Title: **H-EPLM Design Description**

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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. Cut-off date for the technical contributions was end of April 2002.

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 ESV-type launch vehicle into an orbit around the second Lagrangian point (Libration Point) L2 for individual astronomical observations in the range from 480 GHz to 5 THz (Herschel) and from 25 to 100 GHz (Planck) respectively.

Infrared observations in the wavelength range of about 80 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 photoconducting 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 Buffer Amplifier Unit (BOLA) of the SPIRE instrument
- The waveguides from the Herschel SVM to the EPLM 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. The helium control system, which provides the cryogenic environment to the FPU's is part of the cryostat and is not considered part of the H-EPLM thermal control.
- 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 the valves.
- The Sunshield/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, containing superfluid helium, a passive phase separator and the cryogenic components to operate it. It also features an additional helium tank 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 days in orbit.

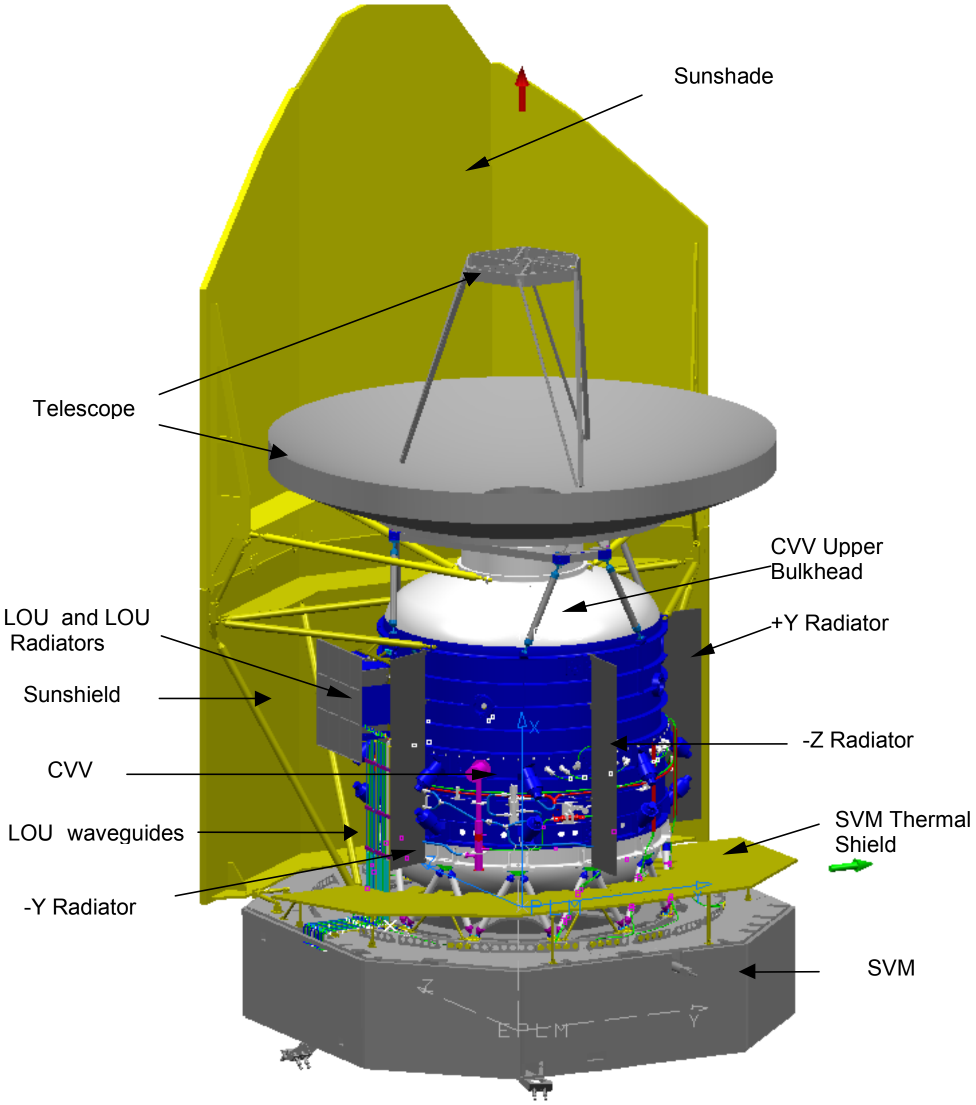


Figure 1: Herschel S/C (Extended Payload Module and SVM)

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 EQM Description, HP-2-ASED-RP-0028.

2 Documents and Abbreviations

2.1 Applicable Documents

[AD1] Herschel/Planck Instrument Interface Document, Part A, SCI-PT-IIDA-04624, Issue 2/0, 31.07.2001

[AD2] Herschel/Planck Instrument Interface Document, Part B; Instrument “PACS”, SCI-PT-IIDB/PACS-02126, Issue 2/0, 31.07.2001

[AD3] Herschel/Planck Instrument Interface Document, Part B; Instrument “SPIRE”, SCI-PT-IIDB/SPIRE-02124, Issue 2/0, 31.07.2001

[AD4] Herschel/Planck Instrument Interface Document, Part B; Instrument “HIFI”, SCI-PT-IIDB/HIFI-02125, Issue 2/0, 31.07.2001

[AD5] Herschel Telescope Design Specification; SCI-PT-RS-07360; Issue 4/0

[AD6] H-EPLM Requirement Specification ;H-P-ASPI-SP-0250; Issue 1; 30.03.2002

[AD7] Herschel EPLM Interface Specification; H-P-2-ASPI-IS-0039; Issue 3

[AD8] H-EPLM Environmental and Test Requirements;HP-2-ASED-0004; Issue 1.2

[AD9] EMC Requirement Specification, HP-1-ASPI-SP-0037

[AD10] General Design and Interface Requirements, HP-1-ASPI-SP-0027

The IIDA and the IIDBs are applicable together with the following:

- HIFI IID-B Convergence Meeting, HP-ASPI-MN-1367, 24/04/02
- PACS IID-B Convergence Meeting, HP-ASPI-MN-1369, 26/04/02
- SPIRE IID-B Convergence Meeting, HP-ASPI-MN-1346, 19/04/02

2.2 Abbreviations

The list of abbreviation is covered in the Documentation Identification Procedure, HP-2-ASED-PR-0001.

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, AD-1 to AD-4. 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. The launch delay of 25 hours has been introduced at the Operations Herschel/Planck Feasibility Meeting (ref. AE/DC/P/N-2001-285 PG/MB, 15/06/01). This duration includes a margin of 6 months for the transfer 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 ±30º around the y axis and ± 1º around x axis shall be possible

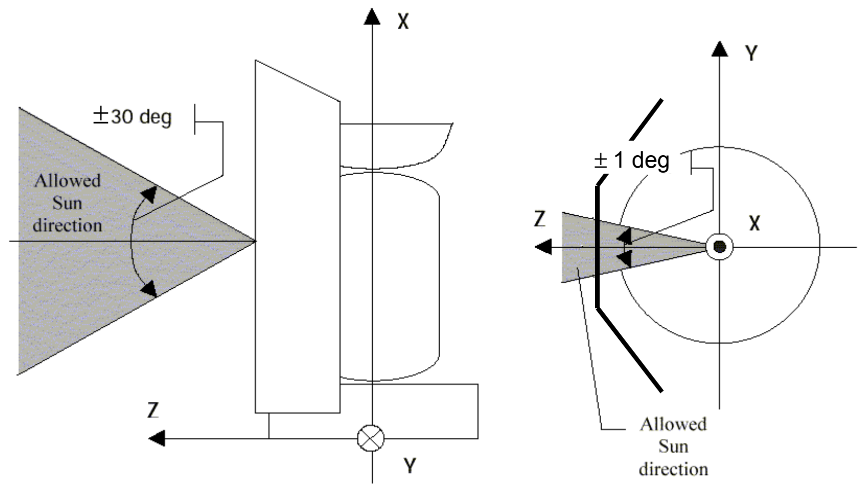


Figure 2: Solar Aspect Angels on H-EPLM at L2

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

The basic launch/flight operations to be expected for Herschel EPLM are specified in the following subsections.

3.1.2.1 Ground Operations

During instrument integration the EPLM shall support HIFI LOU alignment testing by tilting the HEPLM by 90 degrees to determine possible gravity effects in both positions (vertical and horizontal) [TBC].

During ground operations the Herschel EPLM shall support the recycling of the PACS and SPIRE He-3 cooler which is performed by tilting the cryostat by at least 20 degrees in +y-direction downwards about the S/C z-axis.

During ground operations the EPLM shall support the SPIRE thermal balance test in Spectrometer mode by operating the cryostat in horizontal position (90 degrees ±y-direction downward about the S/C z-axis).

3.1.2.2 Pre-launch/Launch Operations

The He II tank shall be filled up to 98%, containing super-fluid He.

Prior to and during the launch a sequence of valve switching commands shall guarantee the following conditions for the He subsystem.

Pre-Launch Phase

- Before start of the autonomy phase the He II tank shall be closed.
- During the autonomy phase cooling of the Optical Bench and the Heat Shields shall be performed via He I tank venting only.
- Shortly before launch (6 hours, tbc) the residual He in the He I tank shall be depleted without icing of the external ventline.
- After depletion the He I tank shall be closed w.r.t. the outer atmosphere.

Launch Phase

During ascent, correct starting conditions for the Phase Separator shall be provided by:

- Opening of the vent line after the payload fairing jettisoning to evacuate the vent line.
- Opening of the He II tank with start of the Phase Separator operations before the first onset of the zero gravity phase.

3.1.2.3 In Orbit Operations

Following the separation from the launcher, the following applies:

- Cover opening shall be done after decontamination of the telescope and when the telescope reached a temperature of T < 90K.
- Depending on He mass flow rate assessment, the final flow impedance (nozzle) shall be switched on by TC. This occurs probably before cover opening.
- Direct Liquid Content Measurement (DLCM). It shall be possible to measure the residual He-mass in the He II tank, e.g. twice per year initiated by TC.
- TM compilation

  All relevant cryostat temperature-, pressure- and status measurements shall be routinely collected and prepared for further processing/ground transmission within the OBDH.

3.1.3 Physical Requirements

- The mass of the H-EPLM under ASED responsibility shall not exceed 1653 kg
- The nominal position of the H-EPLM Centre of Gravity (CoG) shall be located:
  - in the range of 0 to –35 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 AD7

- 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)
- EPLM control harness
- Telescope heater and thermistor harness
- Scientific Instrument harness 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	1500 Watts (Option 2: 1600 W)
• Minimum End Of Life power Nominal mission life time = 3.5 years	1350 Watts (Option 2: 1400 W)
• Minimum End of Life power Extended mission life time = 6 years	1230 W
• 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 minimum frequency:

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

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

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

- First lateral mode (in Y and Z) > 24
- 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 [AD-8].

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 [AD 7].

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 ± 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 definition 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 10 %.

3.2.2 Mass Margin

The margin of the H-EPLM mass under ASED shall be margin of 9% of the calculated dry mass.

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 and JFET box, inside the cryostat
- PACS FPU and HIFI FPU inside the cryostat
- PACS BOLA and 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 [AD-2 to AD-4] 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 one JFET box with a total mass of 175.5 kg. The required allocation on the OBP is specified in the IIDA.

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

PACS BOLA:

The PACS BOLA has outer dimensions of 162 x 119 x 121 mm (incl. fixation feet) and with an allocated mass of 2.0 kg.

HIFI Local Oscillator Unit:

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 35.49kg. 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 (incl. its supports/thermal links).

The LOU radiator and its supports/thermal links will be provided by the instrument, its physical data are presently to be defined.

The LOU, LOU radiator and LOU mounting structure interfacing is considered to be very complex w.r.t. mechanical and thermal aspects and needs specific attention.

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 shall also provide 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. The required operating temperatures per instrument are summarised in Table 2 and are based on the IIDBs for PACS [AD-2] SPIRE [AD-3] and HIFI [AD-4]. These temperatures shall be provided by the HERSCHEL cryostat cooling system, which consists of the HTT (Level 0), the ventline of the HTT (Level 1) and the ventline-cooled Optical Bench (Level 2).

The temperatures of the external boxes, which are mounted outside on the CVV, are listed in Table 3. The BOLA is thermally coupled to the CVV, whilst 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.

	PACS	**SPIRE**	**HIFI**
Level 0	1.6 K … 1.75 K (Red Det.) 1.6 K … 2 K (Blue Det.) 1.6 K … 2.2 K (Cooler Pump) 1.6 K … 2.0 K (Cooler Evapor.)	0 K … 2 K	N/A … 2 K Stability: 6 mK/100s
Level 1	3 K … 5 K	N/A … 6 K	N/A … 6 K Stability: 6 mK/100s
Level 2	N/A	N/A … 15 K	N/A … 20 K Stability: 15 mK/100s

Table 2: Instrument Temperature Requirements

Instrument Interface	Operating		Functional testing	Non-operating	
	Min. (K)	Max.(K)	Max.(K)	Min. (K)	Max.
LOU	90	150	175	60	55**°C**
BOLA	60	150	TBD	TBD	60**°C**

Table 3: Temperature limits of units outside cryostat

For the HERSCHEL Telescope, the following requirements exist [AD 01]:

- Telescope: 70 K to 90 K
- Telescope decontamination during early orbit phase: 40°C for a duration of 3 weeks

Further instrument specific requirement and constraints:

<u>SPIRE:</u>

SPIRE requires 3 separate Level 0 straps and one Level 1 strap interfaces:

Level 0

- for the ^{3}He cooler evaporator
- for the ^{3}He cooler pump

Level 1

- For the FPU structure

- for the Spectrometer detector enclosure

The attachment points of the pump and evaporator cooling straps need to be separated on the He II tank structure. The sorption cooler is recycled every 2 days and dissipates 90 mW (tbc) for 2 out of every 48 hours.

Further SPIRE consists of two JFET boxes, mounted on the optical bench next to the FPU. The JFET amplifiers operate around 120 K and are thermally insulated inside the enclosure.

PACS:

PACS requires 4 separate Level 0 and three Level 1 strap interfaces, i.e.:

Level 0

- for the ^{3}He cooler evaporator
- for the ^{3}He cooler pump
- for the Red Detector of the FPU
- 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 5 K/hour above 30 K (tbc).

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 apply for HIFI:

- Level 0: 6 mK/100sec
- Level 1: 15 mK/100sec
- Level 2: 6 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:

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:

PACS BOLA

See chapter 5.9.

HIFI LOU:

See chapter 5.9. 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

Guideline	Short Description
	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

3.3.5.1.1 Instruments w.r.t. Telescope

The alignment errors of the instrument w.r.t telescope are provided in the Table 4 below. They represent achievable values, which are compared to the requirements of the previous issue of the IID-A and to proposed values, discussed during the HOWG Meeting (ref. 11/03/02 at ESTEC). The achievable values given below will serve as a guideline for the future update of the requirements.

Table 4: Alignment errors: Instrument w.r.t. Telescope

	PACS	SPIRE	HIFI	Remarks
Achievable Values X Direction	±5.8mm	±5.5mm	±7.8mm	
Requirement IID-A HOWG HIFI	 ±11.0mm ±7.1mm	 ±11.0mm ±7.7mm	 ±11.0mm ±7.7mm ±8.5mm	 1) 2)
Achievable Values Lateral	4.0mm	4.5mm	16.8mm	3)
Requirement IID-A HOWG HIFI	 8.0mm 6.8mm	 8.0mm 9.5mm	 8.0mm 9.5mm 24.0mm	3) 1) 2)

1) Values proposed by Astrium during the HOWG meeting, 11.03.02 (based on 1σ and rss summation). Must be updated to 2σ as stated during the HOWG meeting.

2) Proposed by HIFI

3) Half cone angle

3.3.5.1.2 LOU w.r.t. HIFI FPU

The LOU w.r.t. HIFI FPU alignment and stability requirements, as specified in AD-2, are summarised in Table 5.

Table 5: Numerical values of alignment and stability requirements

	Δx	Δy	Δz	Rx	Ry	Rz
Alignment Requirements	0.75mm	15mm	0.75mm	137 arcsec	1)	137 arcsec
Stability requirements 2)	0.075mm	0.003mm	0.075mm	10.8 arcsec	144 arcsec	10.8 arcsec

(all values ±):

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.

2) Within 100sec. The very high stability along the y axis should be regarded as a goal (according to HIFI IID-B, issue 2/0)

3.3.5.2 Optical Requirements

SPIRE FPU:

The FPU uses only a part of the nominal 276mm unvignetted field of view provided by the telescope. SPIRE needs a CVV aperture of 285.2mm diameter to avoid obstruction by the rim of the aperture. This number includes all tolerances for diffraction and alignment.

Two footprints of the SPIRE are shown in Figure 3 and Figure 4 respectively, demonstrating sufficient clearance for the telescope beam to reach the SPIRE entrance without obstruction.

CVV aperture plane at X=729 mm

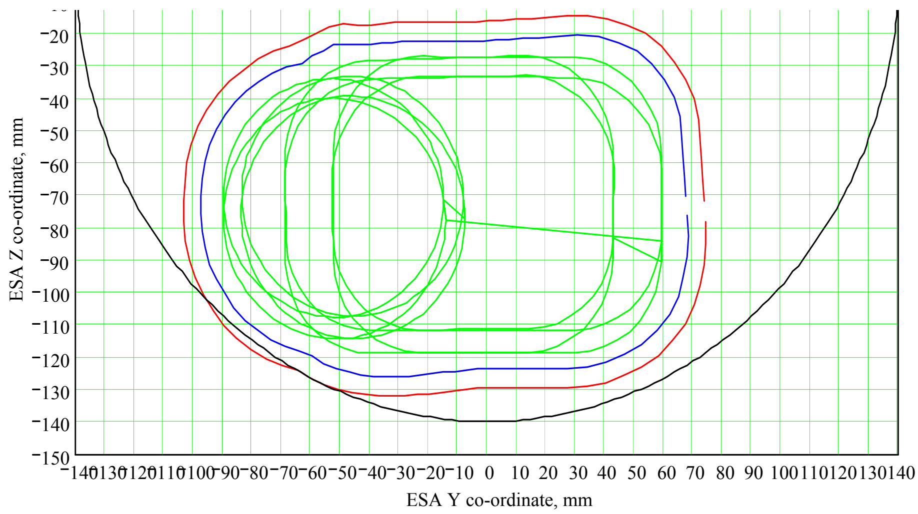


Figure 3: Footprint of the SPIRE beam at the CVV aperture plane.

The outer circular line marks a diameter of 280 mm. Due to the increase of the CVV aperture to 288 mm; there exists a clearance 2.8 mm.

Instrument shield plane at X=505.81 mm

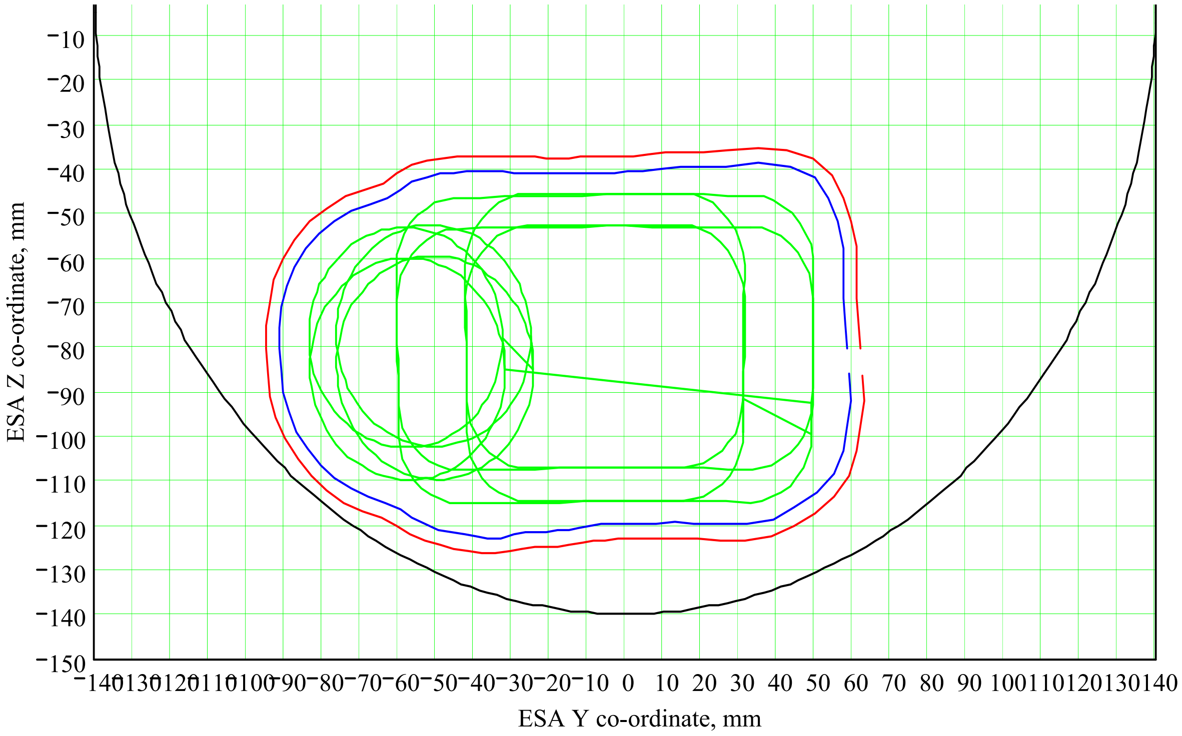


Figure 4: Footprint of SPIRE beam at the level of the instrument shield aperture.

The outer circular line marks the diameter of the shield. The figure shows sufficient clearance for the beam to pass without obstruction.

PACS FPU:

There are no further dedicated PACS optical requirements.

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).

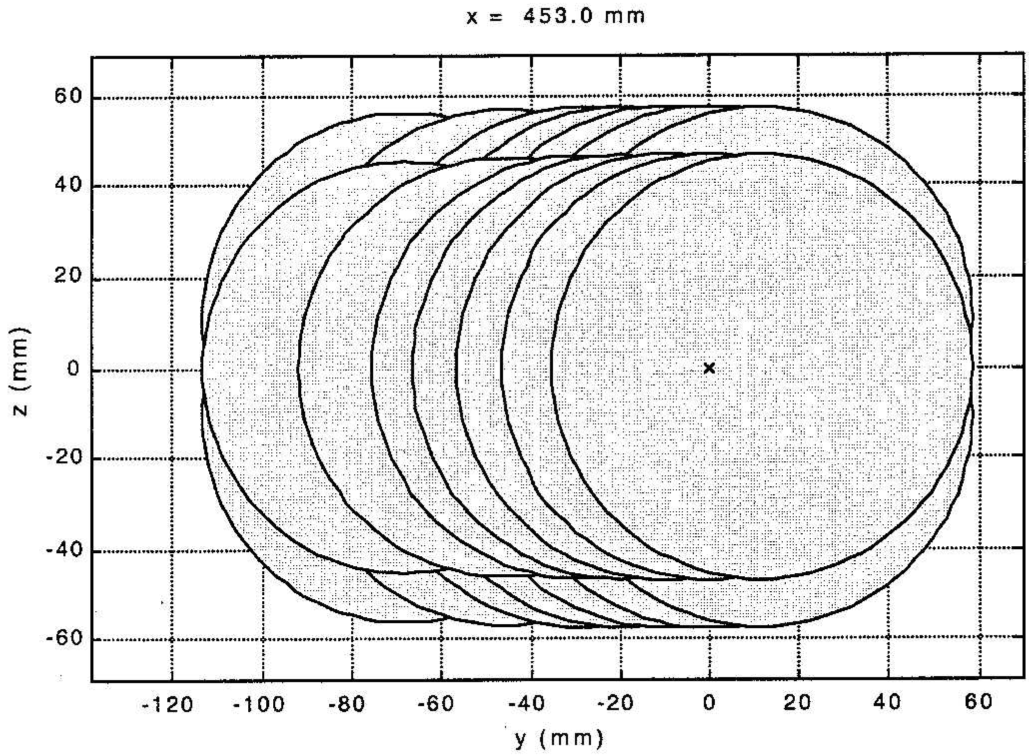


Figure 5: HIFI Beam Shape at the Height of the Cryostat Opening (AD-4)

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 is required for each of the window diameters. The inter-beam spacing is defined as 50 mm. 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.

LOS Stability

In the H-EPLM spec. update it is envisaged to implement requirements for the stability of the line of sight wrt. the PLM/SVM interface plane.

The following values are under discussion:

- 0.2 arcsec (± 0.05 arcsec goal)
- 0.1 arcsec in 1 minute (± 0.02 arcsec goal)

Around each axis taking into account worst case sun aspect angle variation, seasonal effects and temperature gradient at PLM/SVM interface. The PLM/SVM is assumed to be perfect.

3.3.6 Straylight

The requirements as defined in the IID-A, issue 2/0, 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,

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, will be 10 % (tbc) 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, ISO-GR-B1430.009. 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. Helium Control System, HP-2-ASED-TN-0013 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 ´ Final Summary Report ´, HP-2-ASED-RP-0016.

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 ´ Summary Report of performed ISO-NCR Review´s ´, HP-2-ASED-RP-0033, 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 6: 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 , PACS), the telescope, the cryostat and extensions like the Herschel Sunshield Sunshade (HSS). Figure 7 shows the components outside the cryostat, whereas Figure 8 shows the cryostat internal components.

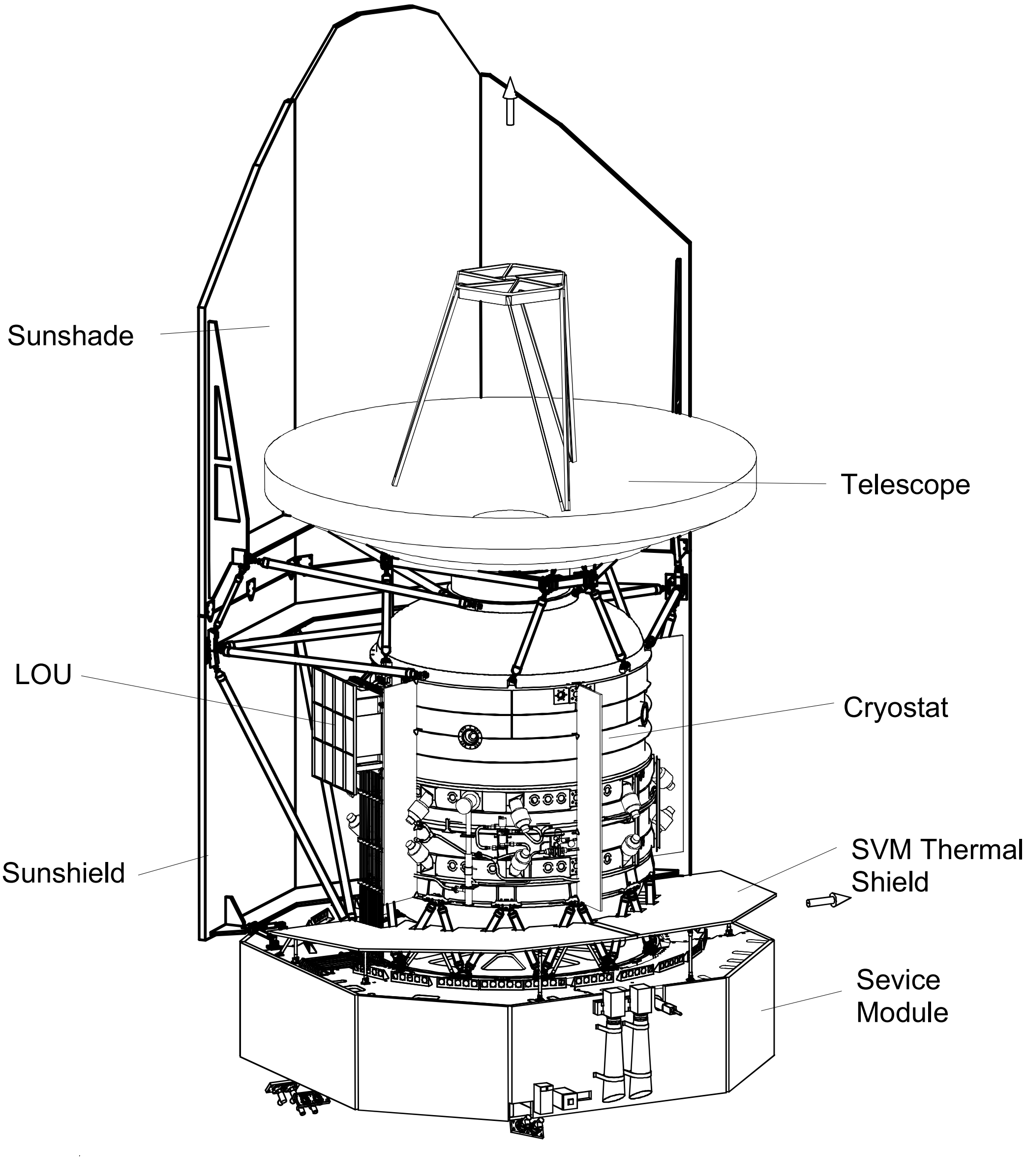


Figure 7: Herschel Spacecraft

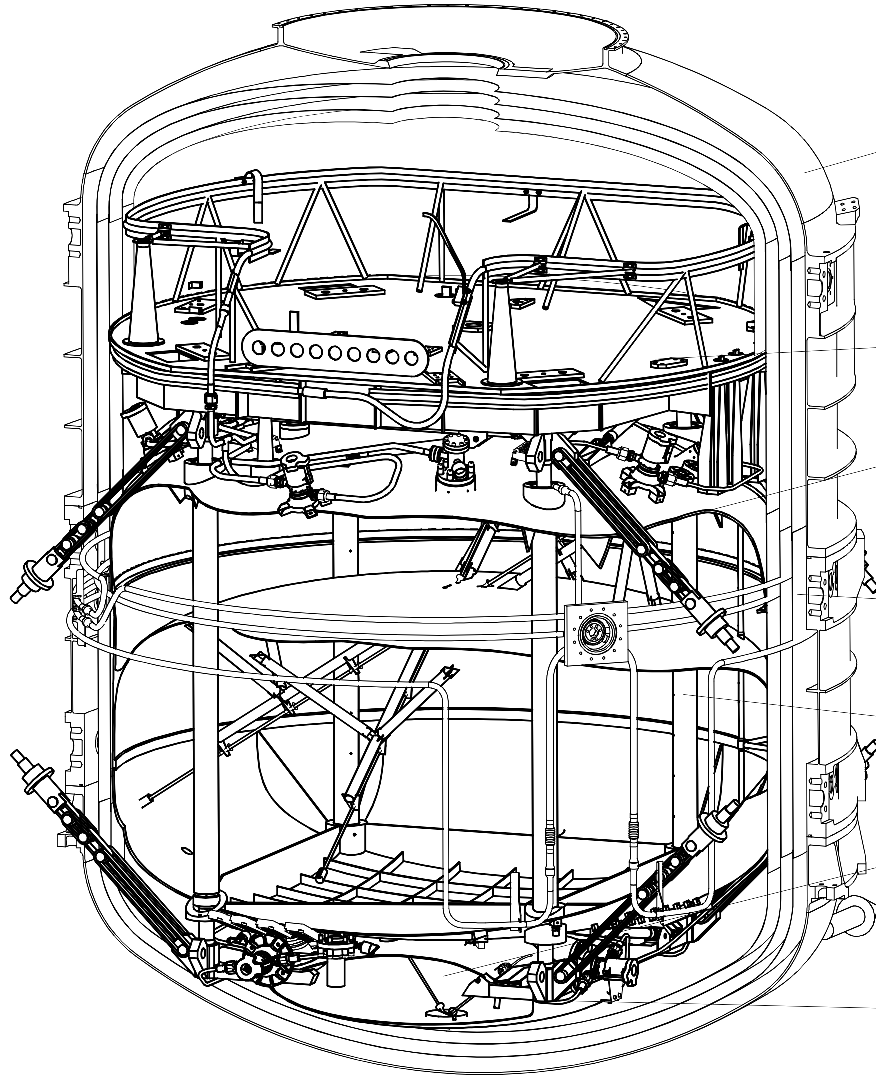


Figure 8: Cryostat cross section

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. the 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.

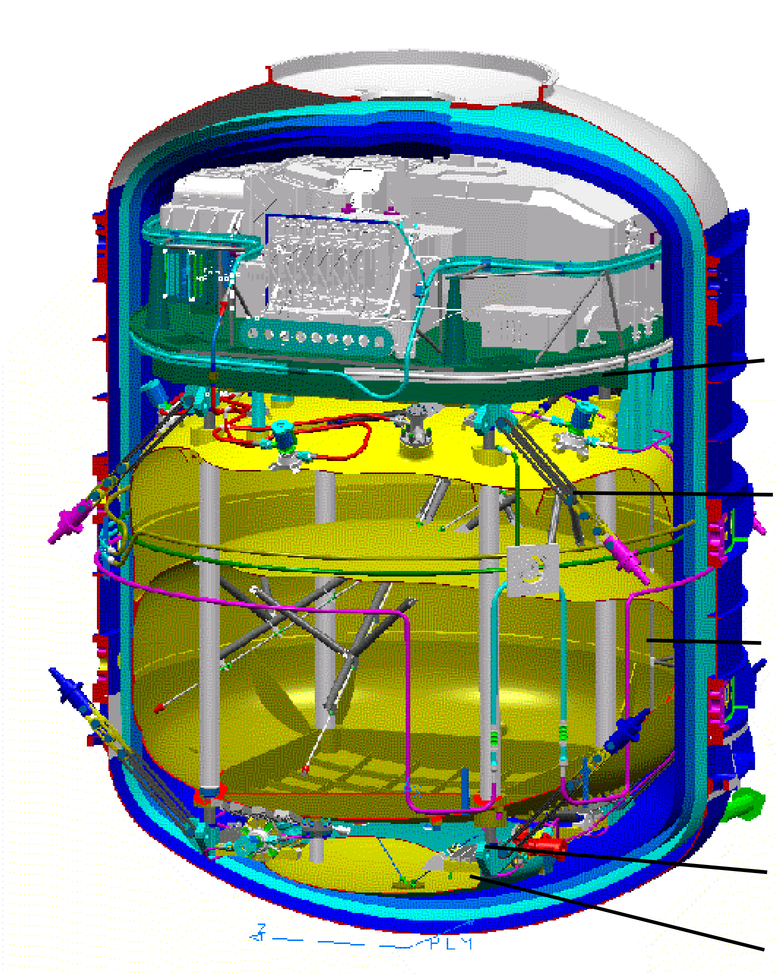


Figure 9: Cross section of the cryostat, indicating the names of the components

The HTT size is dimensioned by the 2.16 m^3 of volume needed to get the required 3.5 years life time. The shape is driven by the restriction in size (mainly height) and is derived from the overall available envelop of the PLM. The HTT provides also interfaces for components (e.g. valves) of the cryogenic system. The pressures resulting from the design of the safety aspects of cryogenic system mainly drive wall thickness and mass.

The instruments are mounted on the Optical Bench (OB). The size and hole pattern of the OB is driven by the geometry of instruments and their mechanical interfaces. To avoid too high mechanical loads on the instruments the OB needs a high bending stiffness (70 Hz) and has consequently a height of 120 mm.

The cooling links to the instruments are realised by three paths. The path for the lowest temperature is a direct thermo-mechanical link between the HTT and the instruments (Level 0). The second path is a link of the instruments to the vent line (Level 1) and third path connection of the instrument to the Optical Bench, which is again cooled by the ventline (Level 2). To minimise radiated heat and stray light impact a thermal shield covers the OBA.

The Helium One Tank (HOT) is used for the autonomy phase prior to launch. The tank is needed to avoid that the HTT gets too warm in the period of time between the last production of He II and the launch. This additional cooling on ground is needed to cool the thermal shields to reduce the thermal radiation of the HTT Tank.

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 bone 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 innermost loop 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 two inner shields are 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 BOLA, 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 seeing 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 Cover closes this path. For all ground operations the cover must be leak tight to maintain the vacuum in the CVV. For ground testing the cover shield is cooled with liquid Helium /Neon /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 40^{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 RF link to the LOU, which is mounted on the - y side of the CVV. To satisfy the HIFI's needs the CVV must have windows of diameter 34 mm (TBC). 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 warm unit in the Herschel Service Module.

To protect the CVV and the telescope from sunlight the Herschel Sunshield/Sunshade (HSS) is used. It shall shadow both parts 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. Triple junction Ga AS solar cells 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. This shall consequently minimise the telescope temperature. The HSS is mounted by glass fibre struts on the CVV and partly mounted by carbon fibre struts on the SVM. The backside of the HSS is covered with a foil, which guarantee light tightness and 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 MLI. 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 below are showing the essential system dimension.

