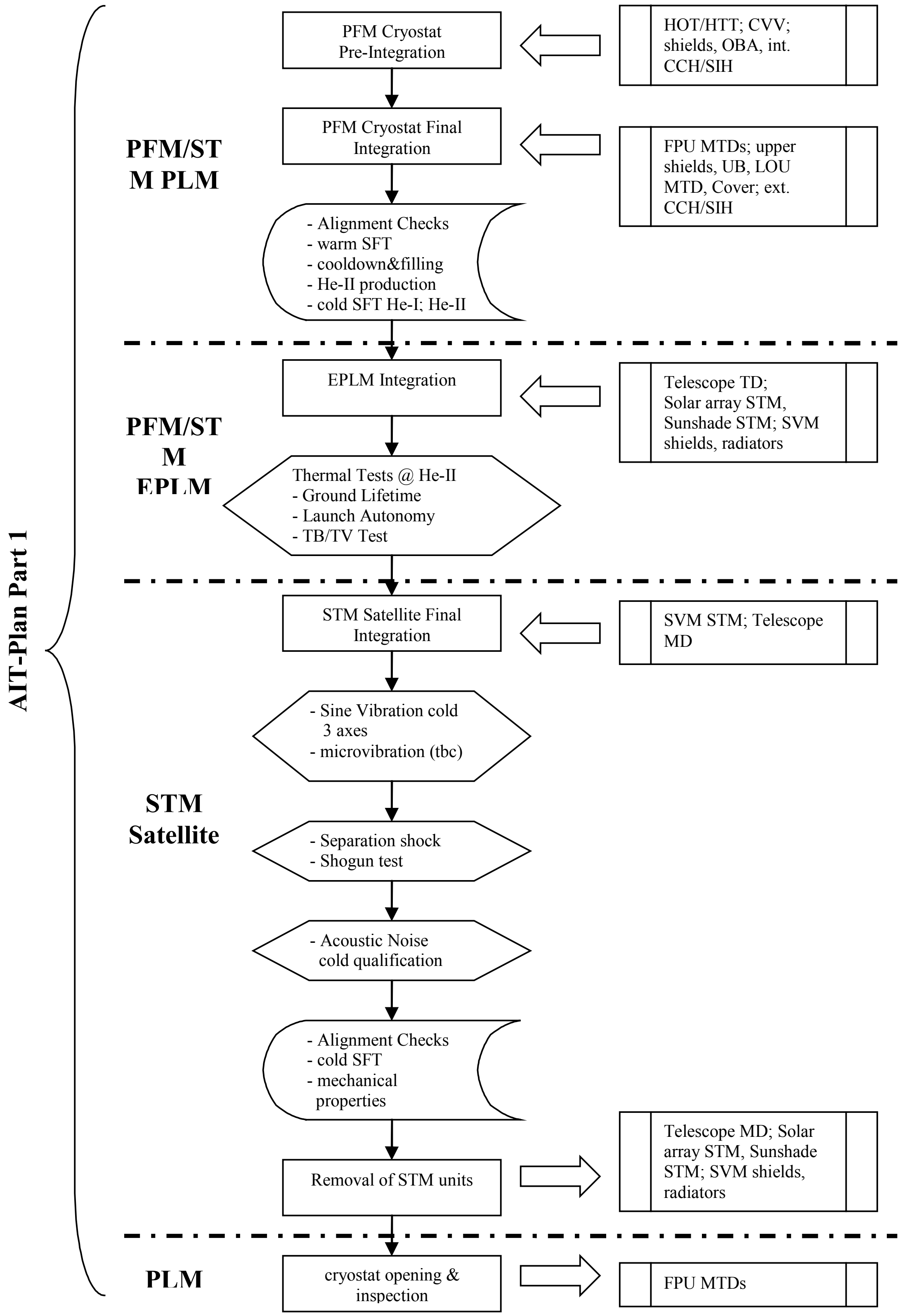


Figure 46: Simplified PLM and Satellite STM qualification AIT Flow

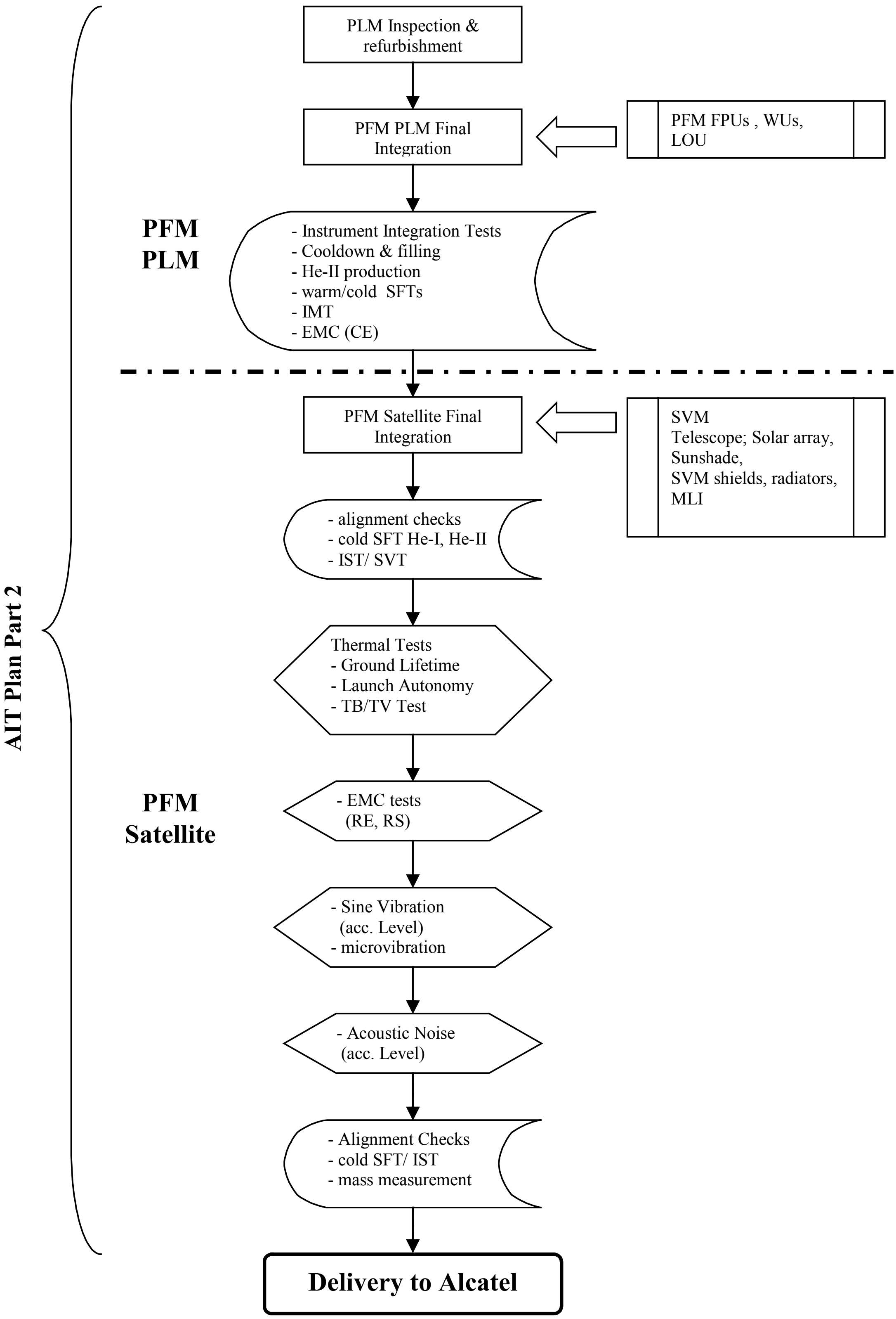


Figure 47: Simplified PLM and Satellite PFM acceptance AIT Flow

12.4 PLM (PFM/STM) Level Integration and Testing

12.4.1 PLM integration

Due to single model philosophy, the PFM PLM will already be used to support the satellite Structural and Thermal Model (STM) testing.
While the complete Cryostat and the SVM thermal shields basically will be completely PFM standard, the following items to be integrated in the PLM are Mass & Thermal Dummies (MTD) or Structural & Thermal Models (STM). These will need to be replaced after satellite STM testing:

- Instrument Focal Plane Units (FPU) for PACS, HIFI, and SPIRE
- LOU incl. support structure

Mechanical and electrical assembly and integration will be performed according to formal step-by-step procedures only. All activities will be given there in correct timely order.
All integration activities on the PFM cryostat will be performed in cleanroom class 100 environment up to and including final closure of the cryostat and evacuation.
The handling and integration activities of all hardware will be carried out using dedicated MGSE as described in a chapter below. It will be done by trained authorised personnel only with the necessary experience (e.g. ISO heritage).
The major activities during the first PFM PLM integration are summarised as follows:

- **HOT/HTT Preintegration**
    - Pre-integration of HOT with valves, tubing, sensors and harness, MLI, lower SFW
    - Pre-integration of HTT with valves, Sensors and harness, MLI
    - Mating of HOT and HTT with upper SFW, final sensor, harness and MLI installation
- **Pre-Integration Cylindrical Thermal Shield Group** (at subcontractor site; no part of this AIT Plan)
    - installation of temperature sensors and harness
    - installation of MLI onto shield elements
    - assembly of shield group
    - shield tubing integration and final checks

PFM Cryostat Pre-integration

- Pre-integration CVV cylindrical part (VGs, strap pretensioners)
- Pre-integration of OBA with sensors and harness anchors
- Pre-integration and leak check of CVV Upper Bulkhead (optical windows, SV921,922)

PFM PLM Integration

- Assembly CVV & tanks & cylindrical shields
- Integration and alignment of Optical Bench (OB)
- Leak test of tubing
- Integration of internal harness (OBA CCH & SIH)
- Integration lower shields & lower bulkhead
- Integration and alignment of Instrument FPU MTDs

- Final integration of SIH (on MTDs)
- Integration of OBA shield incl. instrumentation

PFM Cryostat Final Integration

- Integration of upper shields and MLI
- Integration of upper bulkhead
- Connection of filling port SV121 & leak test
- Integration and alignment of LOU MTD
- Alignment of OBA vs. CVV & LOU
- Integration of Cryostat Cover (CC) and Cryostat Baffle (CB)

Evacuation & leak check

Transport to clean room 100,000

PLM external integration

- Installation external tubing
- Connect CVSE / continue evacuation until start of cooldown
- Integrate external harness (CCH & SIH)
- Integration of LOU waveguides
- Electrical connection to Cryo SCOE and CCS light
- Short Functional Test (SFT1), Warm

The PLM integration sequence is completed with a bake-out . Some of the above activities may be done in parallel to the bake out.

12.4.2 PLM Testing

Before the PLM is finally mated the remaining EPLM elements and lateron the SVM to become the STM satellite it is submitted to the following test and further preparation steps:

- Connection of CVSE
- Cooldown & filling with He-I
- Alignment measurement & adjustment during cooldown with alignment camera
- Short functional test (SFT 2), He-I
- He-II production & top-up
- Short functional test (SFT 3), He-II;
- PPS functional checks and Δp measurement, including HOT evacuation
- Cover flushing with and w/o MTD heaters
- Conversion to He-I

Finally the PLM is prepared for transportation to ESTEC for further integration and testing.

12.5 EPLM Level Integration and Testing

Upon arrival at ESTEC the following steps will be conducted to complete the EPLM configuration. To thermally qualify the satellite a TB/TV tests on EPLM level is foreseen. The Launch Autonomy and TV/TB tests are performed under He-II conditions. The remaining tests are done with He-I.

- Unpacking and setup of the PLM at ESTEC
- Short Functional Test (SFT4), He-I
- Installation of test instrumentation
- Integration of telescope TD incl. mounting structure, harness and instrumentation
- Integration of Solar array STM incl. support structure (only mechanical test)
- Integration of Sunshade STM incl. support structure (only mechanical test)
- Integration of SVM thermal shields
- Integration of LOU and CVV radiators
- Connection of CVSE for refilling
- He-I top up
- He-II production and top up
- Short functional test (SFT5), He-II
- Ground lifetime and launch autonomy verification (in parallel to TB/TV preparation)
- Test setup in LSS with HSS infrared rack
- Thermal balance and thermal vacuum test including alignment checks, He-II
- Conversion to He-I
- Removal of EPLM from vacuum chamber
- Short functional test (SFT6), He-I
- De-integration of sunshade & solar array STM, SVM thermal shield (tbc) and telescope TD

12.6 STM Satellite Integration and Testing

12.6.1 STM Satellite Final Integration

To finally complete the satellite STM, the following steps will be undertaken to assemble the remaining elements to the PLM (still in cold He-I condition). He-I top up will be performed as necessary at the end of this period.

- Preparation of SVM STM
- Integration of STR STM mounting structure
- Mating of SVM STM with the PLM
- Integration of Telescope MD incl. instrumentation and harness
- Integration and electrical connection of Sun Shield/Solar Array STM including support structure
- Integration of Sun Shade STM including support structure

- assembly of SVM thermal shields STM
- integration of LOU and CVV radiators
- Integration/closure of remaining external MLI

12.6.2 STM Satellite Qualification Tests

To mechanically qualify the satellite the following main test and inspection steps are foreseen on the STM satellite. All tests are done with He-I. At the end of the STM test campaign the cryostat is depleted and warmed up to ambient temperature.

- preparation for vibration test including alignment check and short functional test (SFT)
- Sine vibration qualification level, 3 axis, incl. He-I top up steps in-between as necessary
- Microvibration test
- alignment check and SFT, He-I
- Launch vehicle adapter (LVA) fit check, SHOGUN test, and clamp band separation shock test, He-I
- Acoustic noise test qualification level, He-I
- alignment check and Short functional test (SFT), He-I
- Depletion & warm-up; removal of test harness
- Mechanical properties measurement (mass, COG x/y/z, MOI)
- Satellite dismounting incl. removal of CCV & LOU radiators, SVM thermal shield, solar array/sunshade, telescope MD (SVM STM remains mated to PLM!)
- Packing & transportation to Astrium AIT site;
- PLM & SVM STM preparation for CR100
- Setup in CR 100
- PLM disassembly, inspection, and refurbishment definition

12.7 PLM (PFM) Level Integration and Testing

12.7.1 PLM (PFM) Refurbishment and Integration

Based upon final inspection results after completion of STM satellite qualification test campaign and subsequent partial de-integration of the PLM, necessary and agreed refurbishment activities will be completed.

Thereafter the PFM PLM will be re-integrated. In this frame the following items that had been STM units respectively Mass and Thermal Dummies for the STM satellite will be replaced by PFM/FM units:

- Instrument FPUs for PACS, HIFI, and SPIRE
- LOU incl. support structure
- CCU (installed during satellite integration)

During the FPU electrical integration the STM SVM being still mated to the PLM during that period will be populated with the equipped FM WU panels for first integration tests and health checks.

Mechanical and electrical assembly and integration will be performed according to formal step-by-step procedures only. All activities will be given there in correct timely order.
All integration activities on the PFM cryostat will performed in cleanroom class 100 environment up to and including final closure of the cryostat and evacuation.
The handling and integration activities of PFM hardware will be carried out using dedicated MGSE as described in the chapter below. It will be done by trained authorised personnel only with the necessary experience (e.g. ISO heritage).
The major activities during the PFM PLM re-integration are summarised as follows:

Instrument Warm Units and SVM panel preparation

- EGSE/CCS preparation and set-up
- Mechanical integration of WUs on SVM Panels
- Electrical Integration of WUs and associated WIH & SVM harness
- Connection of WU's with PLM EGSE
- Connection of WU's with FPU simulator
- Functional tests of WU's
- Disconnection of EGSE and FPU simulators
- Cleaning & Transport of WUs on SVM panels to CR 100

Integration and alignment of FM Instrument FPUs

- Mechanical/thermal Integration FPUs onto OB
- connection of SIH to FPUs & electrical verification of harness
- FPU Alignment vs. OB and OB vs. CVV

Instrument Integration Test

- Connection of external SIH to WUs via SVM SIH
- Connection to instrument EGSE
- Instrument Integration Test
- Disconnection from instrument EGSE
- Disconnection of WU panels from SIH

PFM Cryostat Final Integration

- Integration of adsorbers
- Integration of OBA shield incl. instrumentation
- Integration upper shields incl. LOU and entrance baffle with MLI and instrumentation
- Integration of upper bulkhead
- Connection of filling port SV121 & leak test
- Integration and alignment of LOU with OBA / CVV
- Evacuation & leak check

Transport to clean room 100,000

PLM external completion

- Mechanical integration of SVM panels onto STM SVM
- Connection of SIH to WU's
- Connection of waveguides to WU's
- Integration of LOU alignment camera
- Connection of CVSE and EGSE
- Short Functional Test (SFT) warm

The PLM integration sequence is completed with the first short functional test.

12.7.2 PLM Testing

Before the PLM is finally mated with the FM SVM and other elements to become the PFM satellite it is submitted to the following test and further preparation steps:

Cooldown & filling with He-I

Alignment measurement & adjustment during cooldown

Short functional test of Instruments (SFT), He-I

He-II production & top-up

Short Functional Test cryostat and instruments (SFT), He-II

Integrated Module Tests (IMT) incl. operational programme

- Cryostat Tests (CCU & Instrumentation)
- HIFI Tests
- PACS Tests
- SPIRE Tests
- PACS/SPIRE Tests (parallel mode)

EMC tests (CE only)

Conversion to He-I

12.8 PFM Satellite Integration and Testing

12.8.1 PFM Satellite Final Integration

To complete the EPLM and finally the PFM satellite, the steps listed below will be undertaken to assemble the remaining elements and modules to the PLM. The PLM remains in He-I condition during this period.

- De-integration of SVM STM and WU panels from PLM

- Remove Star Tracker and associated mounting bracket (STM)
- Integration of STR mounting bracket FM
- Integration of SVM to PLM and alignment
- Integration and alignment of STR
- Integration of WU panels to SVM
- Connection of SVM harness (CCH & SIH) and waveguides
- Integration and alignment of Telescope incl. mounting structure
- Integration of Solar Array including support structure
- Integration of Sun Shade including support structure
- Integration of SVM shields
- Integration & closure of remaining external MLI

12.8.2 PFM Satellite Acceptance Tests

To complete the qualification and to accomplish acceptance for flight the following main test and inspection steps are foreseen on the integrated PFM satellite.

- He-I top up; He-II production & top-up
- Integrated System Test (IST1) (S/S SFTs & SFPT)
- Conversion to He-I
- Preparation for transportation
- Transportation to Test Facility (ESTEC)
- Unpacking and setup of the Satellite at ESTEC
- Short Functional Test (SFT), He-I
- He-II production and top-up
- System Validation Test (SVT1), He-II
- Ground lifetime and launch autonomy verification (in parallel to TB/TV preparation)
- Thermal balance and thermal vacuum test including alignment checks, He-II
- Short functional test of cryostat (SFT), He-II
- EMC Tests (RE, RS)
- Conversion to He-I
- preparation for vibration test including short functional test (SFT)
- Sine vibration acceptance level, 3 axis, He-I
- Microvibration measurement by activating the reaction wheels
- alignment check & short functional test (SFTx), He-I
- Acoustic Noise Test (acceptance level)
- SFT and alignment check, He-I

- He-II production and top up
- Integrated System Test (IST2), He-II (S/S SFT, SFPT)
- Conversion to He-I
- Mechanical properties measurement (mass, only)

13 System and Unit Description

13.1 Cryo Components

Below a list of all cryo components, needed quantity and expected company is shown.

Components	Needed # - FM/FS/QM/Spare/total					Manufacturer
	FM	FS	QM	Spare	total	
Helium System Components						
Adsorbers (A101 ... A1xx)	10(tbc)	8 (tbc)	1	/	19	FZK/Astrium
Helium Pressure Sensor (P101/501/701) 0 - 1.6 bar	3	3	1	/	7	Gems
Tank Heaters (H103/104, H701/702)	4	4	1	21	30	CPPA
Safety Valves Helium II High Mass Flow (SV123/SV723)	2	2	1	1	6	Phoenix
Helium Pressure Sensor (P502) 0 - 35 mbar	1	1	1	/	3	Althen/Sensotec
Ventline Test Valve (V506)	1	1	1	1	4	B.E.S.T.
Safety Valves Helium I Low Mass Flow (SV521)	1	1	1	1	4	B.E.S.T.
Vacuum Measurement Sensors (VG901/902)	2	1	1	1	5	Pfeiffer
Safety Valves CVV (SV921/922)	2	1	1	1	5	Stoehr GmbH
Rupture Discs (RD124/RD724)	2	2	16	2	22	Rembe GmbH
Internal Liquid Helium Valves (V102/V103/...)	7	1	2	/	10	Astrium, IP
External Liquid Helium Valves (V501/V503/V504/V505)	4	1	/	/	5	Astrium, IP
He-Valve Heaters and Temperature Sensors	7	1	2	/	10	Astrium, IP
Herschel Pt1000 Temperature Sensors (T103/T701/T704)	60	tbd	6	7	106	Rosemount
Herschel C100 Temperature Sensors (T106/T107/T702/...)	34	tbd	6	10	110	Astrium/Rosemount
Ventline Nozzles	3	3	tbd	tbd	tbd	Air Liquide
Ventline External Heaters (H502)	2	6	/	/	8	Nicolitch
Linde Helium System Components						
PPS 111with T 111 / T 112	1	1 (ground model)		/	2	Linde AG
DLCM 1&2 with T101/T102/T104/T105	2	1	/	/	3	Linde AG
Filling Port (with safety valve SV121 & D101/S101/Y201)	1	/	/	/	1	Linde AG
Helium II Level Probes (HTL) (L101/102)	2	1	/	/	3	Linde AG
Helium I Level Probes (HOL) (L701/702)	2	1	/	/	3	Linde AG
Ventline Unit (H501/S501/V502/T502)	1	1	/	/	2	Linde AG
Miscellaneous						
Accelerometers	20	/	/	/	20	ENDEVCO

Table 29: List of all cryo components

Detailed information about the Helium Control System can be found in [RD3].

13.2 Thermal Shields and MLI

One major part of the Herschel EPLM is the Cryostat comprising the Helium II tank (HTT), the Helium I tank (HOT) and the Optical Bench Assembly (OBA) with the three focal plane units of the scientific instruments. The HERSCHEL Thermal Shields and MLI shall minimize the heat flow into the cryogenic system of the HERSCHEL PLM on ground and in orbit and thus forms an important item for the thermal performance and lifetime. The three vapour-cooled thermal shields are arranged concentric around the tanks and the Optical Bench Assembly. These thermal shields are polished on their internal side and are equipped with MLI blankets on their external sides. The OBA comprises among other items the instrument shield, which is also polished but not equipped with MLI.

Figure 7 shows the cryostat cross section with the Thermal Shields.

<u>Thermal Shields</u>

Each of the three thermal shields intercept conducted and radiated heat from their warmer environment and are cooled by the gaseous helium (GHe) boiled off from the superfluid helium (He II) tank or from the normal liquid helium (He I) tank during the launch autonomy phase.

Each thermal shield consists of a lower and an upper bulkhead that are mounted by bolts to the central cylindrical part that is connected to the ventline as shown in Figure 48.

The evaporated GHe flowing out of the tanks is used to cool the instrument interfaces as well as the thermal shields in several stages. First the ventline is linked to the instrument interfaces at a temperature of 2K to 6 K called level 1. Then the ventline is attached to the Optical Bench Plate in order to cool it at the so-called level 2 temperature that is in the order of 12 K. Then the ventline is linked to the J-FET interfaces at a temperature level of approximately 15 K called level 3 before it is connected to the cylindrical thermal shields as shown in Figure 49.

Cooling of the cylindrical thermal shields starts with shield 1 followed by shield 2 and 3. The cryostat upper and lower shields are passively cooled via the mechanical/thermal interface to the GHe cooled cylindrical shields by multiple screw connections. The shield diameters are the same as for ISO. All shields are covered with MLI. In addition all thermal shields are polished on their internal side in order to obtain a low emissive surface.

The shields are made of aluminium alloy AlMgSi1. The wall thickness of the shields is 0.8 mm and is locally increased by riveted doubler plates for mechanical reasons. The shields are manufactured by rubber press forming of petal shapes, riveted together to achieve the final bulkhead shapes.

The upper thermal shield bulkheads and the OBA shield have a circular opening of approximately 280 mm in diameter through which the telescope beam of Herschel shall enter to the scientific instruments. A cylindrical baffle with an aperture plate attached to the thermal shield 2 surrounds the beam entrance area. A further baffle is attached to the OBA shield. In Figure 38 the attachment of the baffle to the heat shield is shown.

For the LOU (beams and alignment windows) nine specific apertures are foreseen in the upper heat shield bulkheads.

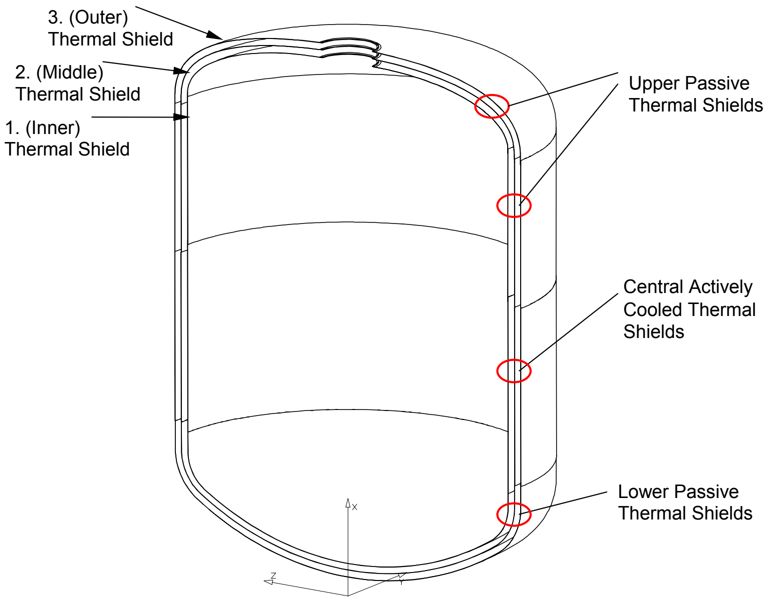


Figure 48: Arrangement of HERSCHEL Heat Shields

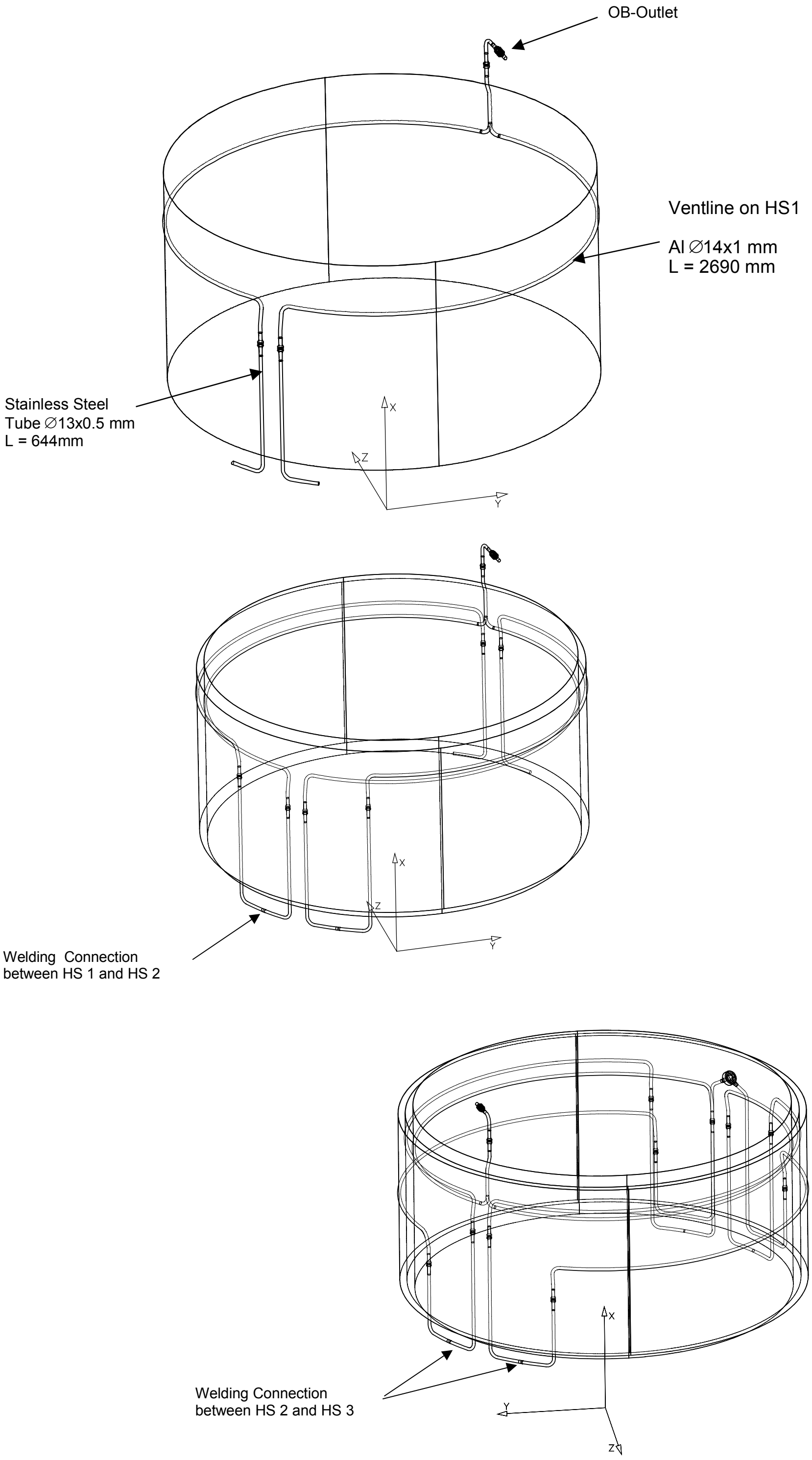


Figure 49: Ventline routing on cylindrical thermal shields

CVV internal MLI

The following components within the CVV are covered with MLI blankets:

- He I tank
- He II tank with filling port and components on it
- 3 thermal shields

The MLI on the thermal shields is composed of none-spacered supercrinkled perforated Mylar foils of 0.25 mil thickness that are coated with a 250E-10m thick aluminium layer (VDA) on one side. This "Herschel-type" MLI was extensively calorimeter-tested at Forschungszentrum Karlsruhe. The thermal performance parameters as derived in [RD47] and compiled in Table 30 allow the computation of the heat flow through an ideal test blanket at pre-defined boundary temperatures.