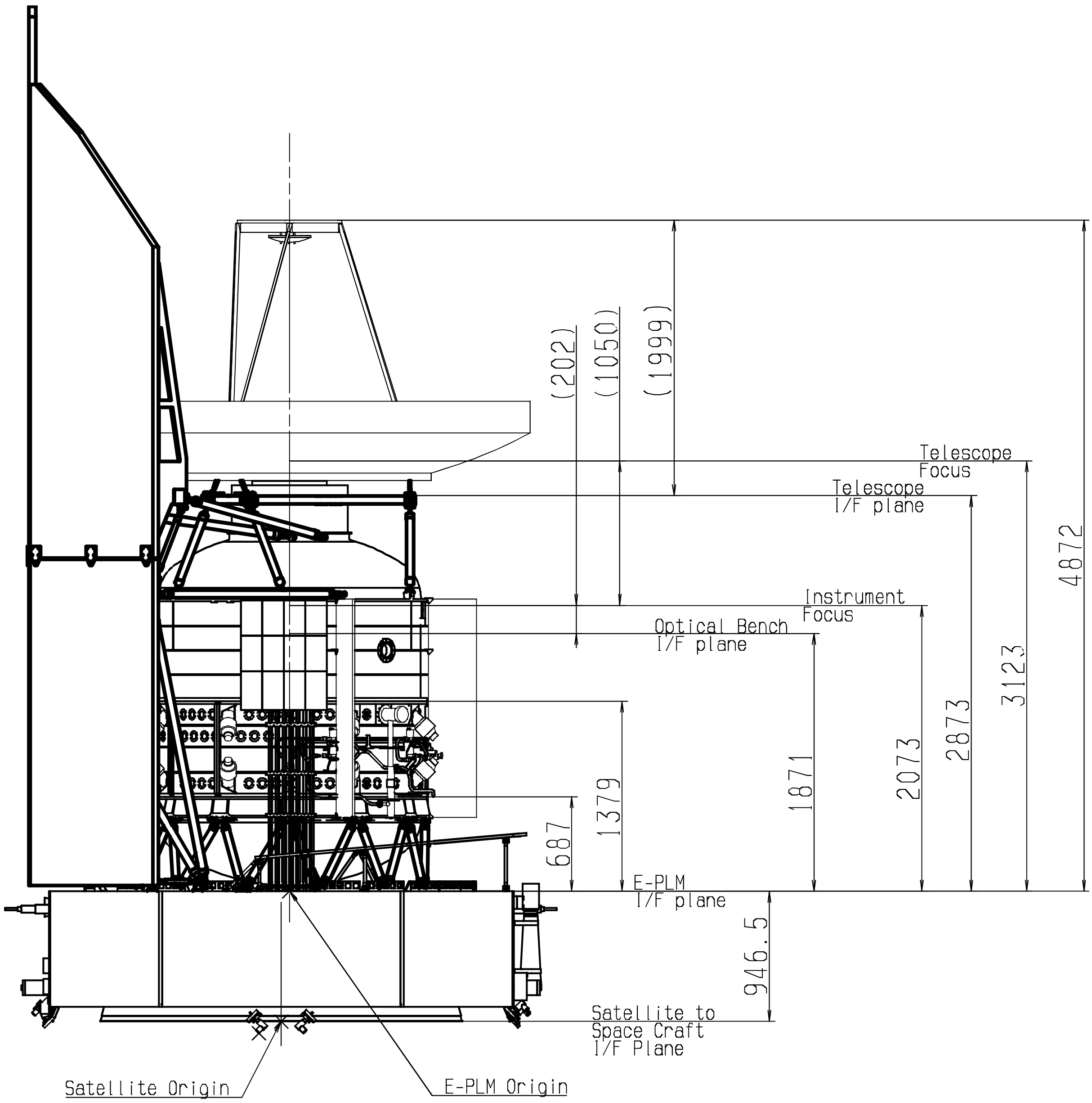


Figure 10: Herschel S/C view from -y

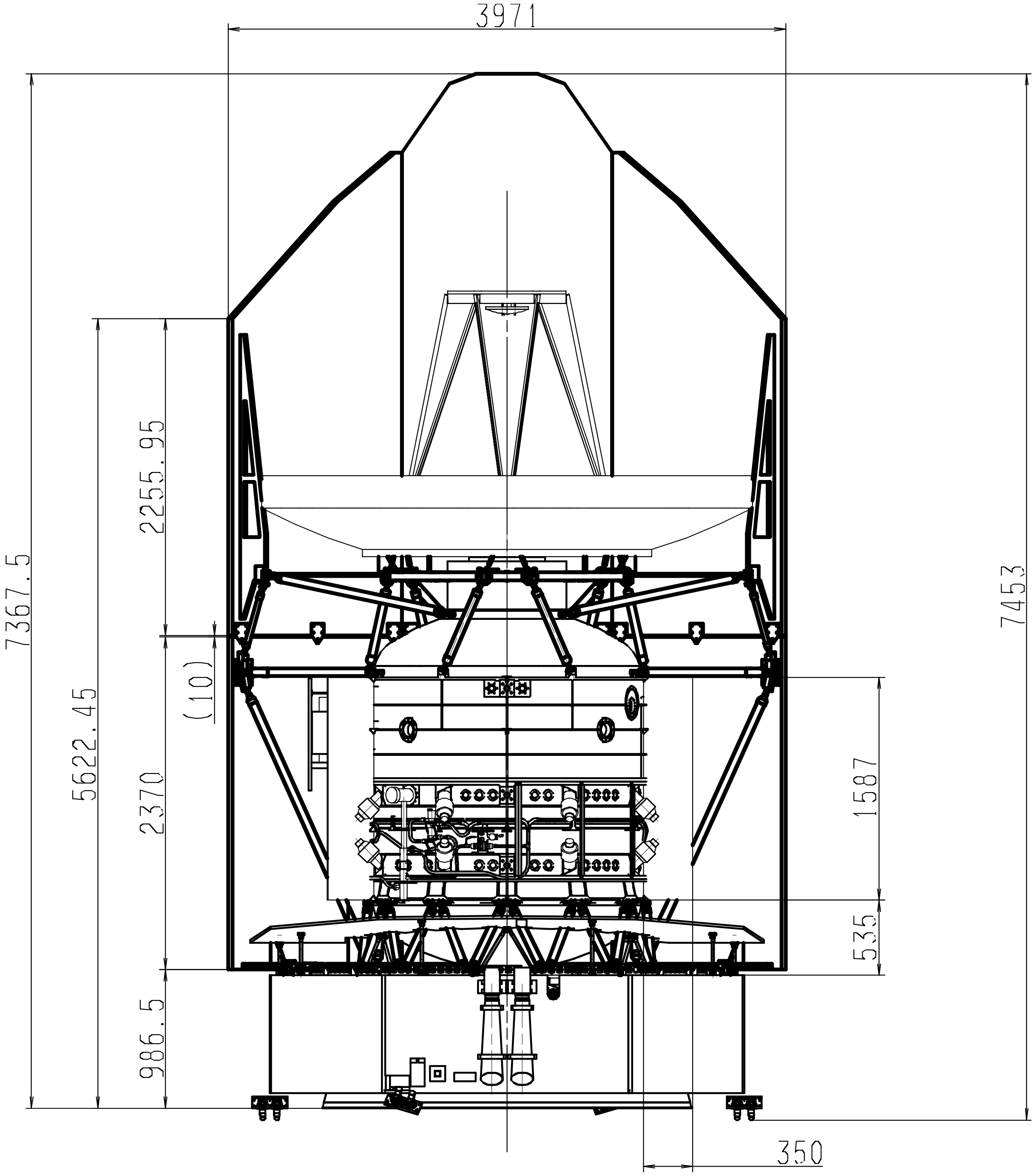


Figure 11: Herschel S/V view from -z

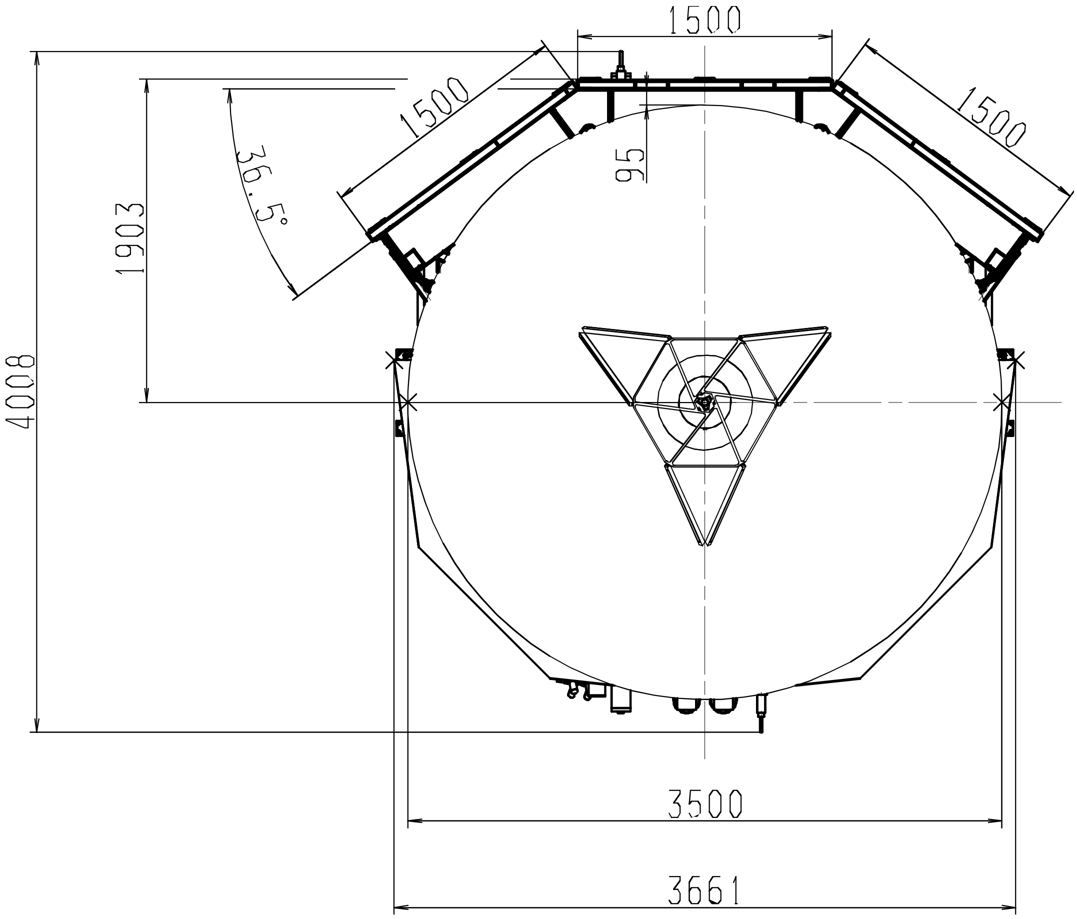


Figure 12: Herschel S/C, view from +x

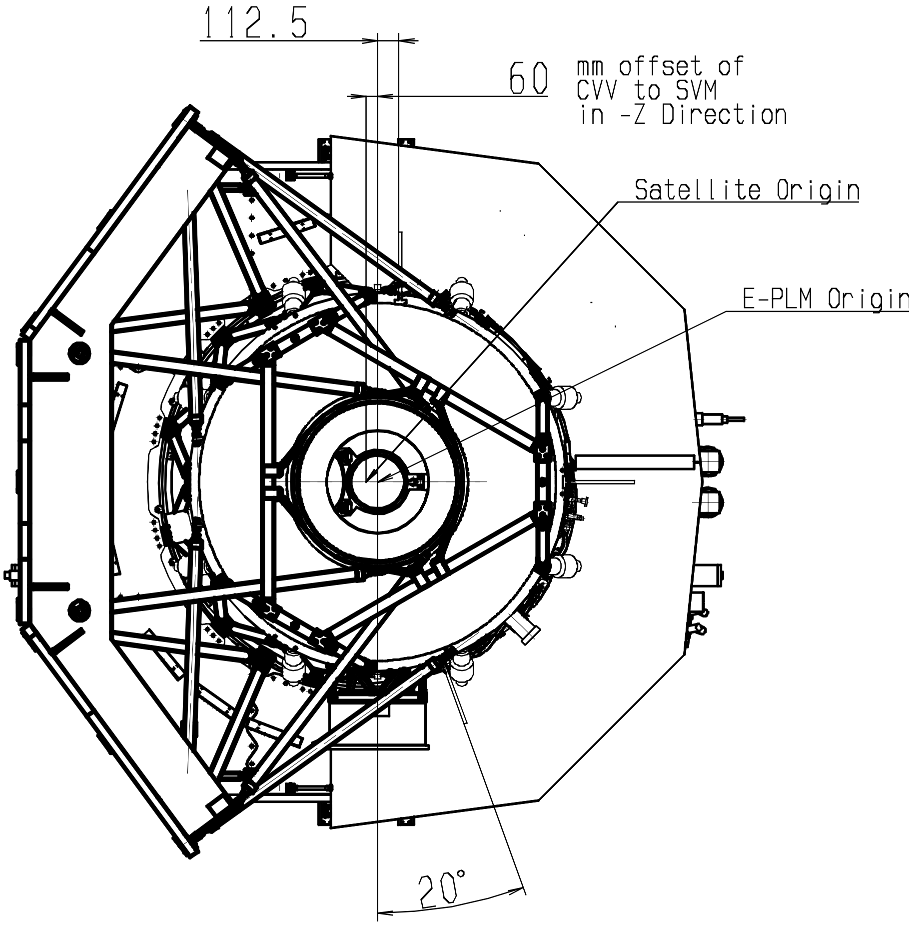


Figure 13: PLM View from –x w/o telescope

5.2 Envelope and Internal Clearance to Fairing

The Figure 14 shows that H-EPLM has sufficient clearance and respects the envelope of the ARIANE 5 fairing, as defined in AD-7.

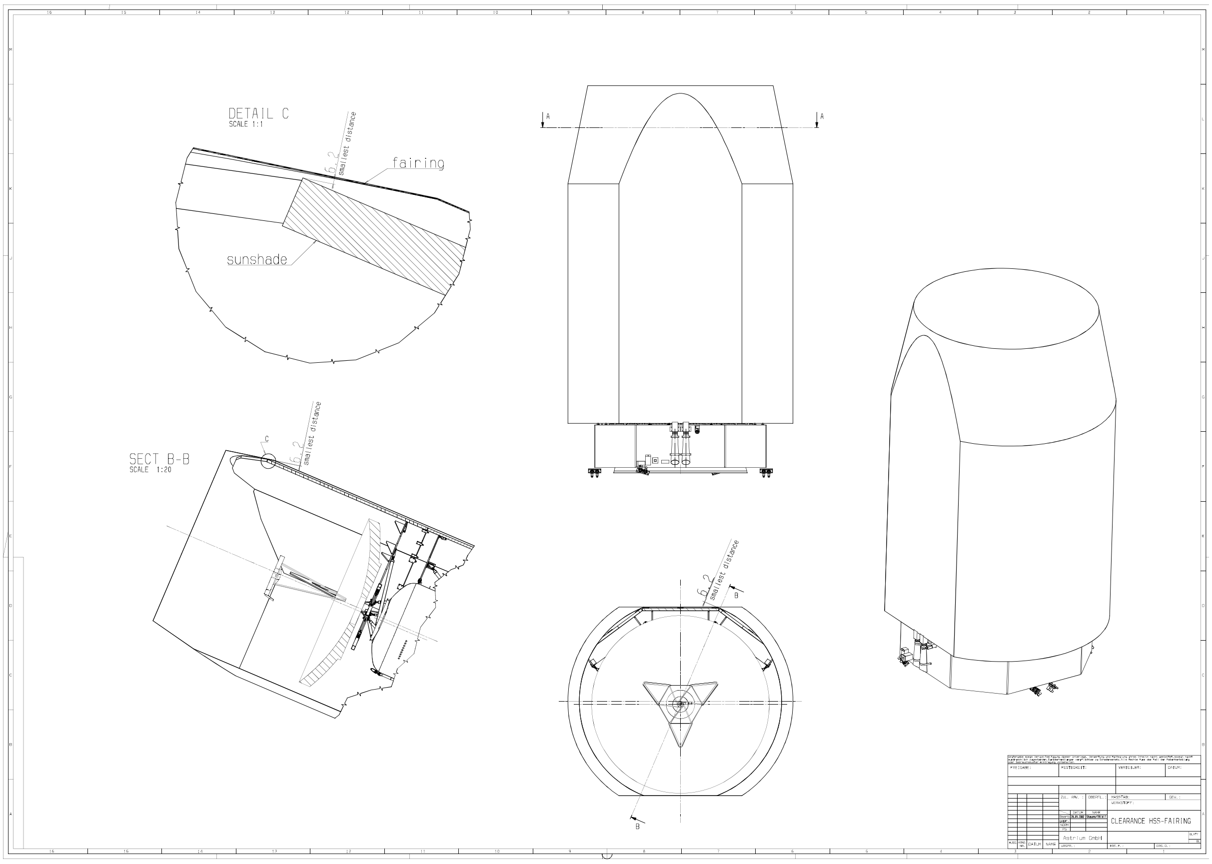


Figure 14: Clearance of the EPLM wrt. envelope defined in [AD7].

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)
PACS BOLA	Outer CVV, - Y + Z side
SPIRE FPU, incl. JFET boxes	Optical Bench Plate (OBP)

The optical bench 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 Plate

The Optical Bench Plate (OBP) is a ribbed plate structure, to which the focal plane units of HIFI, PACS and SPIRE will be mounted. The OBP itself is mounted above the Helium tank, and is adjustable in three directions via the tank support straps. The adjustment range is 1.5 mm in ech direction.

Figure 15 shows the overall dimensions of the OBP. The oblique view of Figure 16 shows the ribbed structure on the lower side and the FPU mounting points on the upper side of the plate.

The FPUs are mounted by conventional bolts as defined in AD-2 to AD-4.

The numbers of fixation points are:

HIFI: 4

PACS: 3

SPIRE FPU: 3, Photometer JFET: 5, Spectrometer JFET: 4

Mounting accuracy and position stability is assured by dowel pins in the instrument feet (TBC), 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. the 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.

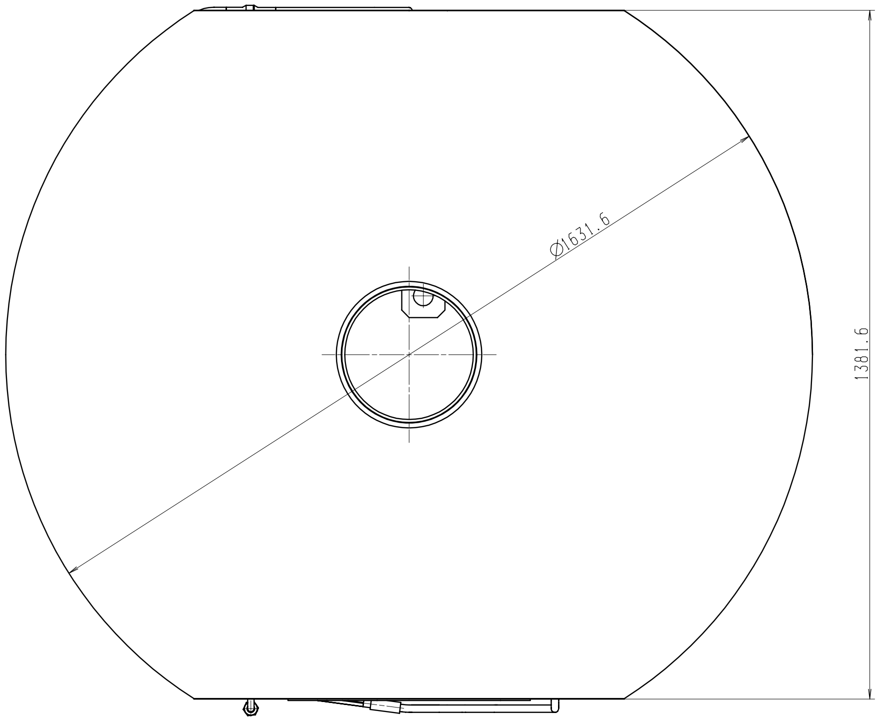


Figure 15: Dimensions of the Herschel Optical Bench (top view)

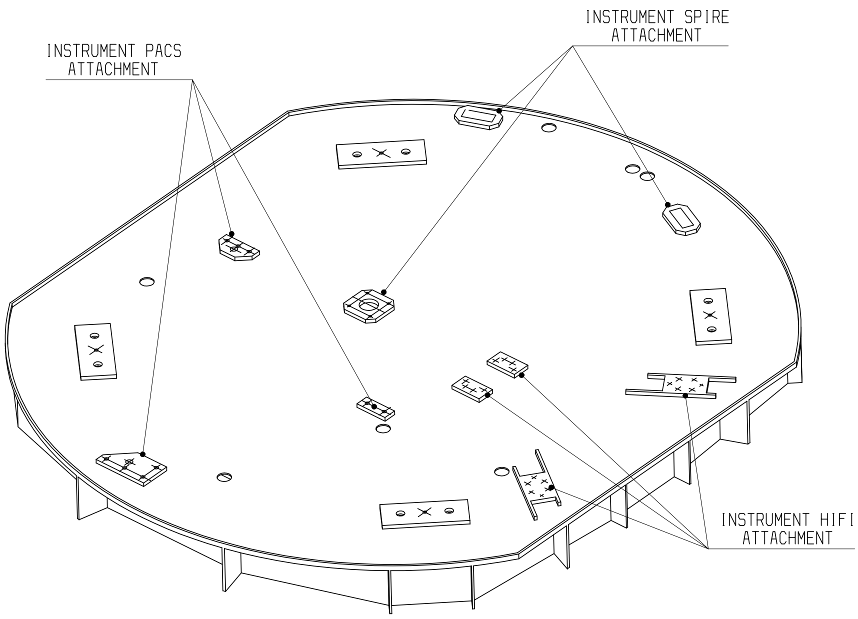


Figure 16: Herschel Optical Bench: Structural layout and instrument mechanical interfaces

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

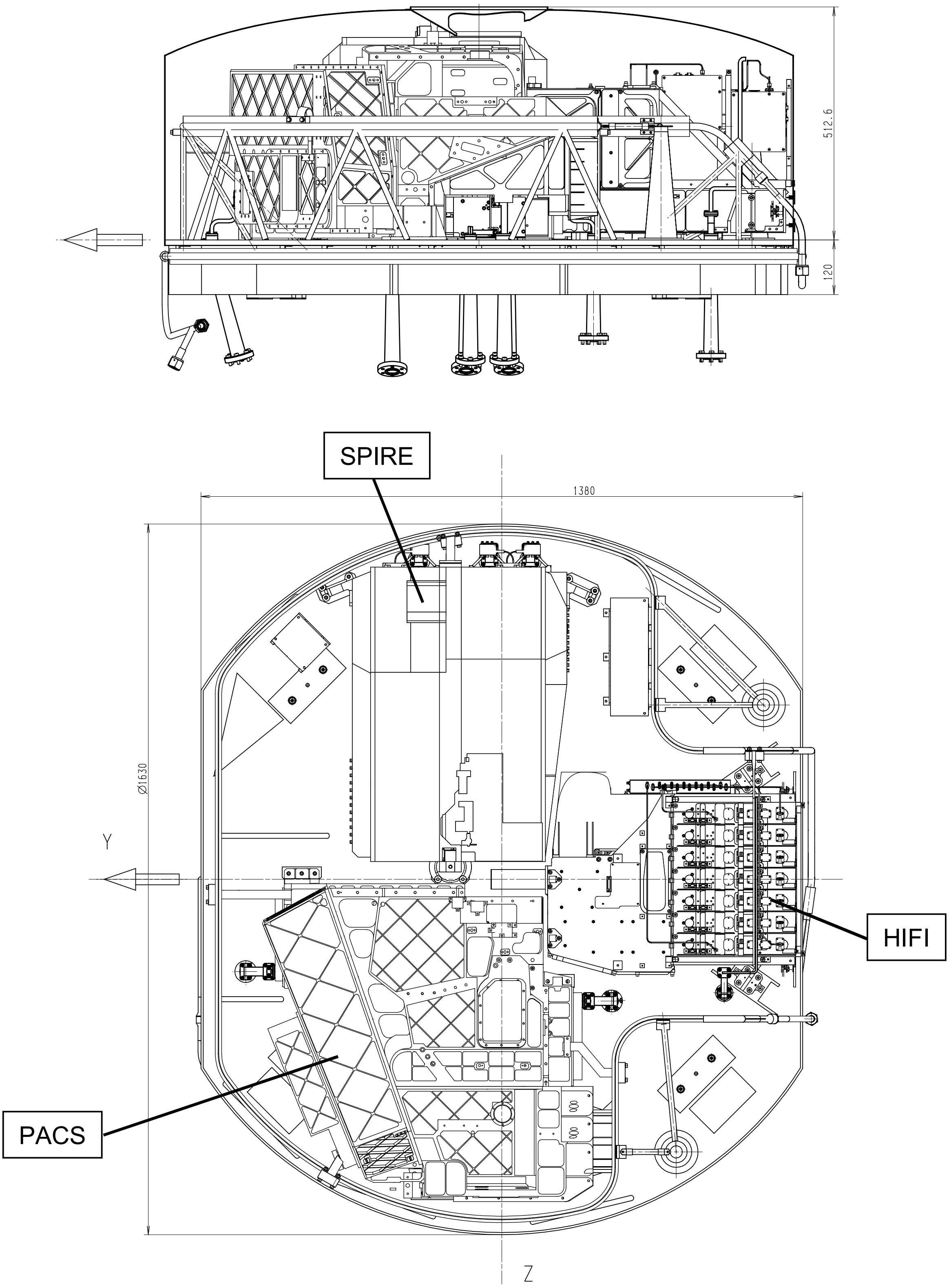


Figure 17: Herschel Optical Bench equipped with instruments, View from +Z Side and Top View

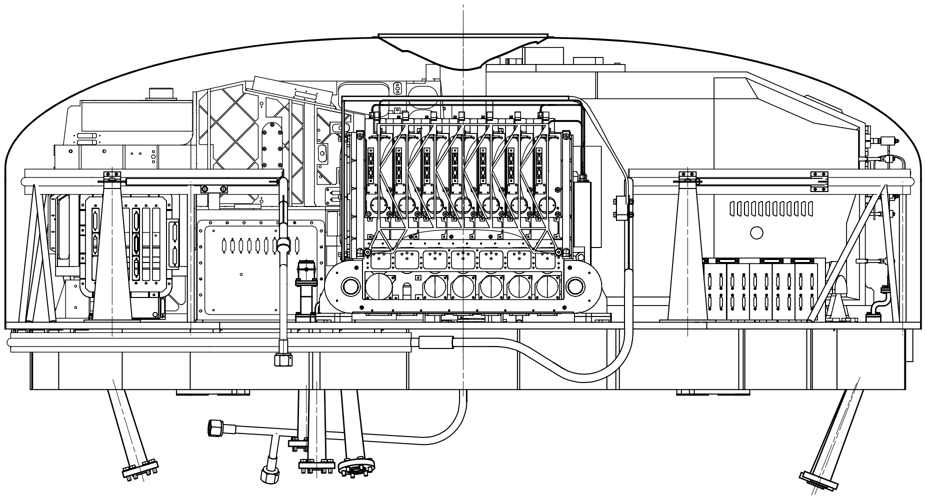


Figure 18: Herschel Optical Bench including instrument shield equipped with instruments, View from –Y Side

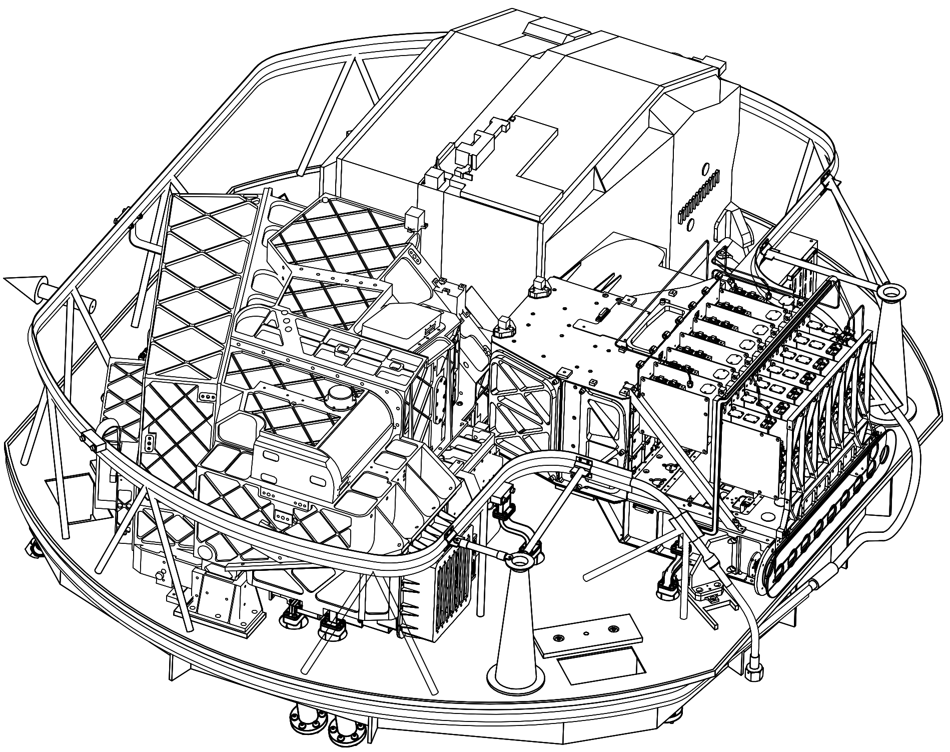


Figure 19: Herschel Optical Bench equipped with instruments (PACS front left, HIFI front right, SPIRE in the back).

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

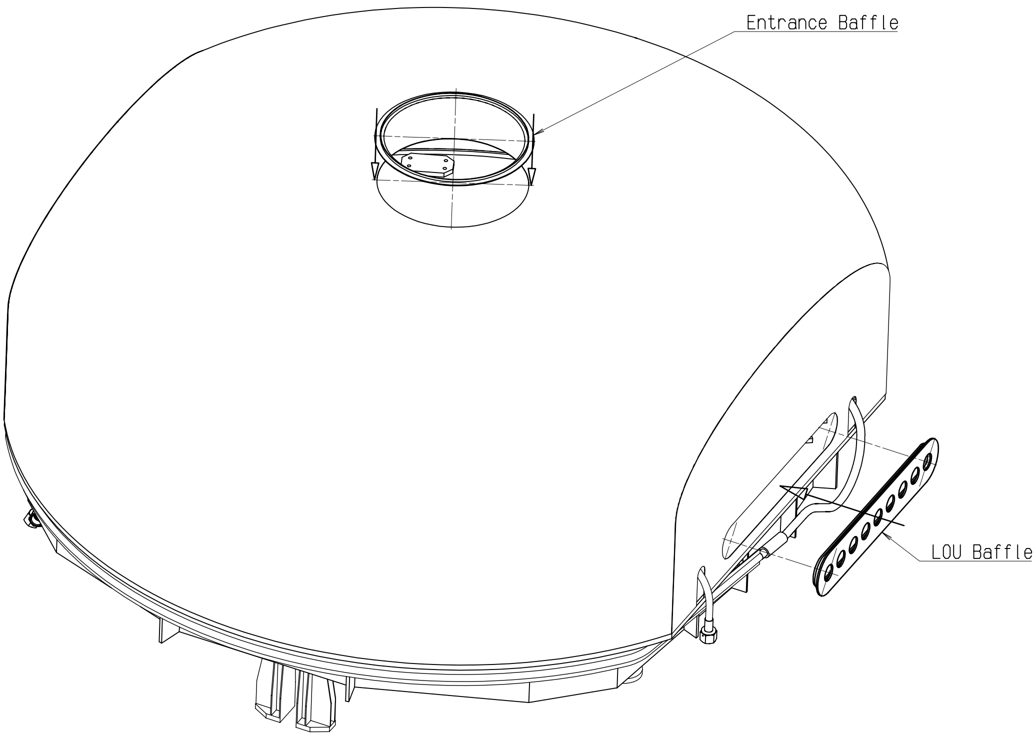


Figure 20: As Figure above, oblique view, LOU baffle shown detached

5.3.2 Units mounted outside the cryostat

Two units of the instruments are mounted on the outer side of the CVV:

- BOLA of PACS
- LOU of HIFI

BOLA

The BOLA is bolted onto a simple bracket on the outer side of the CVV and wrapped in MLI. The BOLA interface is shown in Figure 21.

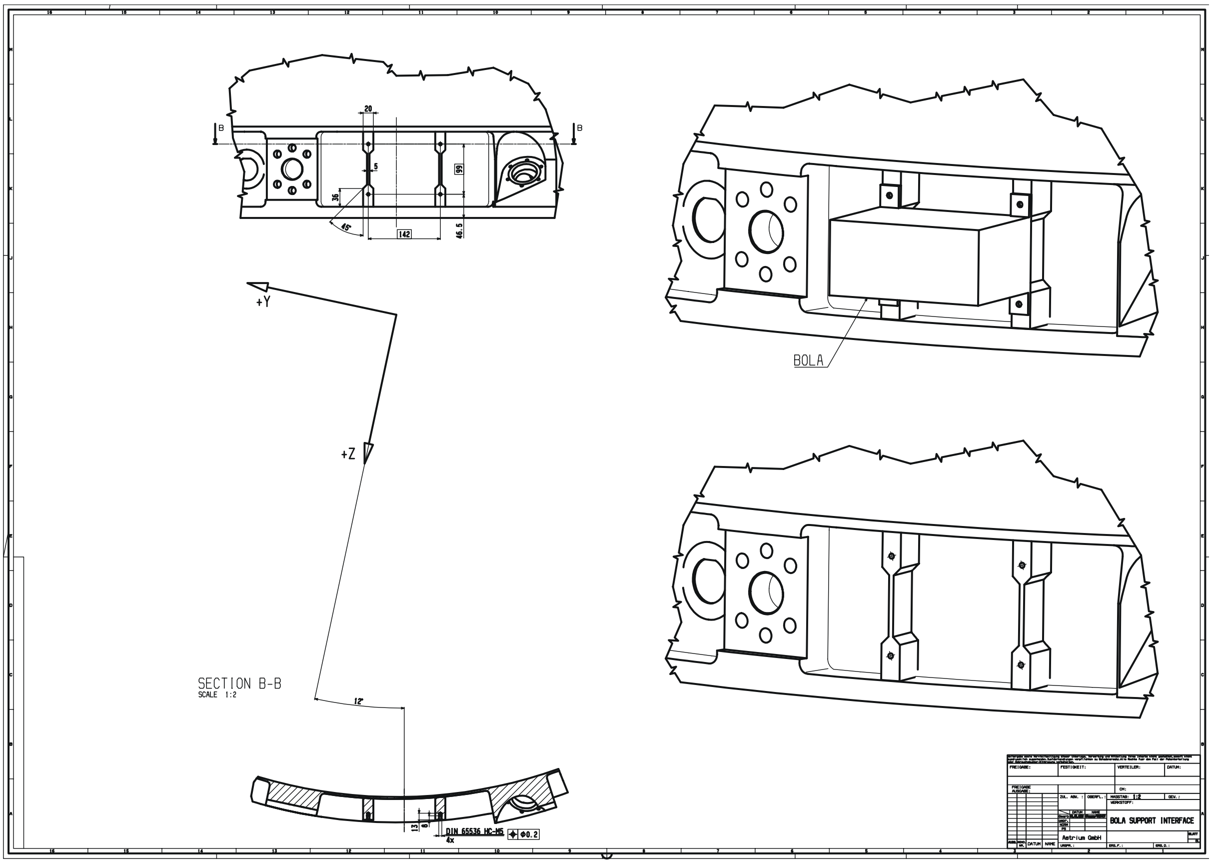


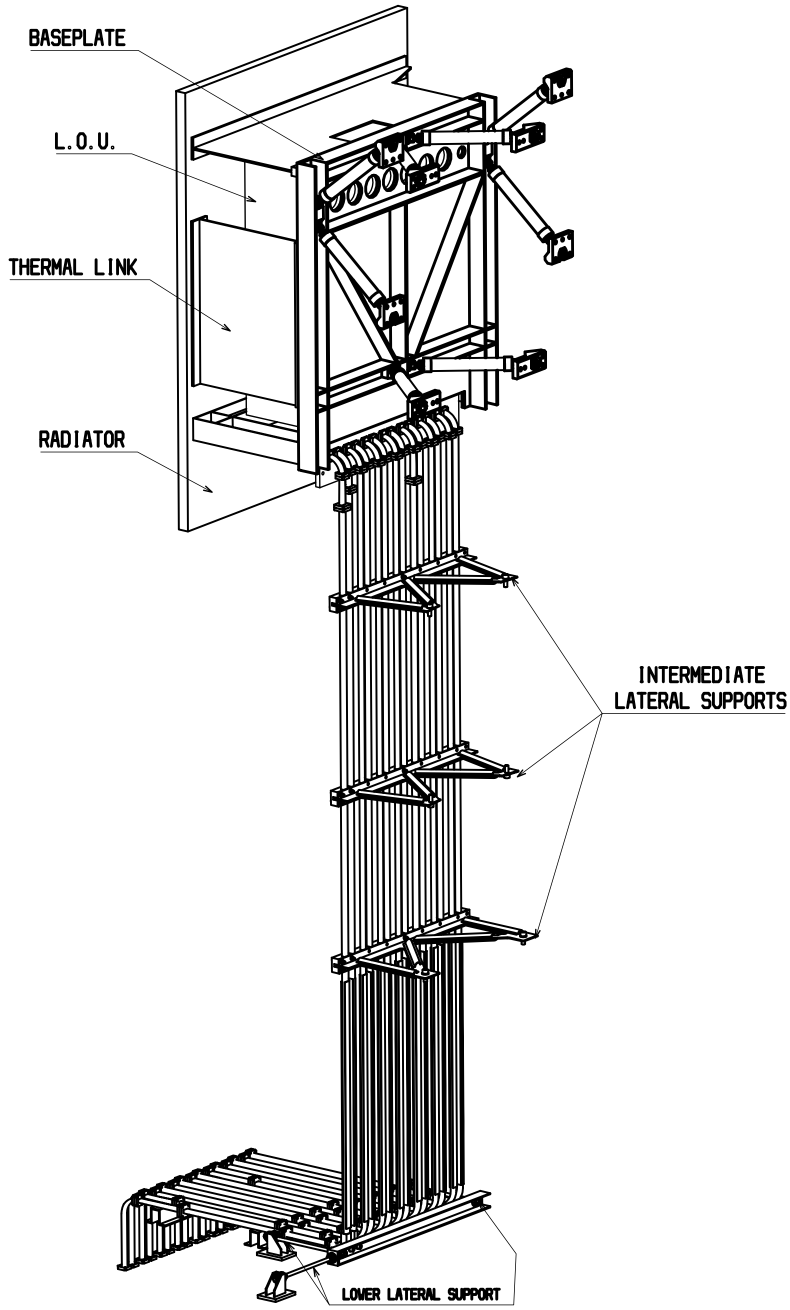
Figure 21: PACS BOLA Interface

HIFI LOU

The LOU mounting structure 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

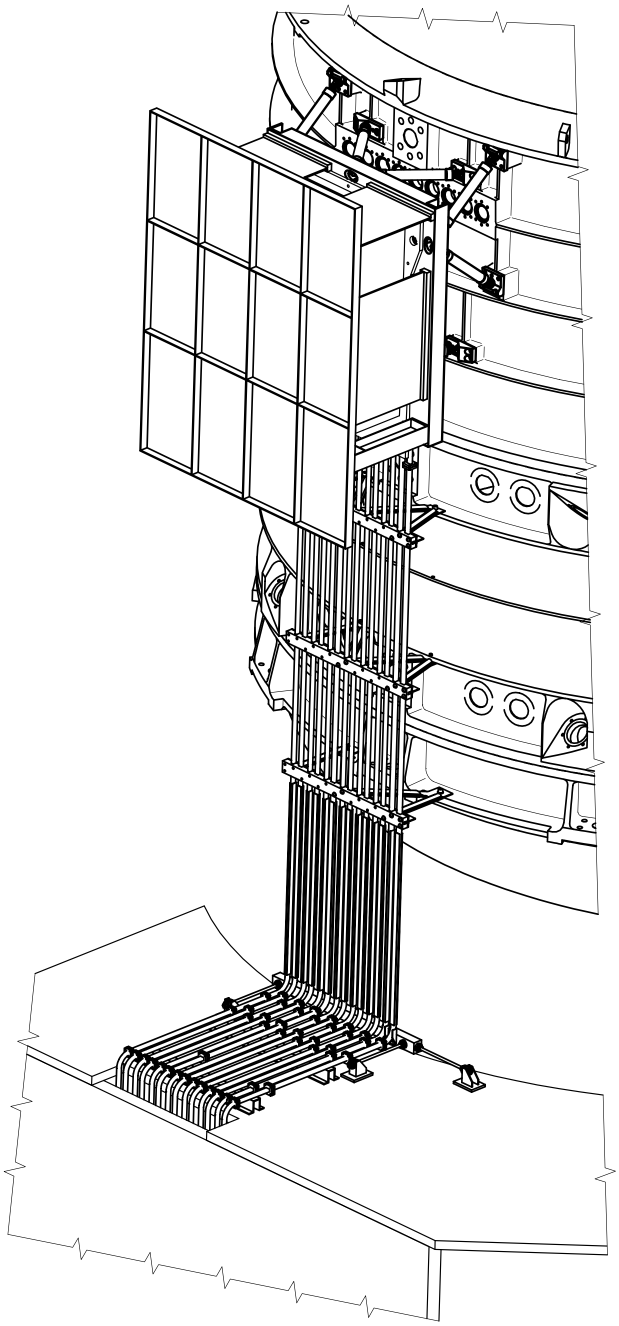
The design of the LOU mounting structure and a typical routing of the LOU waveguides to the SVM is shown in the following figures.