"ISO-type MLI" consisting of 2 x VDA 0.25 mil perforated Mylar foils spacered by a Dacron net is used for the HTT and the HOT. The corresponding performance parameters are compiled in Table 31 and are taken from [RD49]. These parameters allow to calculate the heat fluxes through an ideal test blanket for different boundary temperatures T_H and T_C. Herewith T_H corresponds to the temperature of the outermost MLI blanket layer while T_C corresponds to the structure temperature the MLI blanket is attached to.

	$q = (a (T_H + T_C)/2 + b) (T_H - T_C) + \varepsilon \sigma ((T_H^4 - T_C^4)$		
	a	b	ε
10-layer MLI	8.720E-06	2.353E-05	0.00395
20-layer MLI	4.360E-06	1.177E-05	0.001975

Table 30: Derived MLI Performance Data for Herschel Type MLI as used for the thermal shields

	$q = h (T_H - T_C) + \varepsilon \sigma ((T_H^4 - T_C^4)$	
	h (W/m²K)	ε
10-layer "ISO-type" MLI	3.50E-04	0.0030
20-layer "ISO-type" MLI	1.80E-04	0.0024

T_H = "hot" temperature of outermost blanket layer

T_C = "cold" temperature of innermost blanket layer = identical to thermal shield temperature

Table 31: Derived MLI Performance Data for ISO Type MLI

In order to compute the heat fluxes through the FM-blankets the ideal heat fluxes have to be multiplied by the so-called "integration factors" as compiled in Table 32. These factors have been analysed in [RD47] and take into account all differences between FM- and test blankets that have an influence on the thermal performance. The main contributors are edge-effects caused by cut-outs and butt-joints as well as stand-offs and electrical grounding points.

MLI on	Layers	radiative emissivity (ε_{rad})	linear conductance H [W/m²K]	Integration Factor Orbit	Ground	emissivity of ext. layer (ε_{ext})	specul. of ext. layer (ρ_{ext})
HTT	10	0.003	3.5 E-4	2	2	0.05	0
HOT	10	0.003	3.5 E-4	1	1	0.05	0
TS 1 upper bulk	10	0.00395	H(T) *	1.86	2.57	0.05	0
TS 1 upper cylinder	10	0.00395	H(T) *	2.60	4.05	0.05	0
TS 1 lower cylinder	10	0.00395	H(T) *	1.50	1.99	0.05	0
TS 1 lower bulk	10	0.00395	H(T) *	2.43	2.75	0.05	0
TS 2 upper bulk	20	0.001975	H(T) *	1.66	1.66	0.05	0
TS 2 upper cylinder	20	0.001975	H(T) *	2.05	2.03	0.05	0
TS 2 lower cylinder	20	0.001975	H(T) *	1.42	1.43	0.05	0
TS 2 lower bulk	20	0.001975	H(T) *	1.83	1.80	0.05	0
TS 3 upper bulk	20	0.001975	H(T) *	1.64	1.63	0.05	0
TS 3 upper cylinder	20	0.001975	H(T) *	2.09	2.05	0.05	0
TS 3 lower cylinder	20	0.001975	H(T) *	1.55	1.53	0.05	0
TS 2 lower bulk	20	0.001975	H(T) *	1.60	1.58	0.05	0

*) see Table above

Table 32: Overview on CVV internal MLI Performance Data

External MLI

To reduce the heat radiation from the warm Solar Array/Sunshade and the SVM to the CVV, the Cryostat Vacuum Vessel (CVV) as well as the Cryostat Baffle external surfaces are partly covered with MLI. These MLI blankets belong to the so-called external MLI. Those areas of the CVV and CVV baffle facing deep space serve as radiators and are black anodized as illustrated in Figure 50. The cryostat baffle and the CVV upper bulkhead (+X side) are completely covered with MLI at the interface to the telescope in order to reduce the heat radiation from the Telescope during decontamination heating at about 50°C.

All external MLI compositions are compiled in Table 33. Due to the barbeque modes the compositions have been completely re-defined. The thermal performance of the various MLI compositions is defined in RD53 and RD54.

For the HSS MLI and the SVM Thermal Shield MLI the performance calculation approach as proposed by Doenecke [RD48] has been taken. This approach is valid for a temperature range between 130 K and 410 K and features a calculation procedure for an effective MLI emissivity ε_{eff} without using any linear component.

Due to the barbeque modes the External MLI is currently re-defined.

MLI-Blanket	**CI-No.**	**MLI composition**	**Outermost layer, perforated**	**Remark**
CVV Lower Bulkhead MLI	121 351-100	CVV_7e / CVV5 / CVV5 / CVV5	2 mil VDA/Kapton/VDA	Fig. 50, 55
CVV Upper Cylinder MLI	121 351-200	CVV_7e / CVV5 / CVV5 / CVV5	1 mil VDA/Kapton/VDA	Fig. 50, 55
CVV Lower Cylinder	121 351-200	CVV_7e / CVV5 / CVV5 / CVV5	1 mil	Fig. 50, 55

MLI			VDA/Kapton/VDA	
CVV Upper Bulkhead MLI	121 351-300	CVV_7e / CVV5 / CVV5 / CVV5	2 mil VDA/Kapton/VDA	Fig. 50, 55
Cyostat Baffle MLI	121 352-000	CVV4_0 / CVV5 / CVV5 / CVV5	1 mil VDA/Kapton/VDA	Fig. 50, 54
Cryostat Baffle / Telescope closing single foil	121 352-000	2 mil VDA/Kapton/VDA single foil	2 mil VDA/Kapton/VDA	Fig. 50
CVV -Y Radiator MLI	121 354-100	CVV_7e / CVV5 / CVV5 / CVV5	1 mil VDA/Kapton/VDA	Fig. 50, 55
CVV +Y Radiator MLI	121 354-200	CVV_7e / CVV5 / CVV5 / CVV5	1 mil VDA/Kapton/VDA	Fig. 50, 55
LOU Box MLI, +Y	121 353-100	CVV4_0 / CVV5 / CVV5 / CVV5	1 mil VDA/Kapton/VDA	Fig. 54
LOU Box MLI, +X	121 353-100	CVV_7e / CVV5 / CVV5 / CVV5	2 mil VDA/Kapton/VDA	Fig. 55
Telescope Mounting Structure MLI	122 200-000	CVV_7embossed with exception of -Z struts as shown in Fig. 51	2 mil VDA/Kapton/VDA	Fig. 55
Solar Generator Support Struts MLI	123 312-000	STRUT_7embossed	2 mil VDA/Kapton/VDA	Fig. 56
Sunshade Support Struts MLI	123 323-000	STRUT_7embossed	2 mil VDA/Kapton/VDA	Fig. 56
CVV / SVM Support Struts MLI	124 200-000	STRUT_7embossed	2 mil VDA/Kapton/VDA	Fig. 52, 53, 56
SVM Thermal Shield MLI	132 200-000	Single foil	5 mil VDA/Kapton/VDA	
SVM Thermal Shield Fixation MLI	132 400-000	STRUT_7embossed	2 mil VDA/Kapton/VDA	Fig. 56
HSS / SVM Gap MLI	123 311-000	SSH_Gap	1 mil Kapton/VDA + 5 mil ITO Silver/Inconel FEP tape with 966 acrylic adhesive	Fig. 57
Solar Generator Panel MLI	123 311-000	SSH_7embossed	2 mil VDA/Kapton/VDA	Fig. 58
Lower Horizontal Stiffener MLI	123 311-000	SSH_15embossed	2 mil VDA/Kapton/VDA	Fig. 59
Middle Horizontal Stiffener MLI	123 311-000	SSH_15embossed	2 mil VDA/Kapton/VDA	Fig. 59
Upper Horizontal Stiffener MLI, +X-side	123 322-000	SSH_15e+5mil	5 mil VDA/Kapton	Fig. 60
Sunshade Horizontal Stiffener MLI, -X-side	123 322-000	SSH_15embossed	2 mil VDA/Kapton/VDA	Fig. 59
Solar Generator Stiffener Brackets MLI	123 311-000	SSH_15embossed	2 mil VDA/Kapton/VDA	Fig. 59

Sunshade Panel MLI, Xs < 3600 mm	123 322-000	SSD_7embossed	2 mil VDA/Kapton/VDA	Fig. 61
Sunshade Panel MLI, 3600 mm < Xs	123 322-000	SSD_7e+5mil	5 mil VDA/Kapton	Fig. 62
Sunshade Vertical Stiffener MLI, -Y	123 322-000	SSD_7e+5mil	5 mil VDA/Kapton	Fig. 62
Sunshade Vertical Stiffener MLI, +Y	123 322-000	SSD_7e+5mil	5 mil VDA/Kapton	Fig. 62
Sunshade Panel MLI, between horizontal stiffeners	123 322-000	SSD_7embossed	1 mil VDA/Kapton/VDA	Fig. 61
Sunshade Stiffener Brackets MLI	123 322-000	SSH_15embossed	2 mil VDA/Kapton/VDA	Fig. 59

All VDA surfaces feature a hemispherical infrared-emissivity of 0.05 and a specularity of 0.8.

Table 33: Overview on External MLI Blanket Compositions

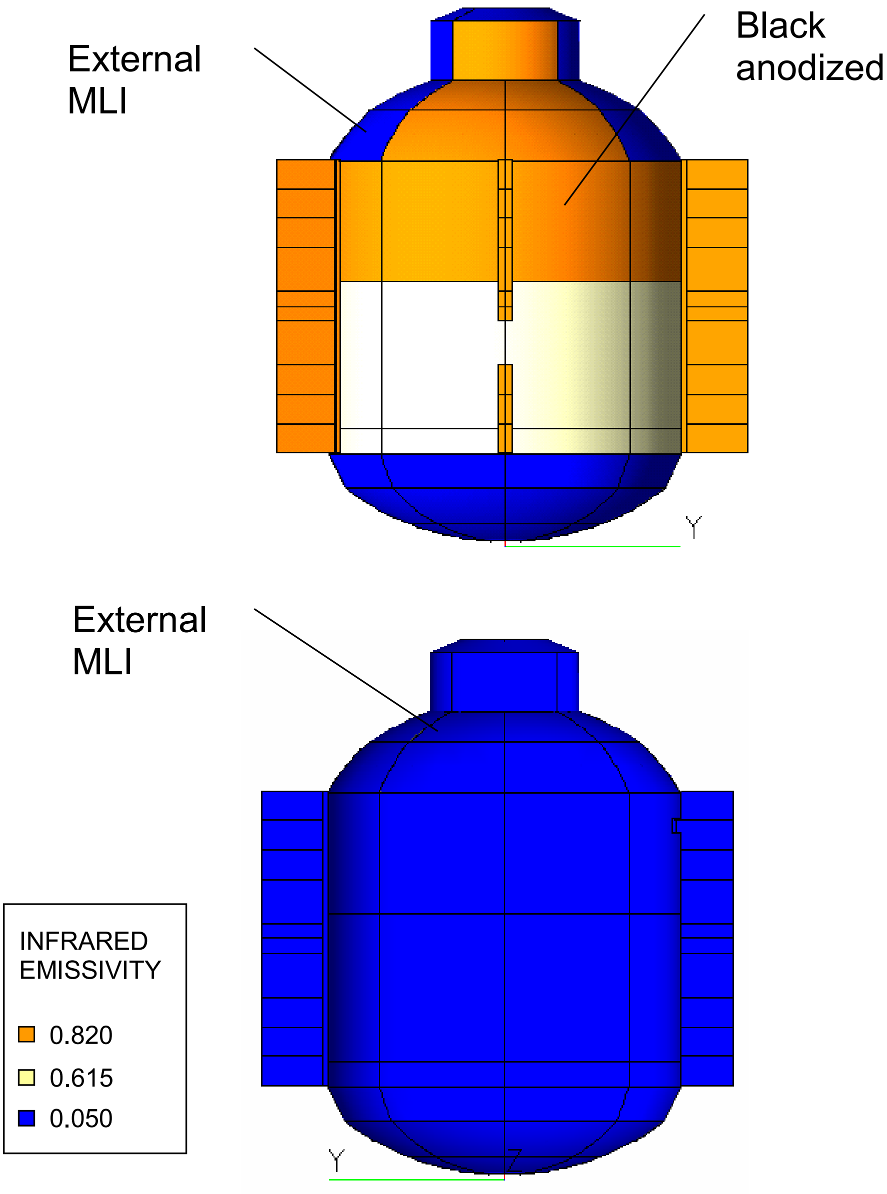


Figure 50: CVV external MLI and radiator areas

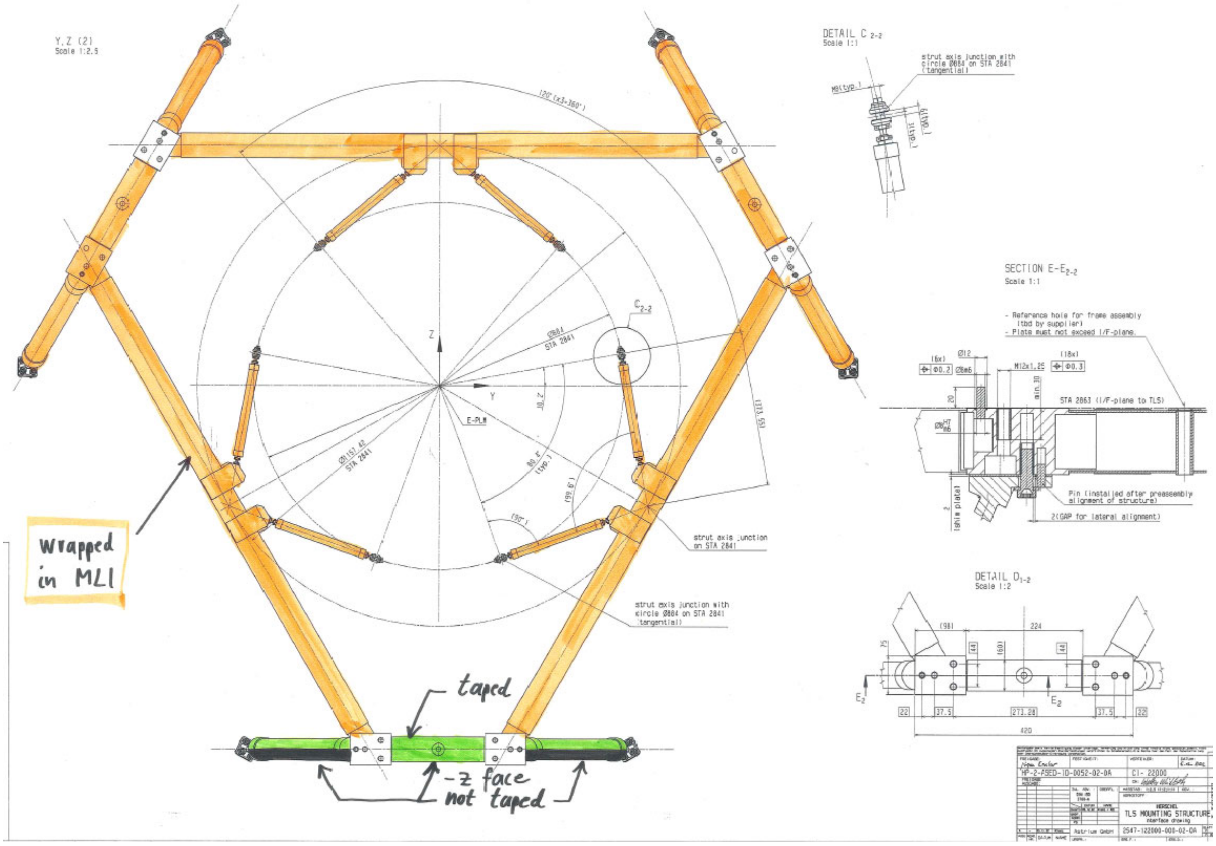


Figure 51: Telescope Mounting Structure MLI Design

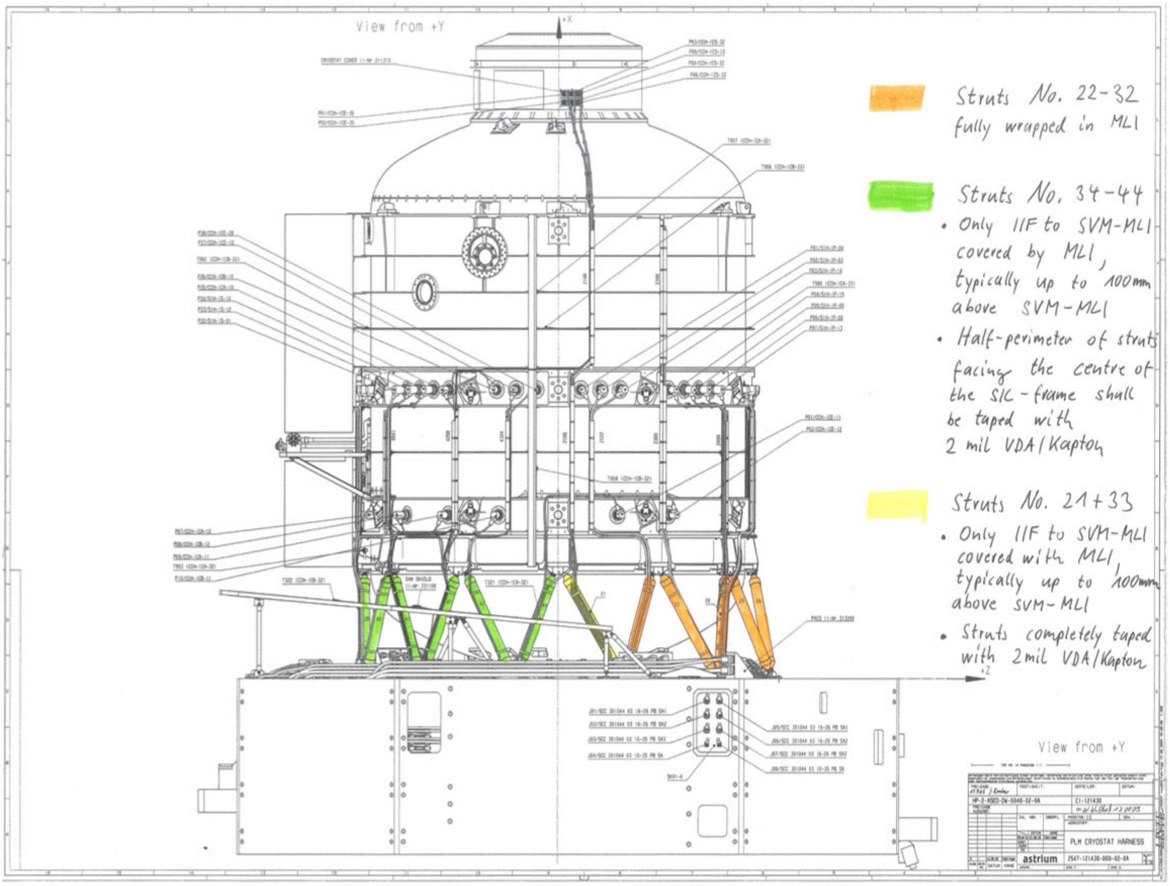


Figure 52: Definition of MLI and taping areas on the CVV / SVM struts, view from +Y

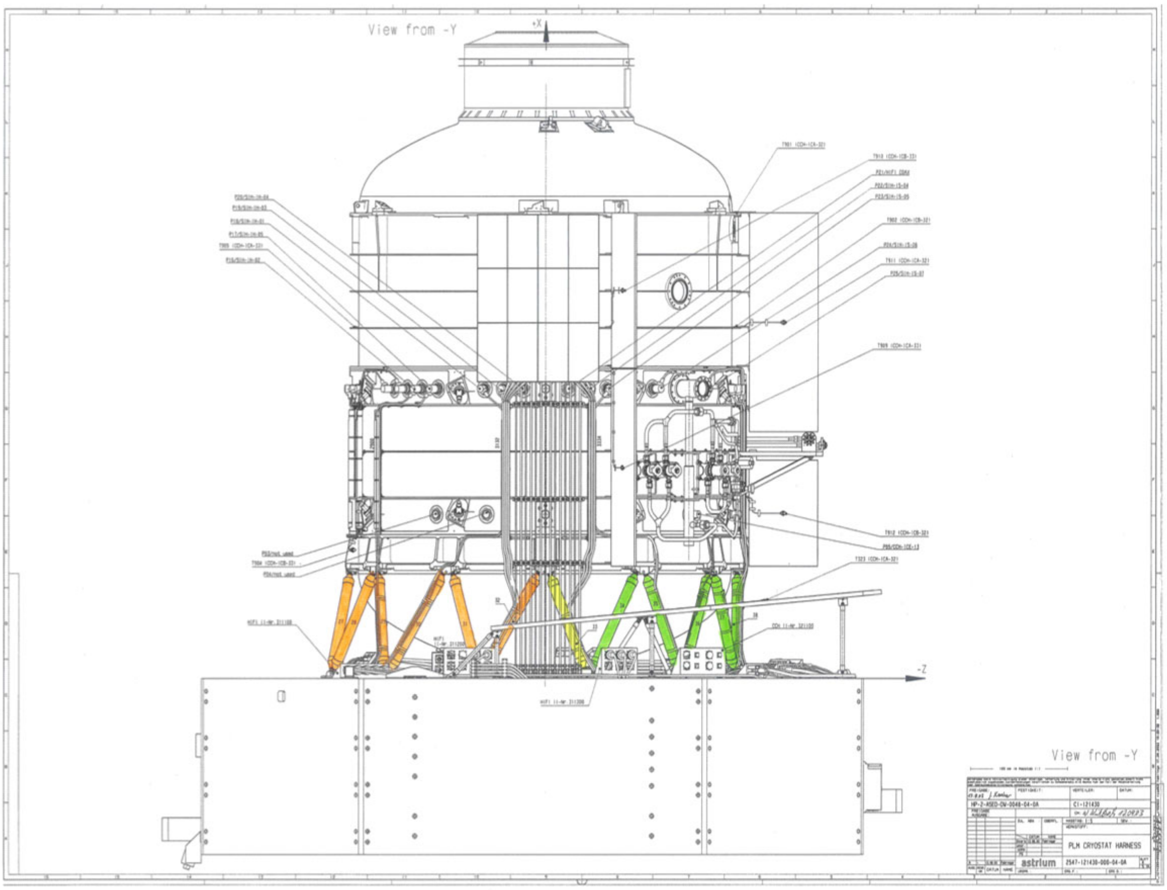


Figure 53: Definition of MLI and taping areas on the CVV / SVM struts, view from -Y

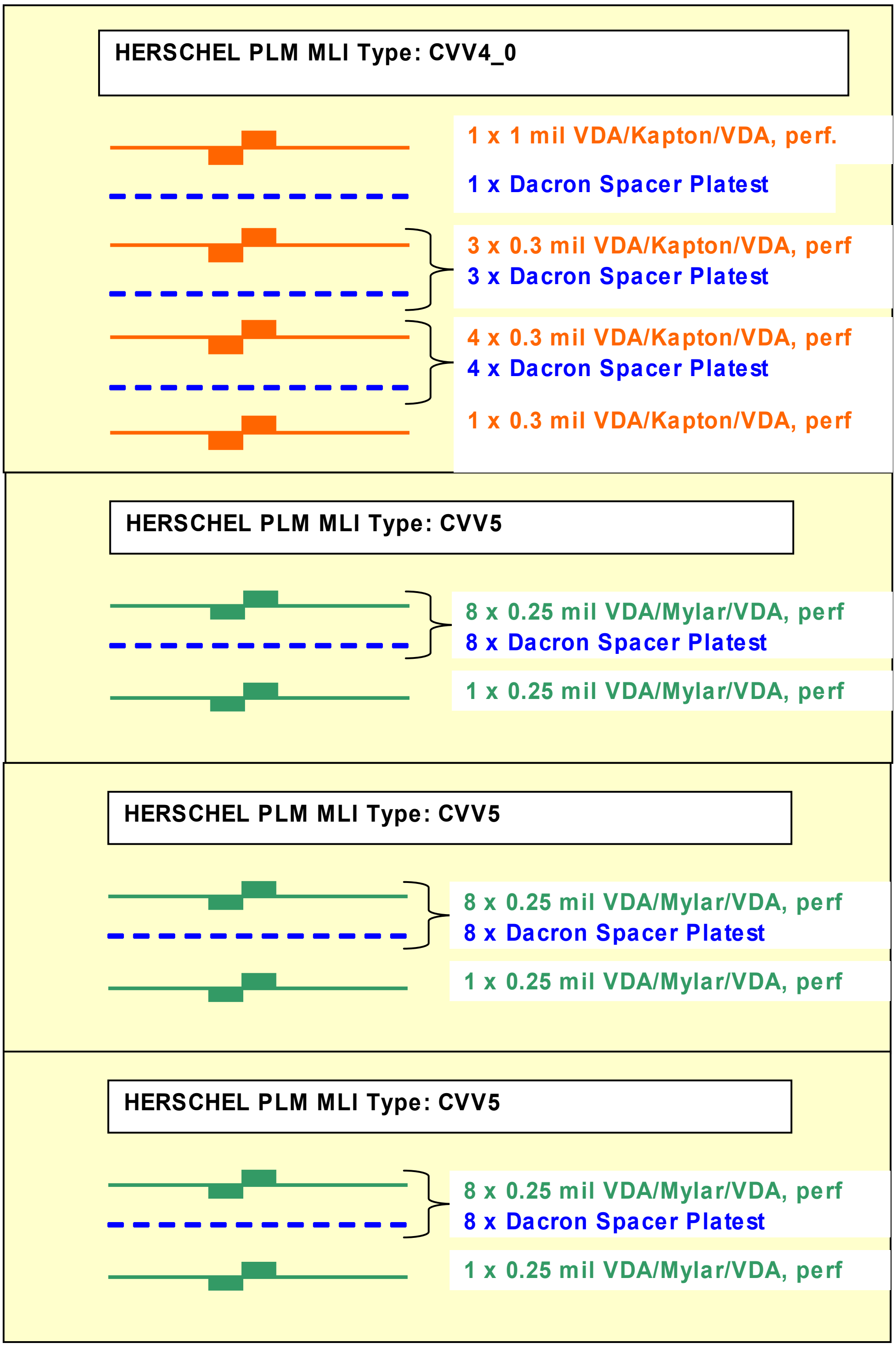


Figure 54: MLI Composition CVV4_0 / CVV5 / CVV5 / CVV5

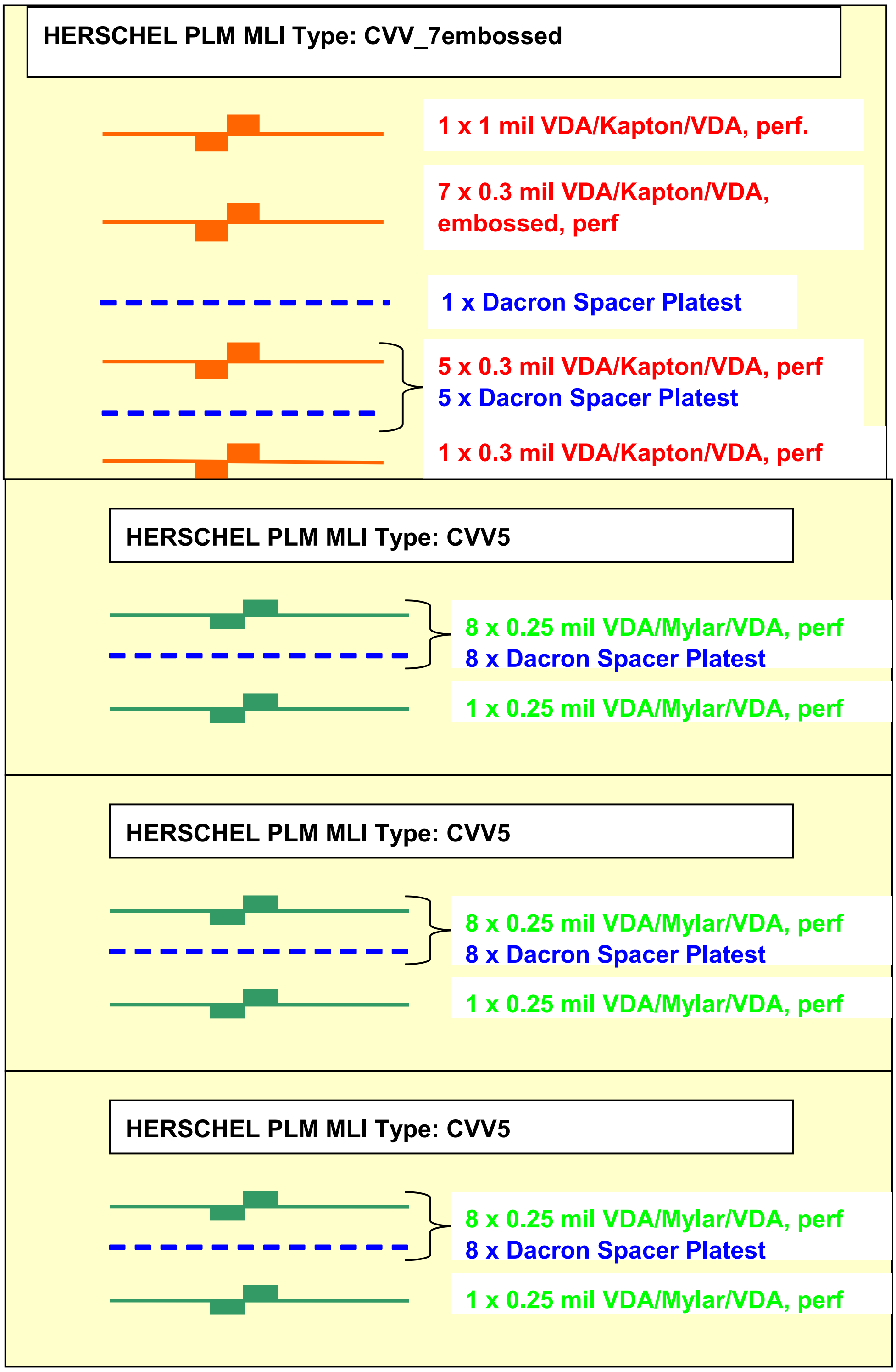


Figure 55: MLI Composition CVV4_0 / CVV5 / CVV5 / CVV5

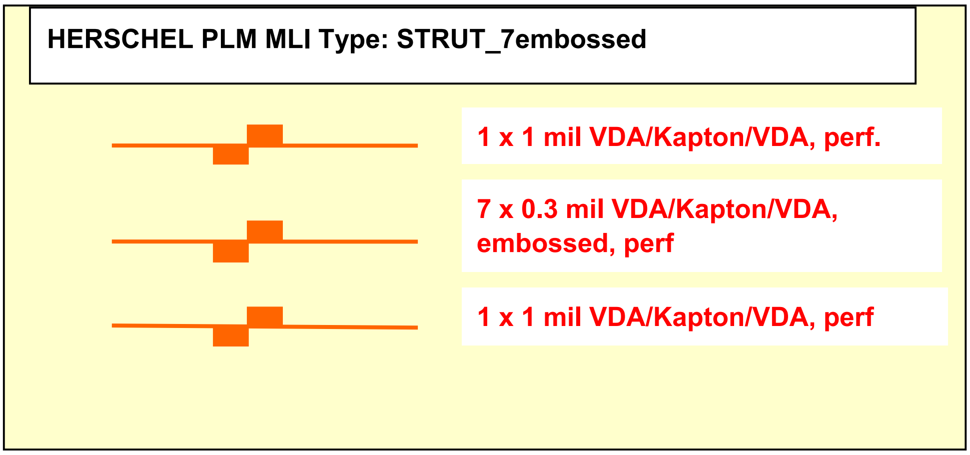


Figure 56: Strut MLI Composition STRUT_7embossed

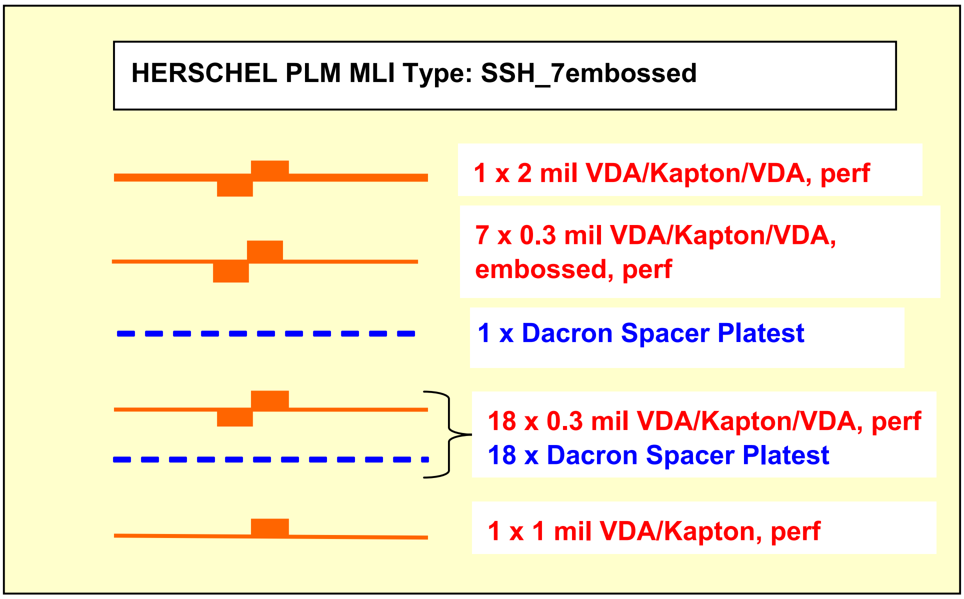


Figure 57: Composition of Solar Generator Panel MLI

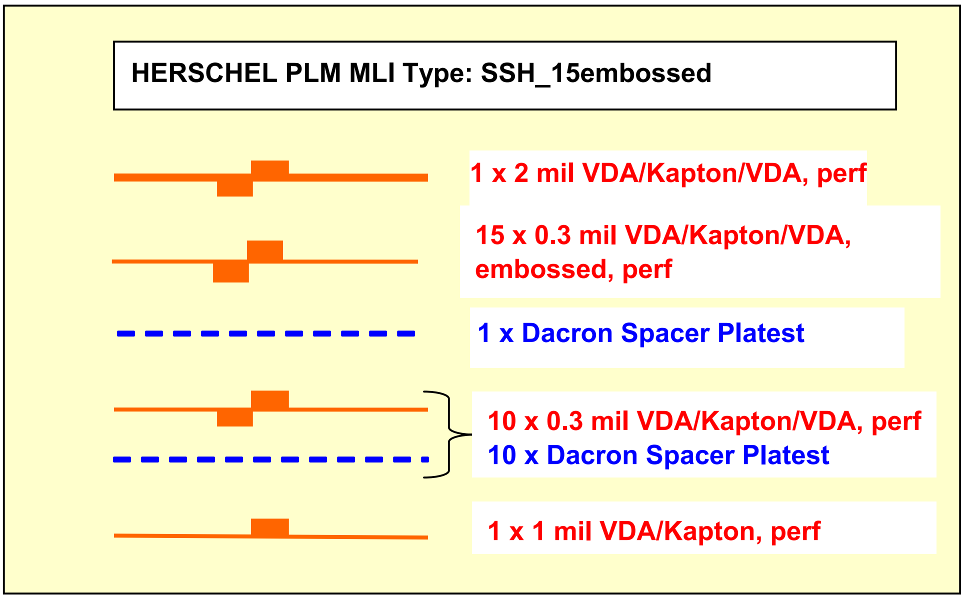


Figure 58: Composition of Horizontal Stiffener MLI

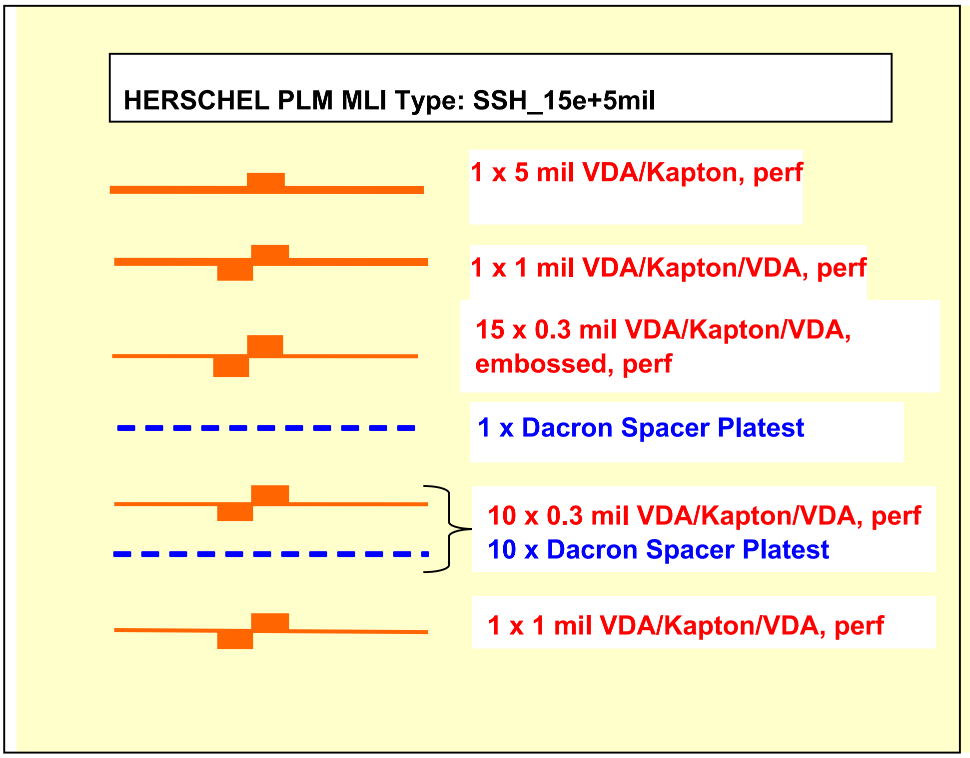


Figure 59: Composition of Upper Horizontal Stiffener MLI, +X-side

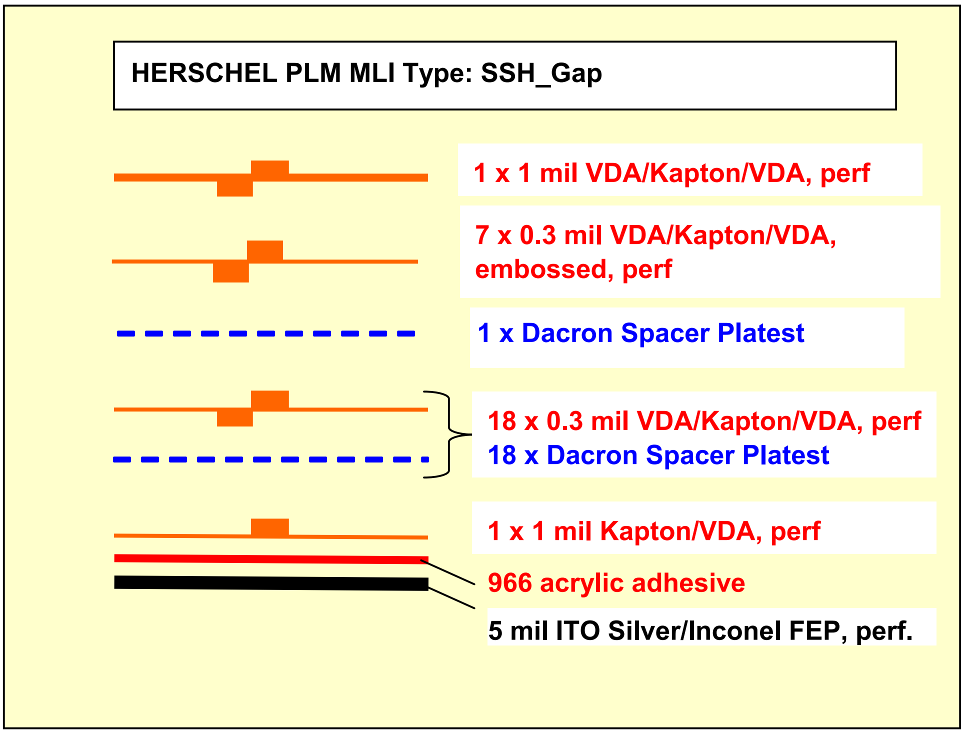


Figure 60: Composition of HSS / SVM Gap MLI

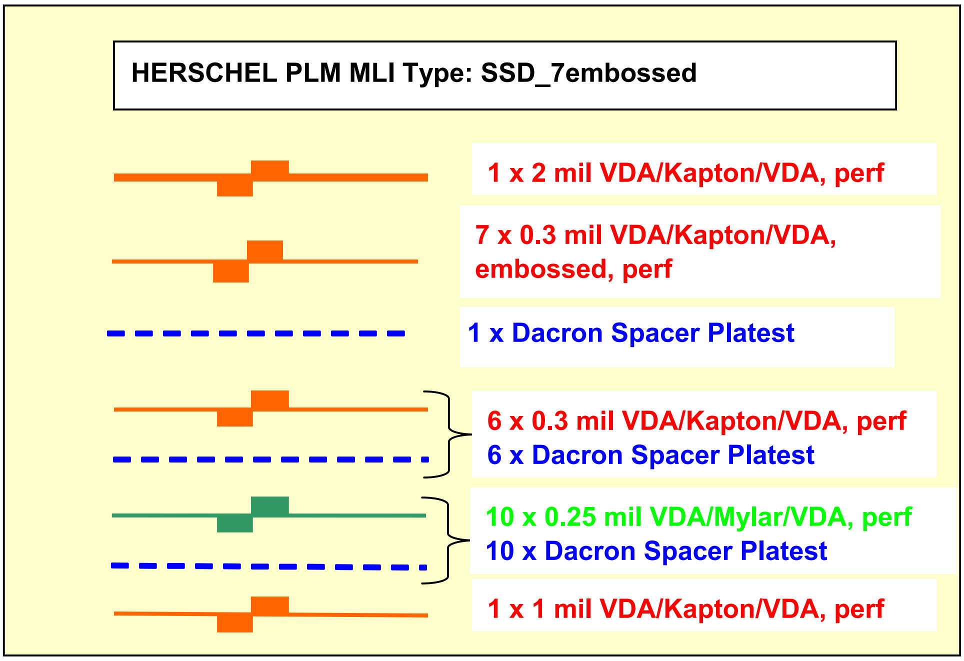


Figure 61: Composition of Sunshade Panel

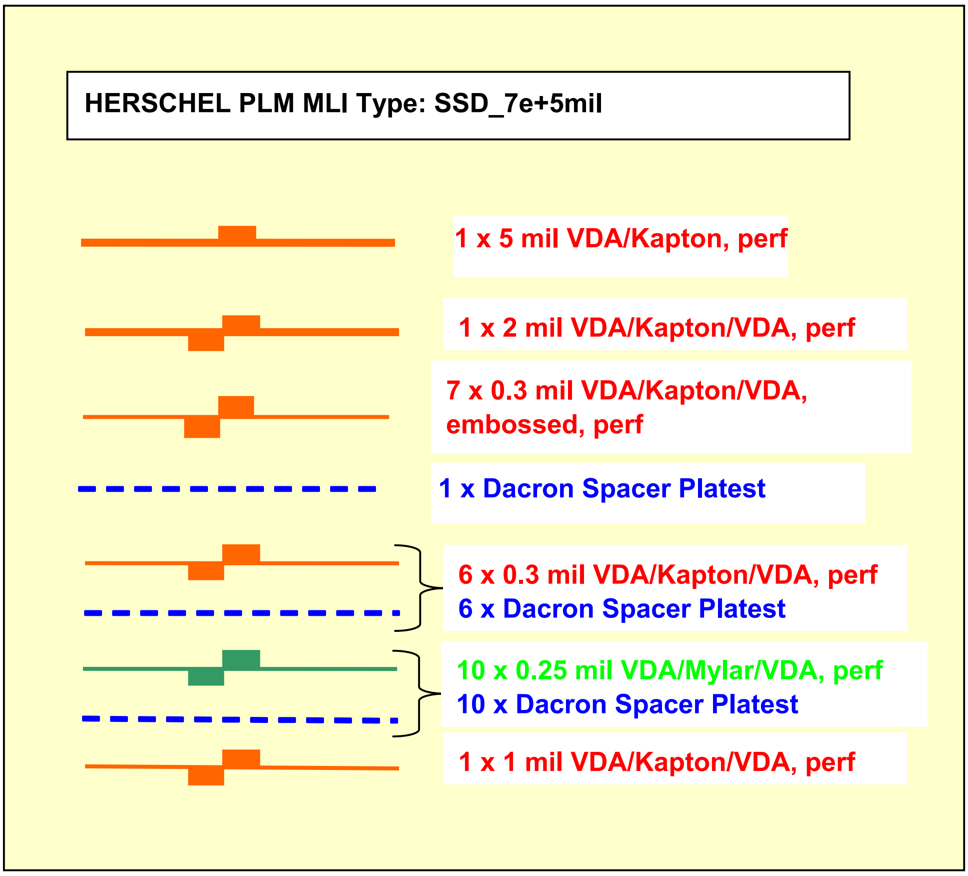


Figure 62: Composition of Sunshade Panel

13.3 Cryo Harness

The comprehensive description of the cryo harness is provided in [RD45].

13.4 Cryostat Control Unit (CCU)

As part of the electrical subsystem of the H-EPLM the CCU is located on the –z panel of the SVM.

Via the SVM subsystems, the CCU will provide operational access to the cryostat instrumentation (temperature sensors, pressure sensors, heaters and liquid He valves) as well as to the telescope and SSD temperature sensors.

The design, without a microprocessor and software, is based on the ISO Cryo Electronics.

The CCU is internally redundant with identical functions for both physically self-contained units.

Since the majority of the sensors of the cryostat instrumentation is not redundant and the He valve activation during ascent must be single point failure free, hot redundant operation of the two CCU's is mandatory. The DLCM system is allocated within both redundancies and therefore the loss of one CCU would only cut the still working sensor by 50 % but the remaining sensors provide sufficient information for predictable operation of the cryo system.

Each unit is operated by the CDMU via a MIL-STD 1553 B bus interface and is powered via a LCL by the PCDU.

Through its user interface the unit monitors the cryostat status by acquisition of the pressure and temperature sensor readings, operates and monitors the liquid helium content measurement system and operates the LHe-valves and acquires their status indicators.

Any electrical input into the cryostat ends up in heat dissipation, which has to be compensated by additional liquid He evaporation. It is therefore of utmost importance for the operation of the CCU to avoid any unnecessary and inadvertent activation of heaters or any other heat dissipating circuits in the cryostat control system.

The CCU is tailored to operate only the cryo control instrumentation required in orbit. Additional cryo control instrumentation needed for ground testing and during launch preparation is operated by the Cryo SCOE, respectively the Cryo COTE in the final launch preparation phase.

A principle blockdiagram of the CCU is given in the figure below.

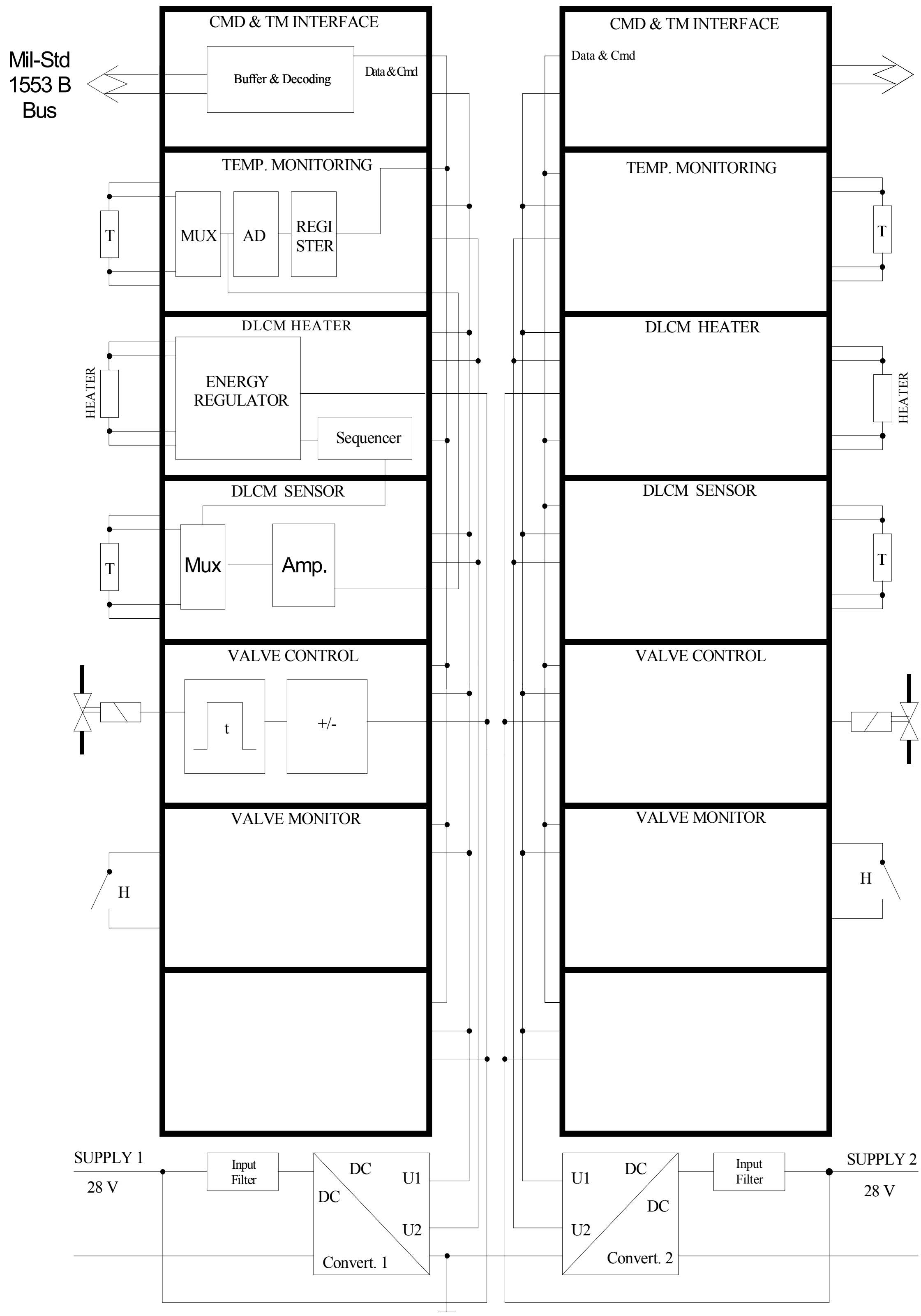


Figure 63: CCU Principle Blockdiagram

For the operation of the cryo system the CCU provides three major functions:

- Switching of the He valves.
- Execution of the Direct Liquid Content Measurement (DLCM).
- Monitoring of the cryo system.

LHe valve switching

In order to avoid a single point failure case, the six He valves, operated by the two CCU's, are grouped into three functional pairs (V 103 / V 106; V 501 / V 503 and V 504 / V 505). Consequently the CCU A (nom.) activates the first one and CCU B (red.) activates the second one of each LHe valve pair.

Since erroneous LHe valve activation can have a severe influence on the cryo system operation, the access to a He valve is protected by an arming command. This means that the valves switching is only executed when the related arming and switching commands are received in the correct sequence and timing.

For the activation of the six He valves (V 103, V 501 and V 504 within CCU A; V 106, V 503 and V 505 within CCU B), the CCU is able process and execute the related arming and switching commands received via the Mil Std 1553 B bus.

In addition for the opening of the four He valves (V 103 and V 501 within CCU A; V 106 and V 503 within CCU B) during launch, the CCU is able to process and execute the related arming and switching open commands generated by the Ariane 5 launcher and distributed to the CCU via discrete lines.

According to the CCU WCA, the minimum voltage at the valve activation output of the CCU is 25.6 V considering a mainbus voltage of 26.0 V. The harness resistance of the supply lines for the LHe valves V 501 and V 503, operated during launch at room temperature, is less than 3.26 Ω and the LHe coil resistance at room temperature is less than 52.0 Ω.

Consequently the current supplied by the CCU for the operation of the LHe valves V 501 and V 503, during launch at room temperature, is at least 460 mA, about 15 % more than the 400 mA required by the LHe valves specification for the proper operation of the valves under all environmental conditions. In addition the LHe valves qualification tests (more than 230 cycles) demonstrated that LHe valve operation at room temperature is guarantied with a current below 350 mA in any case.

Direct liquid content measurement (DLCM)

The liquid helium content of the helium II tank is determined by measuring the temperature increase of the liquid helium caused by a constantly monitored injection of an exactly defined heat pulse. For that purpose the injected current and voltage drop over a heater within the helium bath is precisely measured every 125 ms for a predefined measurement period of up to 850 seconds.

The DLCM is initiated by a command from the CDMU via the Mil Std 1553 B bus, which contains a parameter for the selection of the time duration of the measurement.

The heater has a nominal resistance of 50 Ω at 1.8 K (90 Ω at ambient) and is supplied via two brass AWG 30 (2.0 Ω/m) wires with a length of about 3.5m. For the voltage sense lines two stainless steel AWG 38 (130 Ω/m) wires with a length of about 3.5m are taken into account. For the DLCM temperature sensors (T 102/T 105 and T 101/T 104) the standard four wire stainless steel AWG 38 (130 Ω/m) interface with a length of about 3.5m per wire is assumed. The DLCM temperature sensors (T 102/T 105 and T 101/T 104) in nominal mode is part of the cyclic cryo system monitoring. For the operation in the DLCM these four sensors are operated in a high precision mode in the temperature range of 1.6 K to 1.8 K with an accuracy of less than ± 2mK.

Since the execution of the DLCM results in a considerable increase of He consumption, the activation of the DLCM is protected by an arming command.

This means that the DLCM command will only be executed when the related *arming* and *DLCM ON* commands are received in the correct sequence within less than 180 seconds.
The two commands received in the right order and time by the CCU will trigger the sequence below:

- the *DLCM arming* command will enable (but **not** switch-on) the supply of heater current to the DLCM heater (H 101 in CCU A / H 102 in CCU B) for the next 600 seconds.
- the *DLCM ON* command will trigger an internal sequence with the following functions:
  - start of the DLCM monitoring (acquisition of the readouts of the DLCM temperature (T 102/T 105 and T 101/T 104), heater voltage and heater current sensors every 125 ms).
  - switch on the DLCM heater (H101 or H102) 200 seconds after starting the DLCM monitoring.
  - switch off the DLCM heater after 0 to 200 seconds (according to the first parameter content in the CMD).
  - switch off the DLCM monitoring 0 to 450 seconds (according to the second parameter content in the CMD) after the DLCM heater switch-off.
  - disable the DLCM arming within one second after switch off the DLCM monitoring.
  - DLCM monitoring acquisition of one complete set of DLCM sensor readouts per related command.

At the end of a DLCM cycle a complete data set of DLCM monitoring parameters is assembled into a table and is ready for transfer to the CDMU. During the DLCM the nominal cyclic monitoring is suspended.

<u>Monitoring Function</u>

The cryo system monitoring function provides the acquisition of the readout of the cryo system temperature, pressure and He valves status sensors. Selected by the command parameter the monitoring is performed as data set acquisition (sequential readout of all enabled sensors).The command parameter contains at least as many bits as cryo system sensors are implemented in the CCU user interface. Each bit in the command parameter field represents a dedicated cryo system sensor in the CCU user interface. A logical one enables the measurement acquisition of the related sensor, whereas a logical zero skips the measurement acquisition of the related sensor.

Temperature measurement

Temperature measurement is accomplished by measuring the voltage drop over a temperature dependent resistor (sensor) caused by an imposed constant current. The sensor interface is implemented as a 4-wire interface consisting of two voltage sense lines and two lines for the exciting current. For the design of the interface an average length of 6.5 m for each of the four stainless steel AWG 38 (130 Ω/m) wires was taken into account.

Since the heat dissipation inside the CVV must be kept to the absolute minimum the temperature sensors are only powered (supply of constant exciting current) for less than 50 ms during the measurement acquisition for each sensor.

Pressure measurement

Pressure measurement is accomplished by measuring the differential voltage of a resistive bridge with one pressure sensitive resistor (sensor). The bridge is supplied with an imposed constant current. The sensor interface is implemented as a 4-wire interface consisting of two voltage sense lines and two lines for the exciting current. For the design of the interface an average length of 6.5 m for each of the four stainless steel AWG 38 (130 Ω/m) wires was taken into account.

Since the heat dissipation inside the CVV must be kept to the absolute minimum the pressure sensors are only powered (supply of constant exciting current) for less than 50 ms during the measurement acquisition for each sensor.

LHe valve status

The He valve position is indicated by a reed contact which is closed when the valve is open. The status of the LHe valve is acquired by a standard digital relay status (DRS) interface.

Since the heat dissipation inside the CVV must be kept to the absolute minimum the valve position sensors is only powered (supply of constant exciting current) for less than 50 ms during the measurement acquisition for each sensor.

Similarly to the cryo system monitoring the CCU provides the status and housekeeping information of the unit itself. Initiated by a command via the Mil Std 1553 B bus from the CDMU, the CCU provides the unit housekeeping telemetry by sequential acquisition of all housekeeping parameters necessary for the determination of the units health status. After acquisition and proper formatting the CCU HK monitoring table is ready for transfer to the CDMU.

Operation

CCU operations aspects are covered in Section 5.6.

Electrical Interfaces

SVM power interface

The CCU has two primary power interfaces (one for CCU A, one for CCU B) via two separate connectors. The average power consumption of the CCU is less than 6.0 W per power line.

The average power demand is defined as the maximum average power drawn from its dedicated power lines in the worst case voltage conditions.

Specifically, the maximum average is defined as the average during a period of 5 minutes shifted to any point in time where this average will yield a maximum and does not include peak power defined hereafter.

The CCU has a long peak power consumption of less than 35 W per power line.

Long peak power demand is defined as the maximum peak drawn from its dedicated power lines, in the worst-case voltage conditions. Specifically, the maximum long peak is defined using the integral during a period of 5 minutes shifted to any point in time over 100 minutes where the integral will yield a maximum.

The CCU will have a short peak power consumption of less than 35 W per power line.

Short peak power demand is defined as the maximum peak drawn for its dedicated power lines in the worst case voltage conditions.

Specifically, the maximum short peak is defined using the integral during a period of 1 ms shifted to any point in time where the integral will yield the maximum.

To be defined as a short peak, the power demand will last less than 100 ms.

The Imax defined for the LCL supplying the CCU corresponds to the current drawn during the short peak condition.

SVM data handling interface

Each CCU (the nominal one as well as the redundant one) provides two Mil Std 1553 B bus interfaces (one to the nominal and one to the redundant Mil Std 1553 B bus). The data handling bus interface is implemented according to the reference standard MIL-STD 1553B Notice 2. The MIL-STD-1553B bus connectors is dedicated (no sharing of connectors with any other signal) and segregated (one connector for nominal bus and one for redundant bus) on each CCU.

SVM discrete valve command interface

The CCU has two discrete valve command interfaces (one CCU A, one for CCU B) via two separate connectors. Each discrete valve command interface comprises two valve-switching commands and two related arming commands. The electrical characteristics of the valve switching and arming command interfaces is compliant to the Ariane 5 dry loop command I/F.

Cryo system user interface

The CCU provides the signal conditioning and acquisition circuitry for the following sensor types:

sensor type 0 :	4 I/F’s (2 within CCU A / 2 within CCU B)
sensor type 1:	4 I/F’s (2 within CCU A / 2 within CCU B)
sensor type 2:	10 I/F’s (5 within CCU A / 5 within CCU B)
sensor type 3:	10 I/F’s (5 within CCU A / 5 within CCU B)
sensor type 4:	14 I/F’s (7 within CCU A / 2 within CCU B)

sensor type 5: 60 I/F’s (30 within CCU A / 30 within CCU B

pressure sensors: 4 I/F’s (2 within CCU A / 2 within CCU B

DLCM heater voltage: 2 I/F’s (1within CCU A / 1within CCU B)

LHe valves stat. ind.: 6I/F’s (3 within CCU A / 3 within CCU B

The CCU provides the supply circuitry for the following actuator types:

DLCM heaters: 2 I/F’s (1 within CCU A / 1within CCU B)

LHe valves: 6 I/F’s (3 within CCU A / 3 within CCU B)

Physical Properties

Mass: The CCU has a mass of less than 9.2 kg.

Dimensions: The CCU has the following dimensions (without feet's):

Length: 328.5 mm

Width: 247.5 mm

Height: 190.5 mm

All unit connectors are located on the unit's top face (side opposite to the baseplate) in easily accessible positions. The physical position is compliant with the minimum distances between connectors.

All connectors related to the SVM interconnection are located on one end of the units top face whereas all connectors related to the CCU user I/F (sensors and actuators) are located on the other end of the units top face.