Note: The interface of the waveguides to the LSU has to be updated.

Figure 22: LOU and Waveguides, seen from the CVV side (+Y/-Z direction)

Note: The waveguide routing is not yet finally decided. The figure, therefore, only shows a typical routing.



Note: The interface of the waveguides to the LSU has to be updated.

Figure 23: LOU and Waveguides, seen from –Y/-Z direction

Note: The waveguide routing is not yet finally decided. The figure, therefore, only shows a typical routing.

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 –Z corner a bracket for the telescope heater and sensor lines. Figure 25 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 TMS allows radial shrinkage of the CVV interface and limits the distortion effects to the telescope.

Figure 25 shows the telescope dimensions and the telescope interface struts to be mounted to the upper side of the interface frame.

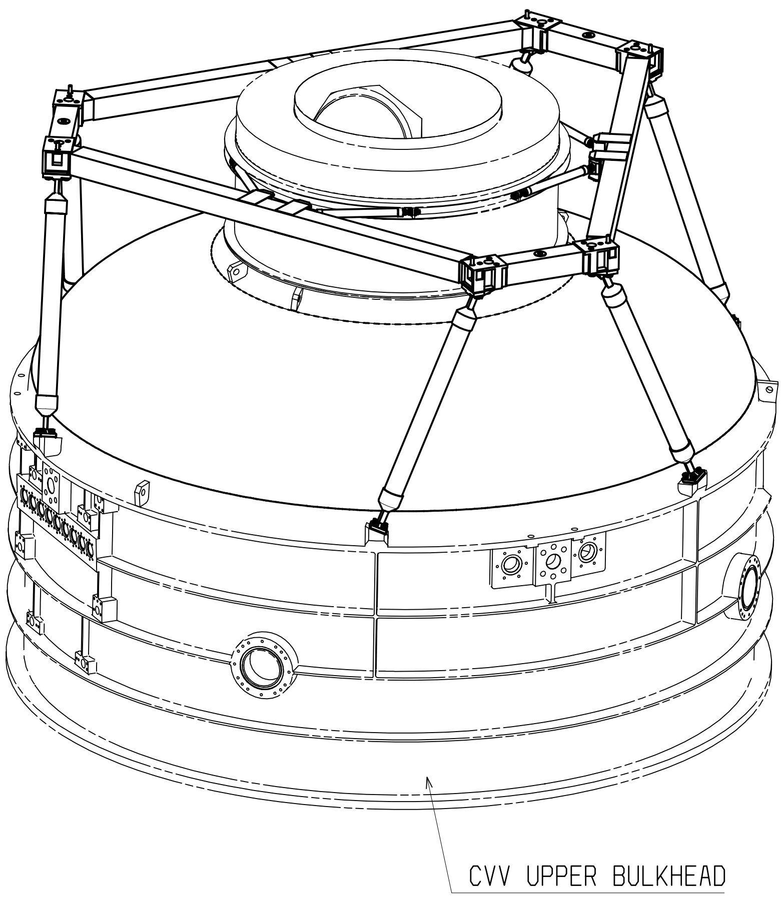


Figure 24: Herschel Telescope CVV fixation structure mounted onto CVV.

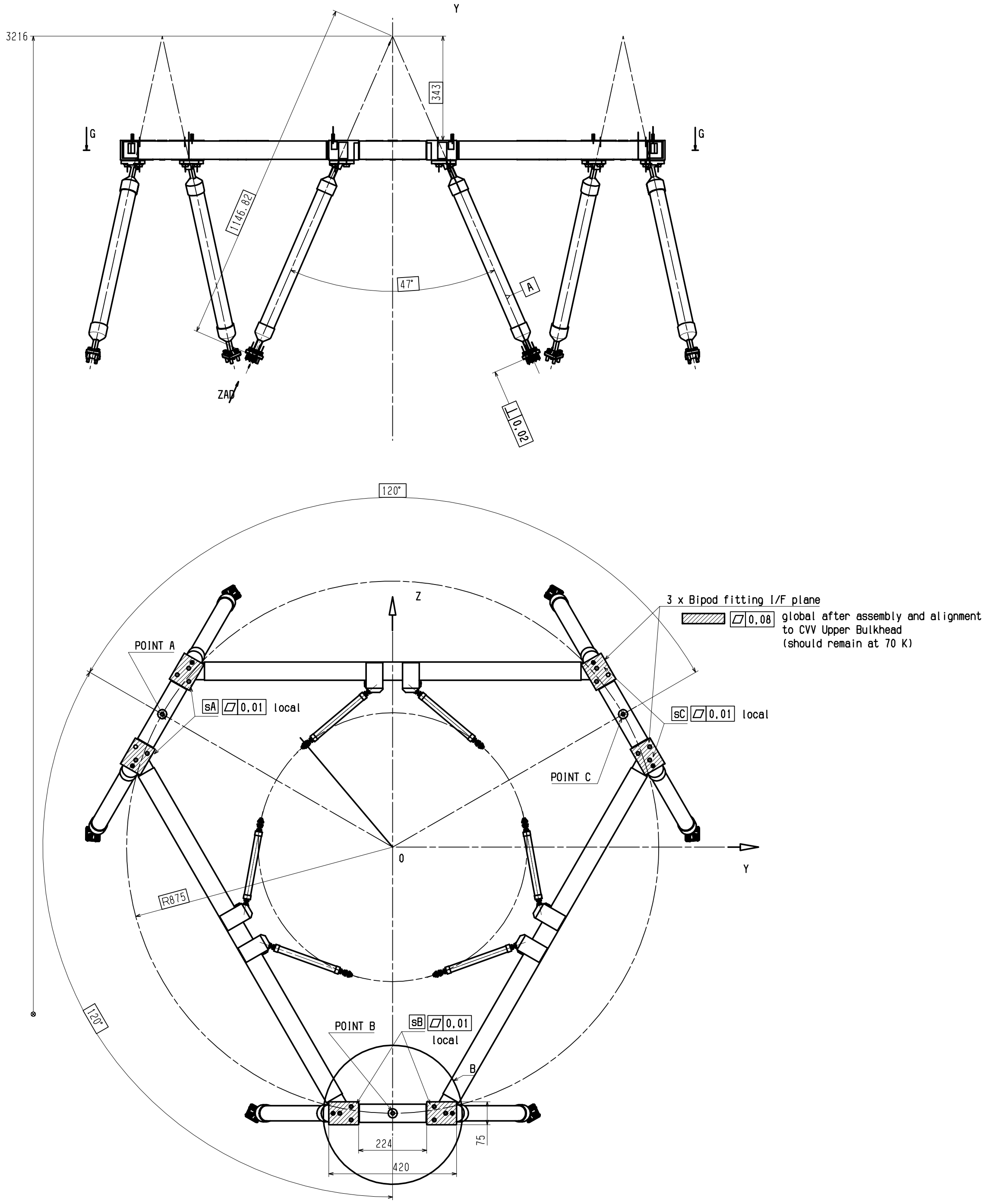


Figure 25: Herschel Telescope Structure layout

5.5 Description of the Helium Control System

Main purpose of the Helium Control System is to cool down the scientific payload and keep it at a specific temperature level. A low temperature level is essential for the proper functioning of the instruments. As the temperature required by the instruments is about 1.7K, cooling has to be performed by cryogenic means. Superfluid and normal boiling Helium are used for cooling. The physical principle behind the approach is to use the low temperature of superfluid Helium and the evaporation heat of liquid Helium for cooling. Therefore the instruments are thermally well connected to the cold tanks by straps (conduction). Dissipating energy from the instruments is led to the Helium tanks. This heats up the liquid Helium in the tanks and causes an increase of evaporation of liquid Helium. The incoming thermal energy from the instruments is consequently converted in evaporation heat to transform liquid into gaseous Helium. The gaseous Helium is vented by a tubing system and released to the environment. The ventline system itself is also thermally connected to parts of the instrumentation, optical bench and shields to enable further cooling.

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

- 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)

The Herschel Helium Control System, shown in Figure 26, is derived from the ISO Helium Control System. Differences result from different mission requirements and in consideration of /ISO Lessons learned, ISO-GR-B1430.009/. Various concepts of the He Control System have been analysed. Details of the assessment are given in /Helium Control System Design, HP-2-ASED-TN-0013/. For cost reduction the ISO CVSE will be used for Herschel after refurbishment. The CVSE is described in detail in /H-EPLM CVSE Specification, HP-ASED-SP-0012/.

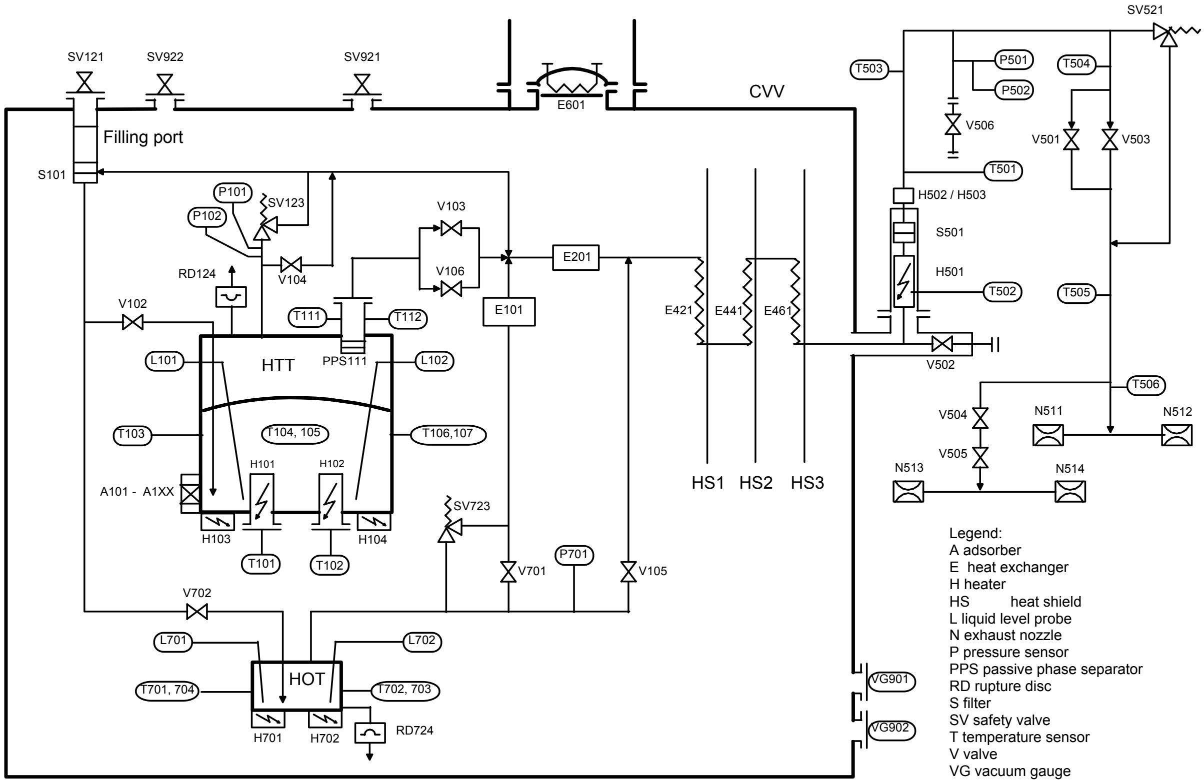


Figure 26: Helium subsystem flow diagram

Main part of the Helium System is the HTT, which contains 2160 litre 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 the HOT with a volume of 80 litre is mounted at the bottom side of the cryostat. To fulfill 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 Optical Bench Plate, FPUs and Heat 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 pairs of nozzles (N511/N512 and N513/N514). The nozzles with the large diameter (N513/N514) will be used during LEOP, the nozzles with the smaller diameter (N511/N512) will be used for nominal inflight operations. 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). Both tanks are equipped with temperature sensors (T103/T104/…). The pressure in the tanks and tubing system can be measured both during ground operations and flight by different pressure transducers (P101/P102/P701/P501/P502).

The tanks are located in the Cryostat Vacuum Vessel (CVV) which provides the necessary vacuum for ground operations and the mechanical support for the handling and suspension of the components. To reduce the thermal radiation from the CVV to the HTT the Cryostat is equipped with three heat shields, which are covered with MLI.

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 /H-PLM Helium System Description, HP-ASED-RP-0034/.

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. Earthorbit, 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, 2160 litre
Launcher	Ariane 4	Ariane 5
Mass Flow Rates	4.3mg/s	2.1 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 Component 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: /Qualification Program for EPLM Cryo Components, HP-2-ASED-PL-0024/) 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.

The safety concept is derived from the ISO safety concept. Nevertheless a presentation of a safety philosophy (assessment of failure cases etc.) shall be performed.

5.6 Cryo Instrumentation

Please refer to Description of PLM FM Cryo Control Instrumentation, HP-2-ASED-TN-0048.

5.7 Herschel PLM Operations

5.7.1 Mission Phases

The PLM operations activities of the pre-launch/launch phases are covered in the AIV sections and documents. For instance, specific cryo-system operations activities (e.g. start of phase separator) are not included. Following the separation from the launcher and when control of the spacecraft is taken over by ground, the IOP operations starts with initial Sun acquisition and transition from battery to solar power.

The transfer of Herschel to the L2-Lissajous orbit will take 6 months, during this period all commissioning and performance verification will be performed. The commissioning phase will end with the opening of the cryo-cover. The following table summarises the Herschel PLM activities during the mission phases until routine operations.

Table 7: Herschel PLM and PLM relevant activities during the post launch Mission Phases

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

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

Table 8: Sequence of CCU Events during LEOP

	After Launch				
Event	**Days**	**Hours**	**Operation Description**	**Initiation**	**Remarks**
1. Open Valves V 501 and V 503	L0+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 AR 5 fairing jettison.
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	Tbd days		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 NCA´s (Non Contaminating Actuators).

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.

Any electrical input into the cryostat ends up in heat dissipation which, in turn, has to be compensated by additional liquid He evaporation. Since the mission lifetime is one of the most important system parameters, it is of utmost importance for the design and operations of the CCU, to avoid any unnecessary and inadvertent activation of heaters or any other heat dissipating circuits in the cryostat control system.

According to the Satellite Data Bus Protocol Specification, the CDMU handles the data exchange with the CCU on the Mil-Std 1553 B bus via a dedicated Low Level Protocol, developed by the Herschel-Planck Prime Contractor.

By using the CDMU generated Low Level CMDs the CCU will be operated and the power ON/OFF switching will be performed via the PCDU. In the same way the CCU telemetry, formatted into monitoring tables, will be transferred to the CDMU, where the data will be formatted into source packets for transmission to ground. One full sub-frame per second will be allocated for the data exchange on the Mil Std 1553 B bus with both CCU s for both monitoring and command. 4 Mil-bus messages per second (2 for CCU A, 2 for CCU B) will be allocated for commanding (TBC). 16 Mil-bus messages per second (8 for CCU A, 8 for CCU B) will be allocated for telemetry (TBC).

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. Selected by the command parameter the monitoring will be performed as table acquisition (sequential readout of all enabled 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. In order to keep heat dissipation inside the CVV to the absolute minimum the temperature sensors will only be powered (supply of constant exciting current) for less than 50 ms during the measurement acquisition for each sensor.

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. The pressure sensors will only be powered for less than 50 ms during the measurement acquisition for each sensor.

He valve status: 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. The valve position sensors will only be powered for less than 50 ms during the measurement acquisition for each sensor.

Direct liquid content measurement (DLCM)

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. For that purpose the injected current and voltage drop over a heater within the helium bath will be precisely measured every 125 ms for a predefined measurement period of up to 600 seconds (TBC). 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. For the operation in the DLCM these four sensors will be operated in a high precision mode in the temperature range of 1.6 K to 1.8 K with an accuracy of less than ± 0.25mK.

H-PLM Commanding

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

For the activation of the He valves the CCU will receive, decode, process, and execute the related arming and switching commands received via the Mil Std 1553 B bus. The valves switching will only be executed when the related arming and switching command are received in the correct sequence.

The valves switching will be initiated by the following two commands to be sent to the CCU via the Mil Std 1553 B bus:

- He Valve arming
- He Valve Open/Closed

The He Valve arming will be immediately disabled if the *He Valve arming* command is not followed by the *He Valve V Open/Closed* command within less than 3 seconds (TBC).

5.7.3 Instrument Operations: Observation Timelines

In the following, as example, a timeline for a typical 24 hours observation period for the HIFI instruments is given. The provided timeline information is the basis for the determination of the transient heat loads on the different temperature levels of the instrument during an observation cycle. The final timeline information will cover a period of 48 hours for all three instruments.

HIFI

HIFI selected three different observations, as the heat load varies strongly with time, i.e.

- Observation mode 1: Spectral line observation

In this first mode an observation using the double beam switching technique with a typical observations duration of 30 minutes per line is performed in which the beam switches position from the source to an off position in the sky. A measurement of the calibration source is performed every 5 minutes. In this timeline a total of 20 lines are observed making up a total observation time of 10 hours.

- Observation mode 2: Spectral scan for Band 4

When performing a spectral scan a certain frequency range is being covered in steps of 1GHz. During an integration the chopper switches between the source and an off position in the sky with a frequency of 0.5 Hz. After 6 seconds the telescope is reoriented so that the source moves from one chop position to the next. This operation takes about 10 seconds after which the same procedure is repeated. When switching from one frequency to the next, only the LO frequency is changed. The diplexer is returned after every 5 integrations. Before the first measurement and every time after re-tuning the diplexer, a calibration measurement is performed. Again, at the start of the observation the mixer heater is turned on for 2 seconds. In this timeline the total observation time for this mode is 6 hours.

- Observation mode 3: Spectral scan after switching to Band 6L

When changing to a different band the chopper is moved to a different position, the diplexer unit of the new band is tuned and the LO signal is re-tuned. In this timeline the spectral scan measurement of observation mode 2 is repeated but now for band 6L. Instead of the SIS mixers, which are used for bands 1 through 5 band 6 uses HEB mixers. These mixers do not make use of the magnets that are present in the SIS mixers. The total observation time in this mode is 6 hours.

Before the start of an observation the instrument is activated.

5.7.4 Operational Constraints

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

- An eclipse may be experienced by the spacecraft during the coast arc before the delayed ignition, when the spacecraft are still on the launch vehicle and a possible eclipse during the transfer trajectory to the operational orbits. [TBC]
- During the direct liquid content measurement (DLCM), which is planned to be performed once per year, 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.

- Pre-launch Mode

The pre-launch mode will be used during the final preparation and checkout activities on the launch pad. It is automatically entered when the spacecraft is switched on; in this way it will also be used during all ground testing.

- Launch Mode

The spacecraft is in the launch mode from removal of umbilical until it has autonomously performed all operations after separation to achieve a safe pointing attitude and communications to ground is established.

- Activation Mode

The activation mode follows the launch mode, when control is taken over from ground. It is used until completion of spacecraft check-out and payload commissioning. In principle this is not a specific system mode, but is used to describe the variety of configurations used during check-out operations.

- 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	Standby	Prime (Spectrometer)	Standby
#2	Standby	Prime (Photometer)	Standby
#3	Standby	Standby	Prime (Photometer)
#4	Standby	Standby	Prime (Spectrometer)
#5	Prime	Standby	Standby
#6	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 EPLM 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 Sunshield (SSD) and the Sunshade (SSH), 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 EPLM electrical design consequently includes the following components:

- The Cryo Harness Subsystem consisting of :
  - The Cryostat Control Harness (CCH)
  - The Scientific Instrument Harness (SIH)
- The Electrical Subsystem consisting of :
  - The Cryostat Control Unit (CCU)
  - The Cryostat Control Instrumentation (CCI)
- The Solar Generator (SG) Subsystem mounted on the Sunshield (SSH)

The Cryo Harness Subsystem and the EMC aspects are described in more detail hereafter whilst a comprehensive description of the Cryostat Control Unit (CCU) and the Solar Generator (SG) 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 CVV cover via the CCH
- the electrical interconnection between the EGSE and the CCI on the telescope, the CVV and the CVV 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 Figure 27.

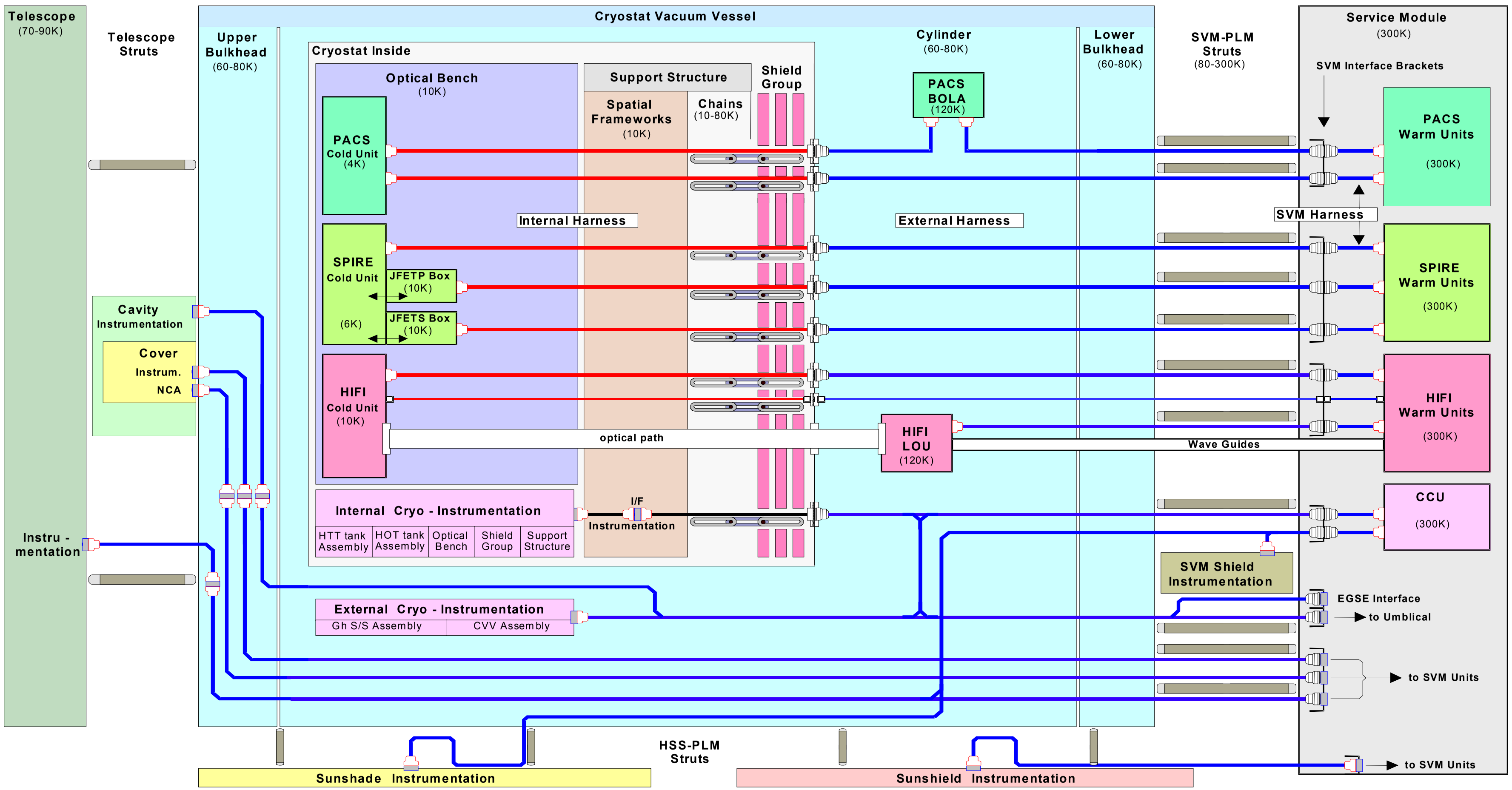


Figure 27: H-EPLM Electrical System Overview

5.9 Harness

5.9.1 General Description

In general the Cryo Harness consists of the two main Sub-harness elements

- Cryo Control Harness (CCH), including the Telescope Harness
- Scientific Instrument Harness (SIH) of HIFI , PACS and SPIRE

The Cryo Control Harness (CCH) and Scientific Instrument Harness (SIH) will provide the electrical inter-connections between the SVM mounted warm units and the EPLM cold units, as well as for the cryo instrumentation.

The CCH will distribute power and signals between the Cryo Control Unit (CCU) within the SVM and all cryostat instrumentation (CVV external and internal). In addition, the CCH will provide all cryostat harness lines to the EGSE and SVM Umbilical interface connector-bracket(s), as need for the pre-launch phase.

The SIH provides the power, data and monitoring lines between the instrument Warm Electronic (WE) units (SVM internal) and their cold units (CVV external, i.e. HIFI LOU and PACS BOLA and CVV internal, i.e. HIFI, PACS and SPIRE FPUs).

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

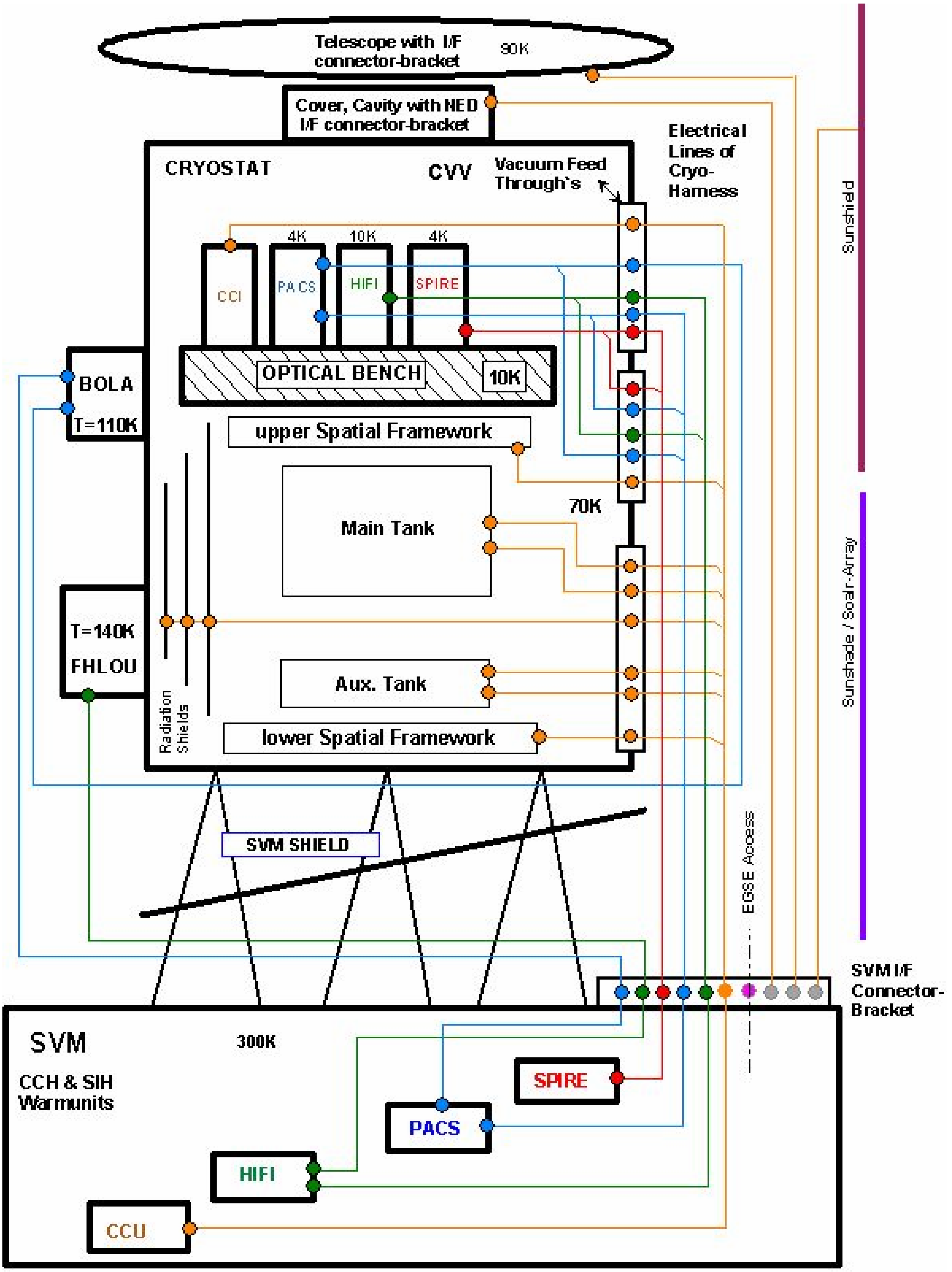


Figure 28: Schematics of the Harness Segments and major Harness Interfaces

5.9.2 Harness Segmenting

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

CRYO-Harness Segment 1	SVM Harness	CRYO Control Harness Scientific Instrument Harness	CCH SIH
CRYO Harness Segment 2	CVV External Harness	CRYO Control Harness Scientific Instrument Harness	CCH SIH
Cryo Harness Segment 3	CVV Internal Harness	CRYO Control Harness Scientific Instrument Harness	CCH SIH

Table 10: Main Cryo Harness Segments

The CCH is further subdivided in component harnesses to consider the S/S and AIV constraints concerning integration aspects and pre-integration's on S/S level, see Figure 28. Additionally, the test harnesses which are need for the Cryo harness manufacturing acceptance tests at contractor level are defined. The harness hardware breakdowns are defined in Figure 28 to Figure 31.

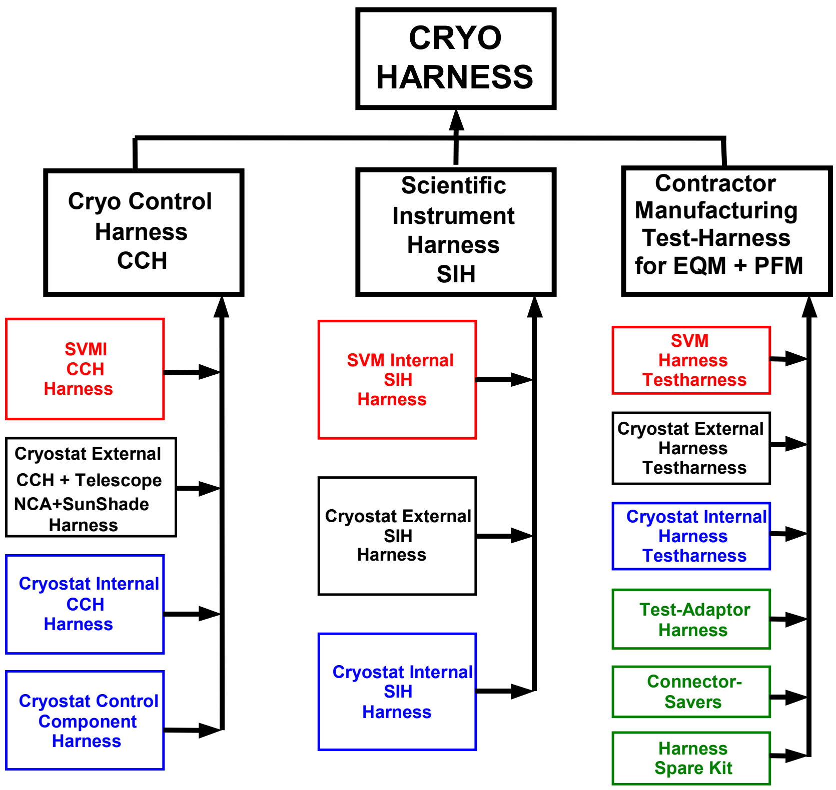


Figure 29: Cryo Harness Break Down

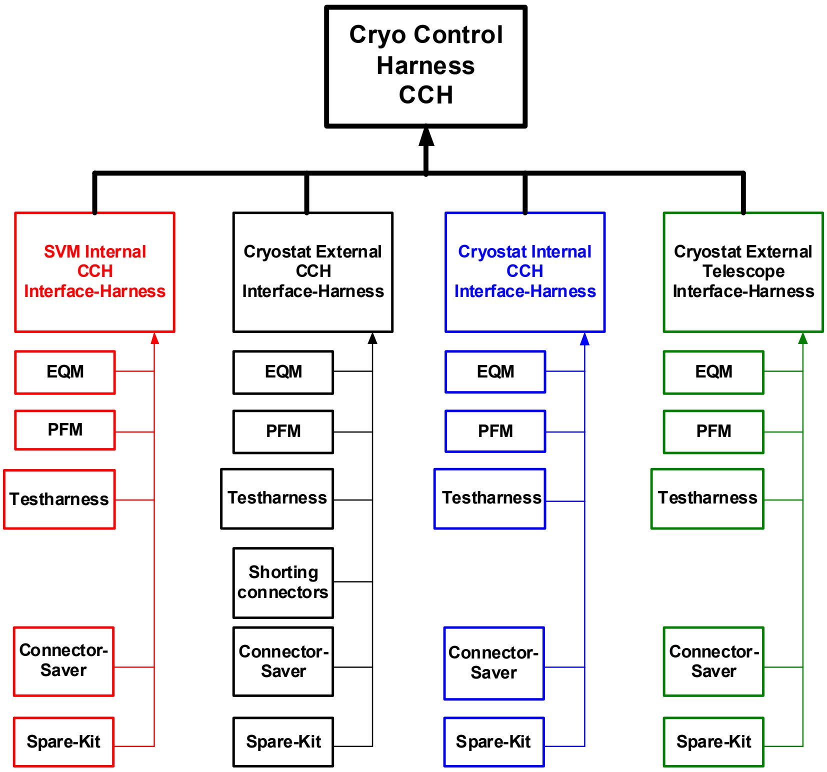


Figure 30: Cryo Control Harness Breakdown

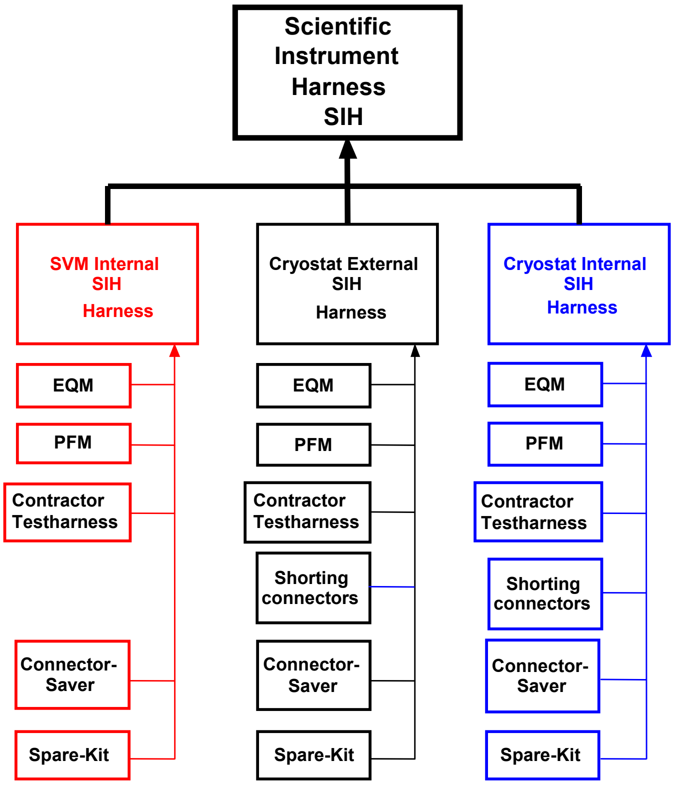


Figure 31: Scientific Instrument Harness Breakdown

5.10 EMC Concept

5.10.1 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 the EMC Control and Verification Plan, HP-2-ASED-PL-0013.

5.10.2 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.
- In particular the telescope will be coated with a suitable finish allowing its electrical bonding to the satellite structure.
- Dielectric surfaces will be minimised in thickness and exposed area in order to minimise the up-charging potential.

The proposed grounding scheme for minimization of pick-up noise as well as minimization of emission is the distributed Starpoint Grounding Concept as reflected in the "HERSCHEL PLM Grounding Scheme", HP-2-ASED-DW-0001. 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.

5.10.3 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 favorable
- wire twisting to be applied
- wire pairs shall be impedance balanced (same cable lengths and type)
- cable lengths to be minimized

5.10.4 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 "HP EMC Analyses", H-P-1-ASPI-AN-0202. This document justifies also the adequacy of the existing CE/CS and RE/RS requirements in order to confirm the payload compatibility.

5.11 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 and the Strength Analysis Report. This section concentrates on

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

The mechanical verification approach is part of the AIV section.

5.11.1 Mechanical Design Drivers

The key drivers for the mechanical design are the mechanical requirements (stiffness and loads), the task to optimise the thermal performance, the safety aspects resulting from the cryogenic system and the wish to keep the ISO heritage as far as possible.

The major contribution of the structure to the thermal performance is insulation of the “suspended mass” from the CVV and the isolation of the CVV from the SVM.