Temperatures: The CCU qualification temperature range is – 20°C to + 50°C in operating mode.
The CCU qualification temperature range is – 30°C to + 60°C in non-operating mode.
The CCU qualification minimum switch-on temperature is – 30°C.
The CCU acceptance temperature range is – 15°C to + 45°C in operating mode.
The CCU acceptance temperature range is – 25°C to + 55°C in non-operating mode.
The CCU acceptance minimum switch-on temperature is – 25°C.

Model Philosophy

One Engineering Qualification Model (EQM) is foreseen for qualification of the design of the unit as well as for the participation in the system level EQM testing.

One Flight Model (FM) is manufactured and tested to acceptance levels and is intended to be embarked on the PFM spacecraft.

Using the EEE spare parts later in the program the CCU EQM unit is refurbished to a Flight Spare Model (FS) by replacing the EQM PCB’s with new assembled flight standard PCB’s. After the refurbishment the FS unit is subjected to acceptance level testing.

13.5 Optical Bench Assembly (OBA)

The OBA [CI 121140] is defined as the assembly which consists of the following items:

- Optical Bench Plate (OBP,) with mounting brackets to the Spatial Framework (SFW) [CI 121 141],
- Optical Bench Shield (OBS), including entrance and LOU baffles [CI 121142],
- Optical Bench Helium Cooling Loops, including mounting brackets (OBHCL) [CI 121143],
- Thermal Interface Links to Scientific Instruments (OBTL)
  - L0 thermal links 'L0TL' [CI 121144-01]
  - L1 thermal links 'L1TL' [CI 121144-02]
  - L3 thermal links 'L3TL' [CI 121144-03]
  - MGSE Items: OBA MGSE [CI 121150]
    - Hoisting Device for OBA: [CI 121150-01]
    - Handling Structure [CI 121150-02]
    - Transport Container [CI 121150-03]
- Optical Bench Instrumentation interfaces
- Scientific Instrument and Cryostat Instrumentation Harness (SIH & CIH) interfaces (*)

The following items will be integrated by the ASED:

- Scientific Instrument Harness (SIH), Cryostat Instrumentation Harness (CIH)
- Instrumentation on the OBA, e.g. Temperature Sensors, Accelerometers etc.

The basic function of the Optical Bench Assembly (OBA), is to provide through the Optical Bench Plate (OBP) itself a solid and alignment stable support of the Scientific Instruments (PACS, HIFI, SPIRE FPU, SPIRE-JFETs) within the Herschel cryogenic environment.

The OBP shall be a light aluminium plate, which is supported at four I/F points and provides I/F for the instruments and associated parts of instrument harness as well as for Optical Bench Instrumentation (OBI).

The following thermal I/F links (OBTL) shall be foreseen:

- Level 0 FPU's to HTT (PFM)
- Level 1 FPU's to OBHCL1 (OBHCL1 thermally isolated from OBP, is defined from PACS level 1 attachment area to HIFI level 1 attachment area)

  OBHCL1 and OBHCL2 thermally isolated by special segment

  OBHCL2 to OBP (OBHCL2 thermally well connected to OBP, is defined from first to the last thermal attachment point to the OBP)
- Level 2 OBP temperature

- Level 3 JFET’s to OBHCL 3

The Thermal Links and the Cooling Loop belongs to the Helium Subsystem. A detailed description is given in the H-PLM Helium Subsystem Description, [RD3].

Two models with identical interfaces shall be delivered. One protoflight model (OBA-PFM) and the other for the H-EPLM EQM program (OBA-EQM).The PFM model is used for the mechanical environmental qualification as defined in the OBA-Procurement Specification.

Figure 64 shows the complete OBA assembly without the OBS.

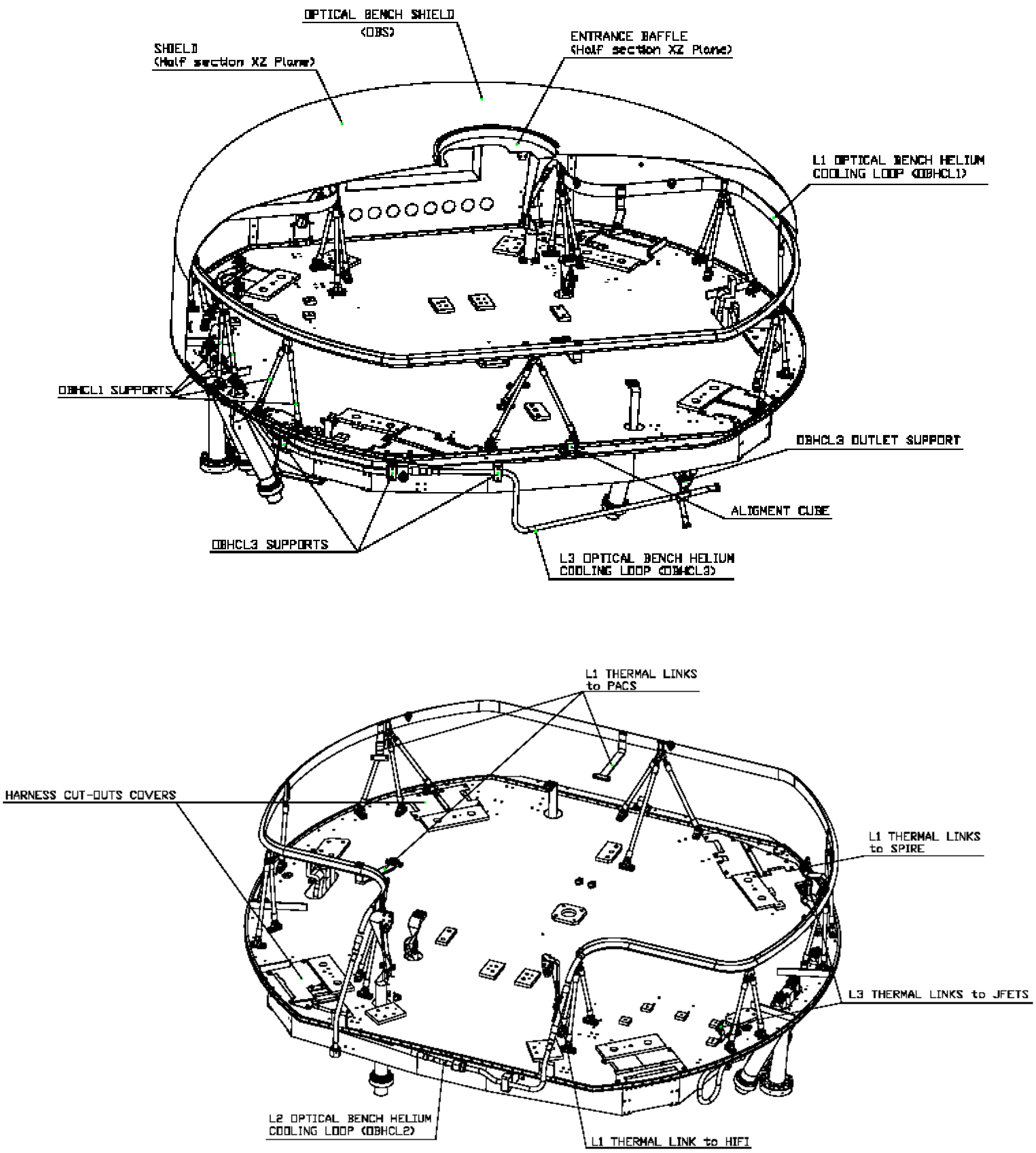


Figure 64: OBA Main Assembly without OBS

13.5.1 OPTICAL BENCH PLATE

The Optical Bench Plate (OBP) is the sub-assembly that provides the interfaces for the

Scientific Instruments Focal Plane Units (FPU's), OBS, OBHCL, Optical Bench Instrumentation (OBI) and for the Scientific Instrument and Cryostat Instrumentation Harness (SIH & CIH). It provides also the attachment points of the OBA to the Spatial Framework through four flexible brackets. Additionally it includes devices to guarantee light tightness of the volume enveloped by the OBS and the OBP itself.

The Optical Bench Plate consists of the following main parts:

- Base Plate
- Blade Brackets (BB)
- OBHCL Supports
- Light Tightness Devices (LTD)
- Alignment Cube

Figure 65 and Figure 66 show an overview of the Optical Bench Plate sub-assembly.

Base Plate:
The Base Plate is the component that provides the interfaces for the FPU's, OBS, OBHCL supports, Blade Brackets, OBI, SIH & CIH and alignment cube.
The Base Plate is a structural plate of Ø1634mm with two flat edges at a distance of 1422mm and a total thickness of 131mm. The upper surface is a thin plate (between 1.5mm and 3.5mm thickness) reinforced by a web of ribs (height 110mm typical and 56mm for some ribs, with thickness between 2 and 13.5mm) to provide the required stiffness and strength for supporting the FPU's. Four small ribs have been provided on the upper face of the plate to stiffen the outermost side the plate.
The plate will be manufactured from a single AA5083-0 plate that will be milled to obtain the final shape.

Blade Brackets
The Base Plate is attached to the Spatial Framework (SFW) by means of four brackets called Blade Brackets (BB) due to their shape.
The main design driver for these brackets is to allow thermal differential distortions between the OBA and the SFW in the radial direction, and to constraint relative motion. This is achieved by brackets that are flexible in one transversal direction while stiff in the other. They are installed every 90° with the flexible direction in the radial direction.
Flexibility is achieved by the U-shape of the bracket, with two thin (2.2 mm) and tall (83.5 mm) plates perpendicular to the flexible direction. Stiffness in the transversal direction is achieved by the width of the bracket (140 mm). Due to the high loads generated by thermal displacements and load transmission from the OBA to the S/C, the Blade Brackets will be made of Ti6Al4V.
A fracture analysis of the OBA titanium blade bracket of the OBA has been performed to determine the Strength Limitation. The crack length to be detected by SENER Blade Bracket NDI is 1.27 mm. NDI inspection (Eddy current) will be performed by SENER.

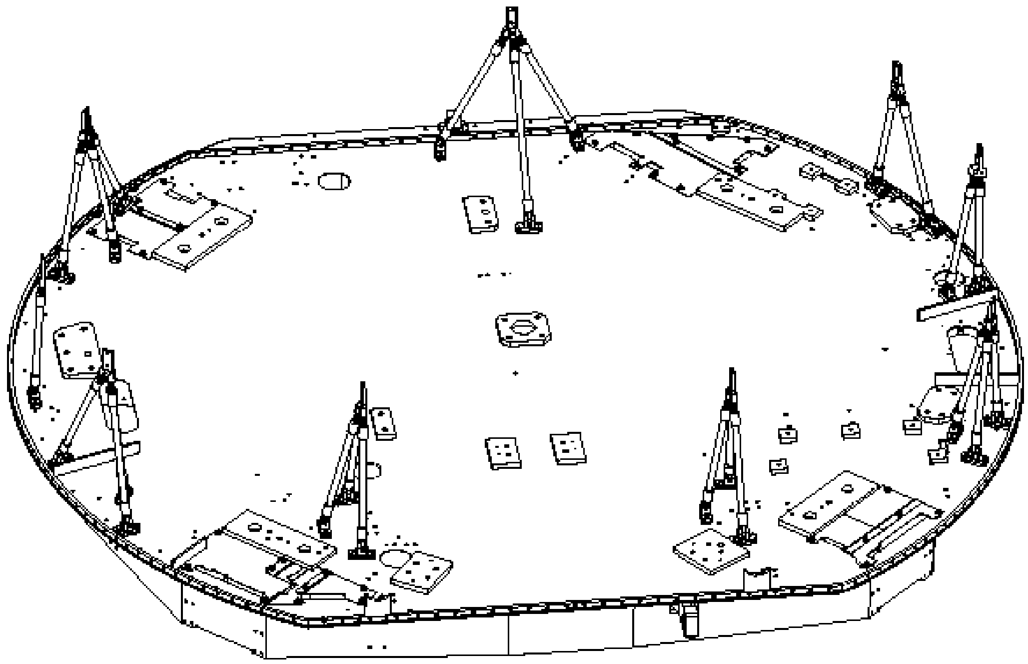


Figure 65: Overview of the Optical Bench Plate sub-assembly, front side

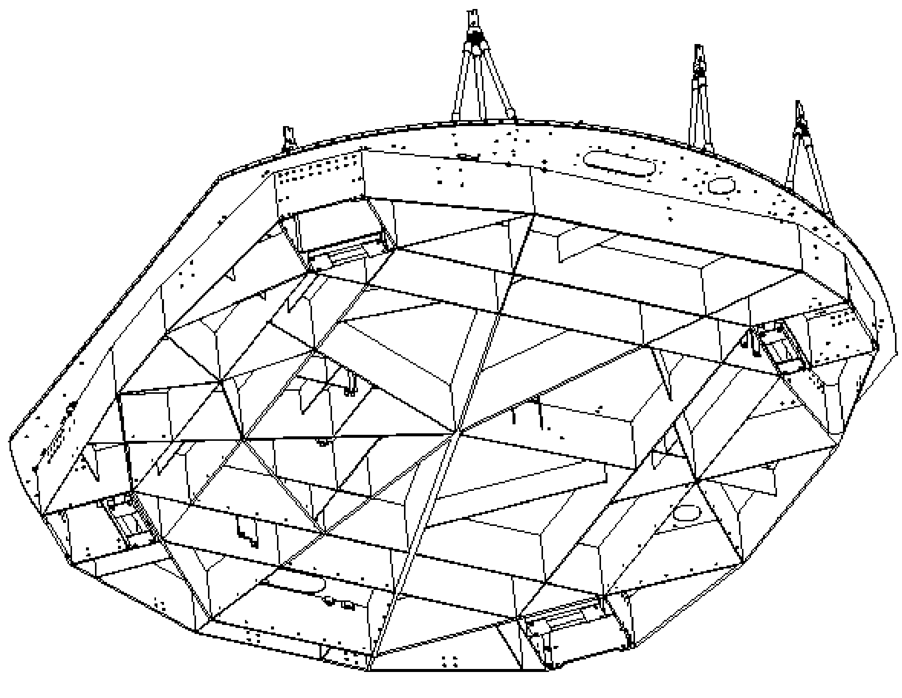


Figure 66: Overview of the Optical Bench Plate sub-assembly, rear side

13.5.2 OBHCL Supports

The OBHCL1 is the segment of the tube above and around the OBP starting from PACS level 1 attachment area to HIFI level 1 attachment area. It is located in a plane 253 mm above OB I/F plane.

The supporting structure of the OBHCL1 attaches the finned tube to the OBP and it maintains thermal insulation between both components. From a mechanical point of view, OBHCL1 supports must guarantee enough stiffness to survive OBA vibration levels, and flexibility enough to absorb thermal distortions between OBP and OBHCL1.

The OBHCL1 supporting structure is based on struts forming tripods, bipods and monopods. There are 9 supports with a total of 23 struts. The tripods are fixed structures that immobilize the attached point of the OBHCL1. The bipods allow the displacement of the attached point in one direction. The monopod only constrains vertical displacement of the tube. The overall arrangement has been optimised to reduce the number of struts and their cross area. Final configuration is shown in Figure 67.

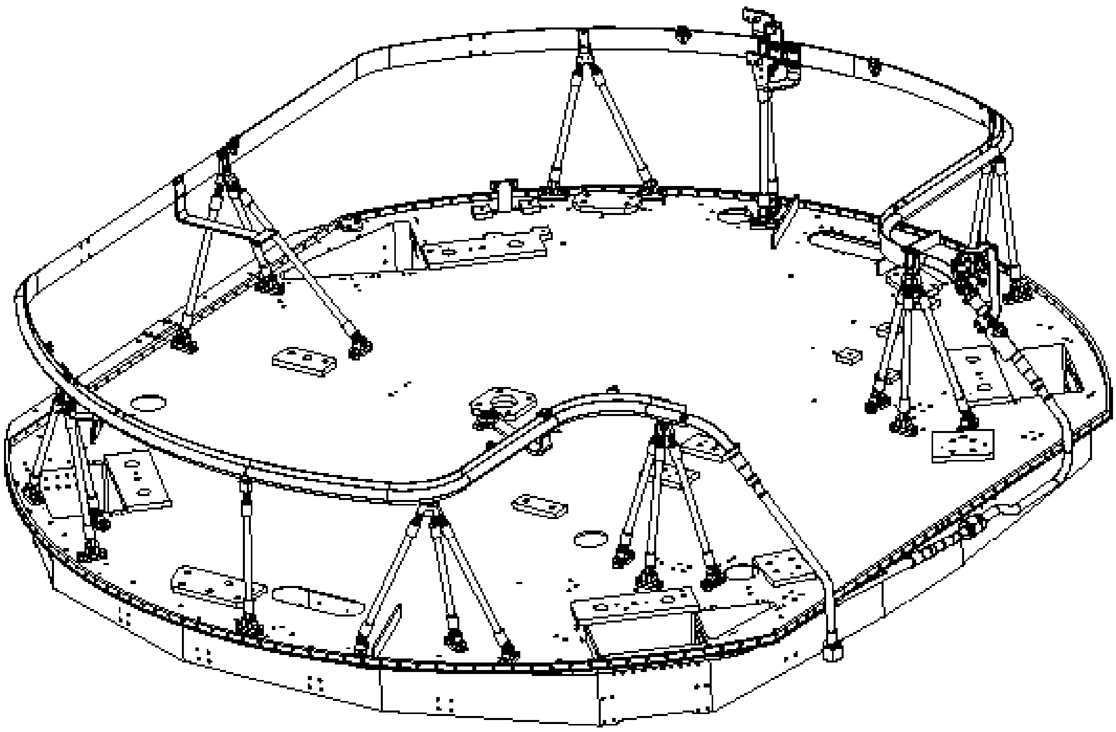


Figure 67: OBHCL1 Supports configuration (view from -Y +Z)

13.5.3 Light Tightness Devices

The openings of the OBP are covered by devices to guarantee light tightness of the volume enveloped by the OBS and the OBP itself. Level 0 Light Tightness Devices prevent light passing through the

Base Plate openings for L0 thermal links. Two different types of L0-LTD are implemented in the OBA: Labyrinth Type LTD, and MLI LTD (not part of OBS subsystem) as shown in Figure 68.

Labyrinth Type Light Tightness Device

Labyrinth Type LTD is based on two parts: the Cover and the Shield. This type of LTD is applied to HIFI and PACS Blue and Red Detector L0 thermal links in the PFM.

MLI Light Tightness Device

MLI LTD is based on a Cover that envelopes the opening of the Base Plate and the L0 thermal link. The MLI wrapping the pods will be attached to these cover by means of clips (MLI and clips are not part of the OBA). This type of LTD is applied to PACS Pump, Evaporator and Open Tank thermal links (three pods wrapped), to SPIRE Pump, Evaporator and Open Tank thermal links (three pods wrapped), and to SPIRE Detector thermal link (one pod wrapped). SPIRE Covers are 20mm tall flanges attached to the bottom face of the plate by M4 bolts. They have Ø4.2mm through holes for MLI fixation pins.

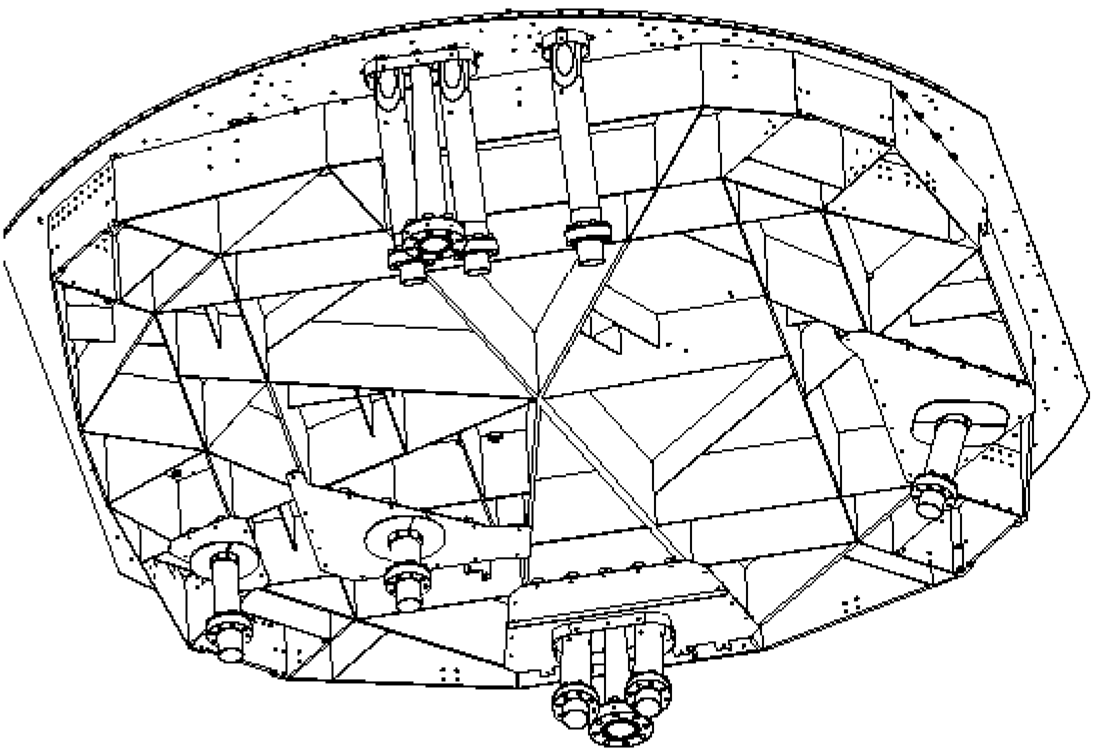


Figure 68: PFM L0 LTD

Harness Cut-Outs Covers

Harness Cut-Outs Covers prevent light passing through them. These covers will be made of aluminium plates. Each cut-out will be closed by more than one cover where needed for integration after harness assembly. Covers are fixed to the Base Plate by M4 bolts. Captive nuts will be provided for the fixation between two covers of the same cut-out. The small gaps between harness brackets will be closed on system level by aluminium tape. A typical Harness Cut-Outs Covers are shown in the following Figure 69.

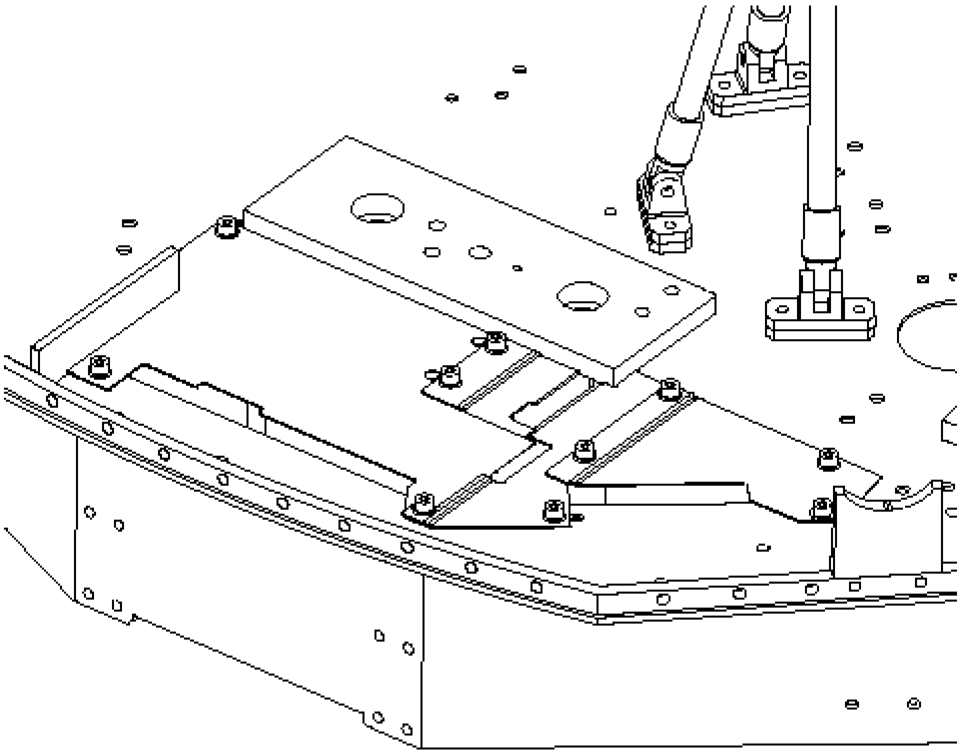


Figure 69: Harness Cut-Out 3 Covers

13.5.4 OPTICAL BENCH SHIELD

The Optical Bench Shield is the sub-assembly that covers the FPU's, and protects them form stray light together with the OBP and light tightness devices. The Optical Bench Shield consists of the following main parts:

- Shield
- HIFI Cover
- Entrance Baffle
- LOU Baffle

- Light tightness devices

The Shield is manufactured from different plates welded together. Two different Aluminium Alloys have been used due to manufacturing reasons. The dome-shaped plate is made of Aluminium Alloy (AA) 1100-0 1mm thick. The rest of the plates are made of AA 6061-T6 1.2mm thick.
The Shield is bolted at its bottom edge to the threaded holes of the OBP ring. Due to thermal conductance requirement between OBS and OBP, a surface roughness of 0.8µm is foreseen. Figure 70 and Figure 71 show an overview of the Optical Bench Shield sub-assembly.

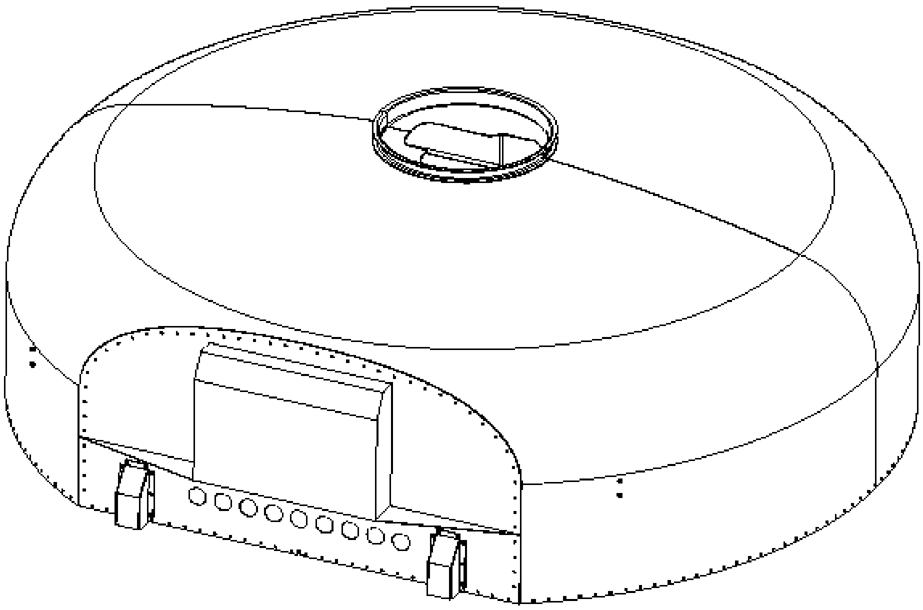


Figure 70: OBS (top view)

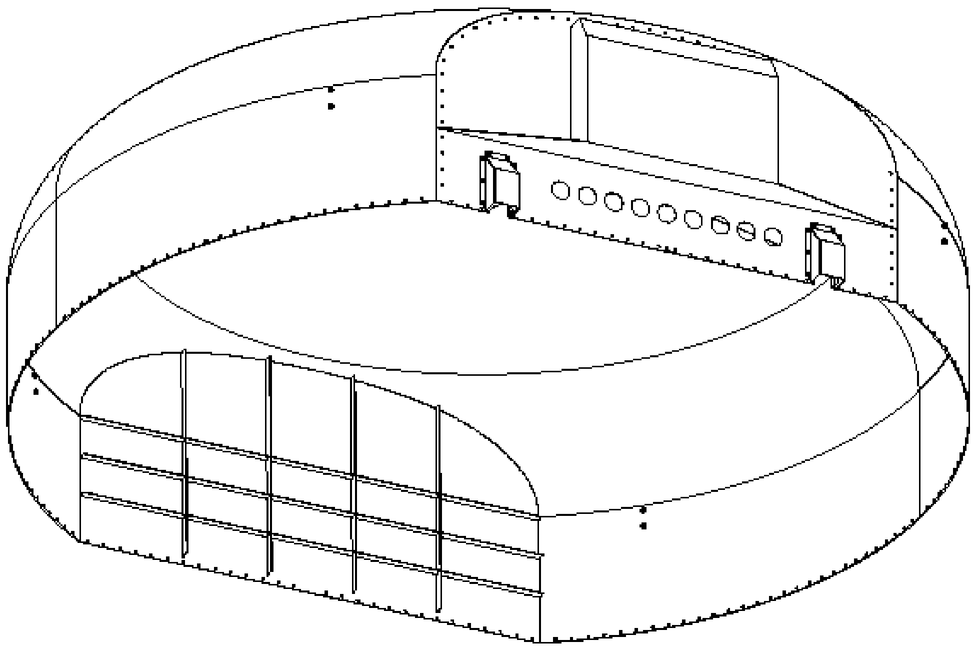


Figure 71: OBS (bottom view)

13.6 Cryostat Vacuum Vessel (CVV)

The primary function of the Cryostat Vacuum Vessel is to provide a high-vacuum environment for the He-subsystem and thermal insulation system for the Herschel cryostat and the Scientific Instruments. This high-vacuum function is mandatory for all ground operations (functional and structural cryostat and instruments tests), launch preparation, launch and early orbital operations up to a duration of three to four weeks. After this period the cryostat cover on top of the CVV will be opened for entrance of the telescope beam to the Scientific Instruments. In orbit, a large part of its –z–side (deep space oriented side) will act as a thermal radiator to reduce its temperature to approximately 70 K. In addition, three radiator panels are fixed to the CVV to increase the total radiator area.

As an essential cryostat component the CVV provides the following functions and penetrations/feed through:

- Mechanical support for the internally suspended He-subsystem, thermal insulation system (heat shields), Optical Bench with Scientific Instruments on it
- One opening for the telescope beam (closed on ground, during launch and early orbit)
- Two evacuation ports for high vacuum generation, both equipped with internal pressure safety relief valves
- Two vacuum gauges
- One LHe-filling port

- One GHe-exit port
- 48 electrical connector feed-throughs for science harness and cryo control harness
- 7 + 2 optical windows for the LOU-beams and alignment beams to the OB

Additionally the CVV provides the following structural functions:

- Ground handling / transportation interfaces (PLM and S/C)
- Mounting basis for 6 Telescope mounting support struts
- Mounting basis for 24 PLM/SVM struts
- Mounting basis for 8 LOU-struts, LOU waveguide brackets and LOU harness brackets
- Mounting basis for 8 HSS-struts
- Mounting basis for Cryostat Cover (to be opened on orbit)
- Mounting basis for Cryostat Baffle
- Mounting basis for Radiators
- Mounting basis for Star tracker assembly
- Mechanical support for external He-ventline and He-heater/filter, external harness, temperature sensors, alignment cubes and MLI

Main design drivers for the design/construction of the CVV are:

- Buckling stability for external pressure
- Strength compatibility against launch/interface loads.
- Accommodation of the large number of I/Fs as described above

13.6.1 CVV main parts

Despite the differences especially in the shape of the Upper Bulkhead the Herschel CVV design has high commonality with the ISO CVV. It consists of the three main parts:

- Lower Bulkhead, providing the I/F for 24 SVM strut I/F and STR
- Cylinder, providing the I/F for TSS, harness feed-throughs, etc
- Upper Bulkhead, providing the I/F for LOU and Telescope etc.

The CVV-parts will be fixed to each other via their interface flanges by a total of 180 high-strength Ti-alloy screws or bolts with nuts, respectively, for each of the two flange connections. As for ISO, the vacuum seal will be a Ø7mm Viton O-ring.

The following Figure 72 provides an overview of the CVV baseline configuration. For more detailed sub-contractor information see [RD36] and [RD37].

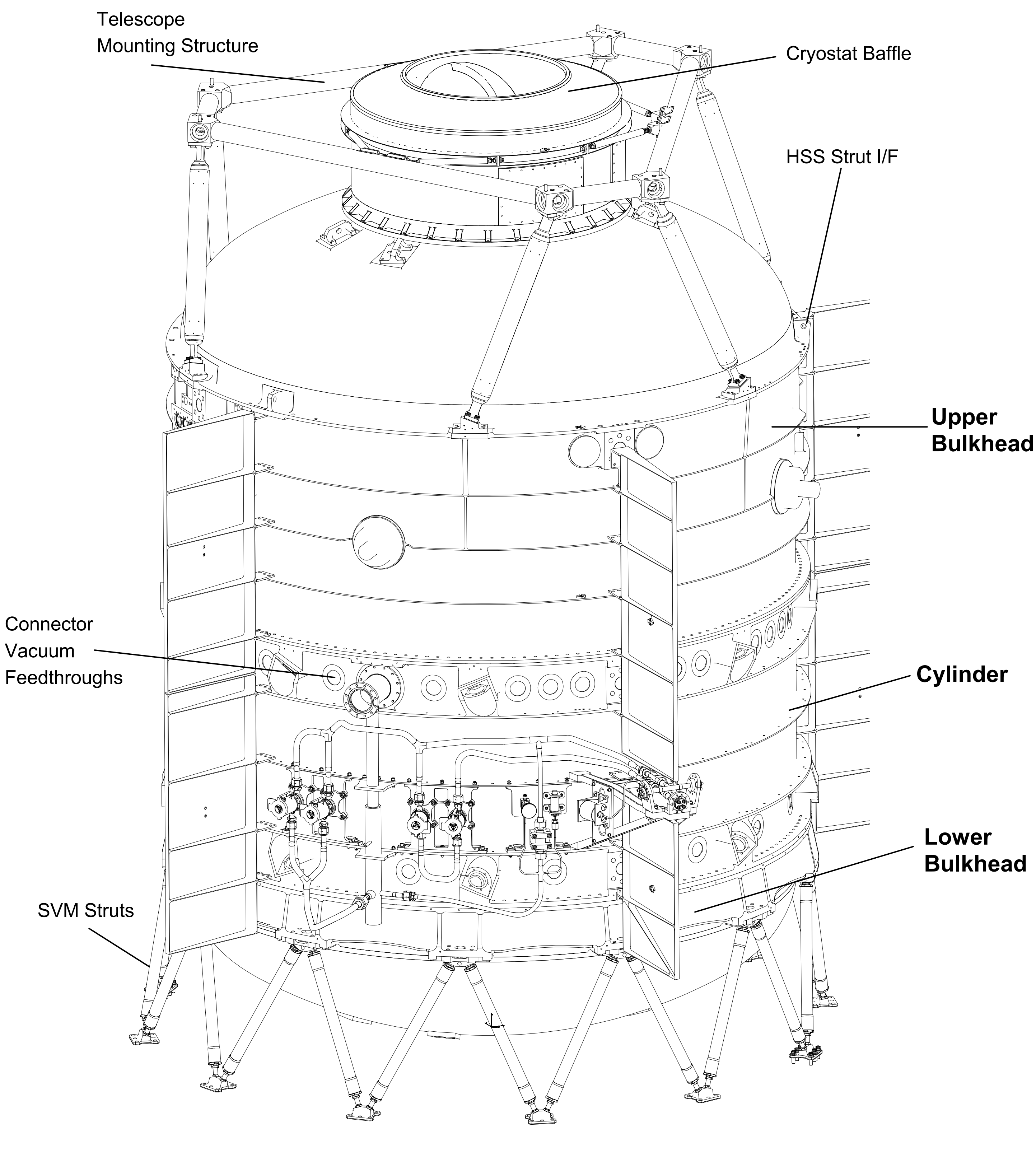


Figure 72: CVV Overview

13.6.2 CVV Radiators

The CVV Radiators ("Nose" and "Ears") are located on the –z-side respectively on the +y and –y-side of the CVV. They are segmented in two parts due to raw material restrictions. Both sides of the –z-radiators are black anodised (tbc) to provide a high emissivity surface, whereas for the +y and –y-radiators only the front sides facing deep-space will be black anodised (tbc); the backsides (i.e. the side facing +z-direction) are covered with MLI. All radiators are attached to the CVV by 4 or 5 brackets onto the CVV rings to ensure sufficient thermal connection (resp. 3 brackets for the shorter lower -z radiator). The radiators are integral milled panel with high ribs for stiffness and better emissivity.

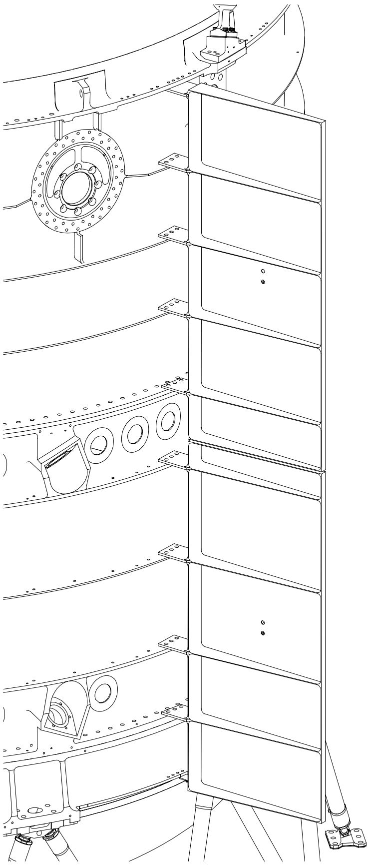


Figure 73: CVV Radiator

13.6.3 Local Oscillator Optical Feed Throughs and LOU fixation

The Local Oscillator Unit is located on the –Y side of the Upper Bulkhead. It is attached to the CVV via 4 pairs of glass-fibre struts, which are designed such that no relative lateral movement occurs between CVV windows and LOU instrument focus during cool-down.

The LOU provides the HIFI FPU with seven reference signal beams which are linked via quartz glass windows into the CVV. For the seven LO beams, seven flanges for mounting of the windows are foreseen. The spacing between the beam centres is 50 mm at CVV in-orbit temperature. By taking into account alignment considerations the inner diameter is 34 mm to provide 30 mm optically free diameter required by the instrument. In addition, 2 lateral windows are used for fine alignment. The diameter of these windows is the same as for the LOU windows, however the CVV aperture is only 24mm in diameter to improve thermal insulation.

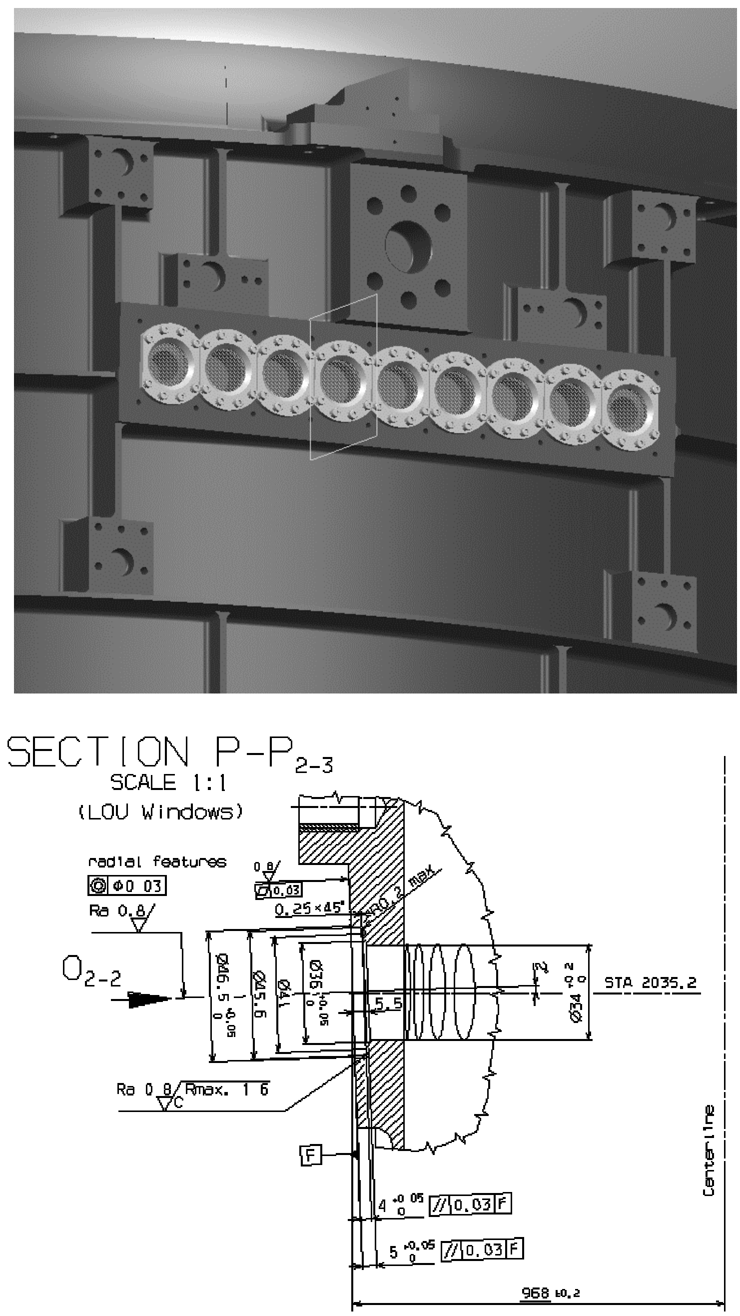


Figure 74: Local Oscillator Optical Feed Throughs

13.7 Helium – II Tank (HTT)

The HTT will provide a cold volume of at least 2367 litres. A fill grade of 98% of its volume with superfluid Helium is foreseen.

The HTT provides I/Fs and apertures for the following components:

- Inlet and Outlet Port
- Passive Phase Separator PPS 111 with T111 and T112
- I/F for 8 L0 thermal links to FPU's
- I/F for 2 open L0 thermal links to FPU's
- DLCM 1/2 with T101/102 and H101/102
- Level Probe L101/102
- Surface Thermometer T103 (Pt500) T106/ T107 (CX)
- Rupture Disc RD124
- External Heaters H103/104
- 4 LHe-valves and SV123
- Pressure Sensor P101
- 36 Adsorber Beds
- Accelerometers (two 3-axes, three 1-axis)
- Supports for He II tank tubing

The He II tank is suspended in the main cylindrical CVV part on a total of 16 (8 upper and 8 lower) tank support straps via an upper and a lower Spatial Framework (SFW).

The main design drivers for the design, construction and operation of the He II tank are as follows:

Tightness to He II conditions

Safety against

- Straps preloading
- Launch and structural testing loads
- Pressure (internal and external)

Geometry allowing good cleanability during manufacturing and AIT

Stiffness/eigenfrequency empty and with He II (resp. He.I for STM testing)

Stiffness/form stability of interface points

The axial (± x-axis) loads acting on the tank (by pretension of the straps, dynamic payload forces) are transmitted through the tank via 4 tubular pillars, which have openings for the He II inside the tank near the upper and lower pillar ends. The inner sides must be specifically clean in order to prevent contamination. The introduction of the axial forces on the He II tank is foreseen by short and hollow rods (the "bones") with spherical caps.

All lateral (± y-, ±z-axes) loads are transmitted via shear struts from the corner brackets of the SFWK into the upper and lower domes. The domes are equipped with stiffening ribs in order to take the lateral loads and obtain the required tank stiffness (eigenfrequency).

The intermediate dome serves the purpose of increasing the frequency of the axial compression waves in the He II bath by providing a 100 % filled lower tank compartment, while the upper tank compartment is not 100 % filled. The intermediate dome is not connected to the pillars and has sufficient clearance. Several open areas in the centre and near its outer edge (inside the tank near the tank cylinder) ensure He communication between the two tank compartments.

Internal supports are needed in the tank to provide a sufficiently stiff fixation of the 2 liquid level sensors (requiring the full tank length) and the filling tube.

The basic design of the He II tank is shown in the pictures below. For more detailed sub-contractor information see HP-2-AIR-DD-0001, iss. 1: HTT Design Description.

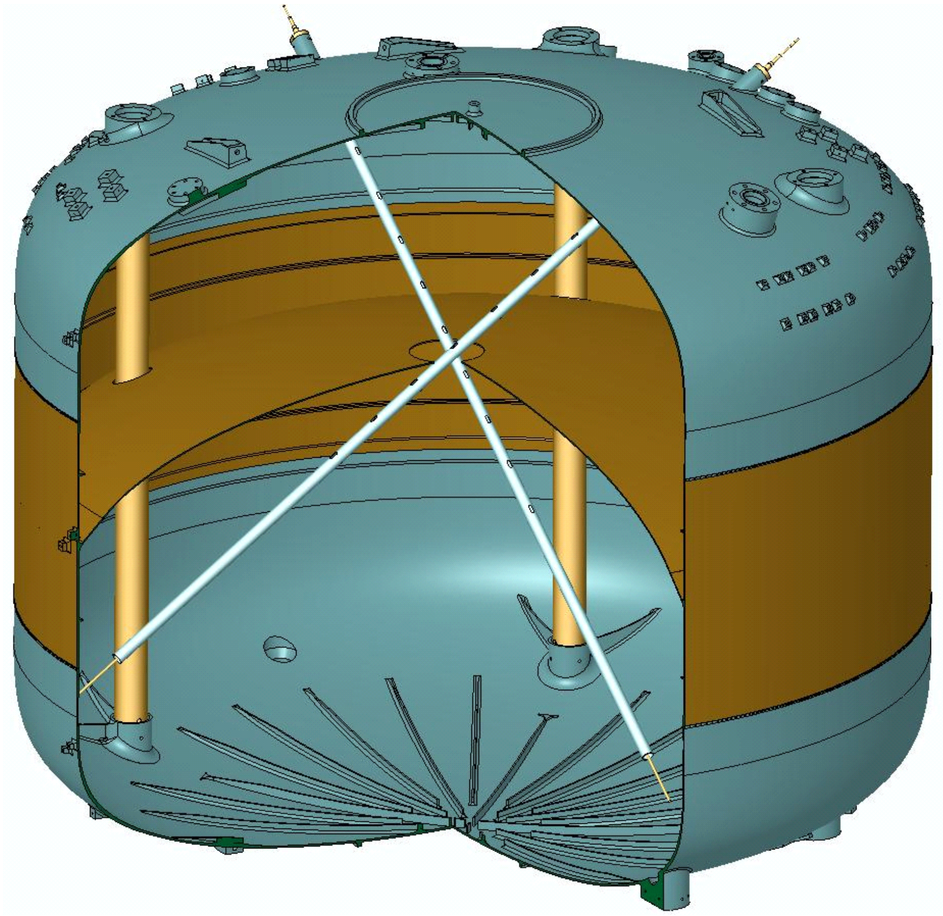


Figure 75: Section through HTT; shown with level probes and supports

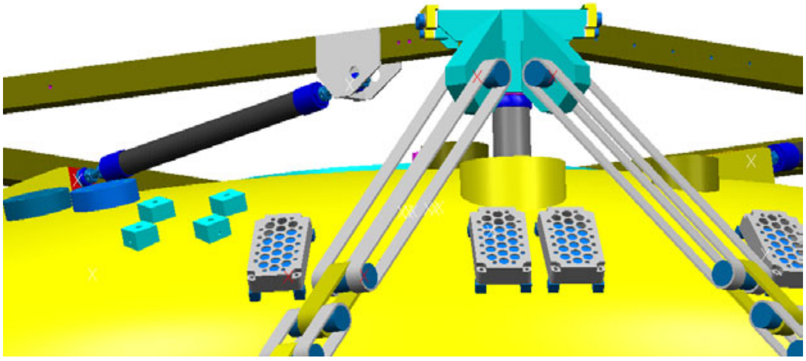


Figure 76: HTT fixation in the SFW

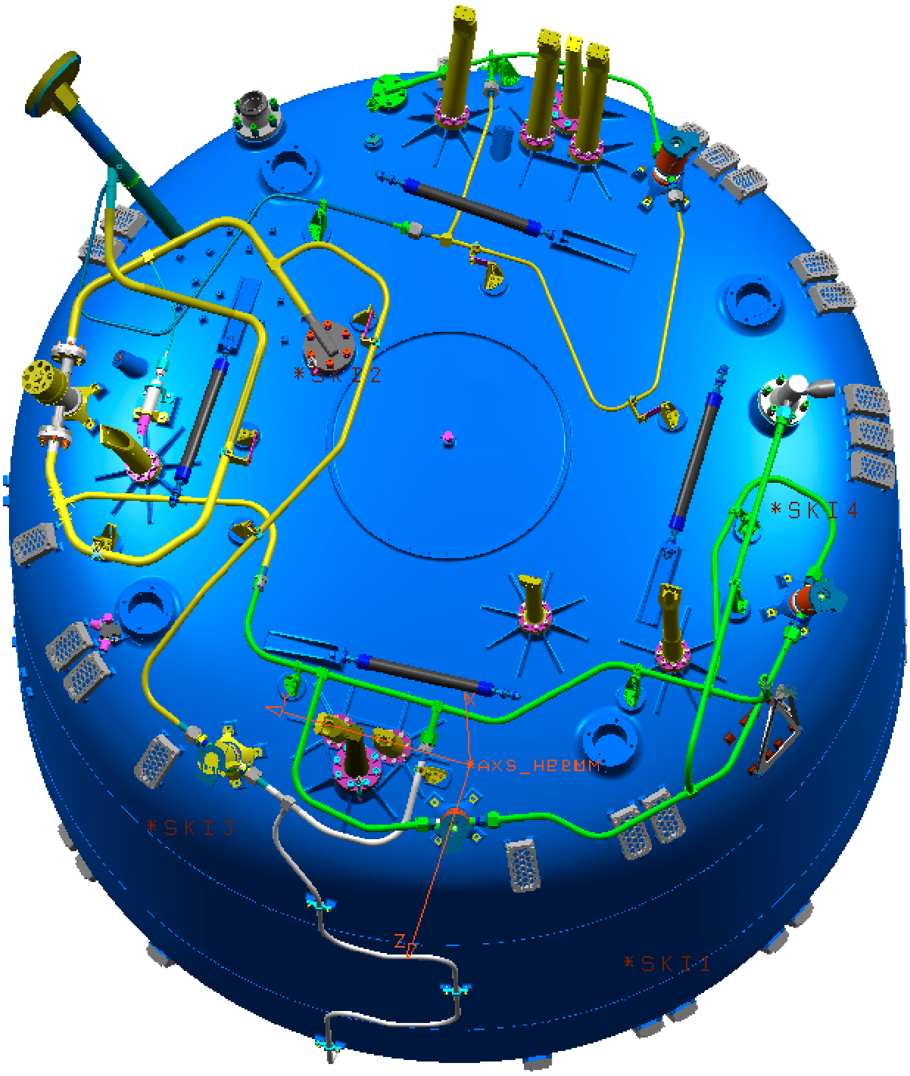


Figure 77: Top view of fully integrated HTT shown with He sub-system equipment, L0 links and accelerometers (w/o SFW and MLI)

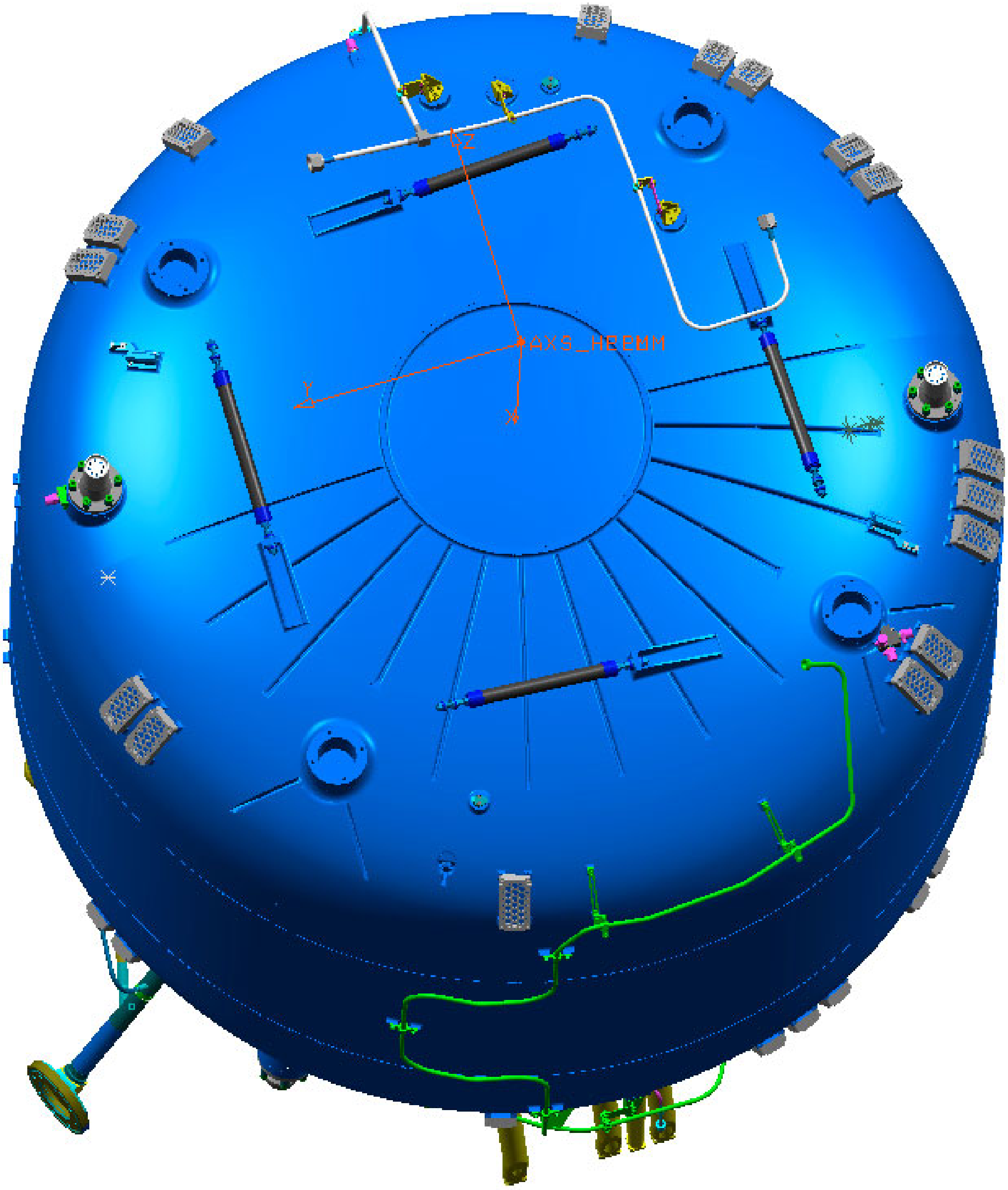


Figure 78: Bottom view of fully integrated HTT shown with He sub-system equipment and accelerometers (w/o SFW and MLI

13.8 Helium – I Tank (HOT)

The He-I tank (HOT) provides a cold volume of about 80 l for normal liquid helium (LHe) for cooling the cryostat during ground tests and pre-launch operations (“launch autonomy”, i.e. 6 days after the last filling and thermal conditioning of the He II tank). Especially during the pre-launch operations HOT shall provide a sufficient mass-flow of cold gaseous He (GHe) to cool the cryostat heat shields in order to keep the sub-cooled He II inside HTT below 2.1K.

To provide the necessary cold GHe flow the HOT is electrically heated. Several HOT refillings with LHe, even through the Ariane 5 payload fairing, will be necessary to actually guarantee the required launch autonomy time. HOT will be completely emptied just before lift-off by electrical heating and will fly as a purely passive element of the Herschel cryostat. It has no function during launch and in orbit.

The HOT provides I/Fs and apertures for the following components:

- Inlet and Outlet Port
- Level Probes L701/702
- Surface Thermometers T701 – T704
- Rupture Disc RD724
- Heaters H701/702
- Supports for HOT tubing

The main design drivers for the design, construction and operation of the He I tank are:

Tightness to LHe condition at ≈ 4.2K

Safety against

Launch and structural testing loads

Pressure (internal and external)

Geometry allowing good cleanability during manufacturing and AIT

Stiffness/Eigenfrequency empty

The HOT is suspended below the lower SFW using four brackets with low radial stiffness to minimise thermomechanical loads during cool-down. The HOT design is essentially a Cassini shape with a very short cylindrical part. It is manufactured from two segments with a weld seam in the short cylindrical section to be fully compatible with the welding definition of HTT.

Design and fixation of HOT is shown below. For more detailed sub-contractor information see HP-2-AIR-DD-0002, iss. 1: HOT Design Description

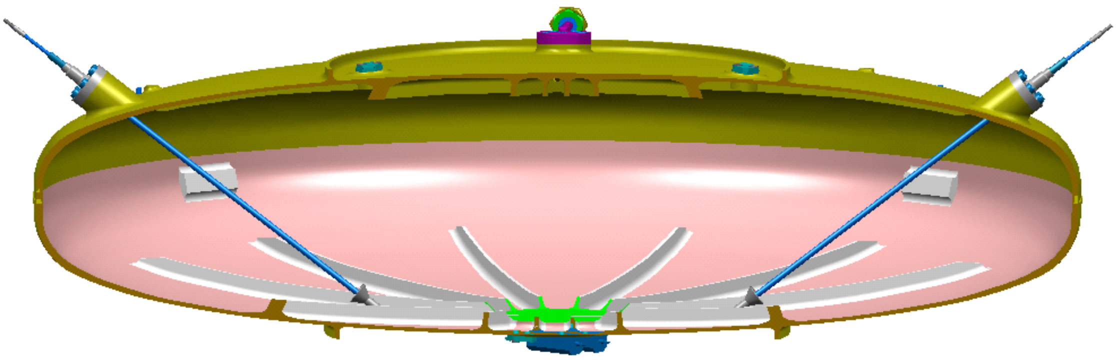


Figure 79: Section through HOT, showing L701/702 and their supports

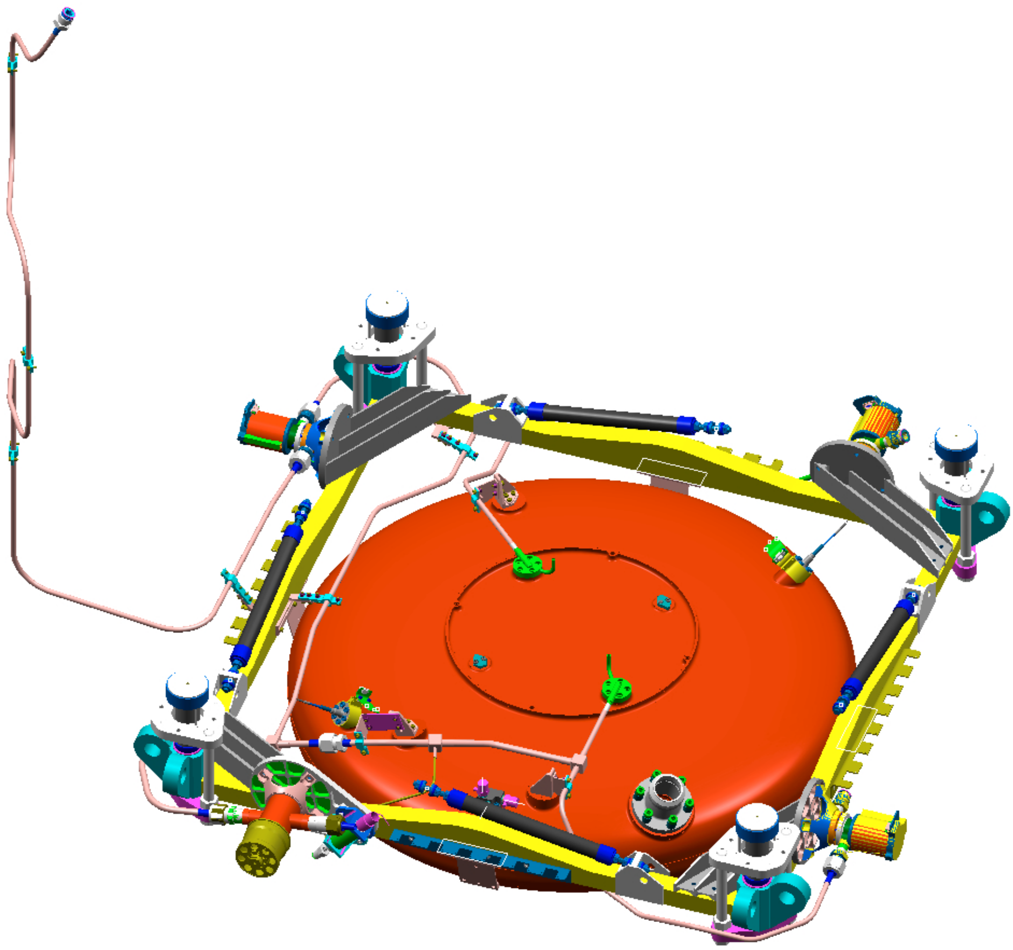


Figure 80: Fully integrated HOT; shown from above with lower SFW, RD724, L701/702, HOT Tubing, LHe valves (w/o harness and MLI)

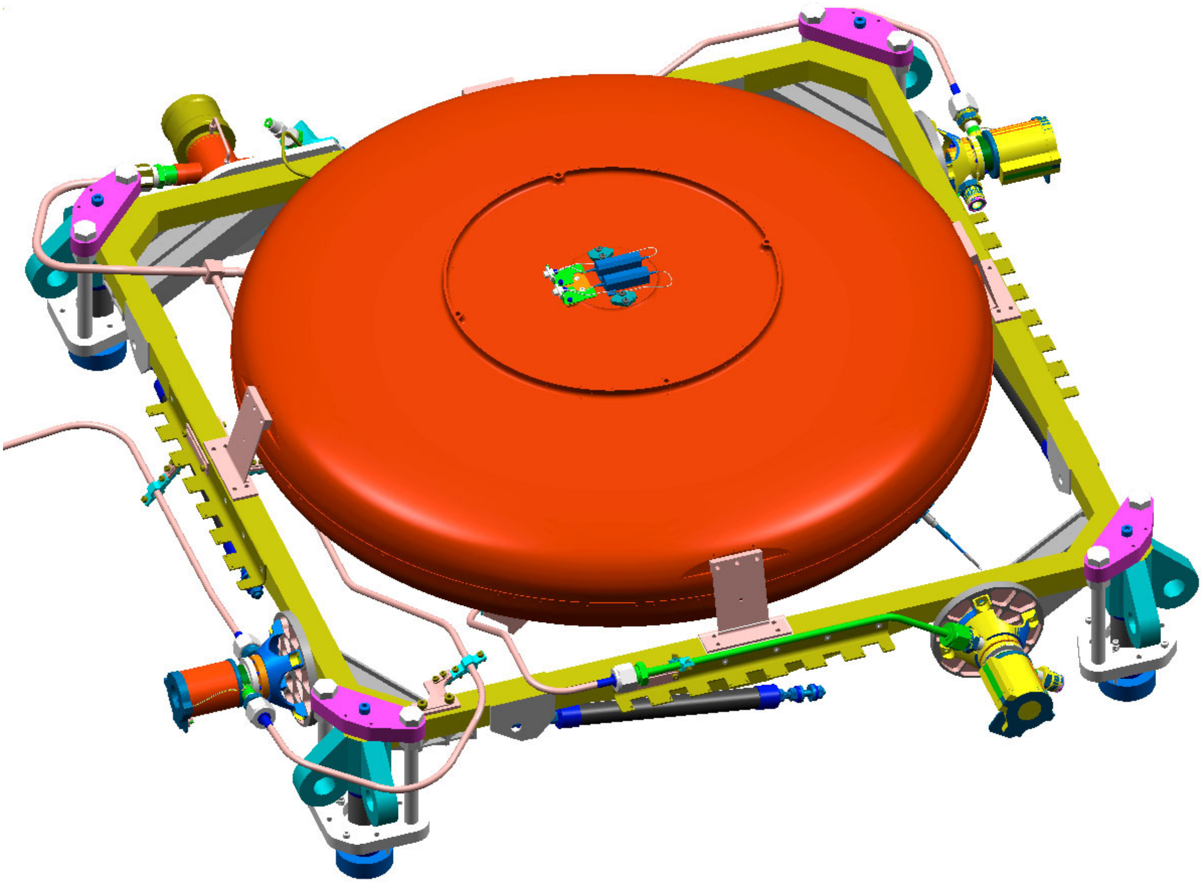


Figure 81: Fully integrated HOT; shown from below (w/o harness and MLI)

13.9 Spatial Framework (SFW)

HTT, HOT and OBA are mechanically supported by the Spatial Framework (SFW). It consists of a lower and an upper part. The upper parts carry the OBA, the lower part the HOT; the HTT is clamped between the upper and lower part. The thermal function is to isolate the HTT from the heat coming from the Tank Support System (TSS) and the dissipation by the instruments on the OBA. Therefore items, connecting the frame with the HTT are made from carbon fibre reinforced plastic. The axial loads are taken by 8 bones and the lateral force by 8 struts.