The insulation of the "suspended mass" is performed by the Tank Support System. The driver for the cross section is the PLM axial frequency requirement. As this stiffness is simply driven by the sum of the stiffness of all 16 straps, it makes no sense to introduce different chain cross section (as this has been done for ISO). To keep the ISO TSS geometry the basic dimensions as the CVV diameter distance of the TSS chains of 891 mm remains unchanged during Phase B.

For optimisation of the insulation of CVV from SVM some investigation has been performed (HP-2-ASED-TN-007). Analysis indicates that the axial frequency requirement is more stringent than the lateral. Therefore the SVM/CVV I/F struts have been more vertically orientated, which consequently justifies the change from 16 to 24 struts. A second impact was the stiffer SVM. In consequence the cross section of the struts has been reduced to about 35% of the cross section we had at the beginning of the Phase B.

The Optical Bench design is driven by the frequency requirement (70 Hz hard mounted), which was established to avoid a coupling to the first global frequency of 34 Hz. The distance of an octave is selected to protect the instruments from high mechanical loads. The height of the plate the orientation of the ribs has been optimised in Phase B.

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 pressure of 1.05 bar, due to the potential failure of the CVV. The outer dimensions are defined by the overall dimensions, the internal pillars are needed, because of the geometry of the TSS, the internal bulkhead is needed to control the internal gas dynamics.

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 iteration 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.

5.11.2 Analysis Approach

The most important tool for the structural analysis is the mathematical model, which is described in detail in HP-2-ASED-TN-0025.

The task of the structural analysis is to ensure that the H-EPLM reaches the orbit in healthy condition. The tasks consist in principle of two steps. The first step is to ensure a dynamic behaviour of the PLM, which generated reasonable loads. The second step is to make sure the PLM survives these loads.

The dynamics has been characterised by analysis of the natural frequencies, the mode shapes and by response analysis. 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. All dynamic results are documented in HP-2-ASED-TN-051. In order to ensure, that the dynamic behaviour is under control stiffness requirements have been established for the whole systems and for sub-system. The most important frequencies for the whole system and the telescope support, the optical bench, the HSS and the LOU are included in the H-EPLM Requirements Spec (AD-6). The actual status design fulfils all these requirements. A comparison of required frequencies and actual status is listed in Section 6.3.

Beside these major contributors to the dynamics, for each item a separate stiffness requirement has been established. For all struts the tension stiffness, which is actually considered in the FEM, has been taken into the unit specs. The local stiffness at load introductions of CVV has been defined where necessary.

Based on these fundament design loads has been derived for each component. These loads are defined in the H-EPLM Requirements Specification (AD-6) by ASPI. A cross check of these loads has been performed by a frequency response analysis, assuming the sine input at qualification testing and assuming notching on I/F loads and moments only. The results are documented in the structural analysis report ASED-HP-2-TN-0049, showing that the definitions are conservative in all cases except HTT lateral load. For the HTT an additional notch for the second bending mode is needed.

Based on these load definitions a static analysis with unit loads in x, y and z-direction has been performed with the mathematical model. All I/F loads and the most important stresses are documented in ASED-HP-2-TN-0049. Multiplying this unit loads with the applicable design load factors for the specific location is the bases for the load definition in the unit specification and is the bases for the stress analysis.

The stress analysis and the resulting margins of safety are documented in ASED-HP-2-TN-0053. This document consists of two parts. The first part shows the analysis of the interfaces between the components the second contains the analysis different components itself.

The stress analysis itself is partly based on the overall mathematical model, partly uses separate models or hand calculations. This was necessary because the loads are only partly because of acceleration during the launch. More driving are pressure loads. In some areas (e.g. HSS struts) thermal distortion loads has to be considered. Buckling analysis requires other element sizes, than a dynamic analysis and need therefore specific FE models.

Additional outputs of the structural analysis are the thermal distortions, which are described, in the H-EPLM Thermal Distortion Analysis Report HP-2-ASED-TN-0046 issue 1. The results are input for the Herschel Alignment Concept HP2-ASED-TN-0002, issue 1.

5.11.3 Analysis Results

Concerning the dynamics all stiffness requirements are met. Of specific interest is the frequency range between about 24 Hz to about 30 Hz under lateral directions with the second lateral mode and rather complex mode shapes, which includes the “suspended mass”, the telescope and the HSS.

The margins are included in ASED-HP-2-TN-0053 and are summarised in Section 6.

5.12 Thermal Design

5.12.1 H-EPLM Thermal Control System

The basic function of the Herschel EPLM 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 LOU.

The H-EPLM is thermally isolated mounted on top of the SVM via 24 GFRP struts. The CVV and the Telescope are protected from solar radiation by the Herschel Sunshield /Sunshade (HSS). The front of the Sunshade is covered with OSRs to minimise the Sunshade temperature and consequently also the Telescope temperature. The front side of the Sunshield is covered with solar cells. The rear side of the HSS is completely covered with high efficient MLI.

To minimise the heat radiation from the warm HSS MLI to the CVV, the +Z half and the ±X side of the CVV is also covered with MLI, the remaining area of the CVV serve as radiator. To shadow this CVV main radiator area from the warmer HSS MLI and to increase the radiator area, the CVV is equipped with three additional radiators. The overall thermal control configuration is shown in Figure 32.

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 called the SVM Thermal Shield. On the +X side this shield is covered with MLI and on the –X side it is covered with gold-plated Kapton foil. Thus the SVM Thermal Shield reflects heat to space (V-groove effect). In addition all external MLI surface is of low IR emissivity and high specularity to reject also parasitic heat to space via V-groove effects. In addition to the CVV radiators, the V-groove effects are mandatory to achieve a low CVV temperature of about 70 K.

The following PLM equipment/components are attached to the CVV with thermally isolating mounting structures:

- Telescope via CFRP T300 struts
- LOU with its radiator via 8 GFRP struts
- LOU Waveguides and LOU Harness via GFRP blades
- Scientific Harness and Cryo Control harness are routed to the CVV Connector Brackets inside C-shaped CFRP profiles

To simplify the design and due to the relatively low dissipation of the BOLA, the BOLA box is thermally directly mounted onto the CVV. The whole box is wrapped in MLI and the BOLA therefore follows the CVV temperature.

The Telescope needs to be thermally isolated from the CVV especially during the decontamination phase where the Telescope is heated to 40°C for 3 weeks. In nominal L2 orbit conditions the Telescope will be at about the same temperature level as the CVV.

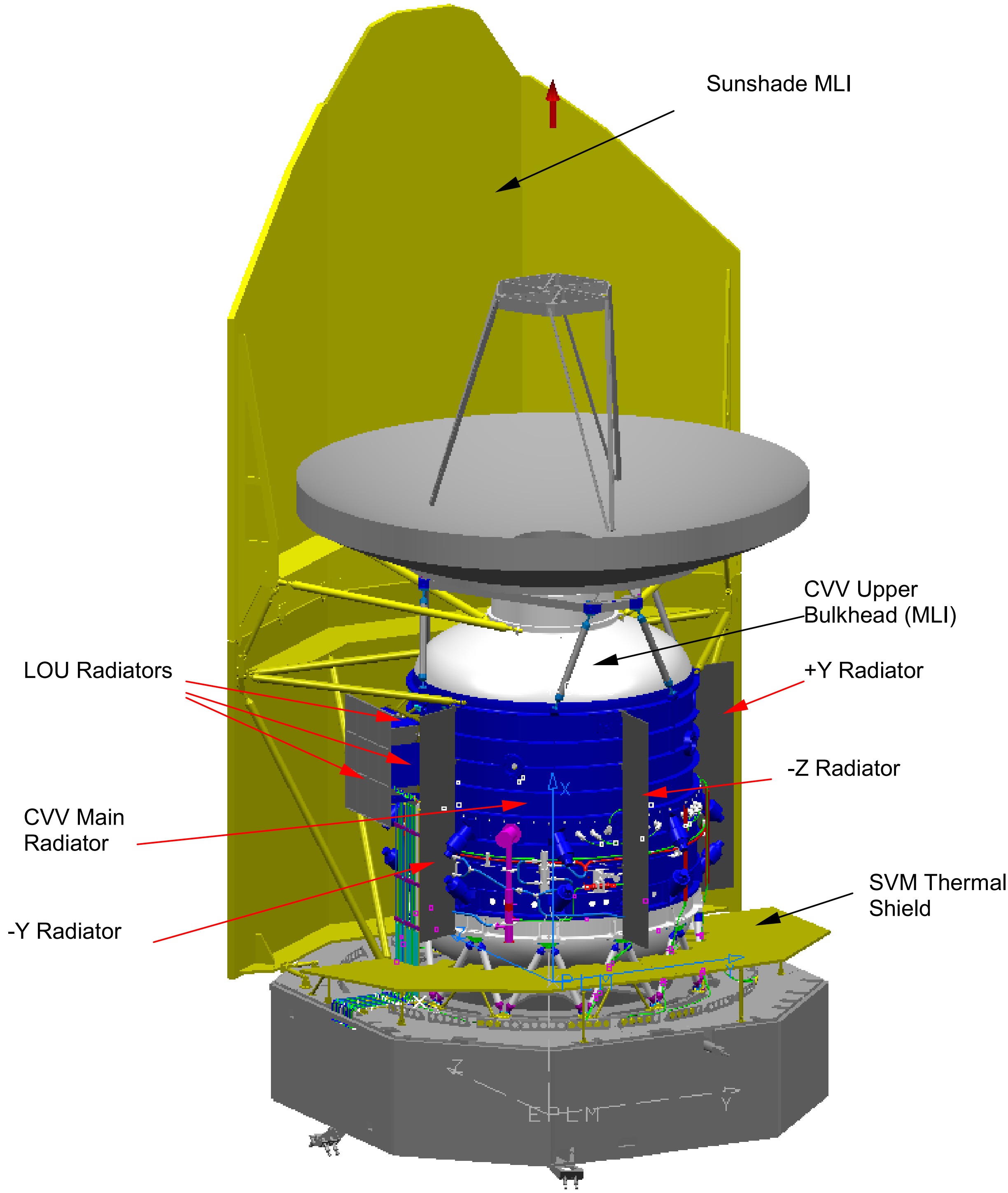


Figure 32: H-EPLM Thermal Control Design

5.12.2 H-EPLM Helium Cooling System

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

The lowest temperature is provided by the Helium II Tank (HTT) at 1.65±0.05 K. This is called the “Level 0” interface. The exhausting gaseous Helium provides two further temperature levels via the ventline. In order to provide a cooling interfaces close to the FPU thermal interface, this ventline is routed around the OBP. The first ventline loop around the OBP is thermally isolated from the OBP and serves for the “Level 1” cooling at about (3-6) K. The second loop is thermally well connected to the OBP and provides the “Level 2” at (9-15) K, see Figure 33. The remaining ventline is then connected to the three heat shields for cooling them.

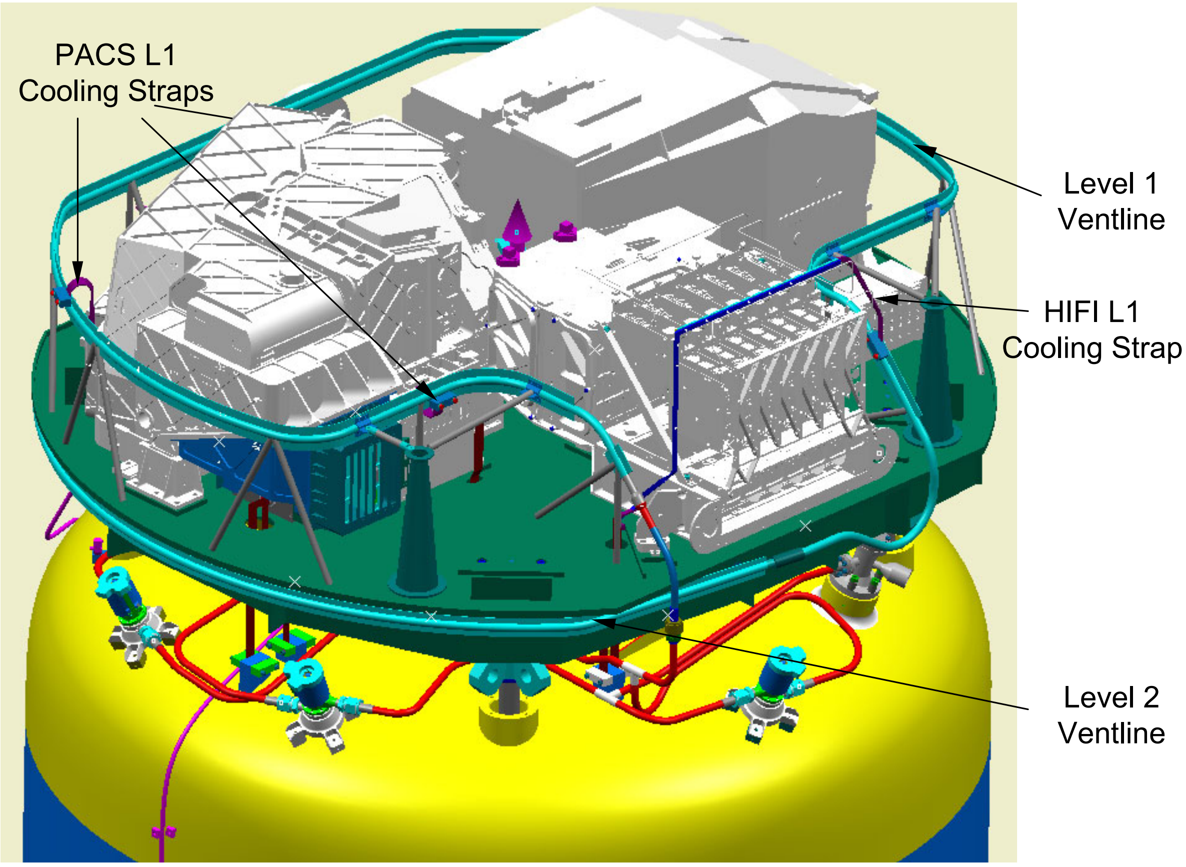


Figure 33: Level 1 and Level 2 Ventline Design

The PACS FPU structure is thermally well isolated from the OBP and is cooled via three copper cooling straps connected to the Level 1 ventline wall. The SPIRE FPU structure is also thermally isolated from the OBP and is cooled via one copper cooling strap connected to the Level 1 ventline wall downstream after the PACS straps. The HIFI FPU structure is directly mounted, i.e. thermally well connected to the OBP and thus cooled via the Level 2 ventline. The HIFI FPU requires also an Interface to the Level 1 temperature which is provided by a cooling strap attached to the end of the Level 1 ventline.

SPIRE 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. To avoid thermal short circuit during cooler recycling, the mounting flanges of the pump and evaporator cooling links at the HTT structure are separated. HIFI requires one Level 0 interface only.

All rigid parts of the L0-cooling links consist of tubular circular bars made of high-purity aluminium with a minimum purity of 99.9% (TBC). They have identical flanges that are mounted to the HTT via 6 x M6 screws in order to achieve adequate thermal contact couplings. The flexible parts consist of packages of thin high-purity aluminium foils and need to be adapted to the appropriate instrument L0-interface.

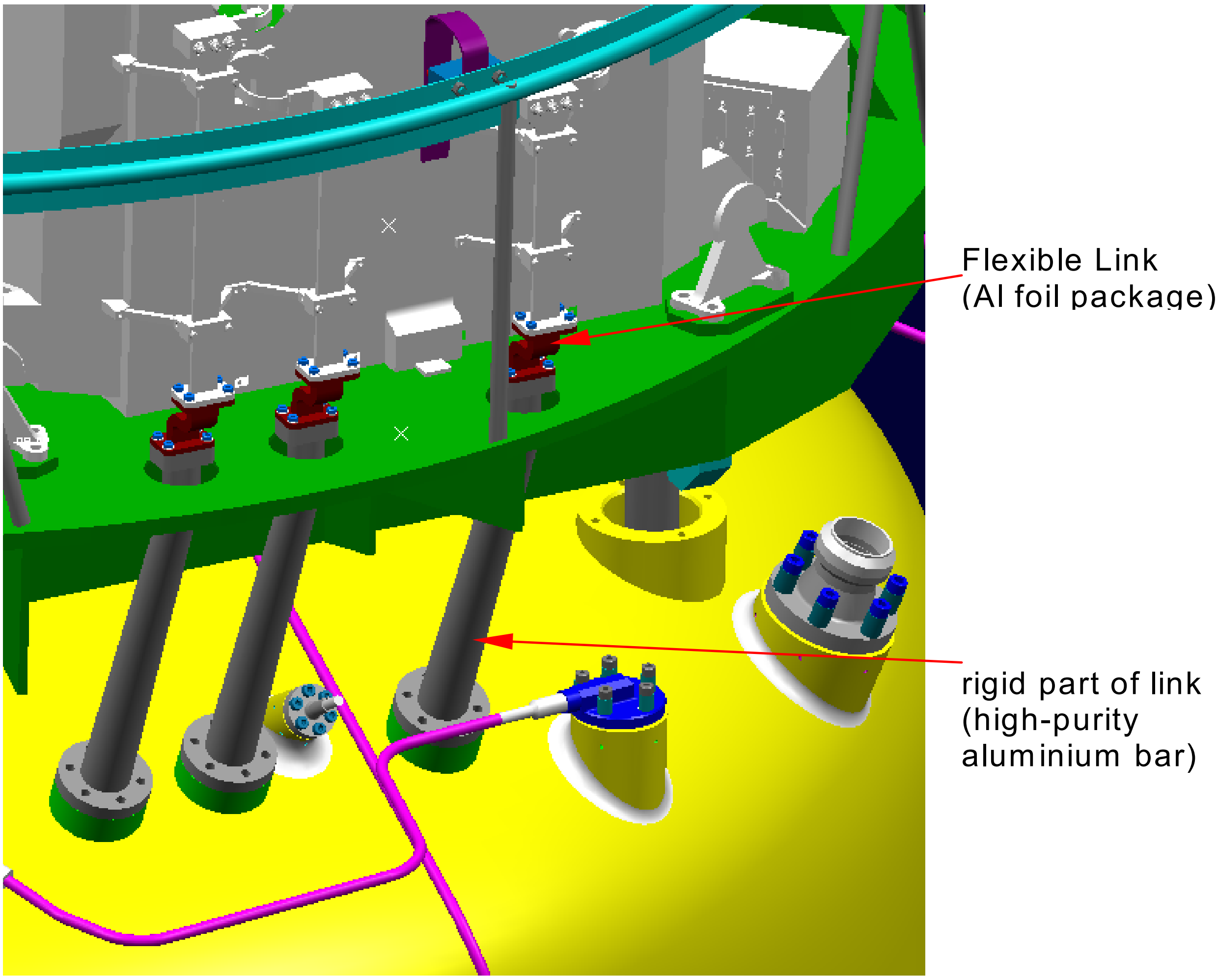


Figure 34: SPIRE Level 0 and Level 1 I/F

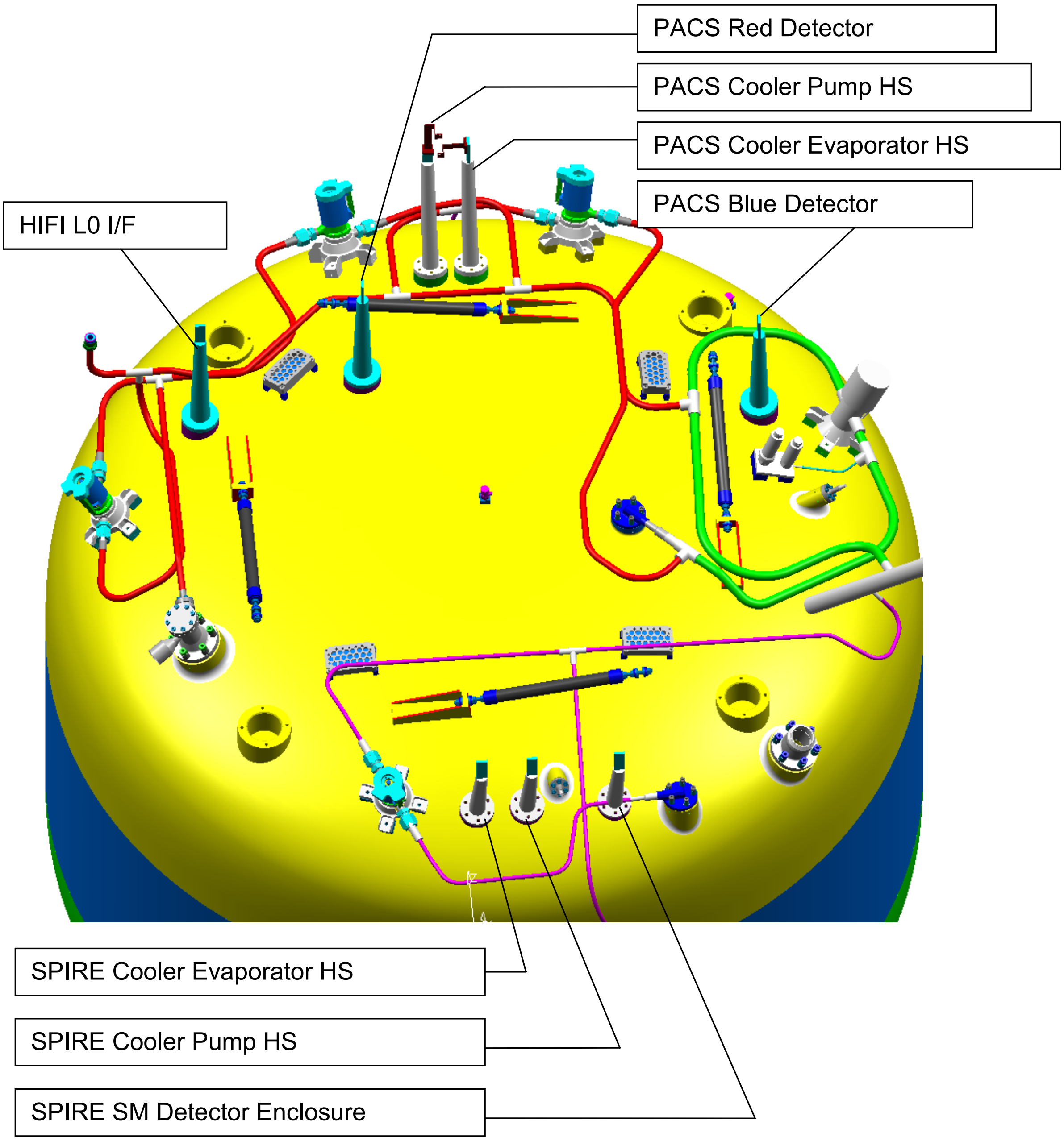


Figure 35: Instrument Thermal Links to HTT (Level 0)

Thermal Design of Harness

The Scientific Harness (SIH) is the main contributor to the CVV internal heat load. The cross-sections and dissipation for the CVV internal harness is summarised in Table 11 together with the Cryostat Control Harness (CCH) data. The CVV external harness (between SVM and CVV) have about the same data, except that the external Harness bundles have overall shields made out of Manganin wires [tbc]. The cross-section of the Manganin overall shields in total amounts to about 58 mm².

CVV Internal Harness	Average Dissip **	Spec Mode Dissip **	Phot Mode Dissip **	Stainl. St.	Brass	Cu	PTFE
	mW/m	mW/m	mW/m	mm^2	mm^2	mm^2	mm^2
PACS FPU	6.02	21.36	14.68	28.67	6.804	-	247
SPIRE FPU	2.501	15.009	0.754	10.31	8.052	-	103
SPIRE JFET-P	0.069	0	0.415	21.5	0.847	-	170
SPIRE JFET-S	0.015	0.088	0	6.146	0.594	-	52
HIFI	8.485	HIFI on: 25.465		10.666	5.816	0.522	134
CCH	~ 0	-		2.18	2.75	-	13.3

** valid for 293K, dissipation at lower temperature expected to be lower

Table 11: Harness Dissipation and Cross-Section inside CVV

Except the SPIRE JFET harness all harness CVV internal is thermalized on Heat Shield 1 (HS1) via a Stycast-Comb bracket similar to ISO, see Figure 36. To reduce heat load to HS 1 the JFET harness is thermalized on Heat Shield 2 (HS 2) as indicated in Figure 37. There might be some optimization potential in sharing the HIFI FPU harness thermalisation between HS 1 and HS 2 that will be investigated after PDR.

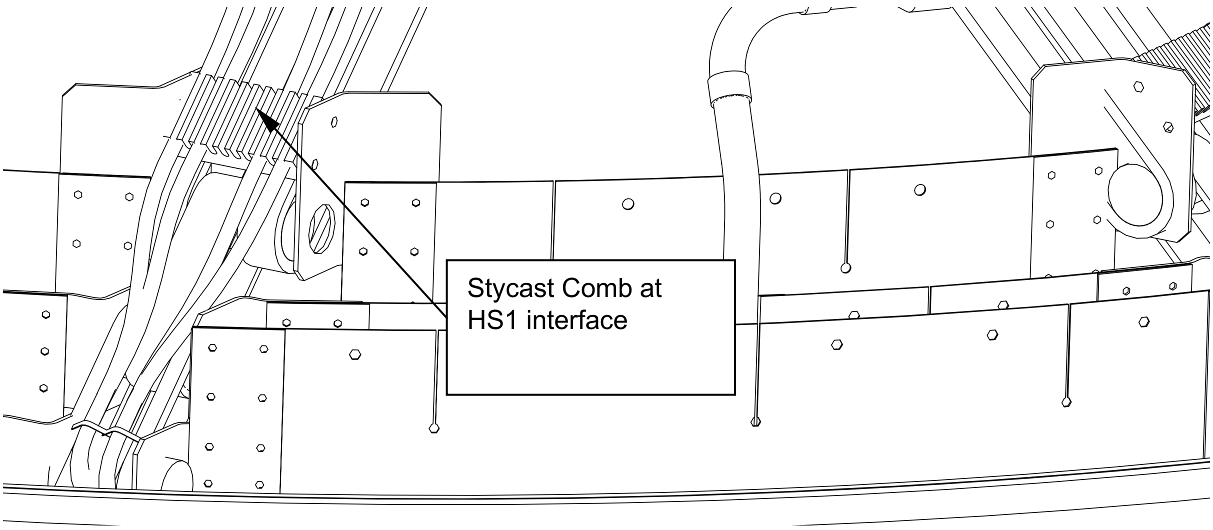


Figure 36: Harness Thermalization on Heat Shield 1

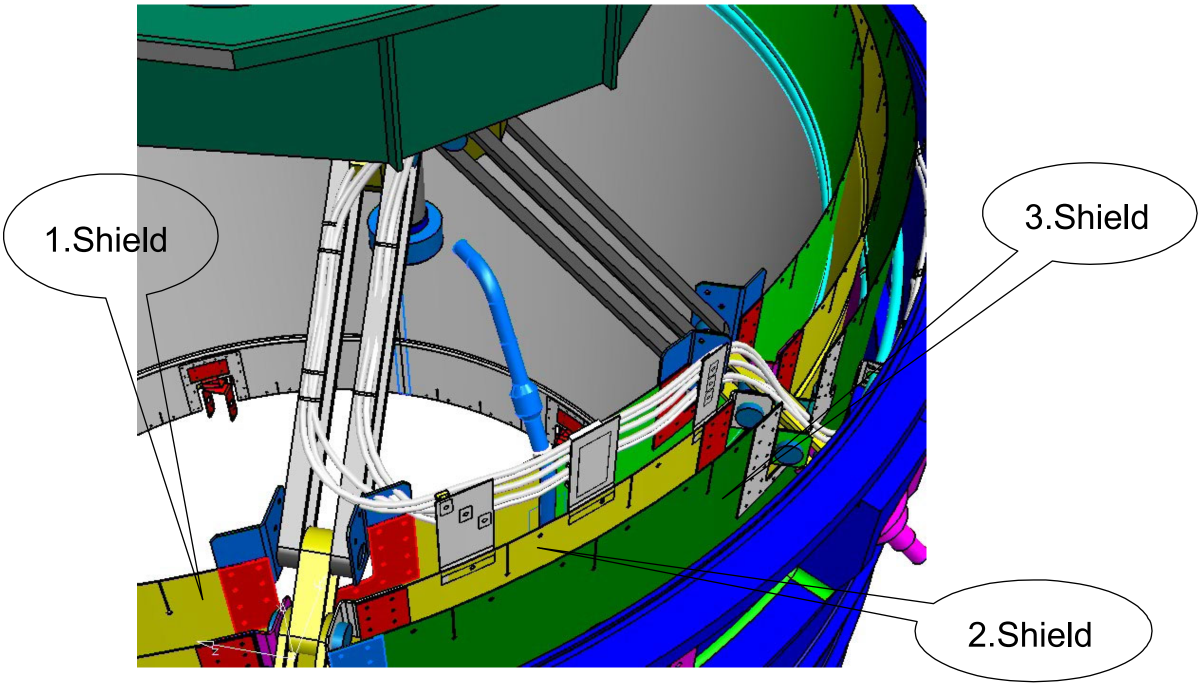


Figure 37: SPIRE JFET Harness Thermalization on Heat Shield 2

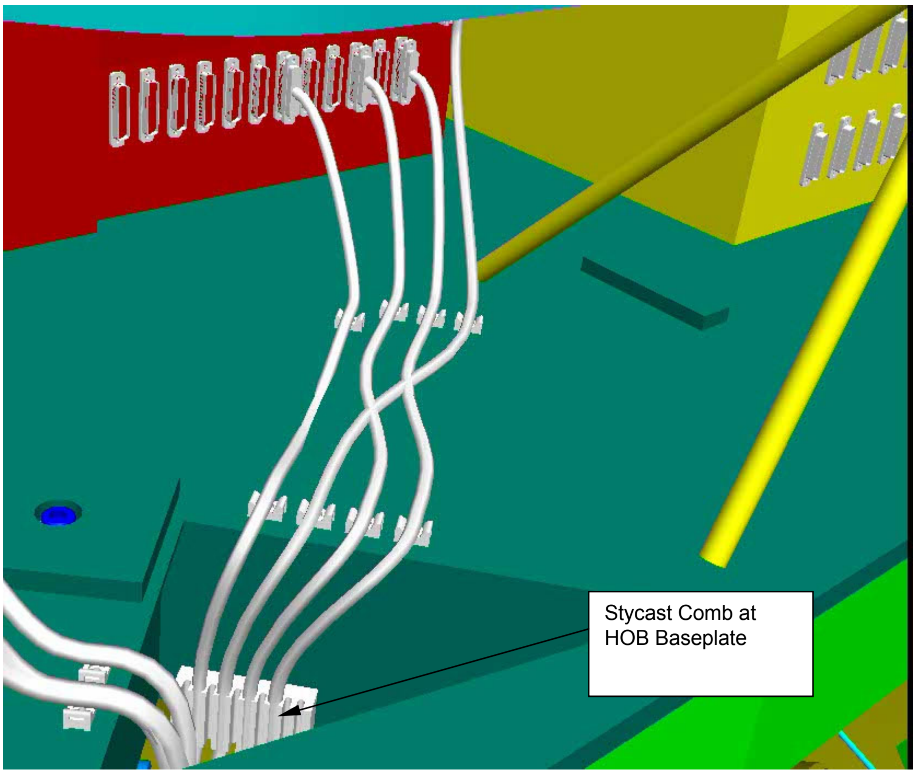


Figure 38: Harness Thermalization on OBP

5.13 Internal and External Interfaces

See Interface Control Documents:

- H-EPLM Electrical ICD, HP-2-ASED-IC-0001
- H-EPLM Mechanical ICD, HP-2-ASED-IC-0002

5.14 The Major Changes Since SRR

5.14.1 The Major Changes of the Overall Configuration

Overall Configuration

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

CVV

- The CVV contour has been modified. Reason was the availability of the raw material. The new contour is less critical wrt. buckling but needs a ring at the transition from the convex to the concave shape.
- The number of radiators on the CVV has been increased from 1 two 3.
- The filling port position has been optimised.

Telescope Mounting Structure

- To the telescope mounting structure an additional frame" has been added, which de-couples the telescope better from CVV thermal distortions and tolerances. This frame is additionally fixed to the telescope baffle for structural reasons. The struts have been changed from GFRP to CFRP.

SVM Thermal Shield

- The size of the SVM shield has been reduced to the half. The reduced shield has approximately the same thermal performance than the full shield but is preferable wrt. mass and integration

HSS

- The HSS mounting structure has been modified to decrease the number of supporting struts (from 36 struts at SSR design to 12 struts now). The advantages are a lower thermal coupling of the SVM and the CVV, better integration and handing possibilities and smaller forces due to thermal shrinkage of the CVV.
- Decrease of HSS panel height (2600 to 2370mm) for mechanical stiffness improvement

Spatial framework HOT and valve location

- The material of the spatial framework has been changed to aluminium:
  - Matching of the thermal coefficient of expansion of the HTT, Special Framework and the Optical Bench
  - for better thermal coupling of the lower HTT suspension straps to the HOT. The location of the HOT valves has moved from HTT to spatial framework.
- Consequence:
  Less heat load to the HTT on ground during launch autonomy.
  More information in: Material Selection for Special Framework, HP-2-ASED-TN-0020 and Helium Control System Design, HP-2-ASED-TN-0013

5.14.2 The Major Changes of the Cryogenic System

Helium control system

- In order to avoid problems with the available time for evacuating the HOT during ascent of the launch vehicle and to prevent thermal acoustic oscillations, the HOT will be closed for launch and the rest of the mission.
- Consequences (Langfermann):
  One additional electromagnetic valves, one additional burst disc and one cold safety valve at the HOT. Pressure drop requirements on vent line decreased.
  No more oscillation damper in filling port.
  More information is found in Helium Control System Design, HP-2-ASED-TN-0013.

Helicoflex

- The cold Kapton seals from ISO will be replaced by Helicoflex.
- Consequences:
  Different flange interfaces from components to the tanks.
  More information in: Low temperature seals, /HP-2-ASED-TN-0047/

Cooled cover shield

- In order to fulfil instruments functional testing requirements on ground, the cover is capable to cool the cover heat shield with different cryogenic fluids.
- Consequences:

  cover design is more complicated, additional CVSE is needed, a CTA for the PLM is obsolete.
  More information in: Helium System Description /HP-2-ASED-RP-0034/

Filling port

- The design of the filling port had to be reworked in order to get an orientation of minimal 45° with respect to gravity for proper superfluid helium filling.

- Consequences:
  New design of CVV I/F, filling port, safety valve housing, evacuation port, payload access doors in fairing
  More information in: HE S/S FILLING PORT, HP-2-ASTP-TN-0012

Heat shield exchanger

- The routing of the tubing on the thermal shields has been changed from one to two flooding flow.
- Consequences:
  more homogeneous temperature distribution and more effective heat exchange
  More information in: Dimensioning of heat exchangers, HP-2-ASED-TN-0027, Issue 1

Optical bench piping

- The routing of the vent-line on the optical bench has been modified due to thermal optimisation and due to harness routing constraints.
- Consequences:
  Better temperature distribution and more effective heat exchange
  More information in: Dimensioning of heat exchangers, HP-2-ASED-TN-0027, Issue 1

Level 0 interface

- Level 0 interfaces to the HTT have been changed due to anticipated (but not yet agreed) lower temperature requirements from the instruments
- Consequences:
  increased thermal conductivity, simpler design of thermal strap support.

5.14.3 The Major changes of Cryo Harness

The major changes of the cryo harness are covered in the Herschel Instrument Interface Documents with the applicable changes, as identified in Section 2.1.

For further details the main technical reasons and impacts on the Cryo-Harness design are described for each Cryo-Harness segment.

CVV Internal Cryo-Harness:

- Deletion of optical bench interface connector-brackets
- Three CVV feed-throughs interface connector-rings
- Harness routing through 4 cut-outs in the optical bench plate
- SPIRE JFET harness thermally bonded to 2. heat shield
- More SIH harness cable types w.r.t. electrical, thermal and mechanical requirements
- Higher density of SIH branches over tank supporting straps
- Modified feed-through connector types and connector assemblies

CVV External Cryo-Harness

- Implementation of the SVM & EGSE interface connector-brackets
- Shift of PACS BOLA and HIFI LOU around CVV w.r.t. critical interface of Cold units
- One-row connector-brackets under SVM Thermal Shield w.r.t. V-groove effect
- Deletion of all interface connector-brackets between CVV & Sunshield
- Increased number of SIH branches request
  - more C-Profiles for harness routing on CVV
  - longer harness distances warm units & cold units
  - development of different cable core & harness overshield materials
  - more CVV harness feed-through connectors
  - development of NON standard connector and assembly parts
  - development of NON standard harness attachment elements
  - more complicated Cryo-harness Lay-out & Routing design around CVV

SVM Harness

- Modified instrument & Cryo-Control Warm unit Lay-out on the SVM side-panels request
  - longer harness distances to the SVM interface connector-brackets
  - different cable core & harness overshield materials
  - additional mouse-hole cut-outs for Cryo-harness routing out of the SVM
  - more complicated Cryo-harness routing design w.r.t. instrument internal & S/C harness separation
  - re-positioning of instrument related SVM interface connector-brackets
- Modified SVM AIT concept with removable instrument side-panels
- Modified HIFI LSU wave-guide interface & routing request a modified Cryo-Harness routing on the HIFI instrument panel SVM internal
  - modified Cryo-Harness routing around the HIFI wave-guides, SVM panel external
  - deletion of one SVM interface connector-bracket close to the HIFI instrument panel

6 Performance and Budgets

6.1 Operational Lifetime

The calculated nominal lifetime is **3.44 years** taking into account the IID-A heat load allocation, a margin of 10% in the amount of helium and taking into account launch delay of 25 hours. The launch delay of 25 hours has been introduced at the Operations Herschel/Planck Feasibility Meeting (ref. AE/DC/P/N-2001-285 PG/MB, 15/06/2001).

The corresponding average helium mass flow at L2 is 2.46 mg/s and the CVV is at about 70 K.

The calculated lifetime using the TMM with implemented instrument models reveal a mass flow of 2.338 mg/s, which leads to a lifetime of **3.60 years**.