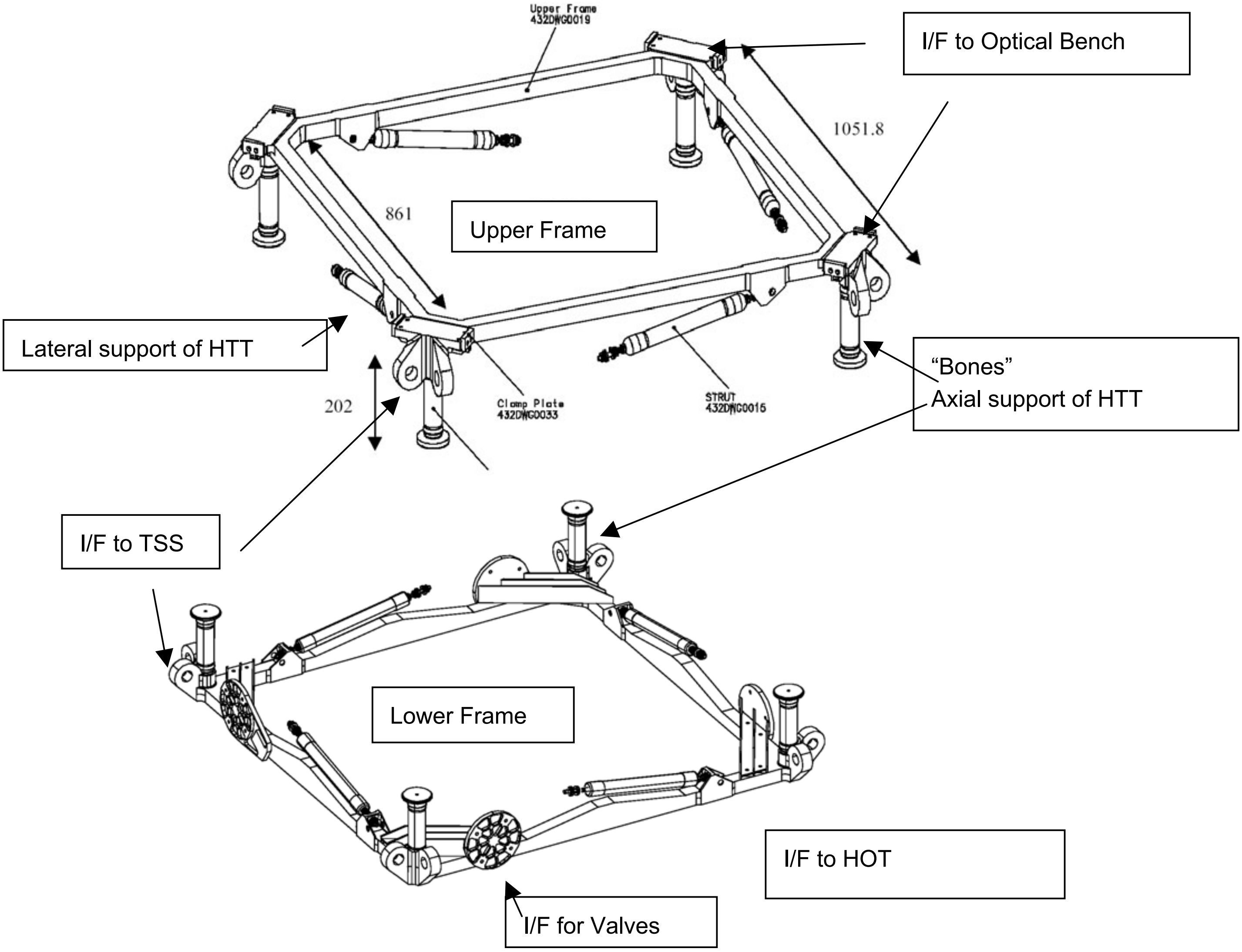
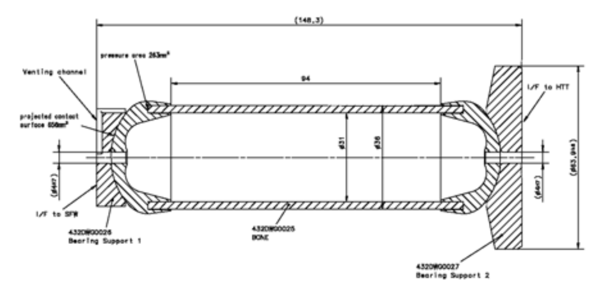


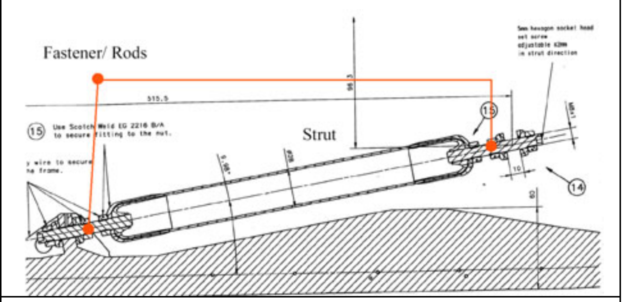
Figure 82: Upper and Lower Spatial Framework

As shown in Figure 82 the I/F of the OBA is at the four corner points of the upper frame, the I/F for the HOT is on the four points in the mid of the frame of the lower aluminium SFW. The TSS is fixed on 16 lugs to the SFW.

The thermal function is to isolate the HTT from the frame. Therefore the 8 bone and the 8 lateral struts, connecting the Spatial Framework with the HTT, are made from carbon fibre reinforced plastic. The frame itself is made from aluminium in order to minimise the difference of the thermal expansion between frame and OBA. The "Bones" and Strut design is shown in Figure 83.



CFRP-Bone Design with End Fittings



CFRP-Strut Design with End Fittings

Figure 83: Design of lateral struts and bones

The SFW is has to be designed for cryogenic temperatures. The following table summarises the main design drives.

Item	***Design Driver***	***Solution***
Aluminium fame Al 2219 T851	Tension stiffness	Aluminium cross: section 30 x 30
	Bending Stiffness of Lower frame	Reinforcements on the frame
Bone Material selection T300 CFRP ±7° Laminate Al 2219 Fitting) Bonding Stycast 2850 FT	Compression Load of 60 kN x 1.25	T300 CFRP, cross section is 256 mm^2 ultimate compression 186.9kN
	Thermal conductance	Material selection T300
	Possibility to compensate differential expansion between HTT and SFW frame.	“bone” design which allows rotation
Lateral struts T300 CFRP ±7° Laminate Titanium Fitting Bonding Stycast 2850 FT	Stress/Strength to take the lateral loads of 13kN x 1.25	Adequate cross section $\varnothing_O$ = 28mm; $\varnothing_i$ = 25mm ultimate tension 46.8kN
	Possibility to compensate the rotation of the due to thermal distortion.	Adequate Design

The end caps of the carbon fibre reinforced epoxy (CFRE) “Bones” must be able to pivot on their fittings in order to compensate thermal expansion mismatches. In order to allow this a solid lubricating coating with a coefficient of friction below 0.105 must be used in either one or on both sides of the fitting interface. (Figure 84). A sputtered Molybdenum Disulphide (MoS2) coating of 1µm thickness will be applied to both sides of the joint.

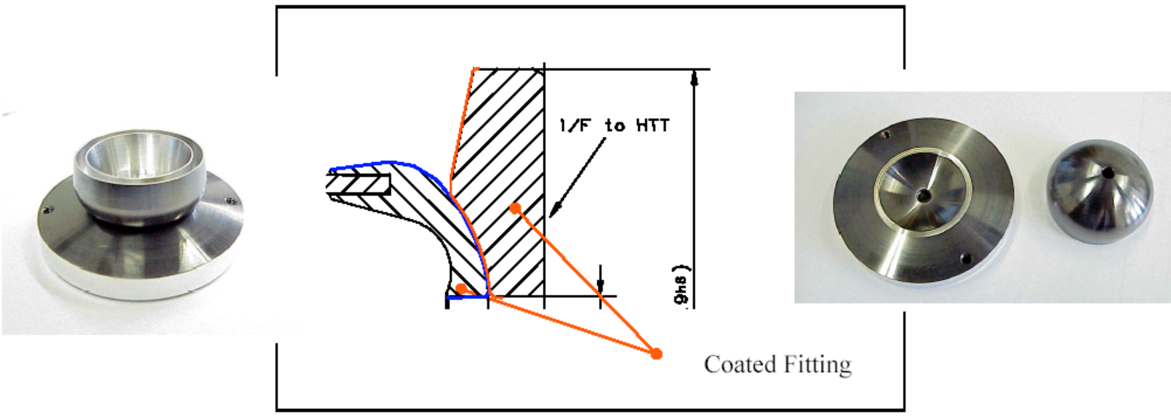


Figure 84: MoS2 coated Fittings of end caps of the “Bones”

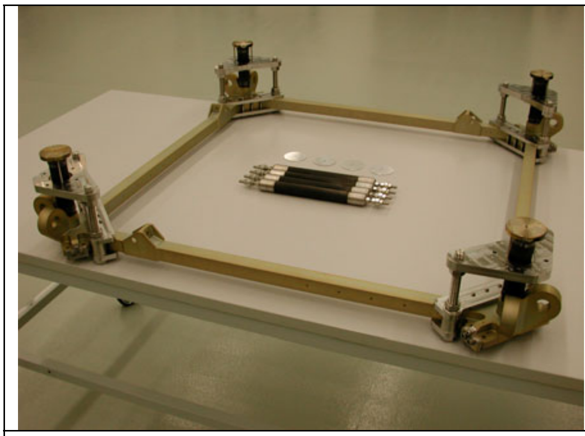
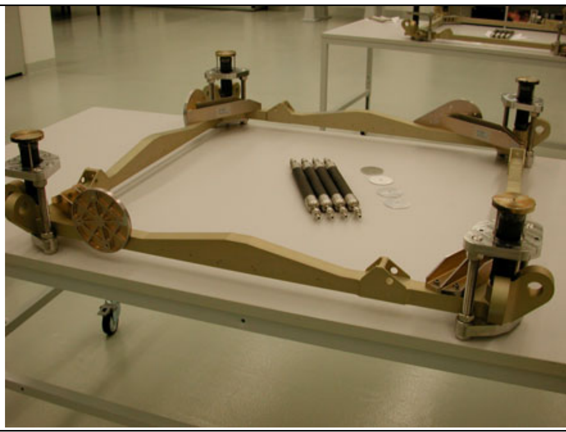
	
Upper Spatial Frame Work H/W	Lower Spatial Frame Work H/W

Figure 85: Spatial Frame Work Hardware as provided by HTS

13.10 Tank Support Suspension (TSS)

The suspended mass of the Herschel cryostat are supported by the Tank Support Suspension (TSS). The TSS consists of 16 identical chains. Tank chain consists out of individual straps made from either Glass Fibre Compound (GFC) or a Carbon Fibre Compound (CFC). Each chain consists of 4 straps. Counted from the inner (cold) side to the outer side the strap cross section and material are as defined in the table below.

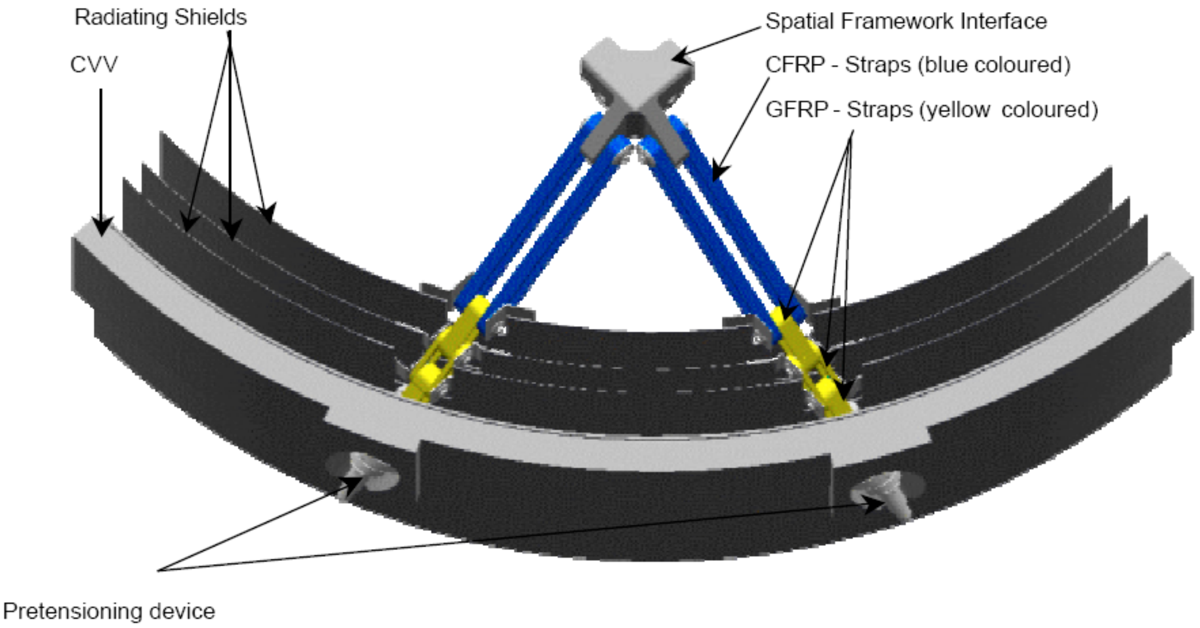


Figure 86: Tank Support System

Strap	Material	Cross section in mm^2
1	Carbon Fibre (T300) 913/40%G801 UD/913/35%/132	137
2	Carbon Fibre 913/40%/G801-102cm UD/913/35%/132/75 mm (T300)	131
3	S2-Glass fibre 913/50%/G801-102cm UD/913/28%/205S2/75mm	168
4	S2-Glass fibre 913/50%/G801-102cm UD/913/28%/205S2/75mm	167

Table 34: Material definition of the straps

Part of the chains is the pre-tensioning device which allows to apply the needed preload of 25 KN to the TSS and which allows to align the OBA.

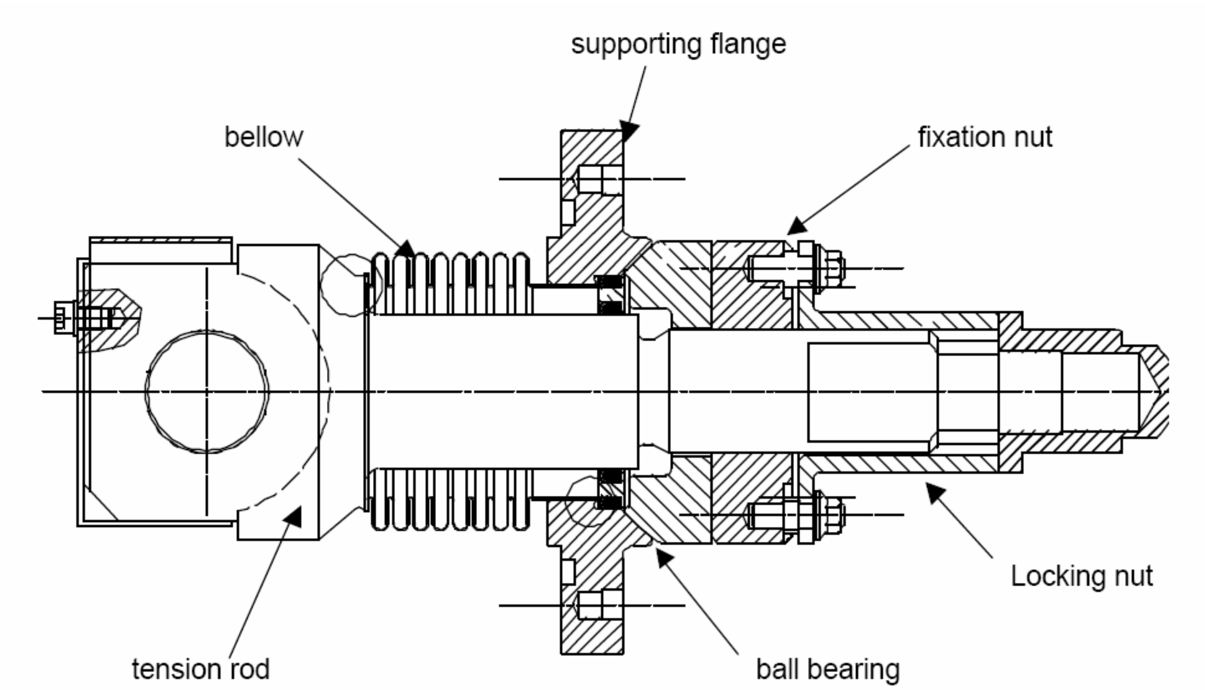


Figure 87: Pretensioning Device

The TSS has an I/F to the CVV, to the SFW provides the I/F to the Thermal Shields. All interfaces are identical to the ISO lower chain interfaces.

The extensive test program shows that all key requirements of the TSS are met. An summary is in the following table.

Requirement	Parameter required	Test Result
Strength/Fatigue	25 KN +- 21 KN with 10000 load cycles	Verified by extensive testing
Stiffness	16100 N/mm	18084 N/mm to 18252 N/mm
Scattering of stiffness chain to chain	< 4%	+- 1.1 %
Thermal Conductance	To be optimised	Due to reduction of cross section thermal behaviour significantly improved

Table 35: TSS key performance parameters

13.11 Herschel Solar Array/Sunshade (HSS)

13.11.1 Introduction

The design of the HSS plus support struts assembly, which is the basis for the HSS and HSS support structure contracts, is shown in Figure 88.

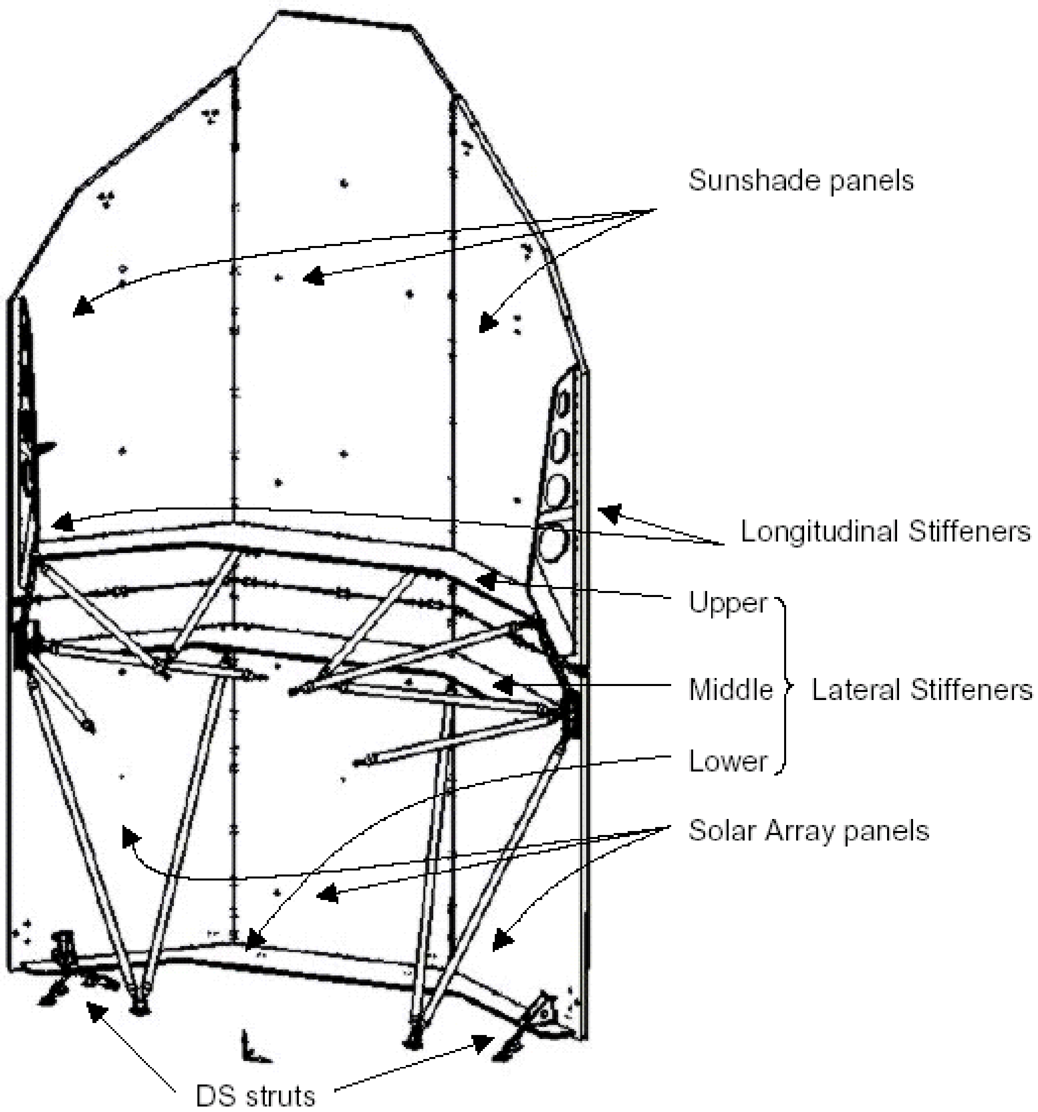


Figure 88: HSS and HSS Support Struts

The HSS is mounted on the CVV and the SVM via 12 struts plus three attachment beams. The mounting concept is as follows:

The upper end of the solar array is attached to CVV and SVM via a strut tripod on either side (6 struts in total). One strut of the tripod goes down to the SVM (CFRP strut for axial load transfer), the other two are linked horizontally to the CVV (GFRP for good thermal isolation). The struts are not part of the HSS procurement, but belong to the Herschel Support Structures. A stiffening element links the two tripods on the solar array in circumferential direction. Two additional struts from the solar array upper end to the CVV help the two axial tripod struts to carry the axial loads.

The lower end of the solar array is horizontally linked to the SVM shear panels via three attachment beams to transfer lateral HSS loads. These attachment beams are part of the HSS. A stiffening element links the two beam attachment brackets on the solar array in circumferential direction.

The sunshade is mounted onto the solar array via 9 thin titanium plates (to limit thermal conduction and transfer mechanical load).

In addition the sunshade is horizontally attached to the CVV via 4 GFRP struts. The strut points on the sunshade are linked via a stiffening element in circumferential direction.

For stiffness increase of the sunshade ears vertical stiffening ribs are placed on the +Y and –Y edge of the sunshade.

A detailed design description for the HSS is given in document HP-2-DSSA-DD-0001, 'Design Description Herschel HSS'.

13.11.2 Physical Properties

13.11.2.1 Mass

The actual nominal mass of the HSS including its fixation struts is 209.2 kg. This mass contains all HSS and fixation struts structural parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc. It also includes the solar generator and all thermal hardware (MLI, OSR's) and Aluminium foil for light tightness. An MLI mass of 30 kg is assumed for the design of the HSS. For a detailed mass breakdown refer to HP-2-ASED-RP-0004.

13.11.2.2 Dimensions and Mechanical Interfaces

The HSS and its fixation struts have the dimensions and mechanical interfaces toward SVM and CVV as defined in the relevant interface drawings.

13.11.3 Mechanical Design

13.11.3.1 Materials

Panels and stiffeners are made of the following materials

- Skin material M55J/950-1, unidirectional plies, ply thickness 0.06 mm (high modulus)
- Honeycomb 3/8-5056-0.0007p (nominal area)
  1/4-5056-0.0015p (reinforced area)
  3/16-5056-0.002p (reinforced area)
- Edge member T300/950-1 CFRP plain weave fabric
- Local reinforcements T300/950-1 CFRP plain weave fabric
- Adhesive CYTEC FM96U (epoxy), for core/face sheet
- Adhesive FM300-2M, for face sheet/edge member, reinforcement

13.11.3.2 Mechanical Properties

The main part of the HSS consists of six large sandwich panels. Three rectangular panels for the solar array have the solar cells on the front side. Three sandwich panels for the sunshade carry the OSR's on the front side. All panels are made of M55 high modulus CFRP skins.

The sandwich construction of all six panels consists of

- Aluminium honeycomb core, thickness = 50 mm
- Nominal skin thickness of 0.18 mm built up out of 3 unidirectional M55 plies, isotropic orientation (60/0/-60), symmetrically applied on both front and rear skins
- Additional 3 and 6 ply reinforcements at local high stress skin areas, isotropic orientation (60/0/-60), symmetrically applied on both front and rear skins
- Where necessary, single extra ply reinforcement is used to increase strength of larger areas of the panel skins, leading to an anisotropic orientation (60/0/-60/30), symmetrically applied on both front and rear skins
- U-profiled edge members made of T300 CFRP weave (0.5 mm nominal, 1.6 mm at reinforcements)

The three lateral and two longitudinal stiffener panels are also made of CFRP material similar to the front panels

- Aluminium honeycomb core, thickness = 22 mm
- Nominal layout of 4 unidirectional M55 plies, isotropic orientation (60/0/-60), symmetrically applied on both front and rear skins
- Additional 3 and 6 ply reinforcements at local high stress skin areas, isotropic orientation (60/0/-60), symmetrically applied on both front and rear skins
- Local reinforced T300 CFC patches and dense honeycomb cores are used U-channel profiles at panel side edges

The HSS support strut properties are defined in Table 36:

Strut No,	from	to	External Diameter [mm]	Thickness [mm]	Young's modulus at RT $[N/mm^2]$	I/F heat flow at cold side (sum over struts) [W]
1 thru 4	**SVM I/F**	**SA I/F**	60	4	271070	2.36
5 thru 8	**CVV I/F**	**SA I/F**	56	4.8	46900	0.44
9, 12	**CVV I/F**	**SSD I/F**	56	4.8		0.256
10, 11			60	4.8		

Note: Brackets and tube end-fitting mechanical properties are not considered in this table.

Table 36: HSS Support Strut Mechanical Properties

13.11.3.3 Stiffness

The HSS including fixation struts has minimum resonance frequencies of

- 24.7 Hz (local mode, SSD ears)
- 28.8 Hz for the first global bending mode
- 70.7 Hz for the first X mode

with the struts hard-mounted at their external interfaces.

13.11.4 Thermal Design

13.11.4.1 Solar Array Thermal Design

The solar array is the lower part of the HERSCHEL solar array/sunshade. The solar array serves as solar generator and shall shadow the PLM from solar radiation. The external surface is therefore covered with solar cells. The inner (rear) side is covered with highly efficiency MLI.

As a conservative approach for the solar cell design and performance prediction, an adiabatic solar array rear side is assumed.

The solar array with bonded solar cells experience temperature of up to 148°C.