Taking into account the physical parameter uncertainties reported in “H-EPLM THERMAL MODEL AND ANALYSIS” (HP-2-ASED-RP-0011) leads to the following uncertainty in the lifetime prediction:

– 109 days for the negative sensitivities (worst case)

+ 135 days for the positive sensitivities (best case)

6.2 Thermal Performance

6.2.1 Heat Flow Charts

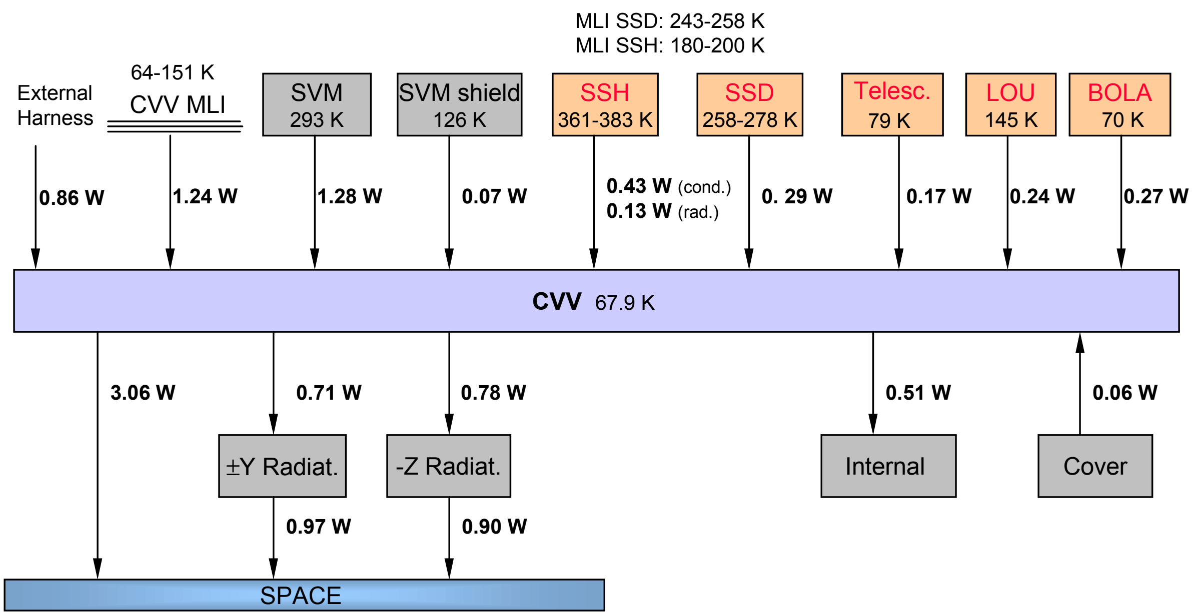
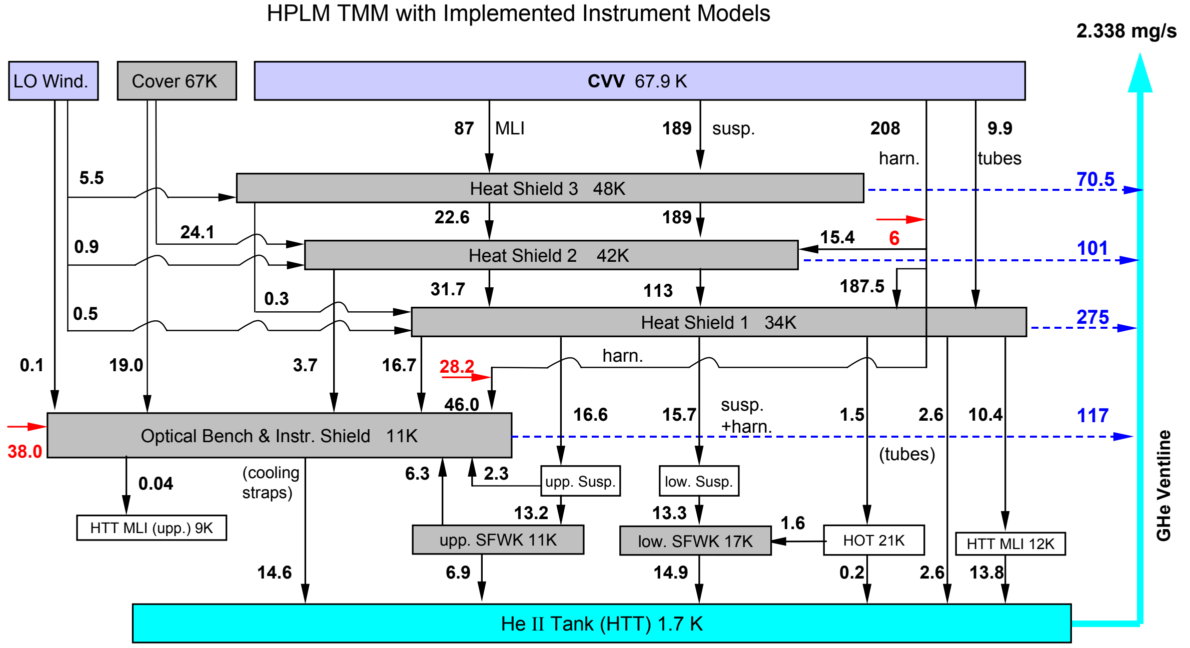
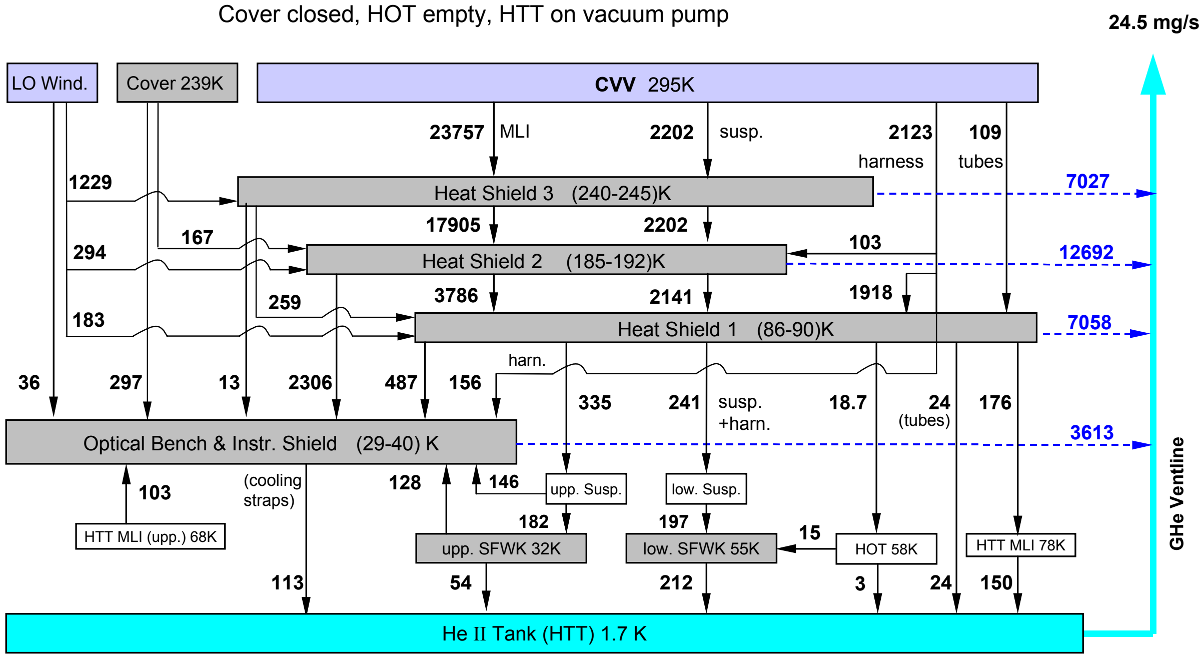


Figure 39: CVV Heat Flow Chart for Hot Case Environment at L2 Orbit



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

Figure 40: 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 41: CVV Heat Flow Chart for On-Ground Environment

6.2.2 EPLM Temperatures

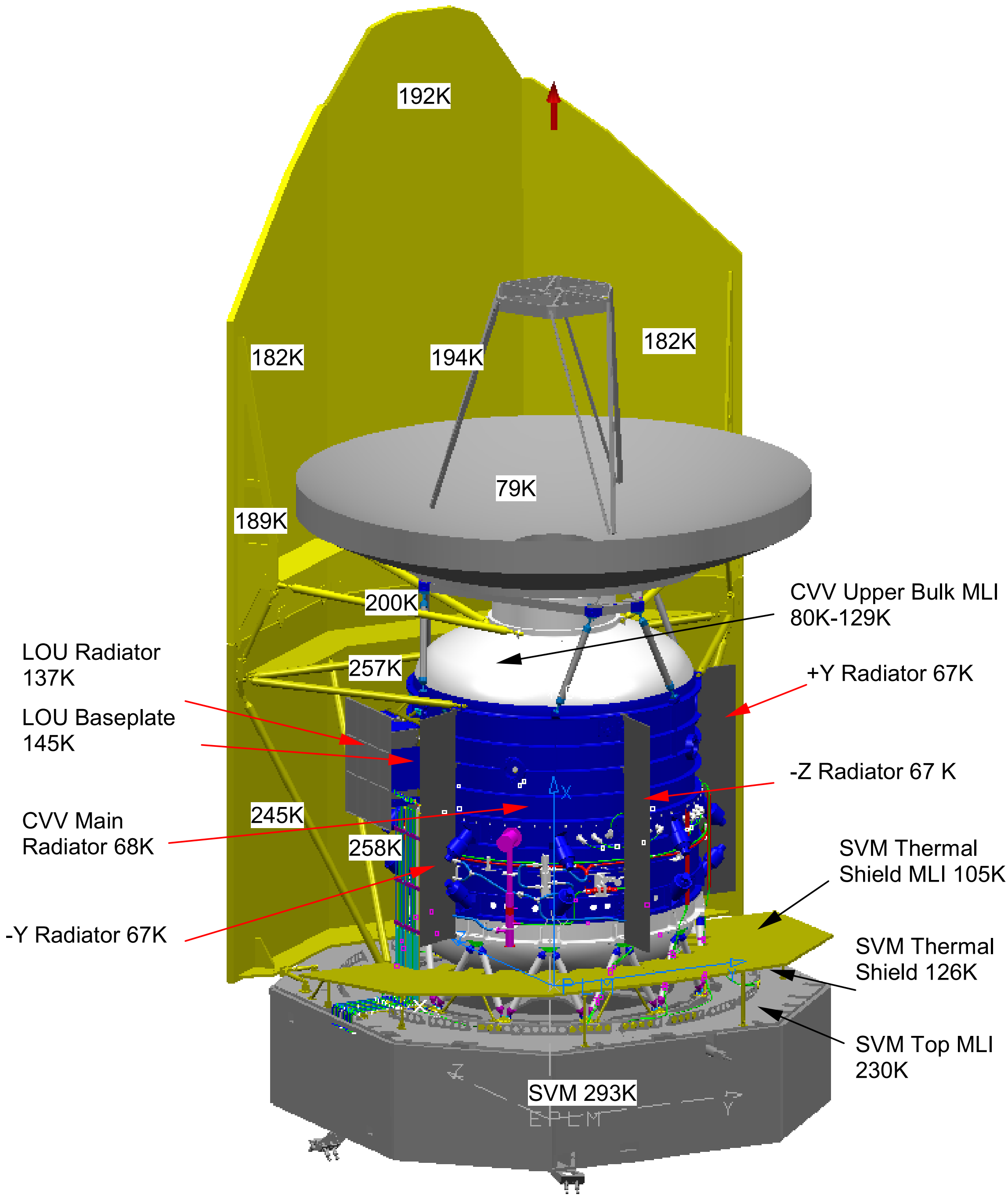


Figure 42: H-EPLM Temperature Distribution for Hot Case Environment at L2

6.2.3 Instrument Interface Temperatures

		Requirement	Analysis Results	
			Photometer Mode	Spectrometer Mode
Level 0	PACS Red Detector	1.6 K … 1.75 K	1.70 K ±0.025K	1.71 K ±0.025K
	PACS Blue Detector	1.6 K … 2 K	1.71 K ±0.025K	1.79 K ±0.025K
	PACS Cooler Pump	1.6 K … 2.2 K	1.95 K ±0.025K	1.77 K ±0.025K
	PACS Cooler Evapor.	1.6 K … 2.0 K	-	-
	SPIRE Detector	0 K … 2 K	1.73 K ±0.025K	1.74 K ±0.025K
	SPIRE Cooler Pump		1.72 K ±0.025K	1.73 K ±0.025K
	SPIRE Cooler Evapor.		1.76 K ±0.025K	1.76 K ±0.025K
	HIFI Detector	< 2 K	1.83 K ±0.035K	
Level 1	PACS FPU	3 K … 5 K	3.06 K* ±0.18K	4.25 K* ±0.18K
	SPIRE FPU	< 6 K	4.90 K* ±0.35K	5.15 K* ±0.35K
	HIFI L1	< 6 K	6.29 K* ±0.32K	
Level 2	HIFI FPU	< 15 K	14.02 K ±0.5K	
Outside CVV	BOLA (PACS)	60 K …150 K	(68-70) K** ±3K	
	LOU (HIFI)	90 K …150 K	(143-145) K** ±3K	

*) includes an uncertainty of + 0.1 K due to modelling inaccuracy

**) cold-hot case environment at L2

Note: for HTT at 1.6 K, the L0 temperatures can reach 1.6 K

Table 12: Calculated Instrument Temperatures for 2.2 mg/s He Mass Flow and HTT at 1.7 K

6.3 Structure

6.3.1 Mass, COG MOI

The following table summarises the mass of the E-PLM.

Item-Description			Mass		
	No.	Develop. Status	Nominal Mass [kg] per unit	Sum Nominal Mass [kg]	Sum Mass [kg] * Dev. Sta.
Sum H-EPLM dry		1,09		1340,20	1459,54
He 2 Tank filling 98 %, 2160 ltr.	1	1,00	307,50	307,50	307,50
He 1 Tank filling 98 %, 80 ltr.	0	1,00	11,00	0,00	0,00
Filled, without Instruments, without Telescope				1647,70	1767,04

Required Mass	1653,00

The position of the centre of gravity is at

Direction	Actual value	Requirement
X	2610 mm	-
Y	-41 mm	± 35 mm
Z	58 mm	< 70 mm

The moment of inertia:

I in kg m²	**X**	**y**	**z**
x	1953	-6	240
y	-6	3458	10
z	240	10	3398

6.3.2 Frequencies

The actual frequencies and frequency requirements are summarised in the following table.

Item	Requirement	PDR Status Design[1)]	Remark
HSS hard mounted lateral	24 Hz	24.87 Hz 26.02 Hz	The “critical” bending mode is the second mode with 26 Hz.
axial	70 Hz	71.55 Hz	
Telescope including mounting structure	36 Hz	36.8 Hz	
LOU hard mounted	60 Hz (TBC)	62.14 Hz	
Optical Bench	70 Hz	71.04 Hz	
Herschel S/C axial	34 Hz	35.62 Hz	
Herschel S/C lateral	13 Hz	13.72 Hz	

6.3.3 Margins of Safety

Interface	***Item***	***Load***	***Failure mode***	***Safety Factor***	***Margin***
SVM/ PLM on cone	Titanium Screw M10	7500 N axial, 2222 N lateral	Ultimate	2	49%
			Yield	1.5	43%
			Slipping	1.5	89%
CVV to Supporting Struts	Titanium M10	13000 N axial 1755 N lateral	Ultimate	2	42%
			Yield	1.5	39%
			Slipping	1.5	184%
CVV/ TMS	Titanium M8	6500 N axial	Ultimate	2	63%
			Yield	1.5	57%
CVV/ HSS	Titanium cross section S1	21000 N	ultimate	2	256%
			yield	1.5	244%
	Screw M16	21000 N	ultimate	2	58%
			yield	1.5	48%
CVV/ LOU	Titanium cross section S1	6000 N	ultimate yield	2 1.5	167% 233%
	Screw M8	6000 N	ultimate yield	2 1.5	86% 77%
	Shear pin quality A4	6000 N	ultimate	2	29%
TSS/ SFW	SFW 2219 T62	56000 N	Stress at load introduction	2	9%
OBA/ SFW	Titanium screw M6 for axial load	3090 N	ultimate	2.0	17%
			yield	1.5	11%
	Titanium screw M8	7200 N	ultimate	2.0	82%
			yield	1.5	72%
HTT/ SFW	lateral strut cross section S1 titanium	8900 N	ultimate	2.0	79%
			yield	1.5	123%
HOT/ SFW	Screws M6	331 N axial, 110 N lateral			
HSS/SVM	Titanium Screw M8	3123 N axial 2440 N lateral	ultimate	2.0	34%
			yield	1.5	27%
			slipping	1.5	75%

Margins of Safety on Components:

Component	***Load Case***	***Failure Mode***	***Actual Load/ Stress***	***Critical Load /Stress***	***Safety Factor***	***Margin***
CVV (w/o) upper bulkhead	combined pressure vibration TSS pre-load	Yield	75	140	1.1	69%
		ultimate	75	260	1.5	24%
	buckling	buckling	1.05 bar	2.4 bar	2	14%
CVV upper bulkhead	pressure	Yield	139	140	1.1	-9%*)
		ultimate	139	260	1.5	24%
		buckling	1.05 bar	5.59 bar	2	166%
CVV lower bulkhead	pressure	buckling	1.05 bar	2.9 bar	2	38%
TSS	vibration load	tensile stress	266	700	1.5	75%
SFW	frame	tensile stress yield	130	250	1.1	53%
		ultimate	130	370	1.5	89%
	bone		257	-	1.5	55%
Optical Bench	OB	Bending stress	42	140 (TBC)	1.1	203%
	I/F Brackets	Compressio n Load yield	371	825	1.1	102%
		ultimate	271	839	1.5	67%
		buckling	1 bar	8.7 bar	2	335
HTT	3.06 bar	yield	120	140	1.1	6%
		ultimate	120	260	1.5	44%
	1.76 + vibration loads	yield	95	140	1.1	33%
		ultimate	95	260	1.5	82%
HTT/bulkhead	1 bar external pressure	buckling	1 bar	2.6 bar	2	31%
HTT/Cylindrical part	1 bar external pressure	buckling	1 bar	2 bar	2	0%
HOT	3.06 bar	yield	113	140	1.1	125%
		ultimate	113	260	1.5	53%
		buckling	1 bar	2.22 bar	2	11%
HSS	100 g on SSD in z-direction	ultimate	263	400	1.5	13%

*) According HP-2-APCO-TN-0001, Issue 1, page 61A of the APCO PDR documentation the margin of safety is 25%. This margin is based on a optimised design of that area.

6.4 Power

The results of the PVA reference design performance prediction are summarized in the Table 13 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	**Power**	-	-						
1420 W/m², non-op.	**Temp.**	136°C	114°C						
BOL, SS, LEOP	**Power**	632	516	**1664**	**1500**				
1328 W/m², operating	**Temp.**	105°C	85°C						
BOL, SS, L 2	**Power**	670	547	**1764**		580	473	**1526**	
1405 W/m², operating	**Temp.**	110°C	90°C			97°C	77°C		
EOL (3.5y), SS, L 2	**Power**	613	501	**1615**		531	434	**1400**	**1350**
1287 W/m², operating	**Temp.**	99°C	79°C			86°C	67°C		
EOL (6.0y), SS, L 2	**Power**	600	491	**1582**		520	425	**1370**	**1230**
1287 W/m², operating	**Temp.**	99°C	79°C			86°C	67°C		

Table 13: PVA performance prediction

6.5 Field of View

The following figures indicate the field of view of the instrument and the clearance to the different structural items.

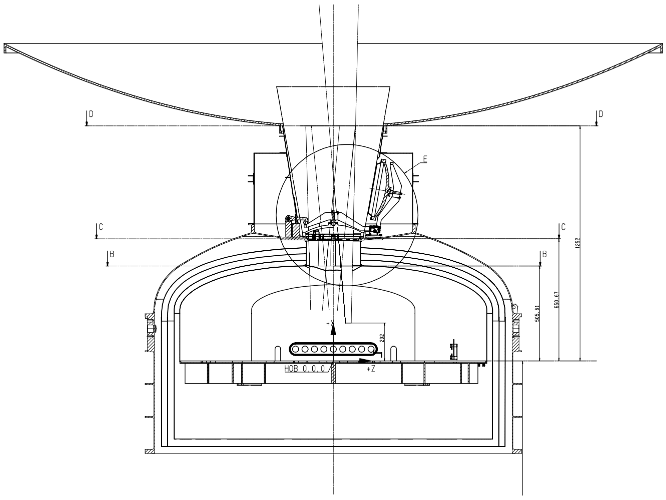


Figure 43: Overall Configuration

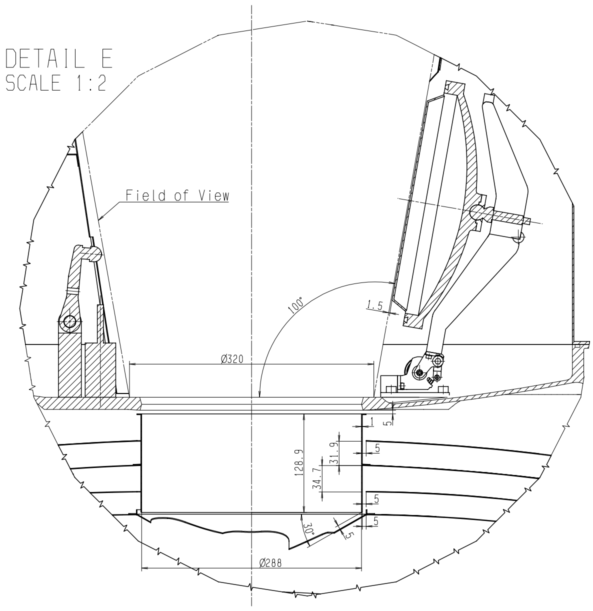


Figure 44: Detailed Beam Entrance Baffle and un-obscured FOV

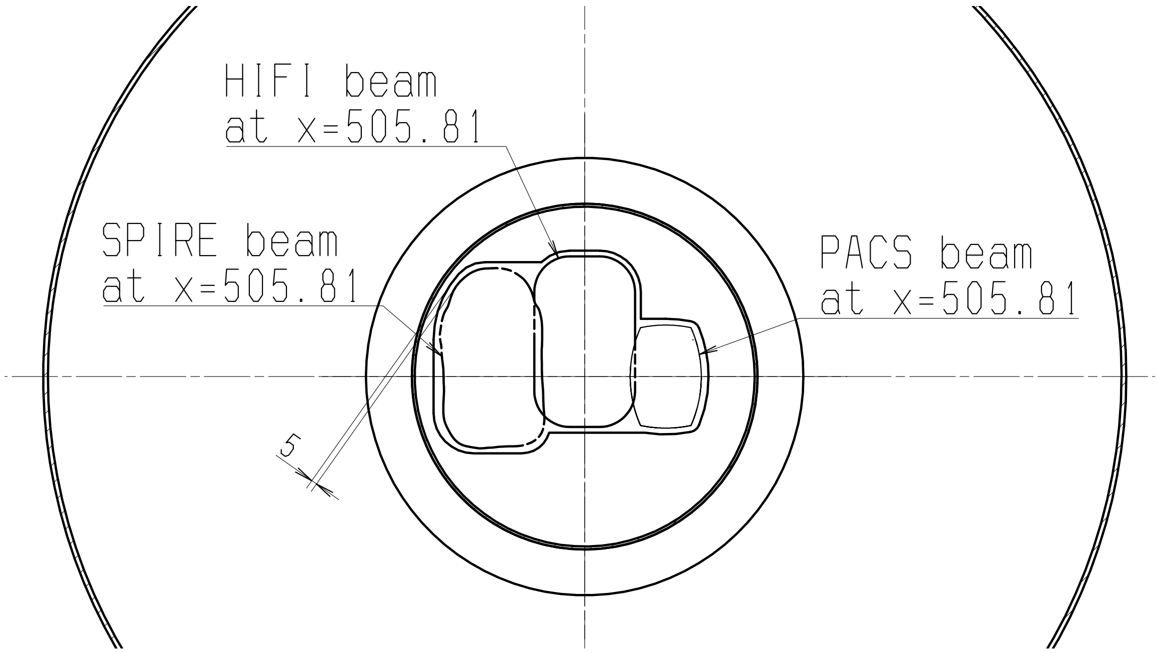


Figure 45: Instrument Beams at Instrument Shield Aperture

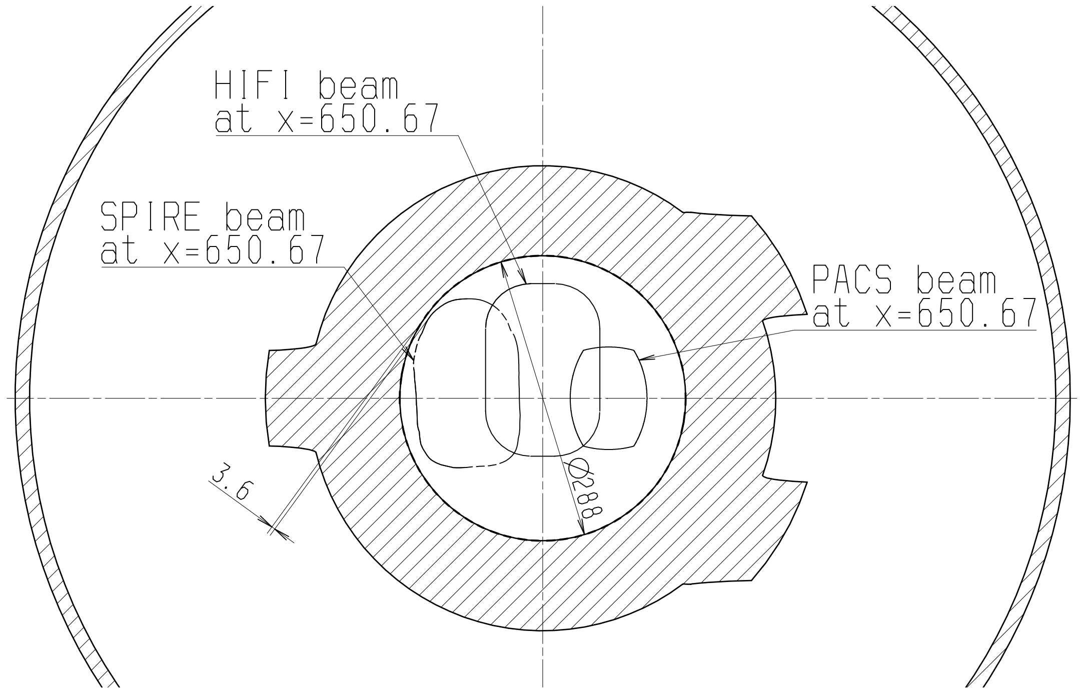


Figure 46: Instrument Beam at CVV Aperture

6.6 Alignment

The following tables summarise the achievable alignment results. The values are compared to the IID-A requirements and the numbers under discussion within the HOWG meetings.

6.6.1 Instruments w.r.t. Telescope

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

Table 14: Alignment Budget: Instrument w.r.t. Telescope

	PACS	SPIRE	HIFI	Remarks
Achievable Values X Direction	±5.8mm	±5.5mm	±7.8mm	
Requirement IID-A HOWG HIFI	 ±11.0mm ±7.1mm	 ±11.0mm ±7.7mm	 ±11.0mm ±7.7mm ±8.5mm	 1) 2)
Achievable Values Lateral	4.0mm	4.5mm	16.8mm	3)
Requirement IID-A HOWG HIFI	 8.0mm 6.8mm	 8.0mm 9.5mm	 8.0mm 9.5mm 24.0mm	3) 1) 2)

1) Values proposed by Astrium during the HOWG meeting, 11.03.02 (based on 1σ and rss summation). Must be updated to 2σ as stated during the HOWG meeting.

2) Proposed by HIFI

3) Half cone angle

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 15: Alignment Budget: LOU w.r.t. HIFI FPU

	Δx	Δy	Δz	Rx	Ry	Rz
Achievable value	0.71mm	0.82mm	0.61mm	89.4 arcsec	63.6 arcsec	101.9 arcsec
Requirement HIFI IID-B	0.75mm	15mm	0.75mm	137 arcsec	1)	137 arcsec

All values ±

1) included in Δx according to requirement

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

Table 16: Alignment Stability Budget: LOU w.r.t. HIFI FPU

	Δx	**Δy**	**Δz**	**Rx**	**Ry**	**Rz**
Achievable value 1)	0.008mm	0.008mm 3)	0.001mm	0.17 arcsec	0.12 arcsec	0.57 arcsec
Requirement HIFI IID-B 2)	0.075mm	0.003mm	0.075mm	10.8 arcsec	144 arcsec	10.8 arcsec

All values ±

1) Calculated for LC3-LC1 (steady state analysis)

2) Within 100sec. The very high stability along the y axis should be regarded as a goal (according to HIFI IID-B, issue 2/0)

3) It is expected that due to the high heat capacity of the HSS and the heat capacity of the LOU the goal value of 0.003mm within 100sec. can be achieved

6.6.3 Line of Sight Stability

For the stability assessment the difference of the 4 load cases has been calculated. The results are as follows:

Definition of the load cases:

- LC 1 WS 0°/0° EOL (Pitch/Roll)
- LC 2 WS +30°/0° EOL
- LC 3 WS –30°/0° EOL
- LC 4 SS 0°/0° BOL

Results: (half cone)

- LC1 – LC2 = 0.055 arcsec
- LC1 – LC3 = 0.81 arcsec
- LC1 – LC4 = 0.63 arcsec
- LC2 – LC3 = 0.86 arcsec
- LC2 – LC4 = 0.69 arcsec
- LC3 – LC4 = 0.18 arcsec

The preliminary data show that the requirement of 0.2 arcsec cannot be met for all cases (assuming unlimited time intervals). However, we assume that in case the stability requirement is applied to a certain time interval, e.g. a typical observation cycle, the requirement could be met. Currently the stability requirements are based on an unlimited time interval and all load cases.

6.7 Straylight

a) <u>Thermal self emission</u>

The following table provides the calculated thermal self-emissions onto PACS and SPIRE detectors in relation to the self emission of M1 + M2. This self emission of M1 + M2 is set to 100 (used as normalisation). So the specification is violated, if the sums exceeds 10 for thermal self emission. The detailed results are covered in the Herschel Straylight Calculation Results, HP-2-ASED-TN-0023.

Table 17: Sum of Self Emission onto PACS and SPIRE detector

Configuration with Cone-Baffle		Configuration with Cylinder-Baffle	
PACS DETECTOR	**SPIRE DETECTOR**	**PACS DETECTOR**	**SPIRE DETECTOR**
17.597	**13.249**	**18.251**	**13.312**

b) <u>Straylight from external sources:</u>

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, i.e. M1 and M2).

Table 18: 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
moon at 13 degrees, cylinder baffle	8.09E-04	4.37E-04
earth at 23 degrees, cone baffle	4.09E-03	1.81E-03
earth at 23 degrees, cylinder baffle	4.22E-03	1.72E-03

Table 19: Specific Moon locations, 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.

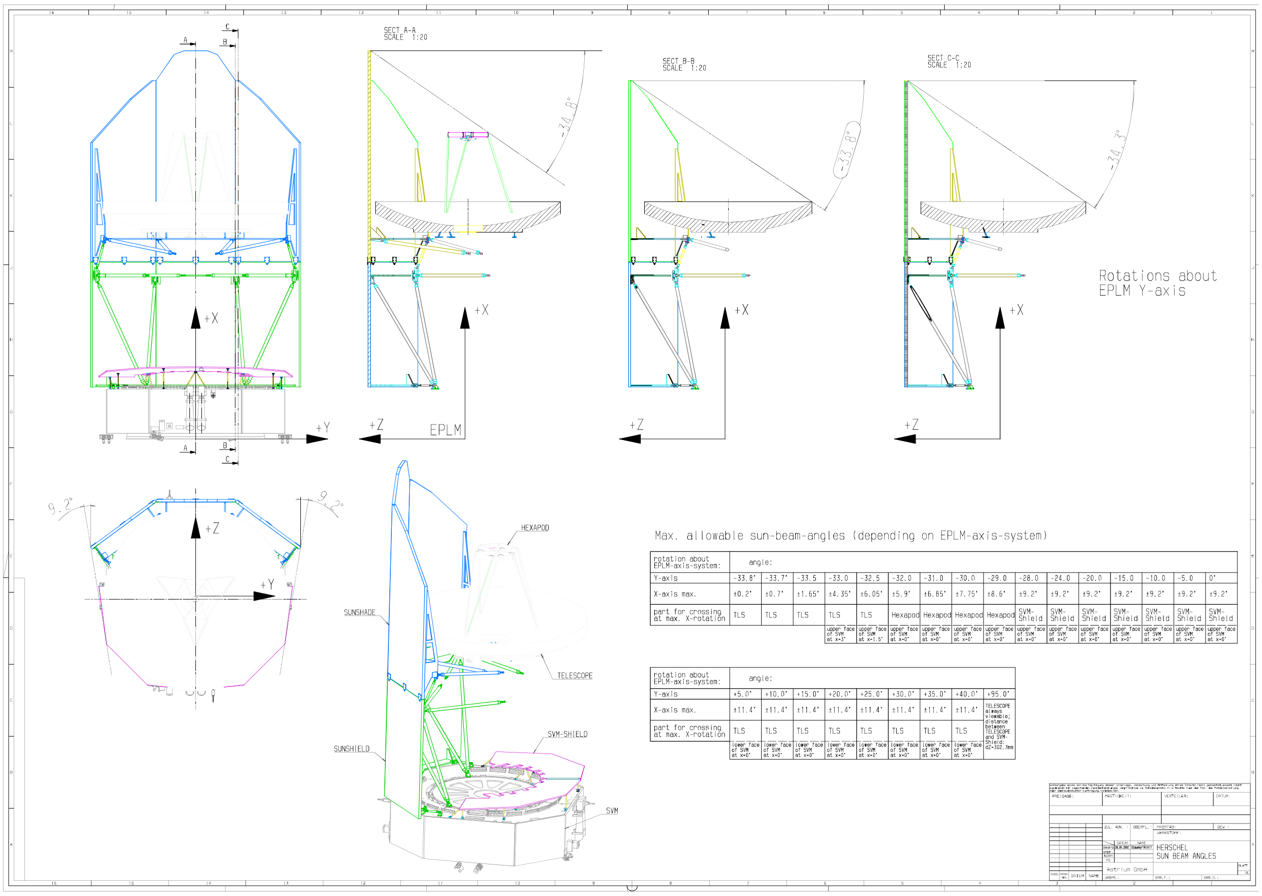
Thus, the specification of 1% is violated.

6.8 Shading Function of HSS

The following figure shows the angle, which causes sun light on the PLM and telescope.

To the requirement of -+ 30 degree around y-axis and +- 1 degree around x- axis a margin of 2 degree for the diffraction and a 0.25 degree for solar radius. The following figure shows that we are well within the requirement for the operation mode.

The other two cases has to investigated more in detail.



rotation about EPLM-axis-system:	angle:															
Y-axis	-33.8°	-33.7°	-33.5	-33.0	-32.5	-32.0	-31.0	-30.0	-29.0	-28.0	-24.0	-20.0	-15.0	-10.0	-5.0	0°
X-axis max.	±0.2°	±0.7°	±1.65°	±4.35°	±6.05°	±5.9°	±6.85°	±7.75°	±8.6°	±9.2°	±9.2°	±9.2°	±9.2°	±9.2°	±9.2°	±9.2°
part for crossing at max. X-rotation	TLS	TLS	TLS	TLS	TLS	Hexapod	Hexapod	Hexapod	Hexapod	SVM-Shield	SVM-Shield	SVM-Shield	SVM-Shield	SVM-Shield	SVM-Shield	SVM-Shield
				upper face of SVM at x=3°	upper face of SVM at x=1.5°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°	upper face of SVM at x=0°

rotation about EPLM-axis-system:	angle:								
Y-axis	+5.0°	+10.0°	+15.0°	+20.0°	+25.0°	+30.0°	+35.0°	+40.0°	+95.0°
X-axis max.	±11.4°	±11.4°	±11.4°	±11.4°	±11.4°	±11.4°	±11.4°	±11.4°	TELESCOPE always viewable; distance between TELESCOPE and SVM-Shield: dZ=302.3mm
part for crossing at max. X-rotation	TLS	TLS	TLS	TLS	TLS	TLS	TLS	TLS	
	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	lower face of SVM at x=0°	

Figure 47: Shading of the PLM via HSS

Note: The values provided in table are shown in Figure 48.

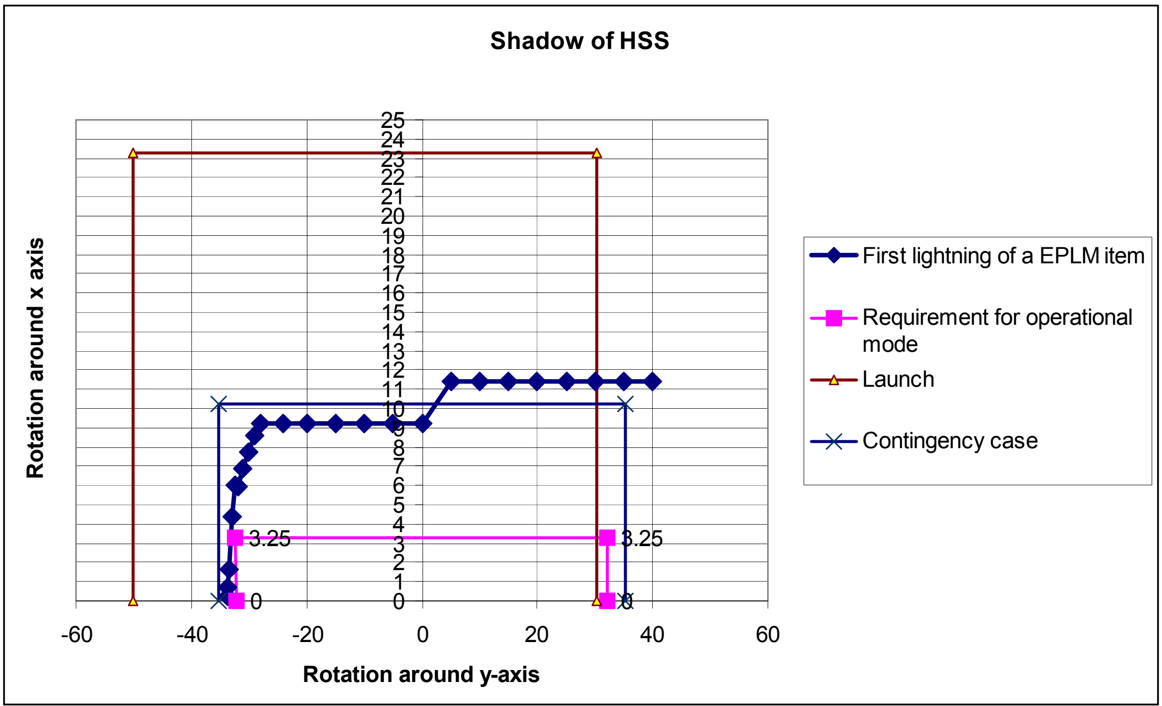


Figure 48: Shading of function

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	S/C outside	TELESCOPE	FPU and Optical Bench
Level at delivery to Astrium	200	400	300	300
AIT, incl. cleaning steps	500	2200	2200 1)	200
Lift off phase	0	1300 3)	1300 3)	0
In orbit (redistribution, µmeteorides)	0	100	100	0
Total EOL	**700**	**4000**	**3900**	**500**
Requirements	1200	4300 2)	4300	1200

PARTICULATE in ppm	PLM inside CVV	S/C outside	TELESCOPE	FPU and Optical Bench
from instrumenters				
Remaining margin	500	300	400	700

1) No cleaning foreseen, but protection with cover during majority of AIT sequence

2) Not required from instrumenters, value taken from telescope requirement

3) Considering 1000 ppm from fairing during lift off, tbc by Alcatel-negotiations with Arianespace

Molecular contamination budget

MOLECULAR in 10-7 g/cm2	PLM inside CVV	S/C outside	TELESCOPE	FPU and Optical Bench
Level at delivery to Astrium	2	2	2	30
AIT, incl. cleaning steps	4	25	2	1
Contamination from CVV internal outgassing	n. a.	n. a.	n. a.	25
Water ice from air permeation	tbd	n. a.	n. a.	tbd
Lift off phase	0	6	6	0
In orbit (outgassing, thruster plume)	0	tbd by ASPI	tbd by ASPI	0
Total EOL	**6**	**33**	**10**	**56**
Requirement	60	40 2)	40	60
Remaining margin	54	7	30	4 1)

1) Low margin for FPU due to high level at delivery

2) Not required from instrumenters, value taken from telescope requirement

7 Cleanliness

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

Since the particle and molecular contamination requirements of the a.m. document were not accepted by ESA, a working group called "Cleanliness Team" has been established, which is led by ESA and which is supported by specialists from Alcatel and Astrium GmbH.