The maximum temperature will typically occur during WS and when all solar cells are in shunt mode. The solar constant is assumed at 1425 W/m² and a solar aspect angle of 0° (nominal sun pointing).

Minimisation of the solar array temperature is very important for the lifetime of the Herschel cryostat. The temperature is minimised by starting operating the solar cells from the upper rim of the solar array towards the bottom.

The solar array is thermally isolated from the SVM by using GFRP attachment beams at the solar array lower edge. The axial struts between solar array upper edge and SVM have to be made from CFRP to carry the axial HSS loads.

The solar array is thermally isolated from the CVV by using GFRP struts between solar array upper rim and CVV.

13.11.4.2 Sunshade Thermal Design

The sunshade is the upper part of the HSS. The sunshade shadows the Herschel telescope from solar radiation. By covering with OSR's the external side of the Sunshade serves as a radiator and the inner side is covered with MLI.

A maximum OSR operating temperature of +33°C (design temperature) is analysed for the hot case at EOL (WS, 0° sun angle). At the worst cold case condition, the side panel OSR's can reach -100°C.

The Sunshade is thermally isolated from the warmer solar array through connecting the two parts by thin titanium plates.

The Sunshade is thermally isolated from the CVV by using GFRP struts between sunshade lower rim and CVV.

13.11.5 Photo-Voltaic Assembly (PVA) Design

The solar array, consisting of three individual panels with identical dimensions caries on its outer, sun-exposed surface the solar cells of the photovoltaic assembly. With the dimensions of 2370 mm x 1500 mm each panel provides an area of 3.555 m² resulting in a total of 10.665 m² which is available as theoretical maximum for the solar cell mounting area.

Driving Requirements

The PVA shall provide a minimum power of 1700 W at the begin of the nominal mission lifetime under summer solstice conditions with a Sun aspect angle around the S/C X and Y-axis of 0°.

The PVA shall provide a minimum power of 1400 W at the end of the nominal mission lifetime (after 3.5 years in orbit) under worst case solar flux conditions (SS or WS) with a sun aspect angle and around the S/C X-axis of ± 1° and around the S/C Y-axis of ± 30°.

The PVA shall provide a minimum EOL power of 1230 W at the end of the extended mission lifetime (after 6.0 years in orbit) under worst case solar flux conditions (SS or WS) with a sun aspect angle and around the S/C X-axis of ± 1° and around the S/C Y-axis of ± 30°.

For the power calculations the related SCA temperatures (as obtained from the thermal analysis) shall be increased by 5°C.

The PVA shall provide its specified powers with a minimum voltage of 30.0 V at the SVM interface connector, i.e. already considering worst case harness and blocking diode losses.

Taking into account the above requirements and considering the related loss factors and environmental conditions as well as the available mounting area it is obvious that a solar cell with a BOL efficiency of better than 25% (under normal conditions) is needed to guarantee the required performance.

Therefore the GaAs/Ge triple junction solar cell GAGET 2 / 160-8040 from RWE Space Solar Power GmbH with the following characteristics is used for the Herschel project:

Main Characteristics	
Type	GAGET 2 / 160-8040
Solar Cell Structure / (substrate)	GaInP2/GaAs/Ge / (Ge)
Size	30.18 cm² (80 mm x 40 mm / cropped corners with 19mm hypotenuse)
Thickness	160 ± 30µm (substrate and epitaxy)
	4 - 10µm Ag thickness
AR - coating	TiO_X / Al_2O_3
Protection Diode	integrated protection diode (ID2)
Cover glass	CMO
Solar Absorptance	0.915
Emittance (Normal)	0.81
Weight	86 mg/cm²

Typical Electrical Parameters	(AM0 / BOL / 135.3 mW/cm² / 28°C / Bare Cell)
Voc =	2.575 V
Vmp =	2.275 V
Jsc =	16.5 mA/cm²
Jmp =	15.9 mA/cm²
Pmp=	36.2 mW/cm²
ηmp =	26.8%

Radiation Degradation (Fluence: 1MeV equivalent Electrons/cm²)

Parameters	**$1x10^{14}$**	**$5x10^{14}$**	**$1x10^{15}$**
Imp/Impo	0.998	0.99	0.98

Vmp/Vmpo	0.93	0.90	0.88
Pmp/Pmpo	0.94	0.88	0.84

Temperature Coefficients	(10°C - 80°C)	
Parameters	BOL	$1x10^{15}$ (1 MeV e/cm²)
Jmp (µA/cm²/°C)	7.3	9.5
Jsc (µA/cm²/°C)	11.5	12.4
Vmp (mV/°C)	- 6.2	- 6.6
Voc (mV/°C)	- 5.9	- 6.5

Based on the above described solar cell the following physical layout for the PVA design is implemented:

Panels:	3 panels with 10 sections per panel
Sections:	Panel 1: 1 section with 4 strings and 9 sections with 5 strings
	Panel 2: 6 sections with 4 strings and 4 sections with 5 strings
	Panel 3: 1 section with 4 strings and 9 sections with 5 strings
Strings:	98 strings with 19 solar cells on panel 1 and 3
	44 strings with 21 solar cells on the centre panel
Solar cells	2786

That results in a PVA with an effective surface of 8.408 m² distributed on the three panels.

Each string is wired to the related section via its blocking diode. Each section is connected individually to the PCDU via two TP AWG 22 within one nominal and one redundant harness branch.

Performance Prediction

For the performance prediction of the PVA reference design the following assumptions have been taken into account:

- Worst case degradation factors as described above
- Both SA side panels tilted by 36.5 deg. with respect to the centre panel
- Solar aspect angles (0 / 30 deg.) as required above for the related case
- Solar cell performance as described above
- Worst case blocking diode losses

- Harness losses up to the SVM I/F connectors
- Sun irradiation intensities as required above for the related case

The results of the PVA performance prediction is given in Section 6.4.

PVA Harness

The PVA will be connected with the SVM via a redundant pig-tail harness with a length of 1.5 m measured from the SA lower end to the SVM I/F connectors. Each section is wired by two AWG 22 twisted pairs within one nominal and one redundant harness branch. The connectors will be two plugs of type ESA/SCC 3401 0044 01 B 06G-16-26-S round connectors.

Grounding and Isolation

The solar cells electrical network is isolated from the electrically conductive solar array panel structure by more than 10 MΩ.

In order to protect from a potential main-bus short circuit caused by a solar cell / panel structure breakthrough, the conductive panel structure will be isolated from the spacecraft structure by more than 10 MΩ. By means of the redundant bleeding resistors, the conductive panel structure will be bonded to the spacecraft structure by about 10 to 100 kΩ for each panel individually.

13.12 SVM Thermal Shield

The complete SVM thermal shield subsystem including fixations is shown in Figure 89.

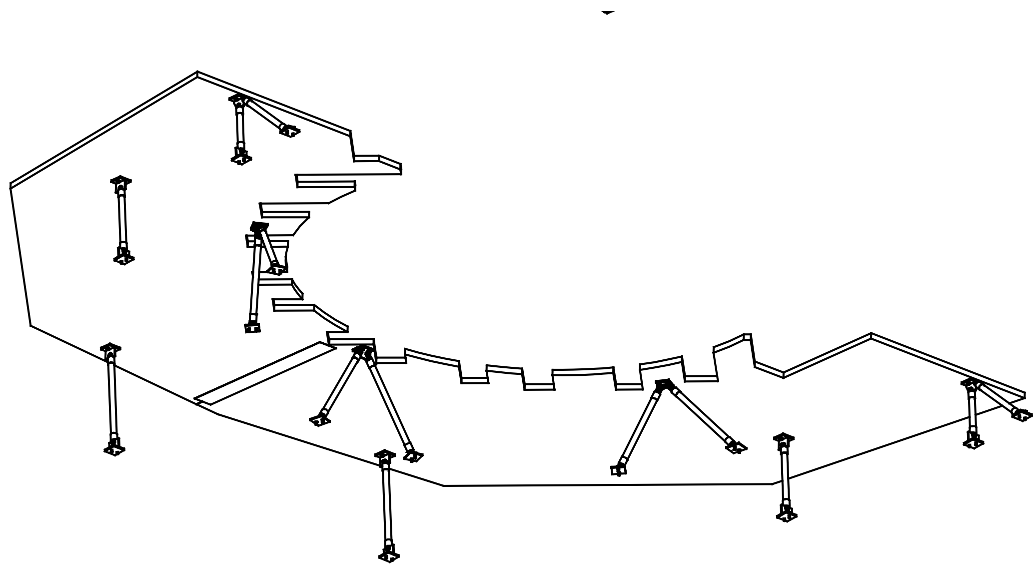


Figure 89: SVM Thermal Shield Subsystem Definition

The SVM Thermal Shield S/S consists of the SVM Thermal Shield and the SVM Thermal Shield Fixation. The fixation struts include strut end fittings, attachment brackets at both strut ends and attachment bolts for fixation on the SVM.

The +X side of the SVM thermal shield is covered with MLI.

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. To optimise radiation the -X surface of the SVM thermal shield has a very low emissivity and a high specularity.

The SVM thermal shield is thermally decoupled mounted on the SVM in order to minimise the temperature of the thermal shield.

Main design driver is

- to minimise SVM thermal shield -X side emissivity (ε<0.045 required, goal: ε<0.04). Such low emissivity is reach by covering the shield surface by gold plated Kapton foil.
- The SVM thermal shield shall be thermally decoupled mounted on the SVM in order to minimise parasitic heat load. For good thermal isolation GFRP struts are foreseen.

The SVM thermal shield is mounted on top of the SVM via five bi-pods and four vertical struts. The shield is split into two parts for easier integration and de-integration once the H-EPLM is mounted on the SVM. Cut-outs are made in the shield in order not to collide with the PLM/SVM interface struts during integration.

The SVM will remain at about 20°C in space. The SVM shield temperature will drop to about 125 K. Fixation strut loads due to thermo-elastic deformations in the SVM thermal shield are minimised by having sandwich panels with CFRP face-sheets.

13.12.1 Physical Properties

13.12.1.1 Mass

The actual mass of the SVM thermal shield is 12.9 kg. This mass contains all SVM thermal shield and fixation struts structural parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc.

2.5 kg are needed for MLI of SVM thermal shield and fixation struts.

13.12.1.2 Dimensions and Mechanical Interfaces

The dimensions and mechanical interfaces towards the SVM of SVM thermal shield and its fixation are given in the H-EPLM Mechanical Interface Control Document PFM, HP-2-ASED-0002.

Thermal radiation into deep space is reach by having a V-groove between SVM thermal shield and by having a low emissivity. A V-groove effect demands a good global planarity of the SVM thermal shield, low emissivity asks for a good local planarity: The planarity of the SVM thermal shield -X side shall be better than 2 mm. The local planarity of the SVM thermal shield -X side shall be better than 0.1/100 mm.

13.12.2 Mechanical Design

13.12.2.1 Stiffness

The SVM thermal shield including fixation struts has a minimum resonance frequency for global modes of

- 58 Hz in X-direction
- > 70 Hz in lateral direction

with the struts hard-mounted at their external interfaces. A non-structural mass of 3 kg (accounting for the attached MLI, bonding straps, etc.) distributed over the shield has been considered.

13.12.2.2 Quasi-Static Design Loads

The SVM thermal shield is designed against the quasi-static design loads as stated in Table 37.

SVM thermal shield	#1	70 g axial
	#2	25 g lateral
Load cases 1 and 2 acting separately		

Table 37: Quasi-static Design Loads SVM Thermal Shield

13.12.2.3 Low Frequency Sinusoidal Vibrations

The SVM thermal shield is designed against the low frequency sinusoidal design loads defined in Table 38 on SVM thermal shield S/S level.

Axis	Frequency range (Hz)	Qualification level (0-peak)
Longitudinal	5 - 12.7 12.7 - 100	+/-10 mm 6.5 g
Lateral	5 - 8.7 8.7 - 100	+/-10 mm 3 g

Table 38: Envelope of SVM Thermal Shield S/S Sinusoidal Vibrations – Qualification Level

13.12.2.4 Acoustic Noise

The SVM thermal shield shall be designed against the acoustic environment.

13.12.3 Thermal Design

The SVM thermal shield -X side together with the SVM upper platform forms a V-groove, radiating heat into deep space. The SVM thermal shield -X surface shall therefore have an emissivity as low as possible and a high specularity.

The SVM thermal shield +X side will be covered with MLI.

An $\varepsilon < 0.045$ is achieved by covering the shield surface by gold plated Kapton foil.

IR specularity of the SVM thermal shield -X surface is better than 90%.

In orbit the SVM thermal shield will see an operational temperature of 125 K.

The SVM thermal shield provides interfaces for the attachment of 4 temperature sensors PT1000.

In orbit the fixation struts will see an operational temperature range between 125 K (SVM thermal shield side) and RT (SVM side).

The SVM thermal shield is thermally isolated from the SVM via GFRP struts.

Radiative heat transfer inside tubes from one end fitting to the other will be minimised by filling the tubes with Eccofoam.

13.13 Cryostat Cover, Cryostat Baffle and Test Components

The subsystem consists of two flight components which are the Cryostat Cover (CC) and the Cryostat Baffle (CB). The cryostat cover closes the CVV on ground and is preventing air-leakage from outside and keeping high-vacuum inside the CVV. It preserves the sensitive optical instruments inside the cryostat from contamination on ground, during launch preparation, launch and the first days in orbit. It will be opened in orbit after the decontamination of the telescope approximately four weeks after launch. The cover is a single shot device and therefore a single point failure for the entire mission. The cover opening occurs typically at 70 K.

The cryostat baffle shall protect the instruments from radiation from sunshade, solar array and telescope rear sides. It shall be able to carry the loads induced by the telescope support.

For functional ground testing the cover shall be opened and closed under vacuum conditions and at any temperatures within the defined temperature range. For this purpose the cryostat baffle shall be replaced by a vacuum tight test-cavity, which is part of this procurement specification. This Cryo Test Cavity for PFM (CTCP) can be used for the qualification of the Cryostat Cover (CC) by the cover supplier, as well as for the AIT program on Herschel level which will be performed by Astrium. In addition a Cryostat Vacuum Vessel Interface Plate (CVVIP) simulating the CVV interface will be used for CC testing.

The cover shall provide the following main functions:

Close and tighten the CVV during ground and launch operations to maintain the insulation vacuum

Safe single opening in orbit to provide sufficient free entrance for the telescope beam into cryostat

Minimized internal heat load on ground, by a passive shielding

Provide a defined thermal/radiative background for instrument testing on ground by active cooling and auto focussing mirrors in front of SPIRE and PACS

The subsystem of the Cryostat Cover, Cryostat Baffle and Test Components is subdivided in the following components:

- **Cryostat Cover (CC) ; CI-No: 121 131**
- **Cryostat Baffle (CB) ; CI-No: 121 132**

13.13.1 Cryostat Cover (CC)

The Cryostat Cover (CC) assembly consists of the subassemblies

- Door Structure
- Cover Heat Shield (CHS),
- Lever
- Deployment Mechanism (DEM)
- Hold Down Release Mechanism (HRM)
- Non-Explosive Device (NED)
- End Stops,
- Kick Springs
- Connector Bracket.

The HRM, DEM, End Stops and Kick Springs have a direct I/F to the CVV Top Plate. The Connector Bracket has a direct I/F to the CB. The Door Structure provides the vacuum-tight closure of the CVV. It is mounted via a ball joint bearing to the Lever, which is used for the pre loading of the Door Structure to the CVV.

This arrangement provides equal load distribution over the circumference of the Door Structure and an equal deformation of the used sealing of about 0.8 mm. The Lever is fixed to the CVV on one side via a one-axis rotational hinge system, which is also used for the deployment and actuation of the deployment. This hinge system is called Deployment Mechanism (DEM) and consists of two hinges with spring actuators. On the other side, the Lever is clamped and pre loaded by the Hold Down Release Mechanism (HRM). This mechanism is driven by 2 torsion springs, and 3 compression springs. Hold down and release will be performed via a Non Explosive Devices (NED).

For deceleration of the opening rotation and for defined opening position of the Door Structure and Lever, two End Stop assemblies are foreseen. A Connector Bracket is attached to the CB with light tight I/F to the CB for harness connection. This Connector Bracket consist of two parts with one FHW part, and one GSE part. The GSE part is replaced before flight against a blind bracket with same design as the GSE bracket.

The Cryostat Cover is shown in Figure 90.

Sealing

The selected sealing is an O-ring sealing, which is located in a special dovetail groove on the Door Structure. The dovetail groove is used to keep the sealing secure in its groove after opening the CC also under adhesion forces. The material of the O-ring sealing is Fluorcarbon (V0747-75) well known as Viton from the ISO project. The selection of an elastomer material is necessary because of the limitation of pre load force introduced into the system Door Structure, Lever, HRM, DEM but also CVV I/F plane. The pre load of 10 N/mm is the optimal value for an elastomer with shore-A hardness of 75. A further rise of the pre load does not lower the leakage rate any more. This load gives a compression of 20% (0.8 mm).

The Cryostat Cover seal area is shown in Figure 91.

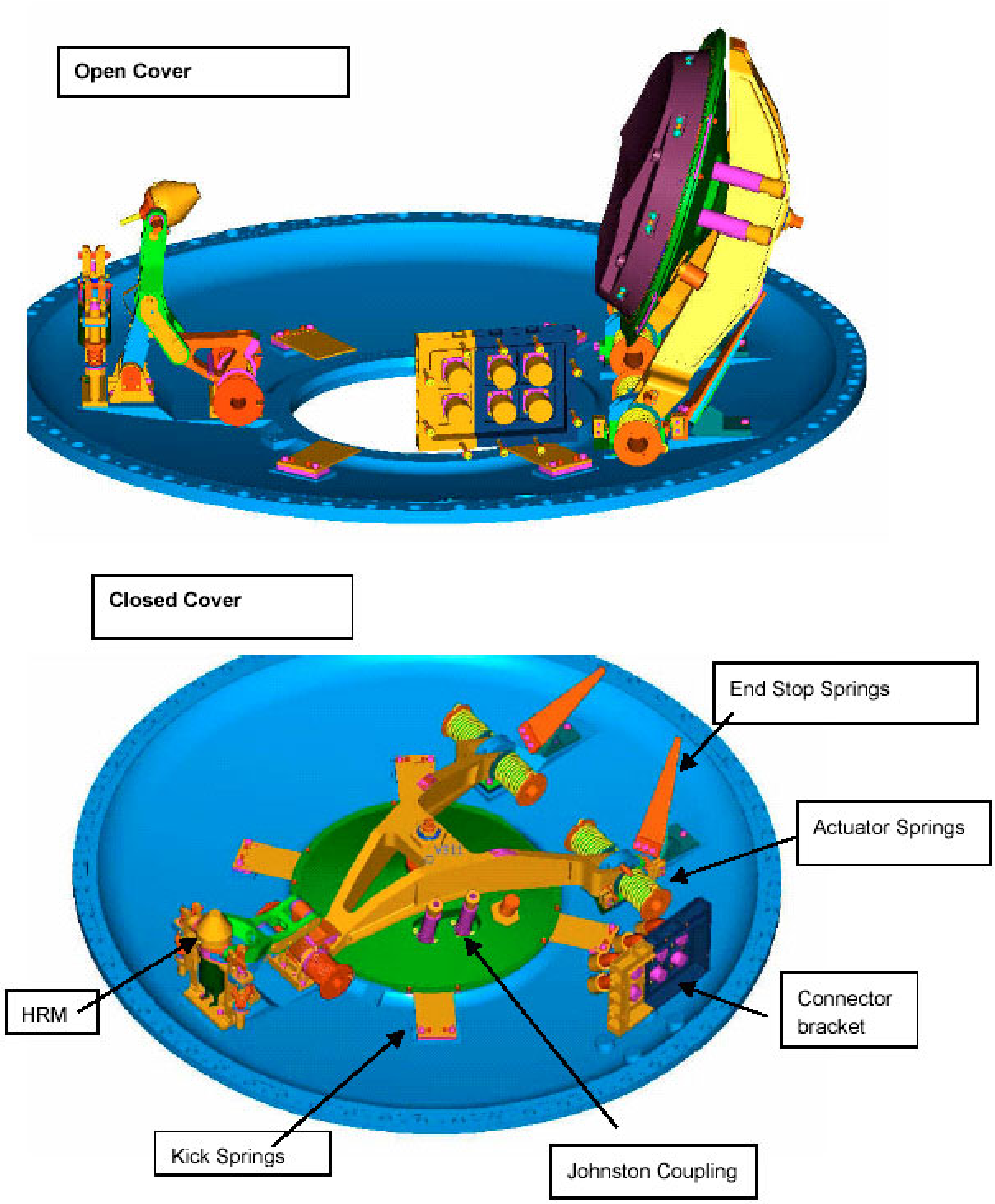


Figure 90: Cryostat Cover

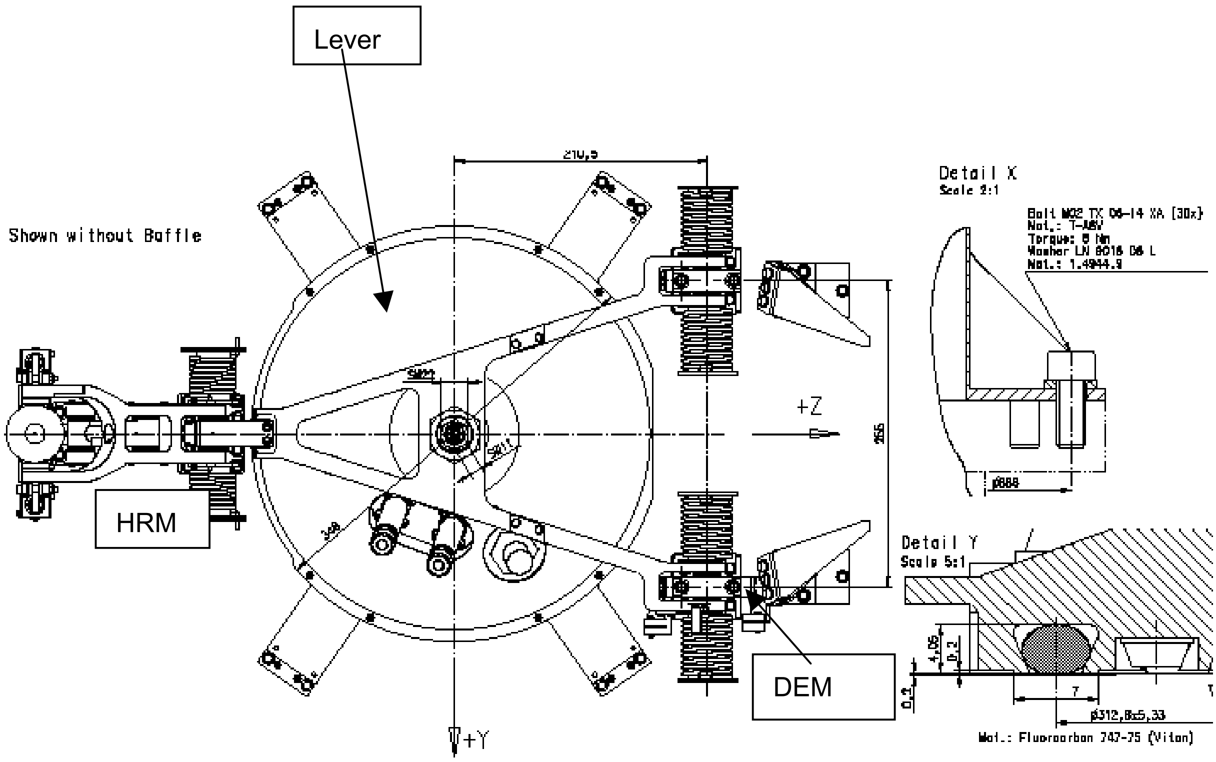


Figure 91:Cryostat Cover Details Top View with seal area.

Description of Main Components:

<u>DOOR STRUCTURE</u>

The Door Structure (Al-6061) is a dome shaped part made of aluminium alloy. It is compressed via the Lever to the CVV Top Plate and closes and tightens the 288 mm opening of the CVV by the means of the incorporated sealing. On its upper area it is equipped with a ball joint I/F to allow free rotation of the Door Structure and provides the feed throughs for the Johnston Couplings and the electric cables.

On its lower surface, it is equipped with the sealing and four I/F areas for the Kick Springs. Inside it comprises the interfaces to the CHS. For thermal decoupling of the CHS to the Door Structure and environment 2 x multi layer insulation blankets are mounted. Mounting of the blankets is performed in a way that contact between the blankets to the Door Structure as well as to the CVV is avoided.

<u>LEVER</u>

The function of the Lever (Al-6061) is to provide the pretension load between Door Structure and CVV(10 kN), which is as high that under worst additional loads like vibrational acceleration or thermal loads the sealing stays under its standard deformation of more than 20% (the Vespel parts in the groove besides the sealing stay in contact with the CVV Top Plate). The I/F of the Lever to the Door Structure is via a ball joint, which provides equal circumferential preloading of the sealing.

DEPLOYMENT MECHANISM (DEM)

The DEM consists of two identical hinges, both driven by two preloaded torsion springs. So for the opening campaign all in all four springs are available, which are redundant against malfunction of one spring element.

HOLD DOWN RELEASE MECHANISM (HRM)

The HRM consists of following main items:

- · Knee Lever / Knee Lever Hinge
- · Rotation Beam / Rotation Beam Hinge
- · Connection Beam
- · Release Unit

The cinematic of the HRM is designed in a way that the rotation of the Knee Lever, which is needed for release of the preloaded Lever, is transformed to almost a translation of the Release Bolt in the Release Nut.

NON-EXPLOSIVE DEVICE (NED)

AAE has developed the Mirror and optical Monitor Doors (MOD) and the Telescope Sun Shield (TSS) mechanisms for the XMM satellite, which is successfully operating in orbit since several years. All release mechanisms used successfully the Separation Nut (now called Non-Explosive Devices, NED) supplied by G&H with the part number 9421-500-001.

The environmental differences between XMM and Herschel are:

Parameter HERSCHEL XMM

	Herschel	XMM
Release Temperature	60 K	193 K to 353 K
HRM structure preload	1100 N (Approx.)	100 N
HRM preload deflection	10 mm (Approx.)	3 mm

Conclusion is that the main environmental difference between HERSCHEL and XMM is the release temperature and the potential energy stored in the release bolt. AAE adapted and qualified the design together with G&H to allow the usage for the environmental difference as described above.

The non-explosive device is a 1/4 inch fastener that quickly releases attached hardware when it receives an electrical signal to separate. Nut separation is complete, reliable and safe. Bolt release is virtually shock-free and no debris, contaminants or pollution is created. The model uses small redundant electro-mechanical devices called spools to initiate the bolt release.

These highly reliable spools have been used extensively in space and military applications. When a separation signal is received (which is the same as for pyrotechnic initiators), the spools unwind in milliseconds and free internal plungers. This releases a compression spring that moves a locking sleeve and separates the nut's threads from the attached bolt.

Concerning the electrical characteristics of the NED a minimum pulse duration (actuation time) of 120msec and a firing current of 3.5A (min) and 6A max is required. A non firing current of 0.8A (applied for 5 minutes in ambient conditions) is used (see RfD, HP-2-AAE-RD-0001 for the updated values). The PCDU provides, according to [AD8], the required electrical interfaces. The cryo harness between the cryo cover and the SVM connector bracket consists of 14 parallel brass wires, approximately 4 metre long, provided an impedance of less than 1.0Ω (at ambient conditions).

Redundancy: Each NED contains a pair of non-explosive spool assemblies. Complete separation will occur if either one, or both, of the spool assemblies is actuated.

The NED has been qualified by AAE to the requested temperature.

COVER HEAT SHIELD (CHS)

The purpose

Passive isolation function: To prevent heat transfer via conductance and radiation from environment into the CVV (in combination with the CC structure)

Active cooling function: To provide a CHS temperature of about 80 K to allow operation of the instruments on ground with parabolic shaped mirror surfaces to allow operation of the instruments on ground.

The CHS consists of a Al-6060 base structure oriented in Y-/Z-direction with a surrounding conical rim. On its upper side, the cooling loop is integrated in a way, which allows excellent heat transfer via conductance from the cooling loop to the CHS, which are the bases for the active cooling function of this unit. The upper side is constructed as a very stiff frame work, which is needed as a stable support for the high accuracy mirrors located on the lower side of the CHS. The PACS- and SPIRE- mirror are an integrated part of the aluminium Al-6060 CHS structure. The shape of the mirrors is defined in the CC Procurement Specification. The CHS design is shown in Figure 92.

CHS Cooling Loop and Johnston Couplings

Cooling Loop and Johnston Couplings are one integrated unit. Both Johnston Couplings are welded to the Cooling Loop at the end of the manufacturing campaign and run the whole test program together. The complete unit is than fixed by the dedicated fixation devices to the CHS, before the CHS is integrated to the CC-structure. Fixation of the CHS to the CC-structure is then via 6 x GFRP I/F plates in combination via the fixation of the Johnston Couplings to the CC-structure via 4 x bolts from the upper outside.

The material selection for the Cooling Loop of aluminium EN AW-6060 F22 took into account that the material is compliant to temperature down to 4 K and has sufficient high conductance for heat exchange from the liquid helium inside the Cooling Loop to the CHS.