The purpose of the Cleanliness team is 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 will be summarised in the Cleanliness Team Report, issued by Alcatel.

7.1 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, together with transport conditions and test chamber environments.

7.2 Cleanliness critical areas

7.2.1 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.

7.2.2 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.

7.2.3 S/C Outside incl. Telescope

The outside cleanliness also encompasses the cleanliness of the telescope mirrors. The baseline is to avoid a cleaning of the telescope by protecting it with a cover during most of the AIT activities.

7.3 Particle Contamination

7.3.1 He Subsystem

From our present level of knowledge the only way to pursue is to follow all 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 to the He filling port as possible. Also the ISO process of generating He II will be scrutinized from a cleanliness aspect.

Special cleaning procedures shall be established for the He dewars. 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.

7.3.2 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 must be 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 added by the contamination budget of AIT activities, including all precaution/cleaning planned, will result in an EOL obscuration factor of < 700 ppm (incl. margin) for all surfaces inside CVV.

7.3.3 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 window for the Local Oscillator 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 Arianespace guarantees a particle fall out of lower than 5000 ppm. Negotiations will be initiated to improve this value to max. 1000 ppm.

Cleanliness of test setups will be commensurate with the above outlined cleanroom category.

Cleanliness of transportation containers shall have a particle fall out of max. 25 ppm per transport.

7.4 Molecular Contamination

7.4.1 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 should only be performed with oil-free pumps or properly trapped pumps in combination with fast closing safety valves. Any molecular contamination will be frozen 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.

7.4.2 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 failures. The cryo pumping action of a cold He reservoir usually 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 electrically actuated shut-off valve at the vacuum port of the cryostat
- ASED investigates the use of an oil free roughing pump e.g. a membrane pump.
- 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 vacuum 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 preliminary 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. Particular problems were encountered in heating all parts of the H-PLM to a uniform temperature. A bake out of 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.

A temperature cycle from cold to warm is one of the most critical activities with respect to molecular contamination redistribution. A potential molecular deposit will be automatically redistributed to the coldest surface during the warm up phase. This must be considered, i.e. the FPU should always be the ´warmest´ area during such a temperature cycle to avoid a molecular contamination deposition on these critical units. Details will be explained in the EPLM Contamination Control Plan.

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 mirror. 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 have been completed. The influence of attitude thrusters need separate attention, which will be defined in the Cleanliness Team Report.

Operational procedures in orbit must be scrutinized for compatibility with cleanliness requirements.

7.4.3 S/C Outside

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

8 Alignment

This chapter provides an overview about the Herschel alignment concept. A more detailed description is given in the document: /Herschel Alignment Concept, HP-2-ASED-TN-0002/.

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 LOU 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 the Herschel Alignment Concept, /HP-2-ASED-TN-0002/. 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. Alignment of the OB w.r.t. the LOU windows
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 TBC (step 6).
6. Alignment measurement of OB reference cube w.r.t. a reference cube mounted outside the CVV.
7. Closing the CVV cover, evacuation and cool down.
8. Re-adjustment of the tank straps and alignment control using the LOU Alignment camera
9. LOU integration and alignment measurement w.r.t. the HIFI FPU via two additional alignment windows using the LOU Alignment camera.
10. Telescope integration.
11. Alignment measurement of the telescope reference cube w.r.t. the CVV cube
12. After mating of the SVM with the PLM the SVM master alignment cube will be measured w.r.t. the CVV cube.
13. Alignment check after evacuation and cool down.
14. Alignment check before and after environmental testing

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.

8.1 EQM Alignment

With the EQM the alignment procedure shall be verified at an early stage of the AIV programme. The effect on alignment due to pressure change and cool down will also be determined. The effect on alignment due to outer CVV temperature change can only be verified with the STM inside the TV chamber and use of the LOU alignment camera. The test sequence for the EQM (concerning alignment) is as follows:

.....PLM Integration → Alignment → Closing Cryostat → Evacuation → Alignment check → Cooling → Alignment check → Other Tests.....

Only the alignment relevant steps have been shown. The complete test plan is shown in the Herschel PLM/EQM AIT Plan, HP-2-ASED-PL-0022.

The main tasks are the following:

- Early verification of the alignment as far as possible (no telescope on EQM)
- Verification of pressure and temperature change effects on alignment (with an outer CVV temperature at 300K)
- Lessons learned with the EQM can already be applied for the STM
- Risk reduction for the STM and FM programme

Monitoring the shift and angular deviation of the OB after cryostat evacuation and cool down will be performed using the LOU alignment cameras TBC.

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). A distance measurement in y direction is also possible, however, with reduced accuracy TBC. This is no problem for the LOU alignment because the distance requirement w.r.t. this axis is very comfortable (± 15mm for LOU w.r.t. HIFI FPU).

With the actual feature having also a measurement capability in y direction (with improved measurement accuracy) with the LOU alignment camera this camera will also be used to re-adjust the tank support suspension devices after cool down under alignment control.

The advantage to have the LOU alignment camera would be, that it can also be used for the STM programme inside the TV chamber and no additional alignment window is needed.

The LOU alignment camera will be used at the following stages during the whole AIV programme:

1. Alignment of LOU w.r.t. HIFI FPU verification.
2. Re-adjustment of Tank Suspension after cool down.
3. Measurement of CVV shrinkage w.r.t. OB (HIFI) inside TV chamber with the STM and confirmation of the mathematical model.
4. Partial measurement of LOU w.r.t. HIFI stability and confirmation of mathematical model TBC.
5. Alignment check before and after environmental testing and after evacuation and cool down.

Measurement no. 3 and 4 will be performed at nearly in-orbit representative CVV temperatures.

8.2 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.

The main tasks are as follows:

- Qualification of the structure (stability)

  (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 LOU alignment camera).
- Confirmation of the mathematical model

The actual test sequence is as follows (only alignment related steps):

.....PLM Integration→Alignment→Closing Cryostat→Evacuation→Alignment check→Warm vibration→Alignment check → Cooling→Alignment check→Telescope integration→ Telescope alignment→.....→TB / TV Test→Alignment check→ .....→Cold vibration→Alignment check→.....→Acoustic noise→Alignment check......

Monitoring of the alignment stability at nearly in-orbit representative CVV temperature will be performed during the TB/TV test using the LOU alignment camera TBC.

8.3 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.

The test sequence is as follows (only alignment relevant steps):

.....PLM integration→Alignment→Evacuation→Alignment check→Cooling →Alignment check→.....→Telescope integration→Telescope alignment →Transport to test facility→.....→Alignment check→Cold vibration→Alignment check→.....→TB/TV test→Alignment check→.....→Acoustic noise→Alignment check

After mating of the SVM with the PFM the SVM master alignment cube will be measured w.r.t. the CVV cube. The alignment of the AOCS related components w.r.t. the SVM master alignment cube is the task of Alenia.

9 Straylight

The following major components contribute to the straylight budget:

- Telescope
- FPUs
- Baffles
- HSS.

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

The iterations performed during the integration of the SPIRE model resulted in suggestions concerning

- the SPIRE FP_UNIT (suggestion: make as much absorbing as possible)
- the SPIRE chopper unit (suggestion: align it with the primary mirror inner hole).

For the telescope the detection of specular straylight paths (different from the desired one via M1 and M2 only) are very important. Here the struts of the telescope spider act as small plane reflecting mirrors opening sidepaths towards the sky. Such sidepaths could only be avoided/reduced, if

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

One of both possibilities is sufficient.

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 cyro-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 of 560 mm. The diameter to be used by the M1-baffle components was set to 550 mm, thus there is gap with 5 mm width.

Two variants of the M1-baffle have survived the first considerations and calculations:

- the cone baffle
- the cylinder baffle

The cone baffle has an upper diameter of 550 mm, thus starts at the gap. In a sense, it replaces warm bodies by cold space within the view of the telescope focal plane. The alternative of the cylinder baffle starts near the CVV opening with the same radius as the cone baffle. This radius is kept for the whole length up to the primary mirror. There a flat ring is placed covering the space out to the gap and the primary mirror.

The decision between cone baffle and cylinder baffle depends not only on the results of the straylight calculations (see HP-2-ASED-TN 0023), but also on astronomical considerations on the view to cold space in case of the cone baffle. In terms of straylight onto the detector, there are no large differences between the cylinder baffle and the cone baffle (the latter is only slightly better for PACS). However, in terms of total thermal flux entering the inner cryostat volume there is a significant advantage of the cone baffle.

The cone baffle, as shown in Figure 49, is the baseline.

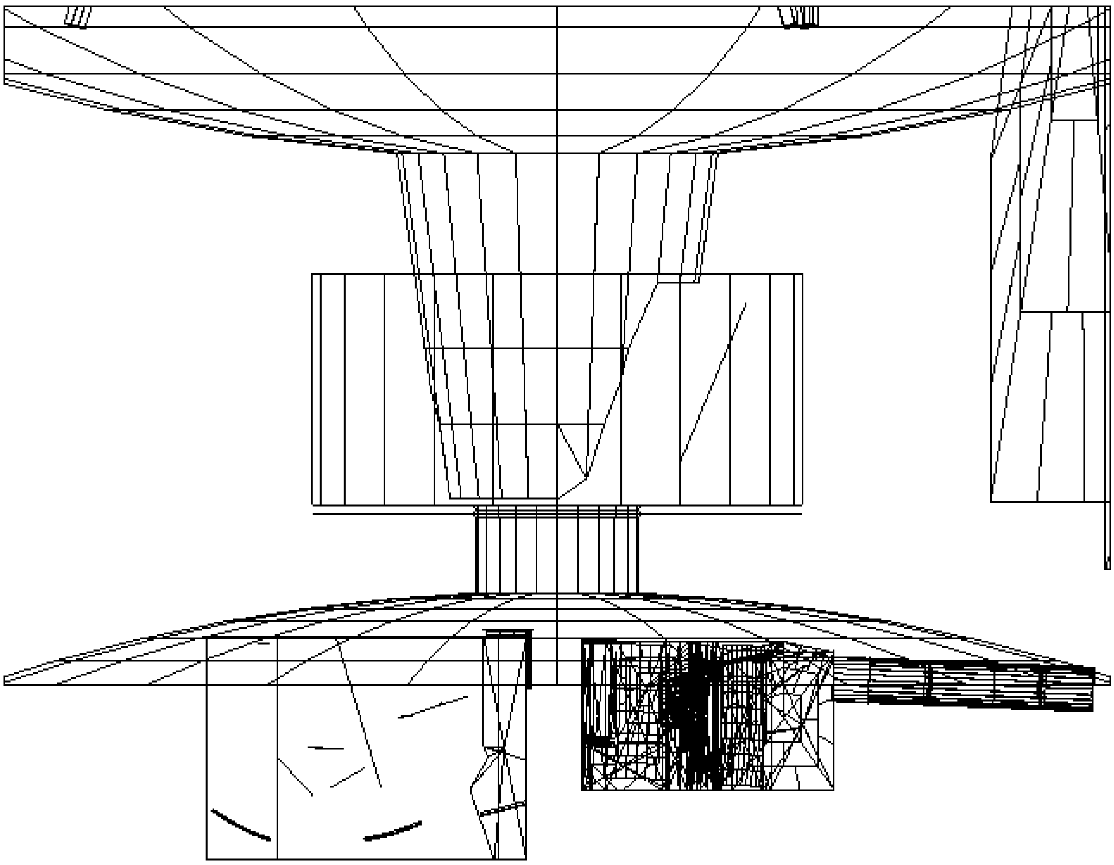


Figure 49: Cone baffle

10 Reliability and Safety

10.1.1 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 based on the design, experiences and lessons-learned from the ISO program.

10.1.2 Reliability and Fault Tolerance

For the Cryo-Control-Unit CCU design a reliability analysis will be performed to demonstrate that all reliability 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 one branch only of the CCU.

FMECA

Failure mode, effect and criticality analysis has been performed for the E-PLM, 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 pipework
- 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 the FMECA, HP-2-ASED-RP-0031.

- 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 present design all ground operation valves of the CVV He system will be in a single non-redundant configuration, and the flight operation valve are redundant. Adequate handling procedures will support all ground operations, which will be applied by properly trained personnel. Furthermore, all necessary system parameters will be monitored via the Cryostat EGSE respectively via the safety vent system so that a false valve position will be detected immediately during ground operations.

The cover actuator is equipped with redundant initiators, and redundant opening drive 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 according to the redundancy concept as applied for ISO.

10.1.3 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 preliminary 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.

Potential hazardous events, e.g. external leakage/burst of an item, will be controlled by adequate procedures defining safety requirements and operational constraints, by tests (leakage tests, pressure 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 foreseen.

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 the Critical Items List.

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 respectively will be applied 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	2,0

These safety factors shall apply to design limit loads.

The implementation of the safety factors will be analytically verified by a positive margin of safety.

Cryostat Safety Philosophy

The E-PLM-cryostat safety concept is based on the successfully performed ISO-cryostat safety system (as described in ISO-AN-BC140.001). The following introduces the safety concept together with the main safety components by means of different potential failure modes.

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. As its predecessor ISO, 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)
- Use of rupture discs with the reversed buckling membrane principle as the ultimate safety device, which are considered as inherent redundant

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), loss of sufficient oxygen in the remaining air and loss of orientation due to dense fog generation.

As shown in the Herschel Safety Analyses Data Package HP-2-ASED-DP-0001 the ISO Safety Concept can be used for Herschel. The following failure cases are assumed.

Category	Failure case	Expected mass flow rates (at 5 K)	Venting via	Release pressure
Negligible	small He-leak	0.23 g/sec	Ventline	
	small CVV leak		SV521	0.25 to 0.35 set pressure (1.35 bara)
critical	medium He-leak medium CVV leak	86 g/sec	Safety valves	
			SV123	1.6 ± 0.16 bara
			SV121	0.45 ± 0.15 set pressure
catastrophic	Loss of insulation vacuum	5 kg/sec	Burst disc	
			RD124 / 724	2.8 ± 0.26 set pressure
			SV921+ SV922	0.4 ± 0.05 set pressure

Due to the fact, that the Helium-II tank (HTT) contains ~2100 litre superfluid Helium and the Helium-I tank (HOT) only approx. 80 litre, the safety concept is driven by the main superfluid tank.

All cryo-vacuum servicing equipment being connected to the cryostat shall be designed such that it will not produce any overpressure in excess of the set values of SV 123,or SV 921/SV 922, respectively, nor produce a He mass flow rate exceeding the flow capabilities of SV 123.

The location of the safety relief valve SV 922 fixed at the vacuum vessel shall be opposite to the rupture disc RD 124 to allow a free exhaust of GHe for the greatest assumed failure case. The heat shields will have holes and the MLI will be sliced on the path between the rupture disc and the safety valve.

For all potential hazardous failure modes, especially by loss of the insulation vacuum in the CVV (on ground or during launch), danger to personnel caused by a burst of the He I or He II tank and consequently a burst of the CVV is in the end prevented by two rupture discs (RD) flanged directly to the He tanks and by the corresponding safety relief valves at the CVV.

The rupture discs are designed to burst far below the burst pressure of the He tanks, the cross sections of the safety relief valves are sufficient to vent the He mass flow produced during loss of the insulation vacuum.

Other safety valves (warm and cold ones) will release any irregular overpressure in the He S/S to the atmosphere well below the burst pressure of the RD. This leads to a consequent and stepwise reaction of the safety system in relation to the different expected pressure levels for the assumed failure modes of the He S/S and guarantees the double failure tolerance.

Potential Failure Effects

A failure in the cryostat subsystem will be caused by 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 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.

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 will strongly increase due to external heat input until the safety valves open and GHe will be released via the filling line or via the vent line to the atmosphere.
- Unintentional closure of the vent system - as described above certain safety valves opened after an overpressure will be recognised and GHe will be released via the filling / vent lines to the atmosphere.
- Unintentional warm-up of the He-bath by electric heaters - 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, 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 will increase the heat input to the He II tank by the high heat conduction of the He gas, the tank pressure will increase significantly until the safety valves open and the GHe will be released as described above.
- Loss of insulation vacuum - in this worst case failure mode, air will penetrate through a leak into the CVV and will condense on the walls of the He tanks. Due to the large latent heat and the heat of condensation of air, the He II and He I tanks will warm up and consequently the He evaporation rate becomes high.

The following leaks in the vacuum vessel can be conceived:

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

In case of a burst of an optical window with a diameter of 34 mm (the maximum air-leak) approx. 0,175 kg/s air would be cryo-pumped by the He II tank resulting in a GHe mass flow rate of approx. 5,03 kg/s according to the ISO Safety Analysis. This will lead to a burst of the rupture disc. The GHe mass flow in the CVV will be released then via SV 921 / 922 to the atmosphere.

11 AIV

11.1 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.

11.2 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 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.

11.2.1 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.

11.2.2 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

11.2.3 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.

11.2.4 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.

11.2.5 Electronic Units Integration

Remark: This and the following chapters 11.2.6 and 11.2.7 are not necessarily applicable for the qualification test phase as all (TBC) electronic units are replaced by MTD's/STM's. However, in case a QM or FM unit (e.g. CCU) will be used during this phase, this chapter becomes applicable.

MTD/STM units will be equipped with replacement heaters and thermistors. Their function will be verified during 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.

11.2.6 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 interfaces 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.

11.2.7 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.

11.2.8 Alignments

11.2.8.1 Alignment Plan

This chapter defines the alignment philosophy and the measurements which will be performed during the various steps of integration and testing with the STM (and PFM, EQM). 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 0 bar
- Outer CVV temperature

These effects must be determined and have to be pre-compensated by a corresponding offset on-ground. The experience gained with theoretical determination of this offset and its confirmation during testing with EQM PLM will be applied for PFM PLM activities.

Also the effects due to internal temperature and pressure changes being confirmed during on-ground testing of EQM shall be considered, however, the effect on alignment of outer CVV temperature change can only accurately be verified during TB/TV testing, and the gravity release effect can only be determined theoretically. Restrictions must also be made for the testing of the temperature change.

Alignment of the Herschel elements has to be performed in multiple steps and can be divided in three main areas.

11.2.8.2 PLM Alignment

The instrument alignments are achieved by multiple measurements during integration and test

- alignment of optical bench (OB) versus CVV after OB integration
- alignment of FPU's versus OB after FPU integration
- alignment of LOU versus HIFI after LOU integration through open cover and/or optical window using alignment camera (TBC)
- alignment check HIFI vs. LOU after CVV evacuation through optical window (warm)
- alignment check HIFI vs. LOU during/after cool down, filling and final adjustment of strap pretension

11.2.8.3 SVM Alignment

ALENIA performs the SVM alignment i.e. AOCS and RCS sensors, actuators, and thrusters during module integration versus a SVM master reference cube.

11.2.8.4 Satellite System Alignment

During satellite final integration, the system alignment consists of two main steps:

- alignment of telescope versus CVV
- measurement of the PLM axis versus SVM axis

During the various steps of PLM refurbishment and reintegration after qualification test phase completion, PFM satellite integration and testing, these measurements are repeated at appropriate steps.

11.2.9 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.

11.2.9.1 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 the refurbished ISO CVSE.

Cooldown and filling will start after successfully performed leak test of the internal Helium S/S to the cryostat isolation vacuum and isolation vacuum to ambient. After filling of the main tank with LHe-I, a cold leak test will be performed.

Similar procedures will be used for filling the auxiliary tank with He-I. Cool-down and filling will be performed with x-axis in vertical direction only.

11.2.9.2 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 the refurbished ISO CVSE.

He-II production and top up will be performed with x-axis in vertical direction only.

Specific constraints (TBD), e.g. thermal gradients limited for instruments, will be strictly observed.

11.2.9.3 Depletion and Warm Up

Depletion and warm-up activities, if necessary, will be performed according dedicated procedures also based on verified ISO and Herschel EQM PLM documents and using the Herschel (refurbished ISO) 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.

11.2.10 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 Handling and Transportation during Qualification Test Phase Technical Note (HP-2-ASED-TN-0024).

A description of the major facilities and GSE needed and the major transportation steps are shown in Facility and Transportation Plan (HP-2-ASED-PL-0014).

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

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

11.3 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.

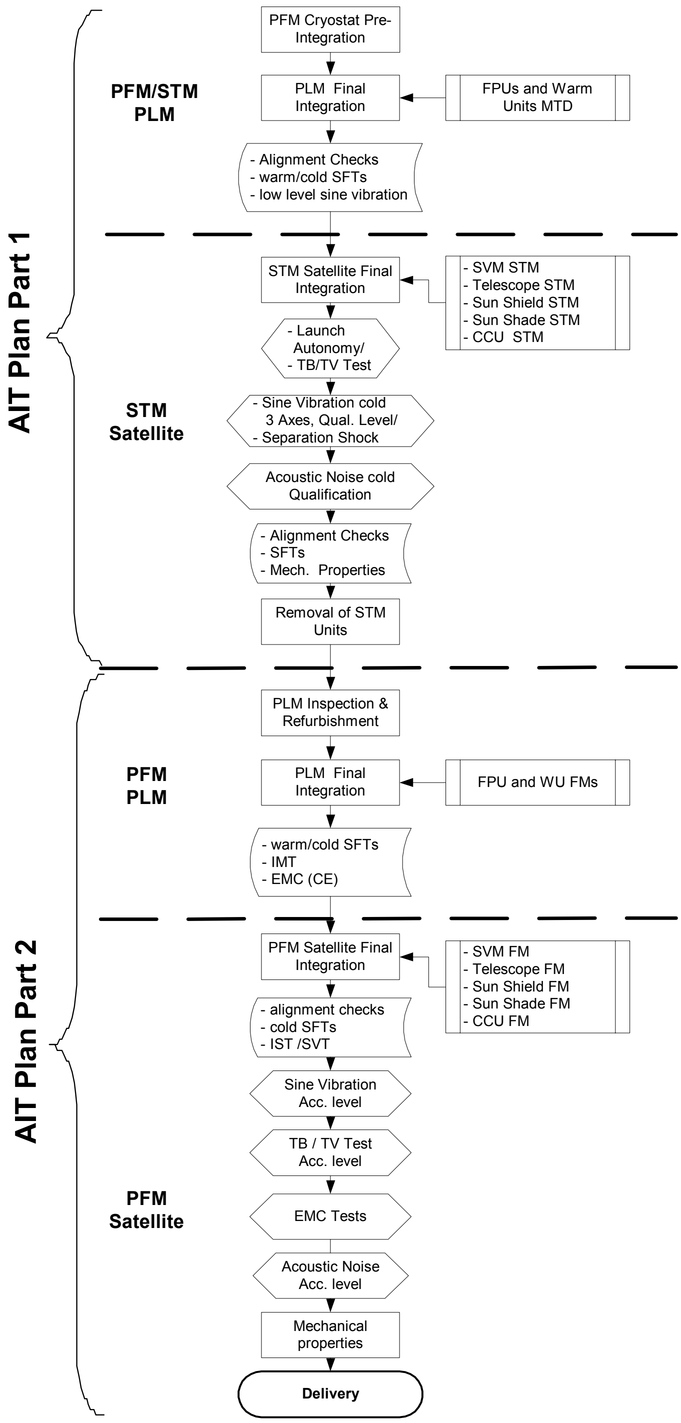


Figure 50: Simplified PLM and Satellite STM/PFM qualification and acceptance AIT Flow

11.4 PLM (PFM/STM) Level Integration and Testing

11.4.1 PLM integration

The PFM PLM will be integrated for the first time to support the satellite Structural and Thermal Model (STM) testing.

While the complete Cryostat, the SVM thermal shields, the support structures and the Harness basically will be completely PFM standard, the following items to be integrated are Mass & Thermal Dummies (STM's/MTD's) and will need to be replaced after satellite STM testing:

- Instrument Focal Plane Units (FPU) for PACS, HIFI, and SPIRE
- LOU incl. radiator
- BOLA incl. radiator
- CCU

The major activities during the first PFM/STM PLM integration are summarised as follows:

- Pre-Integration Thermal Shield Group
  - Cleaning of individual elements to class 100 needs
  - installation of temperature sensors and harness
  - installation of MLI onto elements
  - assembly of shield group
  - welding of tube joints
  - x-ray, proof pressure and leak checks
  - final internal cleaning
- PFM Cryostat Pre-integration
  - Pre-integration SFW & HTT
  - Pre-integration CVV cylindrical part
  - Assembly CVV &He-II- tank & cylindrical shields
  - Installation and functional check of internal harness (CCH & SIH)
  - Integration He-I tank
  - Integration of sensors for vibration
  - Integration lower shields & lower bulkhead
- Integration and alignment of Optical Bench (OB)
- Integration and alignment of Instrument FPU MTD's
- PFM/STM Cryostat Final Integration
  - Integration of OB shield (straylight tight)
  - Integration of OB MLI (straylight tight)
  - Preparation safety valves, shields, upper bulkhead
  - Assembly upper shields (MLI pre-integrated)

  - Assembly upper bulkhead
  - Connection of filling port SV121 & leak test
  - Integration and alignment of LOU MTD & waveguides
  - Integration of Cryostat Cover (CC) and Cryostat Baffle (CB)
- Evacuation & leak check
- Warm alignment checks
- Transport to clean room 100.000
- PLM external integration
  - Installation external tubing
  - Connect CVSE / continue evacuation until start of cool down
  - Integrate sensors for vibration
  - Integrate BOLA MTD
  - Integrate and functional check of external harness (CCH & SIH)
  - Electrical connection to Cryo SCOE and CCS light

The PLM integration sequence is completed with a Short Functional Test Warm (SFT). For more details about the flow and the schedule see AIT Plan Part 1

11.4.2 PLM Testing

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

- Sine vibration low level, 2 axes, warm
- SFT, warm
- Cool down & filling with He-I
- Alignment measurement during cool down & adjustment as necessary
- SFT He-I
- He-II production & top-up
- SFT He-II
- Conversion to He-I

For more details about the flow and the schedule see AIT Plan Part 1.

11.5 Satellite (PFM/STM) Integration and Testing

11.5.1 Satellite (PFM/STM) Final Integration

To complete the PFM/STM satellite, the following steps will be undertaken to assembled the remaining elements to the PLM (still in cold He-I condition)

- Mating and alignment of SVM STM including support structure
- assembly of SVM thermal shield STM
- Integration and alignment Telescope STM including support structure
- Integration and electrical connection (heaters) of Sunshield/Solar Array STM including support structure
- Integration of Sunshade STM including support structure
- Integration of remaining external MLI

This integration phase is completed with another SFT. For more details about the workflow and the schedule see AIT Plan Part 1.

11.5.2 Satellite (PFM/STM) Qualification Tests

To mechanically and thermally qualify the satellite the following main test and inspection steps are foreseen on the STM satellite. The Launch Autonomy and TV/TB tests are performed under He-II conditions. The remaining tests are done with He-I. At the end of the STM test campaign the cryostat is depleted and warmed up to ambient temperature.

- He-II production & top-up
- Ground lifetime and launch autonomy verification (in parallel to TB/TV preparation)
- Thermal balance and thermal vacuum test including alignment checks (TBC), He-II
- Conversion to He-I
- SFT and alignment check, He-I
- Sine vibration qualification level, 3 axis, He-I
- SFT and alignment check, He-I
- LVA fit check and clamp band separation shock test, He-I
- SFT and alignment check, He-I
- Acoustic noise test qualification level, He-I
- SFT and alignment check, He-I
- Depletion & warm-up; remove test harness
- Mechanical properties measurement (mass, COG y/z)
- transportation to Astrium AIT site
- Final inspection, PLM disassembly and refurbishment definition

11.6 PLM (PFM) Level Integration and Testing

11.6.1 PLM (PFM) Refurbishment and Integration

Based upon final inspection results after completion of 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 PFM/FM units will replace the mass and thermal dummies of the PFM/STM satellite:

- Instrument FPU's for PACS, HIFI, and SPIRE
- LOU incl. radiator
- BOLA incl. radiator
- CCU

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 WU's on SVM Panels
- Electrical Integration of WU's
- Interface verification (SVM I/F's provided by PLM EGSE)
- EGSE harness connection
- FPU Simulator Integration
- Test FPU Simulator with Warm Units
    - HIFI test sequence debugging
    - PACS test sequence debugging
    - SPIRE test sequence debugging
    - PACS/SPIRE test sequence debugging (parallel mode)
  - FPU Simulator de-integration
  - Cleaning & Transport of WU's on SVM panels to CR 100

- Integration and alignment of FM Instrument FPU's
  - Mechanical/thermal Integration FPU's onto OB
  - Integration SIH (connection SIH to FPU)
  - FPU electrical interface check
  - FPU Alignment vs. OB/CVV

- Integration WU's and SVM support Structure
  - Integration of SVM Support Structure
  - Integration of pre-integrated SVM Panels to Support Structure
  - Integration LOU Waveguides lower part (SVM)
  - External Cryo Harness Integration
  - Integration external harness (CCH & SIH)
  - FPU electrical interface check
  - Connection external SIH to WU's
  - Instrument SFT Warm

- PFM Cryostat Final Integration
  - Integration of OB shield (straylight tight)
  - Integration of OB MLI (straylight tight)
  - Assembly upper shields (MLI pre-integrated)
  - Assembly upper bulkhead
  - Connection of filling port SV121 & leak test
  - Integration and alignment of LOU & waveguides upper part
  - Integration of Cryostat Cover (CC) and Cryostat Baffle (CB)
  - Evacuation & leak check

- Transport to clean room 100,000
- Bake-out and PLM external integration
  - Short Functional Test (Cryo HK only)
  - Bake out
  - Integrate and mate BOLA
  - Alignment Check warm

The PLM integration sequence is completed with a SFT.

Detail s about the flow and the actual schedule are given in AIT Plan Part 2.

11.6.2 PLM Testing

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

- Cool down & filling with He-I
- Alignment measurement during cool down & adjustment as necessary
- Short functional test of Cryo Control and Instruments at He-I
- He-II production & top-up
- Short Functional Test cold (He-II condition)
- 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

Detail s about the flow and the actual schedule are given in AIT Plan Part 2.

11.7 PFM Satellite Integration and Testing

11.7.1 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 support structure and WU panels
- Integration and alignment of SVM
- Integration and electrical connection of WU panels
- Integration of SVM shields
- Integration and alignment of Telescope incl. support structure
- Mech./thermal integration and electrical connection of Sunshield/Solar Array including support structure
- Mechanical and thermal integration of Sunshade including support structure
- Integration of remaining external MLI
- Final satellite alignment measurements

11.7.2 PFM Satellite Acceptance Tests

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

- He-II production & top-up
- Integrated System Test (IST1) (S/S IST and SFPT)
- Conversion to He-I
- Transport to Test Facility
- Alignment Check and SFT, He-I
- Sine vibration acceptance level, 3 axis, He-I
- Alignment Check and SFT, He-I
- He-II production and top-up
- System Validation Test (SVT)

- Ground lifetime and launch autonomy verification (in parallel to TB/TV preparation)
- Thermal balance and thermal vacuum test including alignment checks (TBC), He-II
- IST2 (S/S IST and SFPT)
- EMC Tests
- Conversion to He-I
- Acoustic Noise Test (acceptance level)
- SFT and alignment check, He-I
- Mechanical properties measurement (mass, only)
- Delivery to Prime

The main test activities are described in detail in the AIT Plan Part 2.

11.8 Risk Mitigation by Early Testing of Components

11.8.1 Harness

The Cry-Harness parts as the vacuum feed-through and CVV internal connectors modified to the former ISO program will be tested on a sample basis within the Astrium Test-Cryostats. Sample procurement has been already started and the test procedure and preparation of the test cryostat are in progress.

Additional Cryo-Harness wire and cable configurations for Herschel use, have been designed in accordance to the ESA/SCC Detailed Specification for ISO-K-101, Issue 2/0 date 09.10.91. Wires and cables, with non cold-flow PTFE isolation of ESA/SCC 3901/024 cables will be used. This PTFE isolation material will be tested on a sample basis within the Astrium Test-Cryostat for Herschel use. Sample procurement has been started. The test procedure and preparation of the Test-cryostat are in progress.

New cables, especially designed for the SIH, like the PACS Triaxial cable will be tested on sample basis by the instrument. Sample procurement already started. The 2 SST cables types already received and in test preparation at PCAS. The third Cable type to be used for the SVM Cryo-Harness is in production at the company GORE.

The RF coaxial cables for HIFI are still under design investigations and evaluation of several international suppliers. All evaluated semi-rigid cables are not acceptable w.r.t. the EPLM life-time. Further special cable configurations have been investigated together with GORE, in sight of modified Micro-cables.

For risk mitigation during the harness manufacturing, all manufacturing personnel will trained & certified. The manufactured processes will be controlled in detail before and during the whole manufacturing periods by the Sub-co and ASED. In addition the Astrium AIT personnel of handling the sensitive Cryo-Harness and those manufacturing the Cryo Component-Harness during the AIT will be trained too.

The Operator Training and Certification Plan ref. HP-2-ASED-PL-0020, the Cryo Harness Interconnection Requirements and Qualification Plan ref. HP-2-ASTP-PL-0012 as well as the Welding Re-certification Plan ref. HP-2-ASTP-PL-0011 are the subject documents.

After harness manufacturing at Sub-co level and before delivery to Astrium, the harness will be tested in accordance to the Electrical Interface Control Document (EICD) ref. HP-2-ASED-IC-0001, which is part of and controlled by the overall EPLM ICD Database. The Cryo-Harness EICD = wiring-list will be extracted from this database and used for the electrical wire and cable Continuity & Isolation Resistance Tests. Afterwards the harness has to pass the thermal vacuum bake-out test at Sub-co level. All subject Cryo-Harness test-requirements are specified in the Cryo-Harness Procurement Specification ref. HP-2-ASED-PS-0024.

11.8.2 Cyrogenic system

It has been decided that all Cryo Components shall undergo a qualification program to cover all potential development deviations, for details see Qualification Program for EPLM Cryo Components, HP-2-ASED-PL-0024.

11.8.3 He II Tank

The main focuses for the design/construction/operation of the Herschel Helium-II tank are as follows:

- Tightness to He II-conditions (which can finally only be verified with He II itself at T < 2,17 K)
- Safety against
  - pressure (internal and external)
  - tank support straps preloading
  - launch and structural testing loads
- Stiffness/eigenfrequency empty and with He II
- Stiffness/dimensional-stability of interface points
- Cleanliness during manufacture and AIT

This will be verified by analysis, measurement, non destructive inspections and testing e.g. welded areas shall be tested by X-ray.

After completion of manufacturing and prior to leakage testing the HTT shall be subjected to quenching to LN2 temperature; He-leak test and pressure test (external and internal over-pressure) shall be performed after manufacturing.

To reduce risks of He leaks extended ultra-sonic NDI will be performed on the tank forging immediately after delivery to the relevant sub-contractor.

Leak tightness test at superfluid conditions and proof pressure test will be performed by the supplier before delivery.

11.8.4 He I Tank

The main focuses for the design/construction/operation of the Herschel Helium-II tank are as follows:

- Safety against

- internal pressure
- external pressure
- launch and structural testing loads

- Leak tightness to He I
- Stiffness/eigenfrequency empty and with 50% He I (tbc)
- Cleanliness during manufacture and AIT

This will be verified by analysis, measurement, non destructive inspections and testing e.g. welded areas shall be tested by X-ray.

After completion of manufacturing and prior to leakage testing the HTT shall be subjected to quenching to LN2 temperature; He-leak test and pressure test (external and internal over-pressure) shall be performed after manufacturing.

To reduce risks of He leaks extended ultra-sonic NDI will be performed on the tank forging immediately after delivery to the relevant sub-contractor.

Leak tightness test and proof pressure test will be performed by the supplier before delivery.

11.8.5 Cryo Cover and Cryostat Baffle

- Early components testing of :
  - Drive Spring characterisation test
  - Release Mechanism Actuator delta qualification
  - End Stop damping characteristic
  - Cover sealing tests
  - Release Mechanism characterisation-, stiffness-, reproducibility- and adjustment capability measurements
- Full qualification on subsystem level by:
  - Cover functional tests at cryo temperatures
  - Cover deployment velocity and torque tests
  - Cover environmental tests with leak tests in between

11.8.6 CVV

The main focuses for the design and manufacturing of the Herschel-cryostat vacuum vessel are as follows:

- Tightness to air leakages from outside
- Safety against
  - * pressure (internal and external)
  - * tank support straps preloading
  - * launch and structural testing loads with all internally suspended masses and all external items integrated

- Stiffness/eigenfrequency with integrated internal and external masses
- Stiffness/dimensional-stability of interface points
- Cleanliness during manufacture and AIT

This will be verified by analysis, measurement, non destructive inspections and testing e.g. He-leak test and pressure test during and after manufacturing.

Specific leak tightness, proof pressure tests and static load tests of individual interfaces will be performed by the supplier.

11.8.7 Tank Support System (TSS)

According to HP-2-ASED-PS-017 the planned verification is performed by the supplier. The scope is as follows:

1. A delta qualification of the straps will be performed. Aim of the test is to verify that the ISO qualification is still valid. It has to be verified that the Herschel straps are in the scattering band of the ISO straps. This delta qualification is made wrt. stiffness, strength, fatigue load and thermal conductivity. The number of needed tests is depending on the test results.
2. For acceptance each chain will see a static load test including a measurement of the stiffness.

11.8.8 Thermal Shield

For the SVM thermal shield S/S the following verification approach is foreseen:

- **Struts qualification models:**
  On at least one strut of every type (bi-pod fixation struts, vertical struts) a thermal conductance test to qualification level, a thermal vacuum test and a static load and stiffness test shall be performed
- **SVM Thermal Shield PFM:**

  Struts:
  On every PFM strut a thermal conductance test to PFM level shall be performed.

  SVM Thermal Shield S/S:
  The fully integrated PFM SVM thermal shield including fixations shall be tested to proto flight levels (qualification level, acceptance duration) in a thermal cycling, a sine vibration, and an acoustic test.

11.8.9 Herschel Support Structure

For the Herschel Support Structure struts the following verification on component and subsystem level is foreseen:

- **Struts qualification models:**
  For every strut type (for PLM/SVM interface struts, HSS lateral struts, HSS axial struts, TMS struts

and LOU struts) at least one qualification strut shall be tested to qualification level. Thermal cycling, thermal conductance (except axial SSH/SVM struts), static load and stiffness shall be tested.

- **Struts and TMS PFM's:**

  Component level**:**
  On every PFM strut and on the TMS frame a thermal cycling test to PFM level shall be performed. On all struts (except axial SSH/SVM struts) thermal conductance shall be measured. Every PFM strut and the TMS frame shall be tested to PFM level in a static load test at RT.

  Subsystem Level:
  Mechanical ICD's of the fully integrated TMS PFM shall be verified by measurement.

11.8.10 Solar Array Cell and Coupon Tests

11.8.10.1 Solar Cells Type Approval Test (TAT)

The solar cells / solar cell assemblies (SCA) and OSR’s used for Herschel will pass a Type Approval Test (TAT) in accordance with the Generic Specification for Gallium Arsenide Solar Cells SPA-TS-006 (incl. high temperature long exposure and UV testing) covering the environmental conditions encountered by the Herschel mission.

11.8.10.2 Design Verification Test (DVT)

Qualification verification of the Herschel solar array design will be performed by means of the Design Verification Tests (DVT’s). The tests will demonstrate that the chosen PVA design and the used parts and materials will have the adequate functional performance and the ability to withstand for the entire mission lifetime the environmental conditions encountered by the Herschel mission.

The DVT coupons will be fully flight representative with respect to design, manufacturing procedures and used parts and materials. In total three DVT coupons shall be provided.

The tests will include:

- Dimensional checks
- Visual inspections
- Physical properties
- Electrical performance checks (absolute performance test)
- electrical tests (incl. capacitance and inductance measurements)
- 20 thermal vacuum cycles under cont. health checking (10 min. dwell time)
- long duration high temperature exposure
- mech. integrity and el. performance verification after tests

12 System and Unit Description

12.1 Cryo Components

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

Components	Needed # - FM/FS/QM/Sp./total					Expected Company
	FM	FS	QM	Spare	total	
Helium System Components						
Adsorbers	6	4	1	/	11	Astrium tbc
Helium Pressure Sensor (P101/501/701) 0 - 1.6 bar	3	3	1	/	7	Transinstruments
Tank Heaters (H103/104, H701/702)	4	4	1	19	28	CPPA
Safety Valves Helium II High Mass Flow (SV123/SV723)	2	2	1	1	6	Phoenix,
Helium Pressure Sensor (P102/502) 0 - 35 mbar	2	2	1		5	tbd
Ventline Test Valve (V506)	1	1	1	1	4	Nupro
Safety Valves Helium I Low Mass Flow (SV521)	1	1	1	1	4	Nupro
Vacuum Measurement Sensors (VG901/902)	2	1	1	/	4	Balzer
Safety Valves CVV (SV921/922)	2	1	1	1	5	Stoehr GmbH, D-86343 Königsbrunn
Rupture Discs (RD124/RD724)	2	2	16	2	22	Rembe GmbH, D-59918 Brilon
Liquid Helium Valves						Astrium, IP
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	96 tbc	2 tbc	6	10 tbc	114 tbc	Rosemount
Herschel C100 Temperature Sensors	44 tbc	2 tbc	6	10 tbc	62 tbc	Astrium/Rosemount
Ventline Nozzles	tbd	tbd	/	tbd	tbd	Astrium
Ventline External Heaters (H502)	1	4	/	/	5	tbd
Miscellaneous						
Accelerometers	20	/	/	/	20	ENDEVCO
Linde Helium System Components	**PFM**	**FS**	**QM**	**Spare**	**total**	
PPS 111with T 111 / T 112	1	1	/	/	2	Linde AG
DLCM 1&2 with T101/T102/T104/T105	2	1	/	/	3	Linde AG
Filling Port (with safety valve SV121 & S101)	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

Table 20: List of all cryo components

Detailed information about the Helium Control System can be found in H-PLM Helium System Description, HP-ASED-RP-0034 and in Helium S/S Specification HP-ASED-SP-0015.

12.2 Cryostat Insulation Subsystem (CIS)

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 Cryostat Insulation Subsystem (CIS) shall minimize the heat input 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. It consists of three heat shields arranged concentric around the tanks and the Optical Bench Assembly. These heat shields are equipped with MLI blankets. The OBA comprises among other items the instrument shield, which is also equipped with MLI.

To reduce external heat radiation from the warmer Sunshield/Sunshade and the SVM to the CVV, MLI blankets are partly attached to the Cryostat Vacuum Vessel (CVV) and to the Cryostat Baffle. This MLI is called external MLI. Only the CVV part facing the warmer Sunshield/Sunshade (+Z side) and the warmer SVM (-X side) is covered with MLI, the remaining CVV area serve as radiative heat sink to deep space. The cryostat baffle and the CVV upper bulkhead (+X side) is completely covered with MLI to reduce heat radiation from the Telescope during decontamination heating at about 40°C.

Figure 51 shows the principle of the CIS configuration and components. The major components of the insulation subsystem are arranged around the tanks and the OBA almost like the skins of an onion.

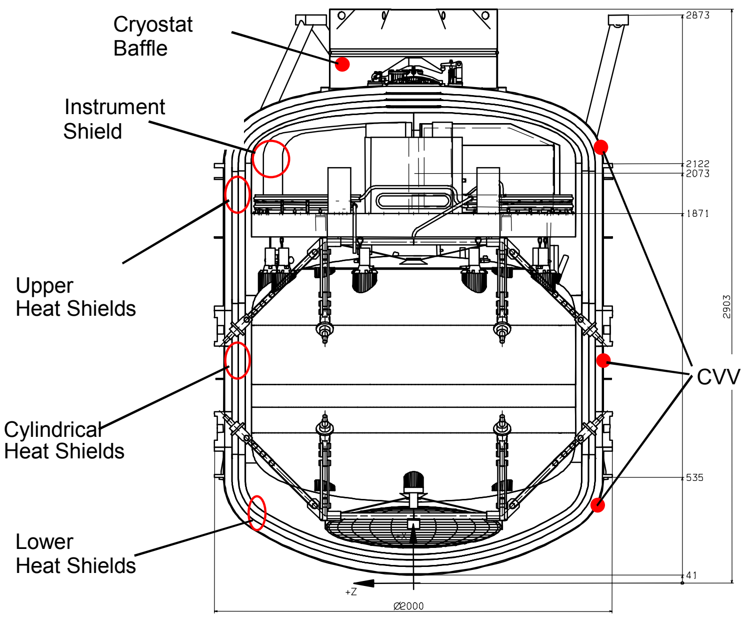


Figure 51: HERSCHEL CIS with Tanks, CVV and other Structural Parts

Heat Shields

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

Each heat shield consists of a lower and upper part and of a central cylindrical part. The Optical Bench Plate forms the lower part of the instrument shield. The cooling with GHe from the tanks will be performed on the cylindrical heat shields starting with shield 1 through shield 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 on ISO. All shields will be covered with MLI. In addition, the innermost heat shield (Heat Shield 1) shall have a low emissive surface on the inner side (towards the tanks) which will be provided by a goldized Kapton foil or surface coating.

The shields will be made of aluminium alloy AlMgSi1. The wall thickness of the shields is 0.8 mm with an increase in the interface areas to about 1.5 mm locally. These changing wall thickness will be obtained by chemical etching of the outer shield surface after forming the shield shape with a basic thickness of about 2 mm.

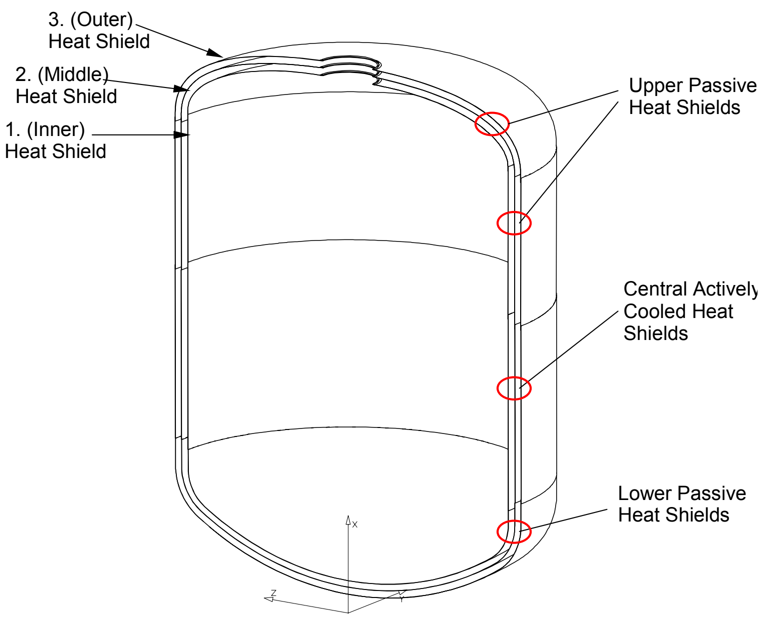


Figure 52: Arrangement of HERSCHEL Heat Shields

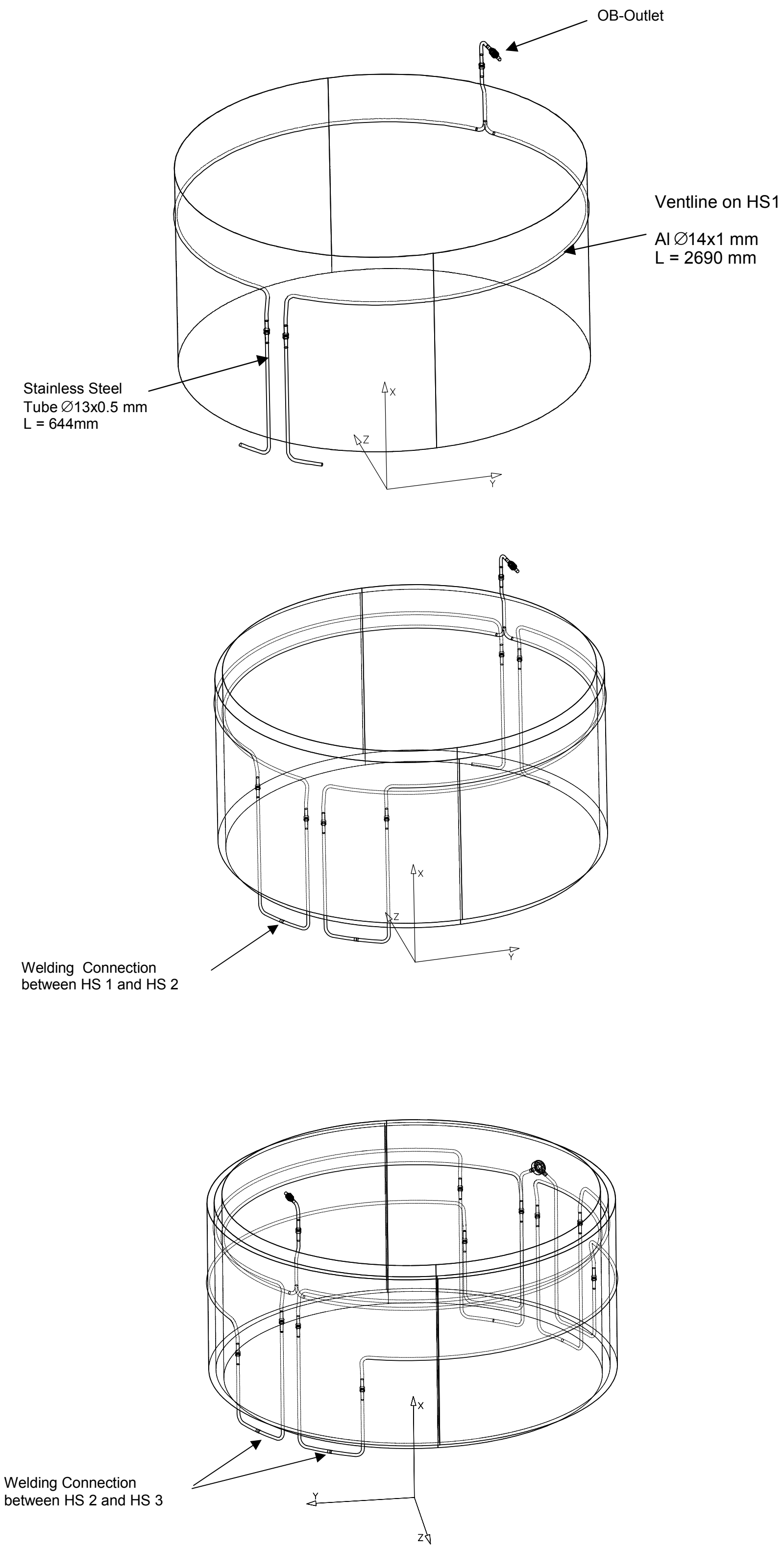


Figure 53: Ventline Routing on Heat Shields

The upper heat 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 attached to the Heat Shield 2 surrounds the beam entrance area, see Figure 54. A further baffle is attached to the OBA shield.

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

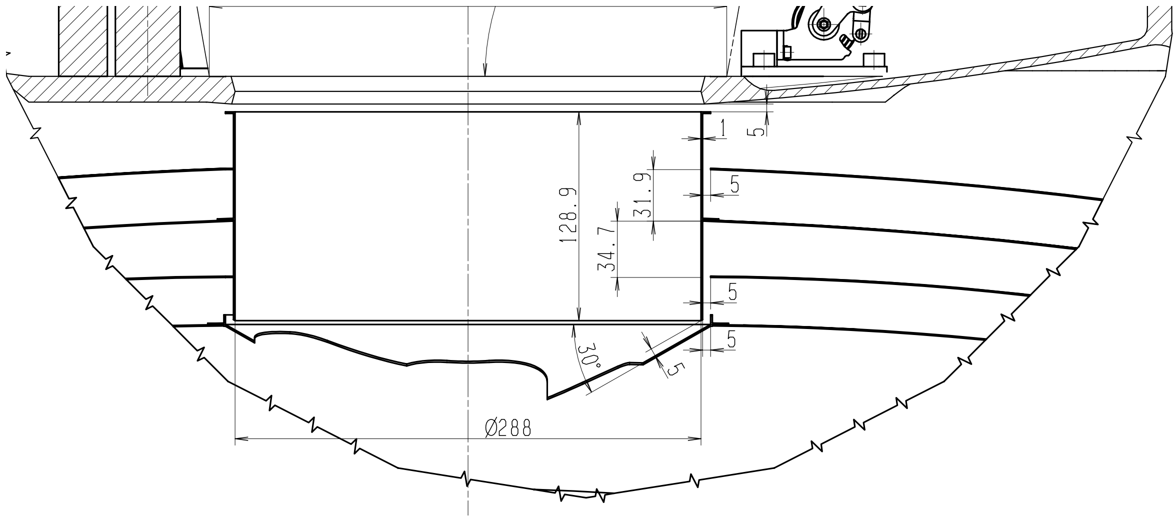


Figure 54: Attachment of Baffle to HERSCHEL Heat Shield 2

CVV internal MLI System

In detail, the CVV internal MLI system consists of the following individual MLI blankets on:

- He I tank
- Filling Port and Valves
- He II tank (lower, cylindrical, upper part) and components on it
- Optical Bench shield (cylinder, top part)
- 3 cryostat heat shields, each of these 3 shields consist of
    - lower bulkhead
    - lower cylinder (cooled by GHe ventline)
    - upper bulkhead (bulkhead with upper cylindrical part)

The CVV internal MLI, especially on the heat shields and on the HTT, has various specific mechanical aspects in order to provide:

- penetrations for the He II - tank support straps between CVV and Spatial Framework (SFW) which carries the tank
- penetrations for harness parts

- penetrations for the He ventline tubes between the shields, the shields and CVV and the He tanks and the shields
- penetrations for He shut-off and safety valves, burst disc, He filing tubes, liquid level sensor and thermometer heads and DLCM´s on the He II tank

The CVV internal MLI design is based on the ISO heritage. Nevertheless, the design of parts and components may be improved where identified.

During the development of the ISO cryostat an MLI concept had been realised and verified successfully. Dedicated conductance tests have been performed at ESTEC and Linde. Based on those data the MLI performance data, as listed in Table 21, can be derived. More details can be found in the H-EPLM Thermal Model and Analysis, HP-2-ASED-RP-0011, Issue 2.

MLI on	Layers	radiative emissivity (ε_{rad})	linear conductance H [W/m²K]	emissivity of ext. layer (ε_{ext})	specul. of ext. layer (ρ_{ext})
HTT	20	ε_{rad} = 0.0024	1.8 E-4	0.05	0
HOT	10	ε_{rad} = 0.003	3.5 E-4	0.05	0
Filling Port	10	ε_{rad} = 0.003	3.5 E-4	0.05	0
Instr. Shield	10	ε_{rad} = 0.003	3.5 E-4	0.05	0
Heat Shield 1, outside	10	ε_{rad} = 0.003	3.5 E-4	0.05	0
Heat Shield 1, inside	(1) *	n.a.	n.a.	0.05	0.9
Heat Shield 2	15	ε_{rad} = 0.0026	2.5 E-4	0.05	0
Heat Shield 3	20	ε_{rad} = 0.0024	1.8 E-4	0.05	0
CVV	32	ε_{rad} = 0.0022	1.093 E-3	0.05	0.8
Cavity	32	ε_{rad} = 0.0022	1.093 E-3	0.05	0.8
Cover HS	14	ε_{rad} = 0.0135	2.5 E-3	0.05	0.9

*) one layer goldized Kapton foil or low emissive surface coating

Table 21: Overview on CVV internal and CVV external MLI Performance Data

12.3 Cryo Harness

12.3.1 Preliminary Overall Harness Lay-out

The preliminary Overall Cryo Harness Layout between the warm and cold units is defined below.

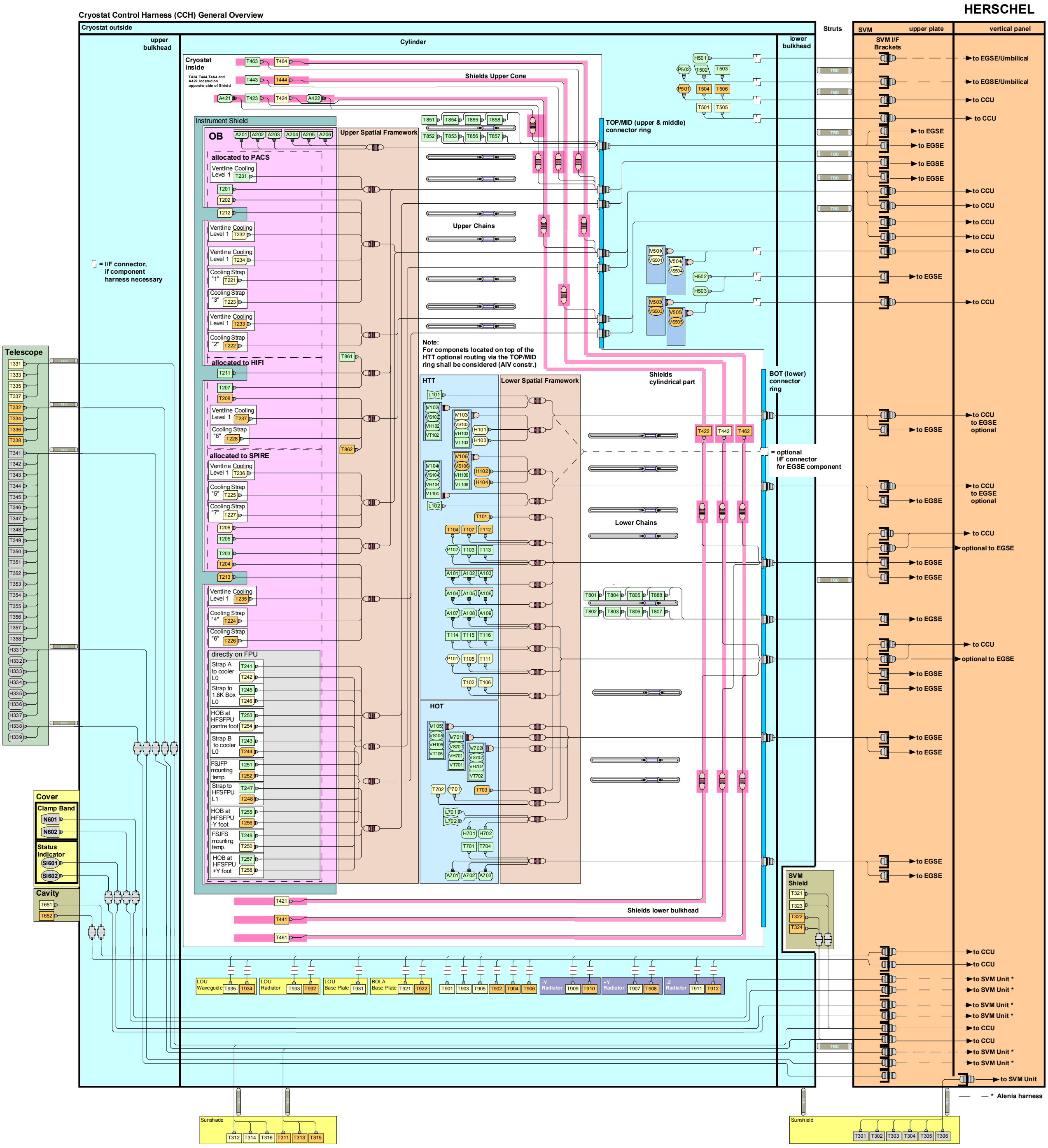


Figure 55: Preliminary Overall Harness Layout

12.3.2 SVM CRYO-Harness

The SVM Harness establish the connection between the Instrument Warm Unit's, the Cryo Control Unit (CCU) SVM internal, the SVM Umbilical and upper platform I/F connector-brackets. The harness between the SVM warm units and the SVM interface connector-bracket servicing Power and Signal lines to the Telescope, NED (Non explosive device) and Sunshield /Sunshade are not part of the Cryo Harness.

12.3.2.1 SVM CRYO Control Harness CCH

In general several harness bundles will be routed from the Cryo Control Unit (CCU) through cut-outs (mouse-holes) to the SVM upper platform interface connector-bracket. Another Cryo interface harness have to be routed between the SVM Umbilical interface connector-bracket to the SVM external I/F-CB, servicing the CRYO instrumentation power- and monitoring lines during Launch phase.

The harness lay-out design is currently under detailed investigation between Alcatel , Alenia and Astrium.

12.3.2.2 SVM Umbilical Interface Connector-Bracket

The electrical and mechanical umbilical interface connector-bracket layouts are not settled yet. (Alcatel-Alenia-Astrium)

12.3.2.3 SVM Scientific Instrument Harness SIH

The instrument Warm Unit layout design is not settled yet. The instrument units as placed on 4 SVM Side / Corner panels, 2 panels for HIFI, one for PACS and on another side panel SPIRE is sharing with the CCU. The units are placed in local areas, which permit short harness distances to their cold units, CVV external and internal.

In Figure 56 a view on the SVM Interface connector brackets (intermediate design status) on the upper platform is shown.

Currently round connectors of similar type to those used on the CVV interface are foreseen, because this requests less connectors than in case of all warm unit interface connectors have to be mounted on the SVM interface connector-brackets. SVM round connectors with compliant I/F`s to the CVV feed-through connectors are preferred.

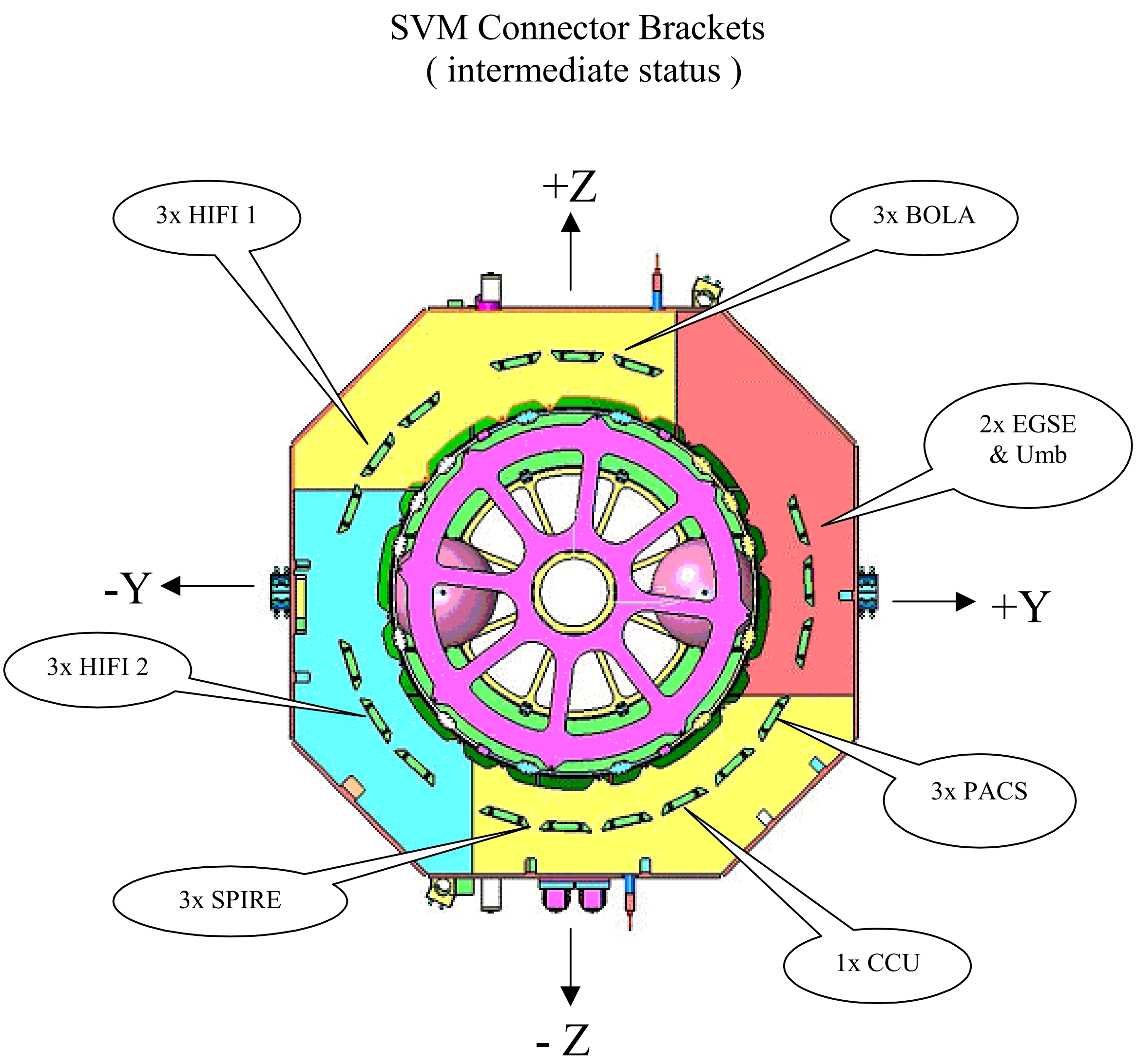


Figure 56: SVM Interface connector-brackets upper platform (intermediate status).

(width and height of I/F-CB's are currently under further investigation; modification of SVM Thermal Shield and Alcatel connector bracket accessibility requirements)

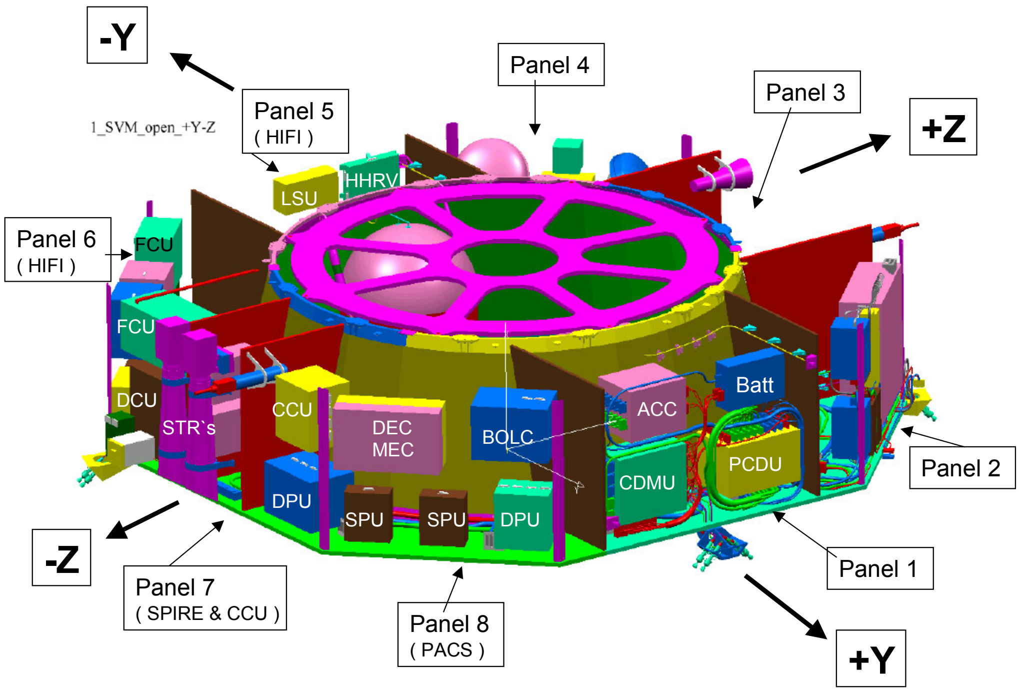


Figure 57: Preliminary SVM internal Warm-unit Layout (-Z / +Y)

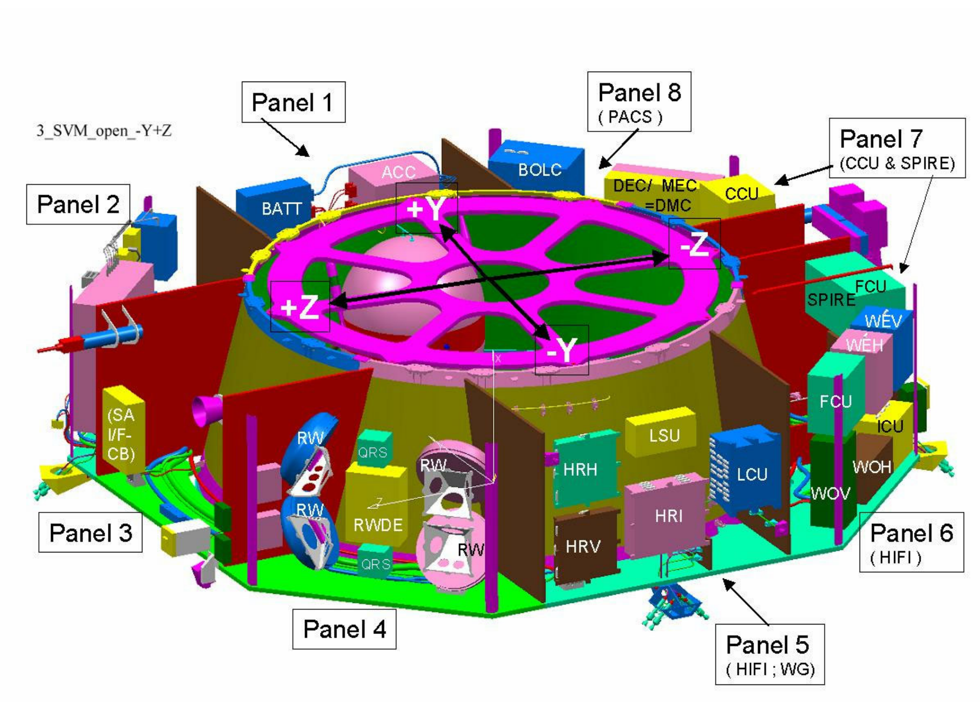


Figure 58 SVM internal Warm-unit Layout (+Z / -Y) of intermediate status

12.3.3 CVV External Harness

The CVV external Harness establish the connection between the SVM Interface Bracket's on the SVM upper panel, the CVV external part and elements and the CVV feed-through. The current amount of vacuum feed-through connectors is defined in table below.

PACS SIH	24
HIFI SIH	10 + 4 RF Coax
SPIRE SIH	26
CCH	14
Total	74 + 4 Coax

Table 22: Current amount of CVV feed-through connectors

12.3.3.1 CVV external CCH

The preliminary CCH will be routed

- from the SVM Interface bracket SVM upper platform external I/F-CB receptacle-connectors to the relevant SVM-CVV struts,
- along the strut to the strut fixation on CVV lower bulkhead
- via this fixation horizontally to the lower connector ring / CCI I/F – connector brackets
- directly to the relevant CVV vacuum feed-through plug-connector, the S/S component I/F bracket or the CCI end-item plug-connectors.
- via a C-shape cable rails along the CVV cylinder to the middle and to the upper connector ring to the relevant CVV vacuum feed-through`s
- via a cable rail along the CVV cylinder (vertical) to upper bulkhead
- along the upper bulkhead to the relevant S/S component I/F bracket on cover, cavity, telescope i/F connector-bracket and to the CCI end-items.

In Figure 59 below a typical harness cable rail routing on the CVV envelope is shown.

The detailed harness routing design is currently under investigation w.r.t. the latest CATIA 3D model SVM Cryo warm unit lay-outs received by Alenia and the SVM connector allocation constraints from Alcatel .

12.3.3.2 CVV external SIH

The harness bundles will be routed

- from the SVM Interface connector-bracket, upper platform external, to the next SVM-CVV strut
- along the strut to the strut fixation on CVV lower bulkhead
- via the C-shape cable rails upwards along the CVV cylinder to the middle and upper connector ring vacuum feed-throuh plug-connectors

The harness routing design is currently under investigation, w.r.t. harness branch, bundling, branch diameters and cable rail sizes.

A typical CVV external Cryo harness routing is shown in Figure 59 and Figure 60.

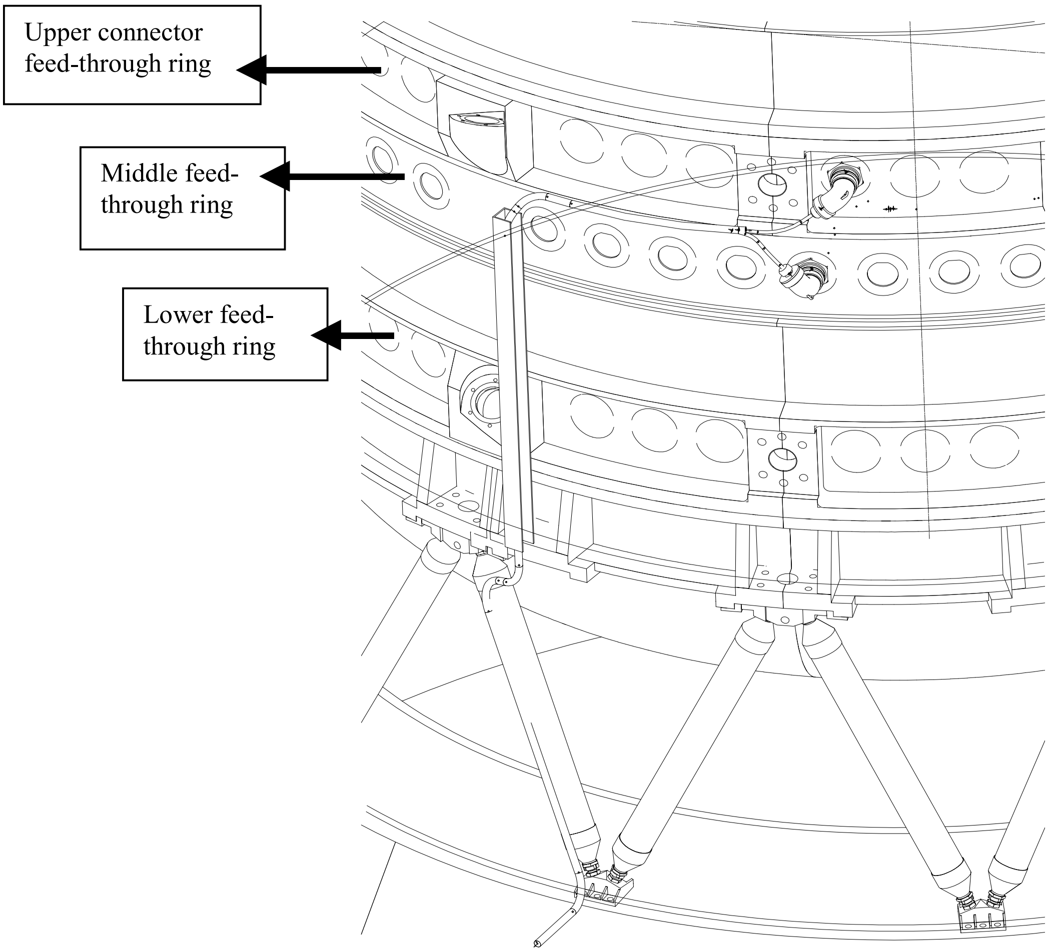


Figure 59: CVV External Harness Routing

12.3.4 CVV Internal Harness

The CVV internal Harness establishes the connection between the CVV I/F vacuum feed-through`s and the relevant Instrument FPUs, the S/S component I/F's and the CCI end-items inside the Cryostat.