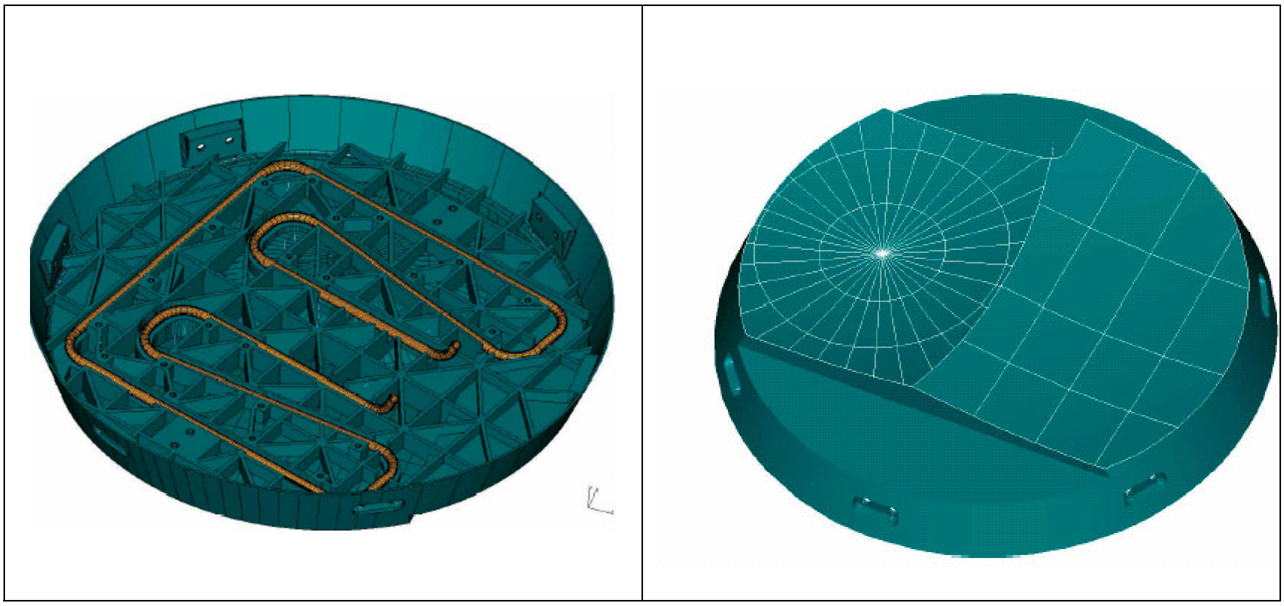


Figure 92: Cryostat Cover Heat Shield with Cooling Loop (Rear Side)

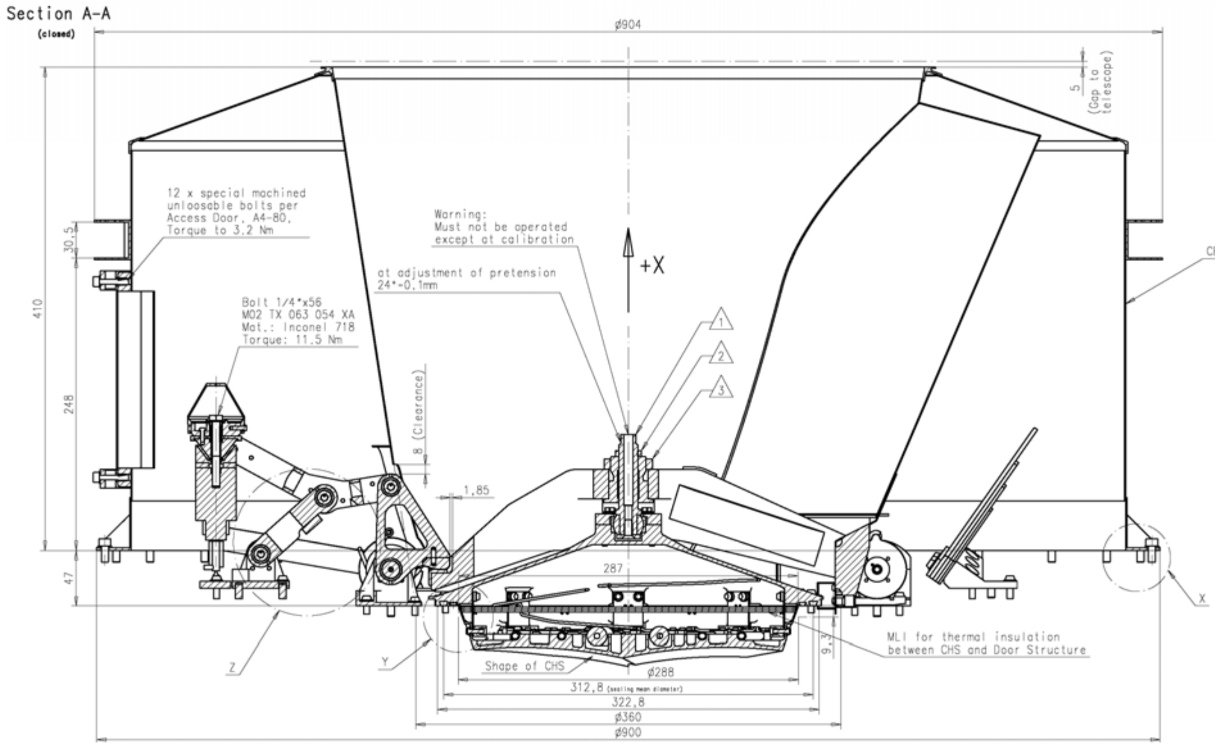


Figure 93: Cover closed with He Cooling System (typical) and SPIRE and PACS

13.13.2 Cryostat Baffle (CB)

The CB, which consists of an Al-5083 cylindrical outer structure and a conical inner baffle part, shall protect the instruments from radiation from sunshade, solar array and telescope rear sides. Additionally all gaps in the inner baffle, resulting from cover cut-out etc. shall be minimised by application of dedicated straylight baffles On telescope side an aperture of ø540mm and on CVV side of ø360mm shall been foreseen. The CB shall be a light weight design. The outer structure shall carry the loads of the telescope support frame via six struts connected to an interface ring which is part of the CB. The struts belong to the telescope support structure. The CB is shown in Figure 94.

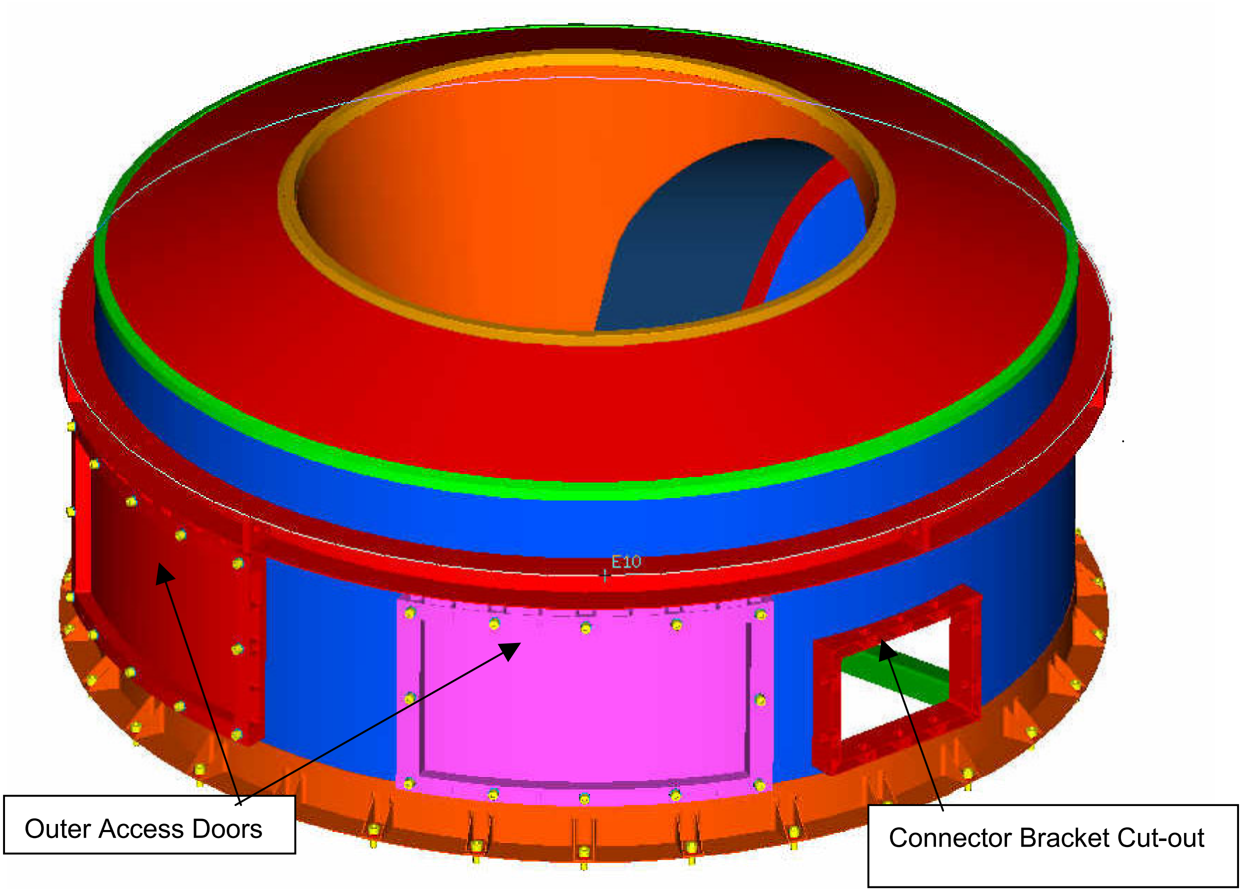


Figure 94: Cryostat Baffle (typical)

13.14 Herschel Support Structures (HSS, SVM Interface, Telescope, LOU)

The support structure S/S consists of a collection of various support structures, mainly struts, mounting the different E-PLM parts like the HSS, the telescope, the instrument LOU on the CVV, or the complete H-EPLM (PLM/SVM interface struts) on the SVM. All structural parts collected in this subsystem have a similar function: They shall carry the attached structural part and at the same time all struts linking warmer parts to the CVV shall provide thermal isolation. The major function common to all parts of the Herschel support structure is

- to mechanically support the mounted structural parts and
- to minimise the thermal conductance between warm and cold parts of the spacecraft.

Main design drivers are

- to provide an alignment-stable interface and minimise the effect of the CVV shrinkage
- to provide a positional stable LOU interface
- to provide support structure which is easy to handle and integrate.

The E-PLM is mounted onto the SVM via 24 PLM/SVM interface struts (GFRP struts for good thermal isolation) as shown in Figure 95: .

The solar array and sunshade support struts are shown in Figure 96. The solar array is supported by the SVM via four struts linking the upper end of the solar array to the SVM central cone (CFRP struts for high mechanical loads). Four further struts laterally attach the upper end of the solar array to the CVV (GFRP struts for good thermal isolation). In addition the lower end of the HSS is linked to the SVM shear panels via three attachment beams. The sunshade is mounted on top of the solar array. Four lateral attachment struts link the sunshade to the CVV (GFRP struts for good thermal isolation). Two struts connect sunshade to solar array (GFRP struts for good thermal isolation). The total number of SA/SSD struts is twelve included in the Herschel support structures S/S and five struts/beams included in HSS S/S.

The telescope is mounted on top of the CVV via the Telescope Mounting Structure (TMS) as shown in Figure 97. The TMS consists of six CVV/TMS struts, a hexagonal frame and six TMS/CB struts. The six CVV struts (T300 struts for high mechanical loads and acceptable thermal isolation) are mounted onto the CVV and carry a hexagonal frame at their upper end. The upper side of the hexagonal frame is the interface with the telescope. The struts are designed such as to allow radial shrinkage of the CVV by 4mm without distorting the frame with its interface to the telescope. To protect the telescope surface from distorting, the frame has to guarantee an interface planarity of 0.08 mm. The TMS struts and frame allow radial shrinkage of the CVV interface and provide a plane and shrinkage free frame/telescope interface to limit the effect on the telescope. The frame is additionally attached to the cryostat baffle via six lateral struts.

0.08 mm TMS/telescope interface planarity are achieved by the aid of some dedicated MGSE, helping integration without distorting the TMS.

The LOU is mounted on the –Y side of the CVV via eight struts (GFRP struts for good thermal isolation) and a baseplate as shown in Figure 98. The LOU has very stringent alignment requirement. In plane translations and any rotations must be minimised.

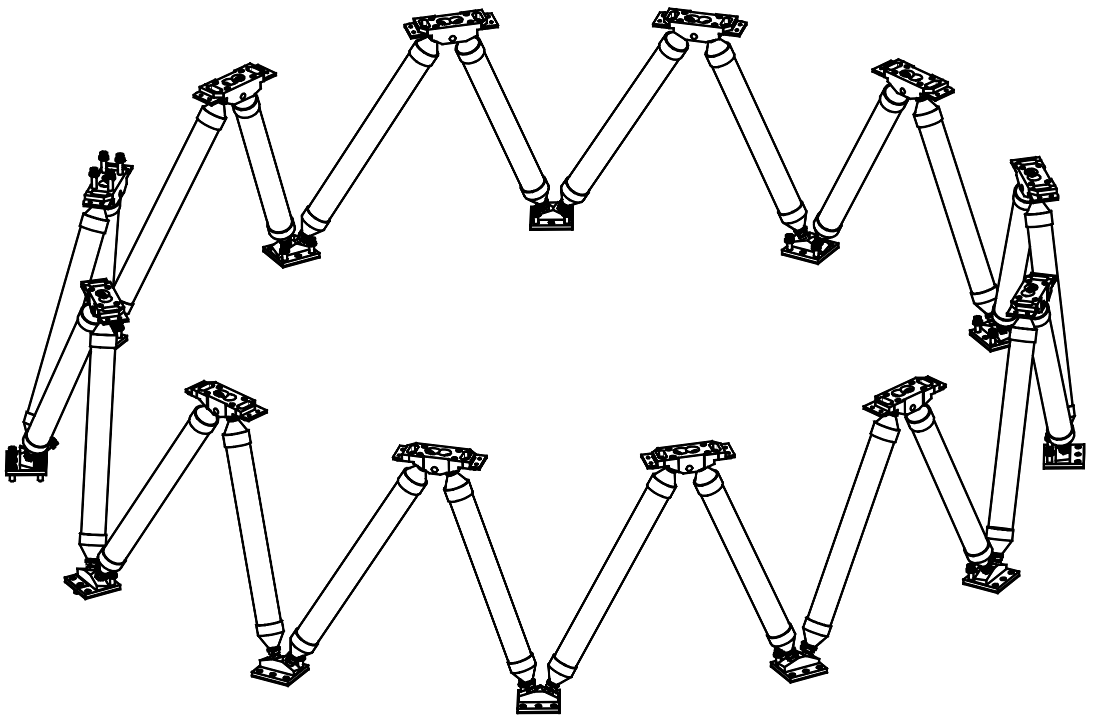
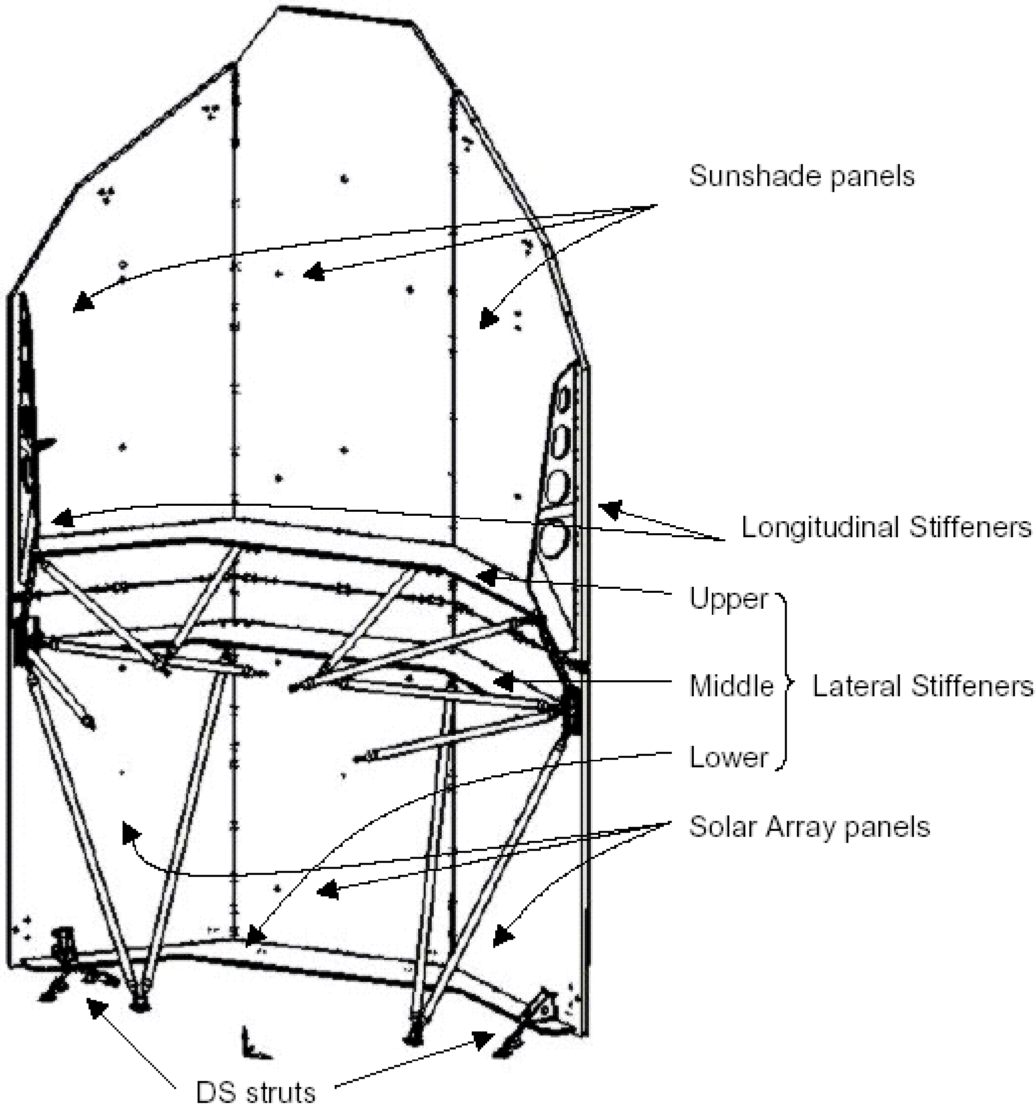


Figure 95: PLM/SVM Interface Struts Subsystem Definition



<u>Note</u>: Panels, stiffening ribs and brackets on panel side are part of HSS and not part of HSS support struts

Figure 96: HSS Support Structure Subsystem Definition

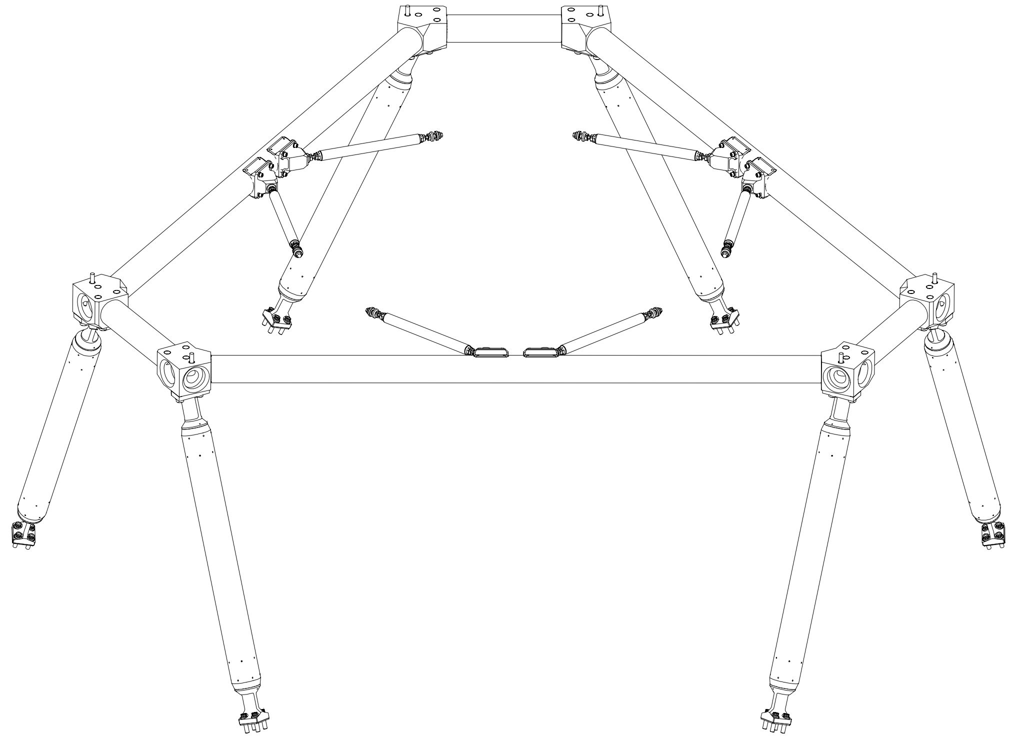


Figure 97: Telescope Mounting Structure Subsystem Definition

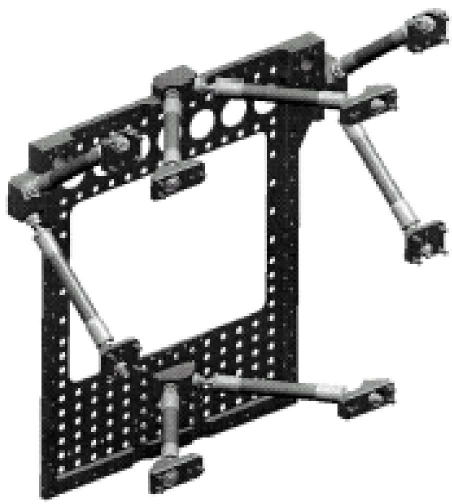


Figure 98: LOU Support Structure Subsystem Definition

13.14.1 Dimensions and Mechanical Interfaces

The dimensions and mechanical interfaces of individual parts of the support structure are given in the H-EPLM Mechanical Interface Control Document PFM, [RD18]. Geometrical properties are listed in Table 39. The TMS/telescope interface planarity of 0.08 mm shall be guaranteed in orbital environment (moisture, temperature)

13.14.2 Mechanical Design

13.14.2.1 Stiffness

The support strut axial stiffnesses are listed in Table 39.

Item	Tube Diameter [mm]	Tube Thickness [mm]	Tube Length [mm]	EA/L (at RT) [N/mm]
PLM/SVM Struts	35	2.1	469	19605
SA/SVM Struts	60	4	2177	64412
SA/CVV Struts	56	4.8	1420 / 1357	23019 / 23966
SSD/CVV Struts	56 / 60	4.8	1431 / 1459	22855 / 24232
TMS/CVV Struts	60	4.94	536	F1 = 37.15 Hz
TMS/CB Struts	20	0.99	218	
TMS Frame	56	1.3 / 1.56	1252 / 231	
LOU Support Struts	20	0.99	136	11997
Note: End fitting properties are not included in geometrical data, but in stiffness				

Table 39: Support Structure Geometry and Axial Stiffness

The HSS Support Struts Bending Stiffness including end fittings and attachment brackets (if applicable) are

71.3 Hz for HSS strut 1 through 4
53.3 Hz to 58.5 Hz for HSS strut 5 through 12.

The TMS including telescope has a first resonance frequency of 37.15 Hz in lateral direction (Y/Z) with the three TMS bi-pods hard-mounted at their external interfaces and considering a dummy telescope model.

13.14.2.2 Static Design Loads

The Herschel support structure struts are designed against interface loads and moments as stated in Table 40.

Item	Load [kN]	Bending moment [Nm]
PLM/SVM Struts	35	45
SA/SVM Struts	35	80
SA/CVV Struts No. 5, 8	11 (thermal distortion load case)	80
SA/CVV Struts No. 6, 7	20	80
SSD/CVV Struts No. 9, 12	11 (thermal distortion load case)	80
SSD/CVV Struts No. 10, 11	21	100
TMS/CVV Struts	-	45 (thermal distortion load case)
TMS/Cryostat Baffle Struts	-	3 (thermal distortion load case)
LOU Support Struts	6	10

Table 40: Struts Interface Loads under Static Design Loads

13.14.2.3 Quasi-Static Design Loads on TMS S/S

The TMS is designed against the quasi-static design loads as stated in Table 41:

Item	Loadcase	Axial load	Lateral load
TMS	#1	12 g	+/- 4 g
	#2	2 g	+/- 11 g

Table 41: Quasi-static Design Loads on TMS

13.14.2.4 Low Frequency Sinusoidal Vibrations on TMS S/S

The TMS is designed against the low frequency sinusoidal design loads defined in Table 42 on TMS S/S level (including telescope).

Axis	Frequency range [Hz]	Qualification level (0-peak) [g]
Longitudinal	5 - 19.3	+/- 10 mm
	19.3 - 40	15
	40 - 100	3
Lateral	5 - 16.6	+/- 10 mm
	16.6 - 30	11
	30 - 100	2

Table 42: Envelope of TMS S/S Sinusoidal Vibrations – Qualification Level

13.14.2.5 Interface Loads

The telescope loads are carried by the TMS/CVV struts and not by the TMS frame and TMS/CB struts. For this purpose the TMS struts go along the same line as the telescope bi-pods.

13.14.2.6 Thermo-elastic Loads

In orbit the PLM will have the temperatures stated in Table 43 and will consequently shrink about 4 mm in radial direction. This shrinkage will cause loads and bending moments in the attached TMS, SVM and HSS struts.

The PLM/SVM interface struts including their attachment brackets allow a radial shrinkage of 4 mm (in spacecraft co-ordinates) at the CVV end.

The CVV/TMS interface will shrink 4 mm in radial direction. The resulting thermo-elastic deformations at TMS/telescope interface are compliant with the required mechanical interface planarity of 0.08 mm.

13.14.3 Thermal Design

The individual parts of the support structure have the operational temperature range as stated in Table 43 and the interface heat flow at the cold side as stated in Table 44.

Item	From (warm side)	Temperature [K]	To (cold side)	Temperature [K]
PLM/SVM Struts	SVM	300	CVV	65
SA/SVM Struts	SA	415	SVM	270
SA/CVV Struts	SA	415	CVV	65
SSD/CVV Struts	SSD	300	CVV	65
TMS(CVV and CB struts)	Telescope	320 [1)]	CVV	85 [1)]
	Telescope	60	CVV	70
LOU Support Struts	LOU	300 [2)]	CVV	65
1) during decontamination phase in orbit 2) maximum temperature during transient test case				

Table 43: Support Structure Operational Temperature Range

Item	From (warm side)	Temperature [K]	To (cold side)	Temperature [K]	I/F Heat Flow at Cold Side [1)] [W]
PLM/SVM Struts	SVM	293	CVV	70	1.7
SA/SVM Struts	SA	380	SVM	293	2.5
SA/CVV Struts	SA	360	CVV	70	0.42
SSD/CVV Struts	SSD	270	CVV	70	0.25
TMS(CVV and CB struts)	Telescope	320	CVV	85	6.2
LOU Support Struts	LOU	150	CVV	70	0.18
1) under vacuum conditions and assuming adiabatic outer surface for each individual strut (i.e. each strut wrapped in MLI)					

Table 44: Support Structure I/F Heat Flow at Cold Side

Radiative heat transfer inside the tubes from one end fitting to the other is minimised by filling the tubes with ECCOSTOCK (Polyurethane foam). Venting holes are foreseen to evacuate interior of struts during TB/TV test and in orbit.

14 Requests for Deviations, Requests for Waivers and Open Points

14.1 Requests for Deviation and Request for Waivers

The status of the RfDs and RfWs is reported in [RD50].

14.2 Open Points

14.2.1 Instrument Interfaces

The HIFI LOU radiator design is finished but still under review.

14.2.2 HIFI Coax Feedthroughs

The design of coax feedthroughs is finally completed. A supplier has been selected, the detailed design was established. Mechanical analysis was performed. Qualification is on-going.

14.2.3 Not performed PDR/CDR

For the following components the PDR/CDR has not yet been performed.

Herschel Solar Array / Sun Shield (HSS)

The following activities are planned:

- CDR planned for mid-April 2005

E N D O F D O C U M E N T

	Name	Dep./Comp.		Name	Dep./Comp.
X	Alberti von Mathias Dr.	AOE22	X	Wietbrock Walter	AET12
X	Barlage Bernhard	AED11	X	Wöhler Hans	AOE22
X	Bayer Thomas	AOA52			
X	Fehringer Alexander	AOE13			
X	Geiger Hermann	AOA52			
X	Gerner Willi	AED11			
X	Grasl Andreas	OTN/AET52			
X	Grasshoff Brigitte	AET12			
X	Hauser Armin	AOE22			
X	Hendry David	Terma Resid.	X	Alcatel	ASP
X	Hinger Jürgen	AOE22	X	ESA/ESTEC	ESA
X	Hohn Rüdiger	AED65			
X	Huber Johann	AOA52		**Instruments:**	
X	Hund Walter	ASE442		MPE (PACS)	MPE
X	Idler Siegmund	AED432		RAL (SPIRE)	RAL
X	Ivády von András	FAE22		SRON (HIFI)	SRON
X	Jahn Gerd Dr.	AOE22			
X	Kalde Clemens	APE3		**Subcontractors:**	
X	Kameter Rudolf	OTN/AET52		Air Liquide, Space Department	AIR
X	Kettner Bernhard	AET42		Air Liquide, Space Department	AIRS
X	Knoblauch August	AET32		Air Liquide, Orbital System	AIRT
X	Koelle Markus	AOA53		Alcatel Bell Space	ABSP
X	Kroeker Jürgen	AED65		Astrium Sub-Subsyst. & Equipment	ASSE
X	Kunz Oliver Dr.	AOE22		Austrian Aerospace	AAE
X	Lamprecht Ernst	OTN/ASI21		Austrian Aerospace	AAEM
X	Lang Jürgen	ASE442		APCO Technologies S. A.	APCO
X	Langfermann Michael	AOA51		Bieri Engineering B. V.	BIER
X	Mack Paul	OTN/AET52		BOC Edwards	BOCE
X	Müller Jörg	AOA52		Dutch Space Solar Arrays	DSSA
X	Pastorino Michel	ASPI Resid.		EADS CASA Espacio	CASA
X	Peltz Heinz-Willi	AOE13		EADS CASA Espacio	ECAS
X	Pietroboni Karin	AED65		EADS Space Transportation	ASIP
X	Platzer Wilhelm	AED22		Eurocopter	ECD
X	Rebholz Reinhold	AOA51		HTS AG Zürich	HTSZ
X	Reuß Friedhelm	AED62		Linde	LIND
X	Rühe Wolfgang	AED65		Patria New Technologies Oy	PANT
X	Runge Axel	OTN/AET52		Phoenix, Volkmarsen	PHOE
X	Sachsse Bernt	AED21		Prototech AS	PROT
X	Schink Dietmar	AED44		QMC Instruments Ltd.	QMC
X	Schlosser Christian	OTN/AET52		Rembe, Brilon	REMB
X	Schmidt Rudolf	FAE22		Rosemount Aerospace GmbH	ROSE
X	Schweickert Gunn	AOE22		RYMSA, Radiación y Microondas S.A.	RYM
X	Steininger Eric	AED44		SENER Ingenieria SA	SEN
X	Stritter Rene	AED11		Stöhr, Königsbrunn	STOE
X	Tenhaeff Dieter	AOE22		Terma A/S, Herlev	TER
X	Thörmer Klaus-Horst Dr.	OTN/AED65			
X	Wagner Klaus	AOE22			