In Figure 60 below an intermediate design approach of the CVV internal harness routing on the optical bench is shown.

The Cryo-Harness design evaluations of routing, bundling, attachment and thermal bonding to the subject structures and the connector accommodation are under investigations

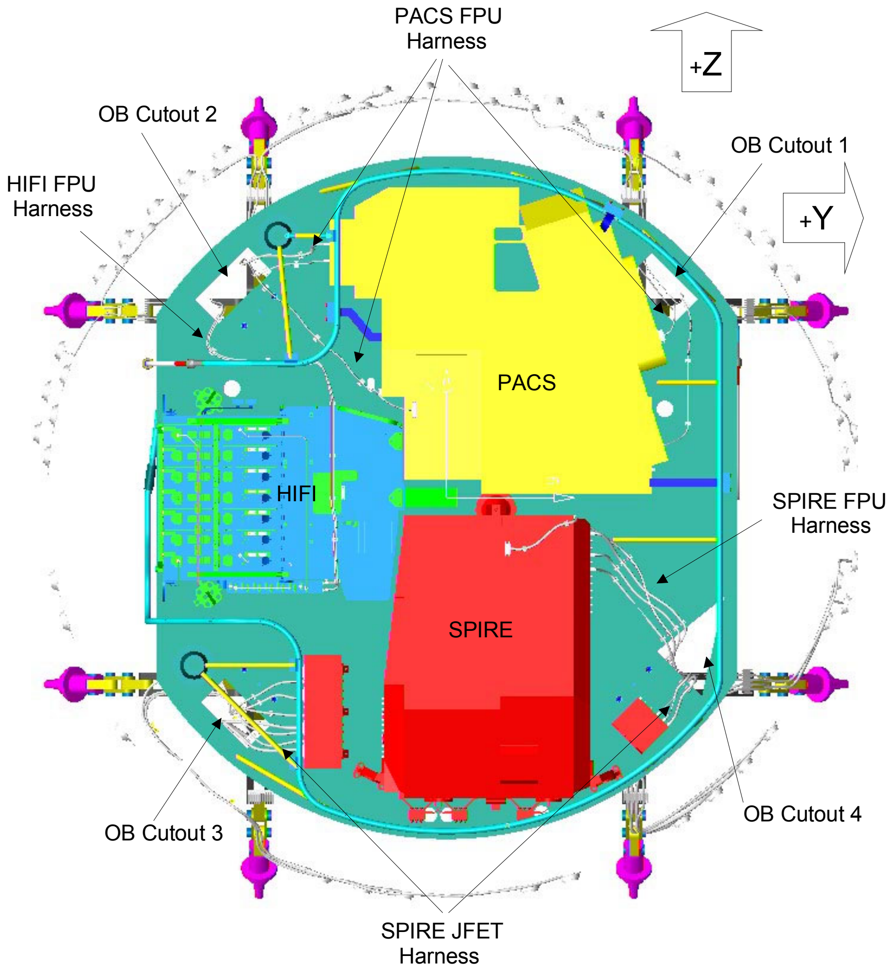


Figure 60: Principle SIH Routing on optical Bench

12.3.4.1 CVV Internal CCH

The CCH bundles will be routed

- from the CVV vacuum feed-through`s along the inside of the CVV cylinder to the belonging tank support straps , the radiation shield CCI connectors , the spatial framework interface connector-brackets and the CCI parts and elements on and around the He tanks
- along the tank support straps, through the thermal clamps on the radiation shields or optical bench (OB) structure
- through the OB cut-outs to the upper side allocated CCI parts and elements.

The CVV internal Cryo harness routing design is currently under detailed investigation w.r.t. attachment & thermal clamp devices, allocation and fixation of CCI interface connector-brackets

In figure below a principle thermal clamp device is shown.

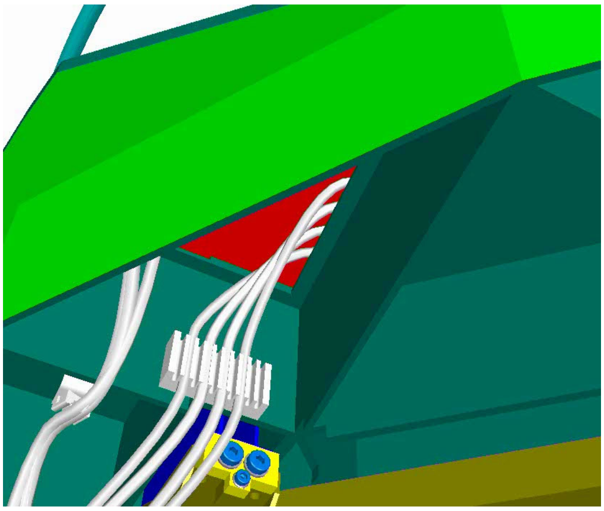


Figure 61: SIH Principal Harness Routing on Optical Bench cut-out with thermal clamp

12.3.4.2 CVV Internal SIH

The SIH bundles will be routed:

- from the CVV vacuum feed-through`s along the inside of the CVV cylinder to the belonging upper tank support straps

- along the tank support straps through the thermal clamp(s) and optical brnch cut-outs directly to the instrument cold units
- or along the radition shield through the thermal clamp(s) and the optical bench cut-outs to the instrument cold units

In figure below a principle harness routing along the radiation shield is provided.

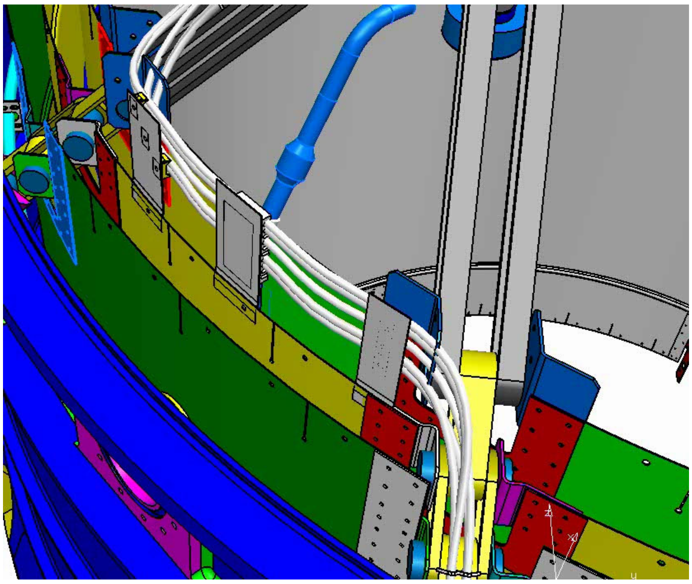


Figure 62: SIH Principal Harness Routing on Radiation shield

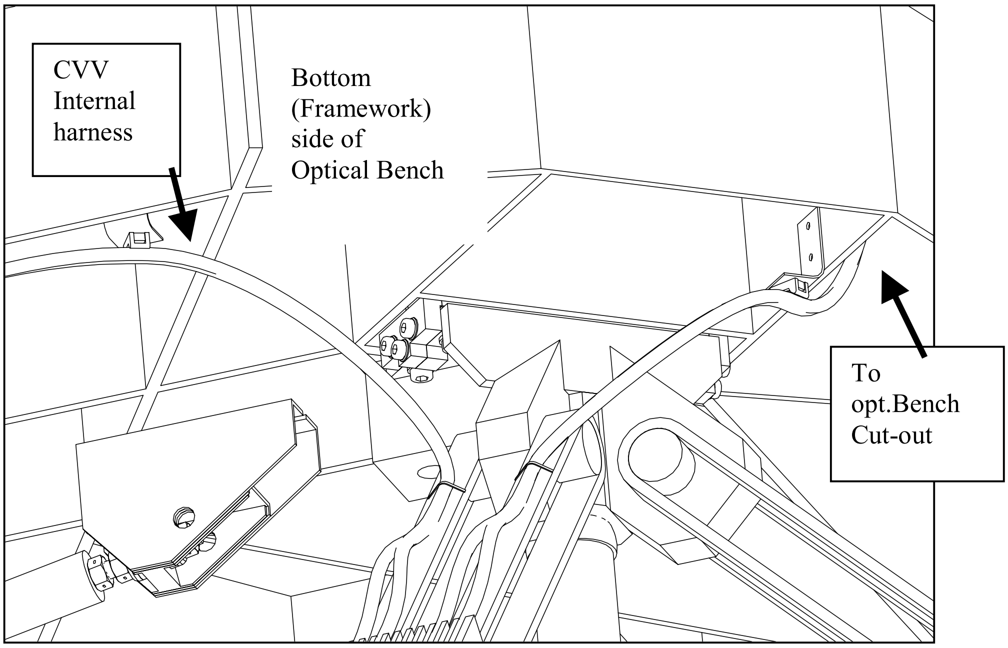


Figure 63: HIFI, PACS and SPIRE SIH Routing on optical Bench

12.3.5 Cryo-Harness Connectors

The Cryo Harness will be manufactured of rectangular and round connectors. The typical space qualified connector series and insert-arrangements as defined below will be used.

D*MA	HD*MA	MDM	Nanonics	"MIL-C-38999/2"
9S		9S	9S	
9P		9P	9P	insert
15S		15S	15S	arrangements
15P		15P	15P	present design
25S	44S	21S		
25P	44P	21P		22-35S
37S	62S	25S		22-35P
37P	62P	25P		
50S		31S		
50P		31P		
		37S		
		37P		

Table 23: Cryo Harness Connector Series and Sizes

In heritage to the former program ISO, where all harness wire interconnections have been welded, the Herschel Cryo harness of MDM and CVV round connector hermetic feed-through with solid wire contacts have been selected. For all other Cryo harness, crimp-connectors have been foreseen to support the manufacturing and repair process.

The Nanonics connectors will be used on the Herschel Cryo control sensor assemblies to avoid flying-lead interconnections within the CCH. This connector series have been used by NASA on Cryo experiments and is currently under customer investigations for Herschel use.

12.3.6 Cryo-Harness Wire and Cables

The Herschel Cryo harness will consist of copper/brass and stainless steel wires, pending on the thermal environment of dedicated harness segment and electrical I/F requirements. The Cryo harness of segments will use the following wire materials.

Conductor material:	Stainless Steel (SST) and Brass	
Shield material:	Stainless Steel (SST)	
Isolation Material:	PTFE, GORE-TEX and Polyimid Tape	
Wire-sizes [AWG]:		
conductor:	SST AWG 38	(diameter = 0,10 mm)
served wire shield:	SST AWG 44	(diameter = 0,05 mm)
conductor:	Brass AWG 38	(diameter = 0,10 mm)
conductor:	Brass AWG 30	(diameter = 0,25 mm)

Table 24: Cyro Harness Cable Materials and Wire-Core Sizes

The harness inside of the SVM and a small amount of cables of the CVV external harness will be of space qualified stranded silver coated copper wires of ESA SCC3901-019 wire and cables and similar to SCC 3902-002 for PACS Triax cable SVM internal.

In Table 25 the solid wires and stranded wires as used within the different Cryo harness segments are shown.

Cryo harness	segment	from	to	wire material
CCH	SVM	CCU	SVM I/F-CB	copper strands
CCH	SVM	UMB I/F-CB	EGSE I/F-CB	copper strands
SIH	SVM	Warm units	SVM I/F-CB	copper strands
CCH	CVV external	SVM I/F-CB	CVV FTHRs	solid brass and SST
CCH	CVV external	SVM I/F-CB	CVV envelope	solid brass and SST
Telescope heaters	CVV external	SVM I/F-CB	Telescope I/F-CB	copper strands
Telescope sensors	CVV external	SVM I/F-CB	Telescope I/F-CB	SST
NED PWR	CVV external	SVM I/F-CB	NCA I/F-CB	copper strands
NED sensors	CVV external	SVM I/F-CB	NCA I/F-CB	SST
SIH	CVV external	SVM I/F-CB	CVV FTHRs	solid brass and SST
SIH PWR (50mΩ)	CVV external	SVM I/F-CB	HIFI LOU	copper strands
SIH	CVV external	SVM I/F-CB	HIFI LOU	solid brass and SST
SIH PWR	CVV external	SVM I/F-CB	PACS BOLA	solid brass and SST
SIH	CVV external	PACS BOLA	CVV FTHRs	solid brass and SST
SIH RF	CVV external	LSU	HIFI LOU	SST + CU
CCH	CVV Internal	CVV FTHRs	opt.Bench sensors	SST
CCH	CVV Internal	CVV FTHRs	He-Tanks +sensors	solid brass and SST
CCH	CVV Internal	CVV FTHRs	radiation shield sensors	SST
SIH	CVV Internal	CVV FTHRs	opt.Bench Cold units	solid brass and SST

Table 25: Cable Materials used on different Cryo-Harness segments

12.3.7 Mechanical Interfaces

12.3.7.1 SVM external I/F Connector-Brackets

Considering integration- and test sequences on top of the SVM upper plate (+X direction) several mechanical interface brackets are foreseen, where the Plug-connectors will be mated to the fixed mounted CVV external harness connectors. This interface will be used additionally to get access to the CVV Units for test reasons in a proper way.

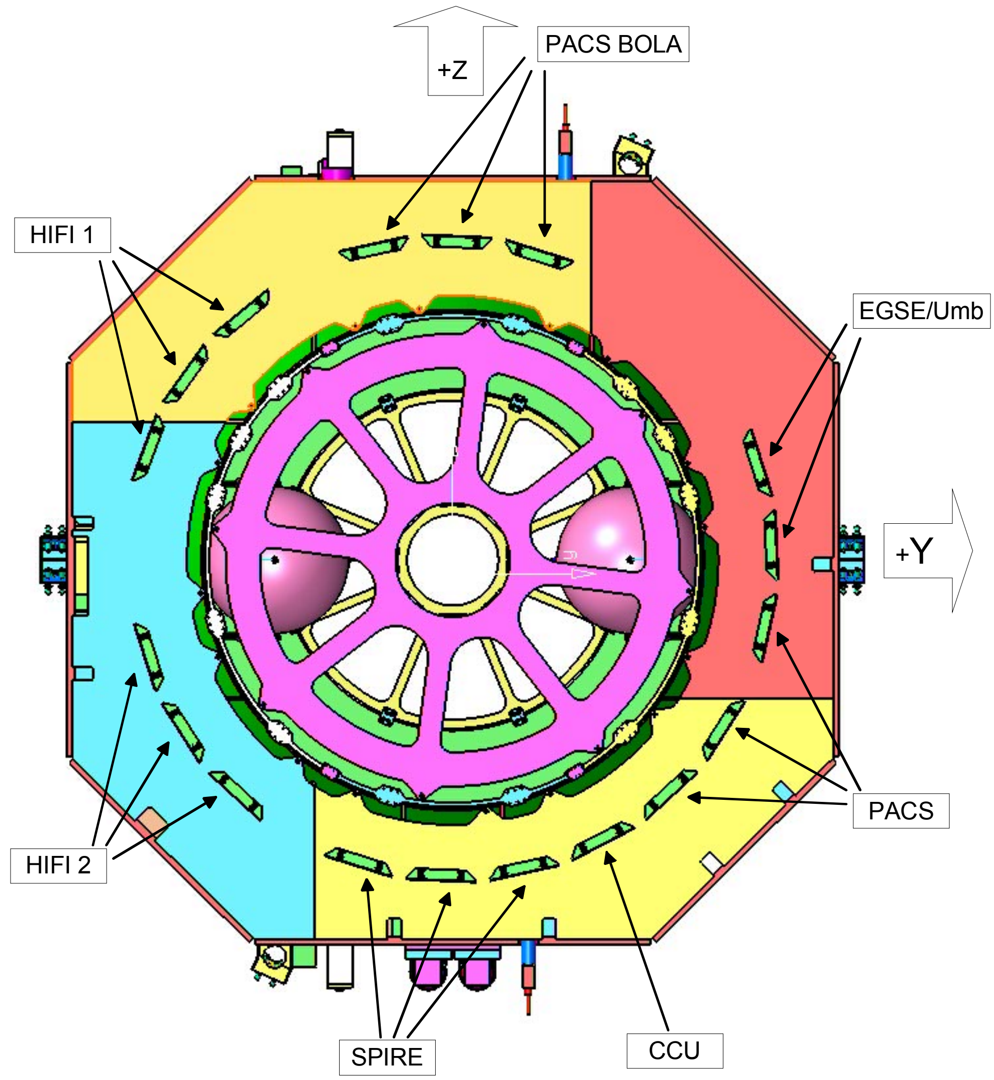


Figure 64: SVM Interface Connector Brackets (intermediate design status)

12.3.7.2 CVV external I/F

The CVV external CHH and SIH plug-connectors will be directly mated to the CVV feed-through receptacles as placed around the CVV on 3 interface-rings. The Cryo Control Instrumentations (CCI) CVV external will be mated via additional S/S component harness interface connector-brackets or direct to the CCI part & element interface connector.

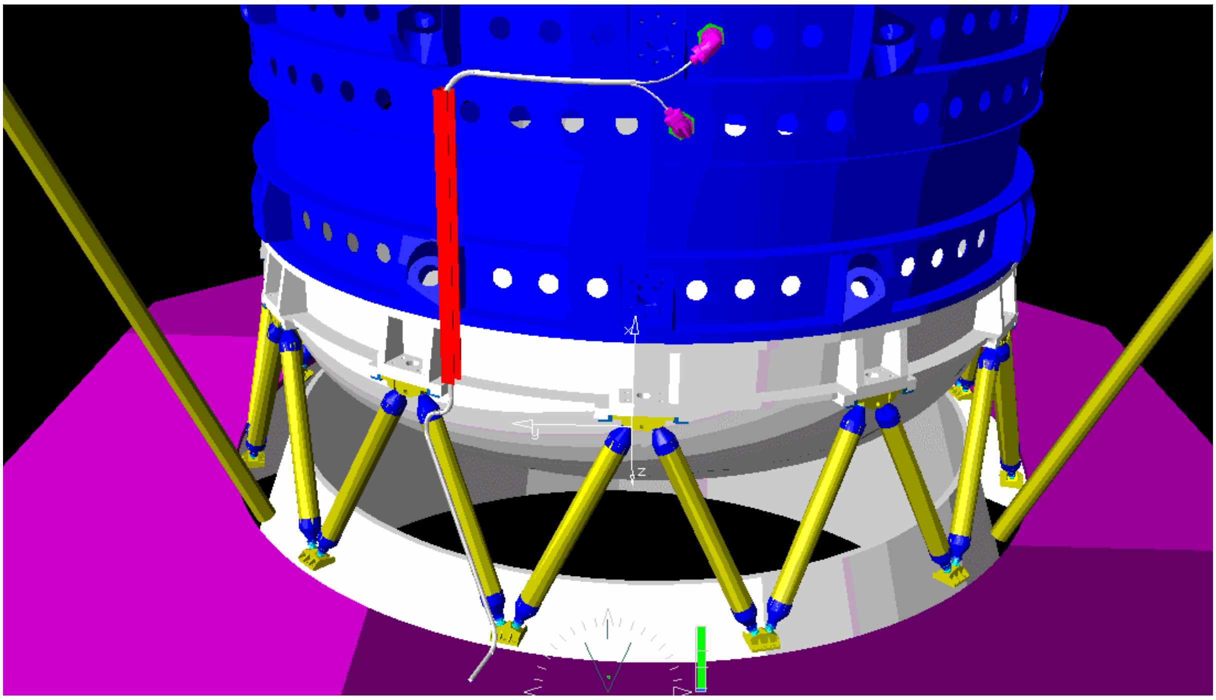


Figure 65: Typical CRYO Harness Routing CVV External

12.3.7.3 CVV Feed-Through Connectors

To perform the electrical connections between CVV external to internal area, hermetically sealed vacuum feed-through connectors will be used. These feed-through connectors will be mounted within the 3 CVV feed-through connector rings, the upper, mid and lower ring.

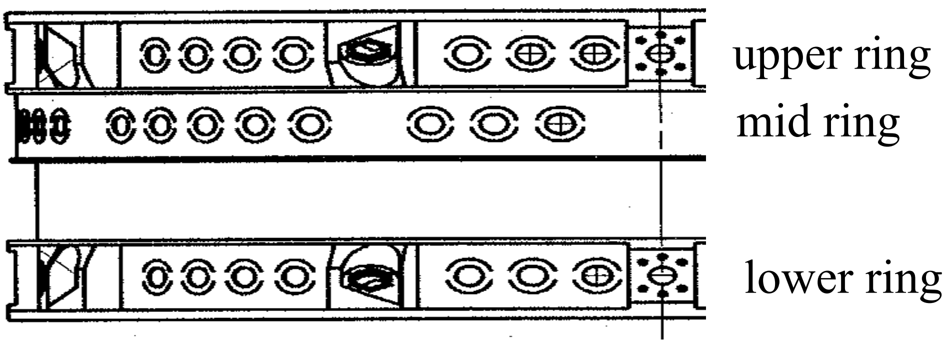


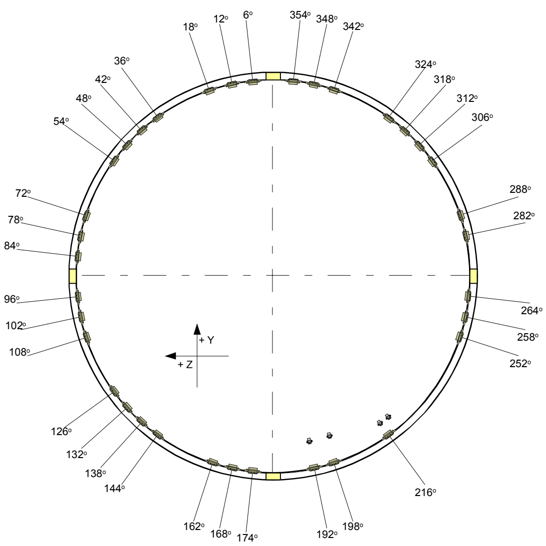
Figure 66: CVV cylindrical part vacuum feed-through connector rings

CVV Feed-Through Connector Allocations

The design of the CVV external harness restricted areas is under investigation and will be settled when the CVV external framing components and pipe-work layouts are finally designed. The baseline design is based on the size of 100 pole vacuum feed-through connectors (MIL38999 Series II) have been analysed. The maximum number of connectors to be mounted within the above mentioned CVV connector rings have been analysed and are given below:

- TOP (upper) connector ring ⇒ 35 Connectors
- MID (middle) connector ring ⇒ 28 Connectors
- BOT (lower) connector ring ⇒ 36 Connectors

The figures below show a current overview of connector rings and the relevant radian, where the single vacuum connectors could be accommodated.



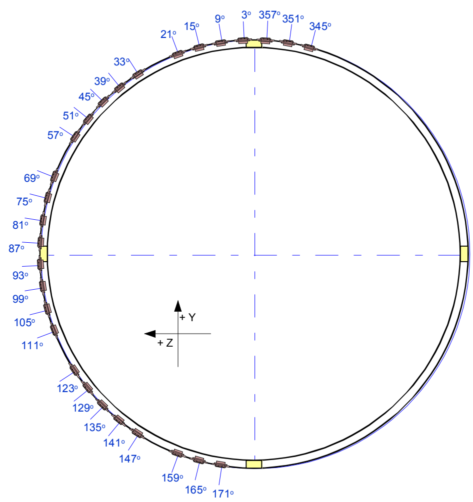


Figure 67: maximum CVV TOP- and MID-Ring Vacuum Connector Location

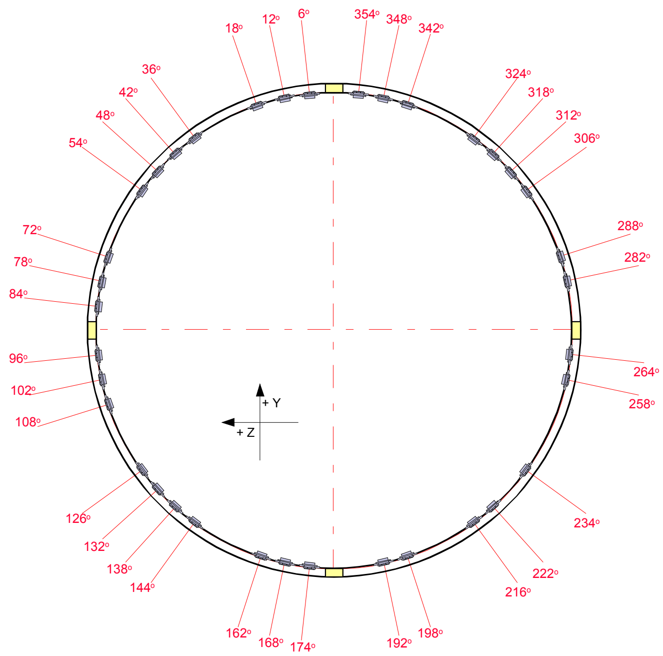


Figure 68: Maximum CVV BOTTOM- Ring Connector Location

The detailed accommodation of CCH and SIH feed-through connector positions are under detailed investigations w.r.t. to latest SVM CCH and SIH warm unit lay-outs, received by Alenia and the SVM interface connector-bracket re-positioning requested by AIT and Alcatel PRIME.

12.3.7.4 CVV Internal

The CVV SIH internal harness will be connected directly to the Instrument Focal Plane Unit (FPU) interface connectors. The CVV CCH internal harness will be connected to the CCI part & element interface connectors or, if necessary for S/S pre-integration by use of an additional interface harness, the Cryo Component harness with the CCI part & element connectors. The Cryo Component harness will be interconnected on the upper and lower spatial framework interface connector-bracktes.

In design and size different types of interface brackets will be used for harness interconnections. The Interface brackets will be designed in accordance to thermal, structural and AIT constraints.

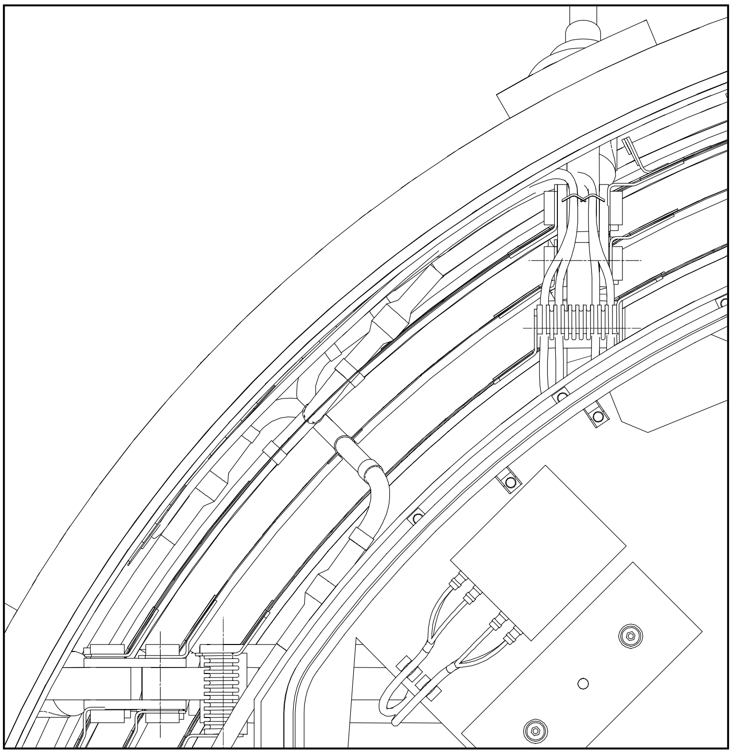


Figure 69: CVV Internal Harness in area of thermal Shields (intermediate design status)

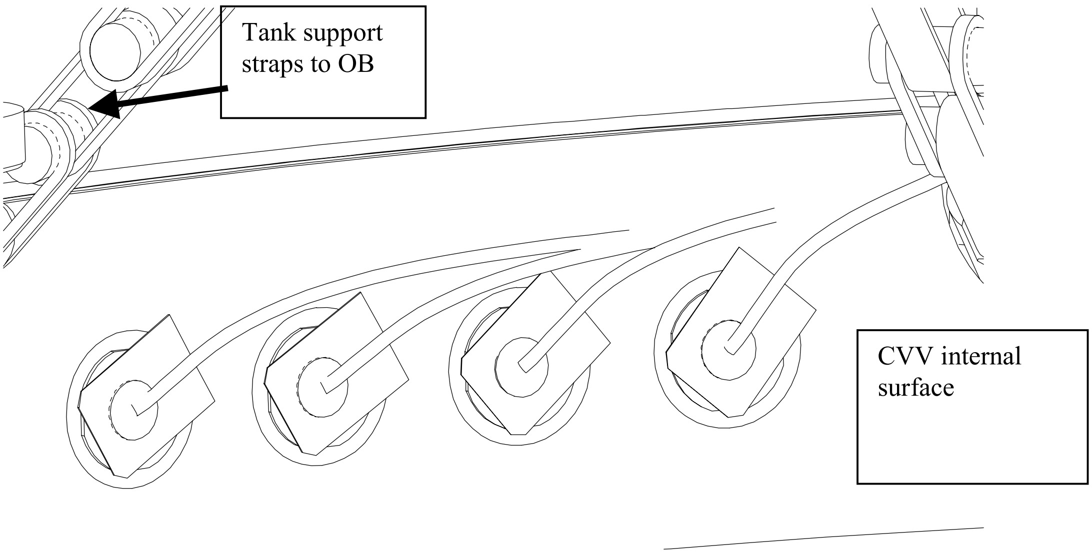


Figure 70: Principle CVV internal Harness vacuum Feed-through connector Back-shells

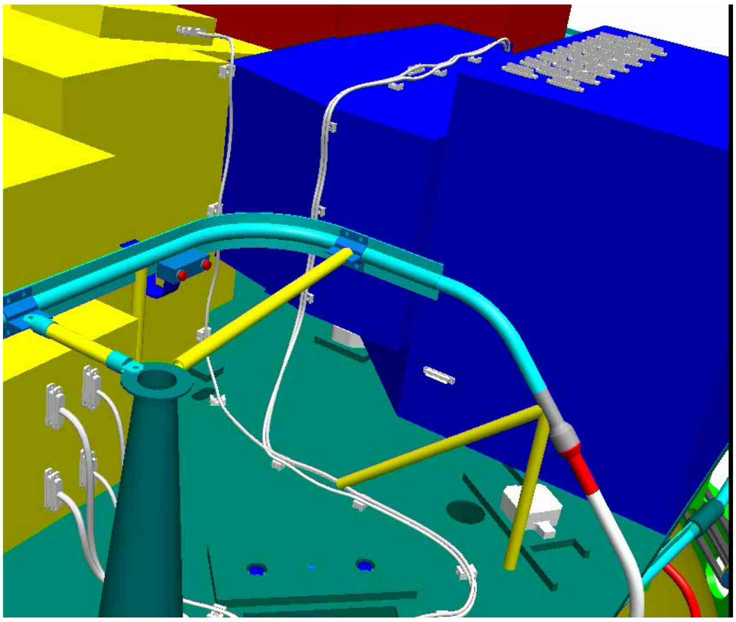


Figure 71: CVV internal Harness to optical bench cold units (intermediate status)

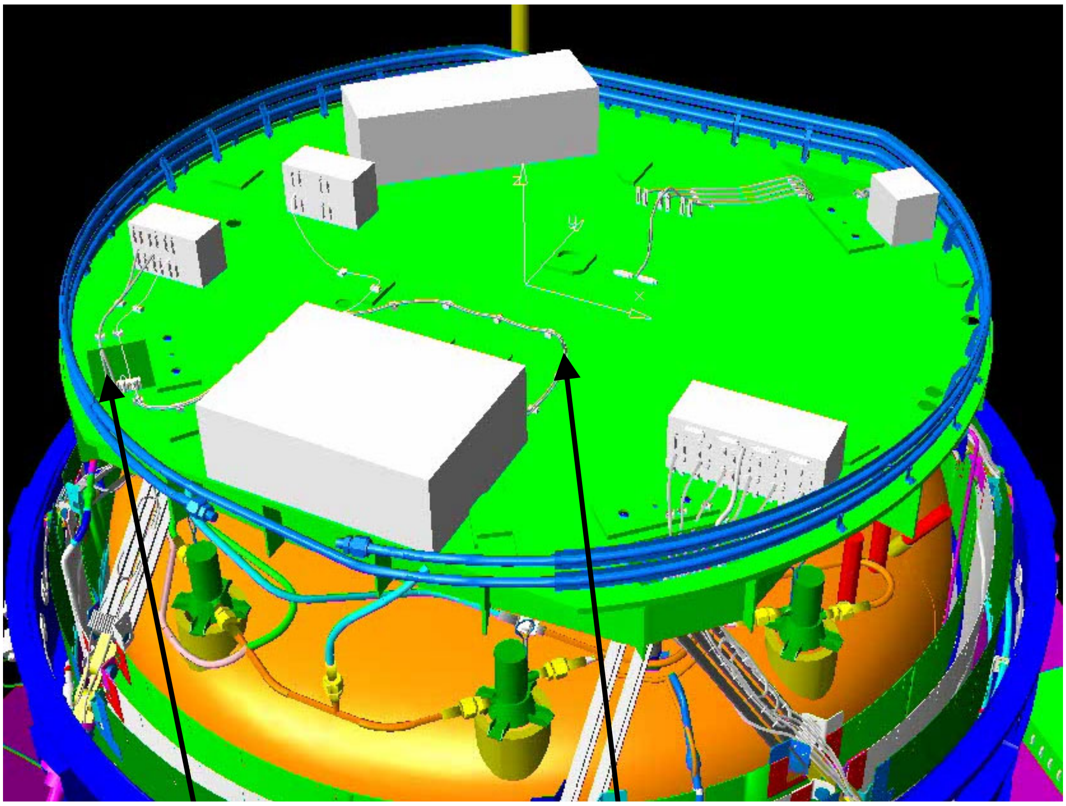


Figure 72: CVV internal Harness Fixation on optical Bench (OB) and Tank support straps (intermediate design status , ventline routing in former position)

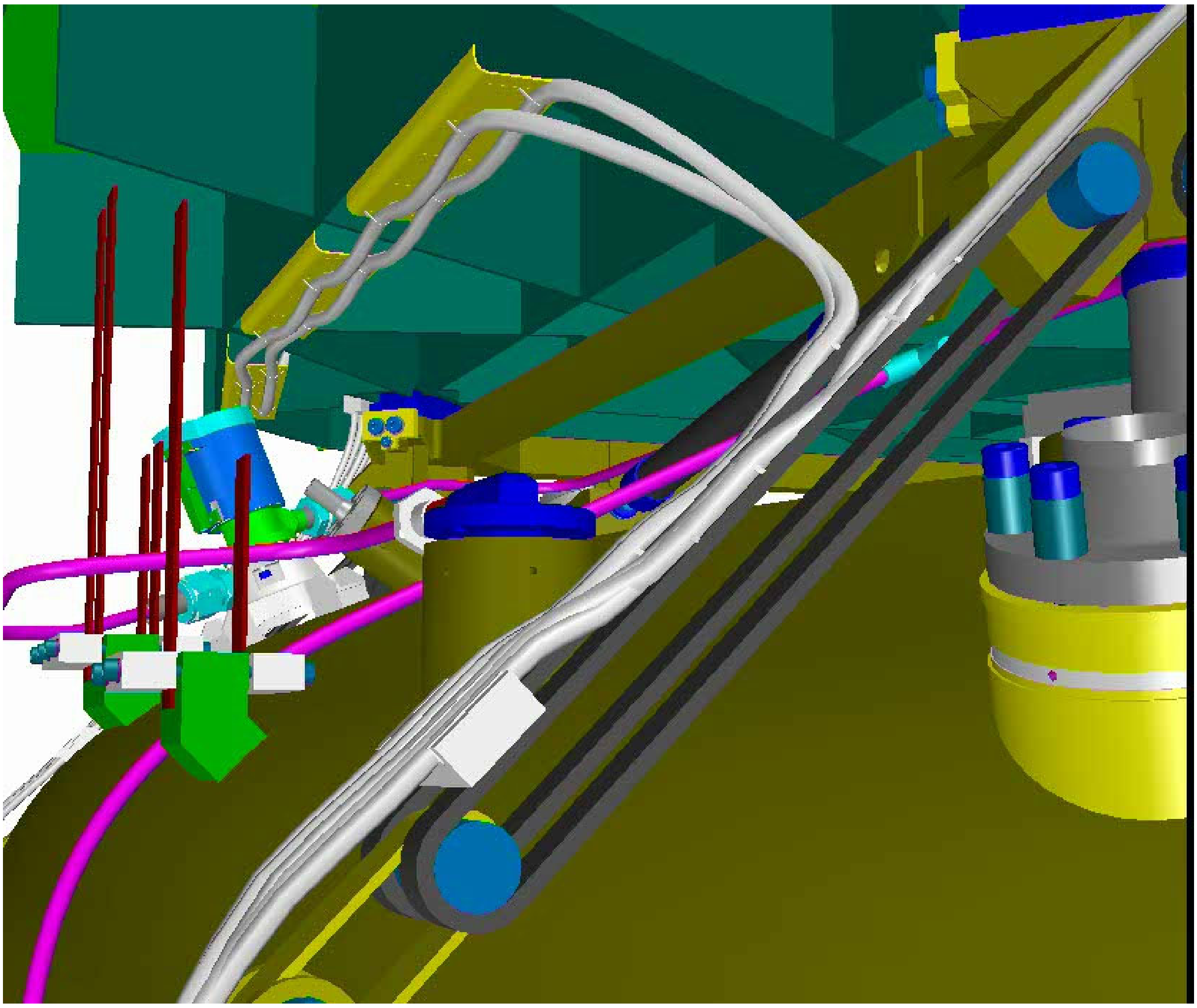


Figure 73: CVV Internal Harness Fixations on Tank support straps and under OB

12.4 Cryostat Control Unit (CCU)

As part of the electrical subsystem of the PLM the CCU will be 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 HSS temperature sensors.

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

The CCU will be 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 would provide sufficient information for predictable operation of the cryo system.

Each unit 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 will monitor the cryostat status by acquisition of the pressure and temperature sensor readings, will operate and monitor the liquid helium content measurement system and will operate the cryogenic-valves as well as to acquire 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 will be operated by dedicated EGSE.

A principle blockdiagram of the CCU is given in Figure 74 below.

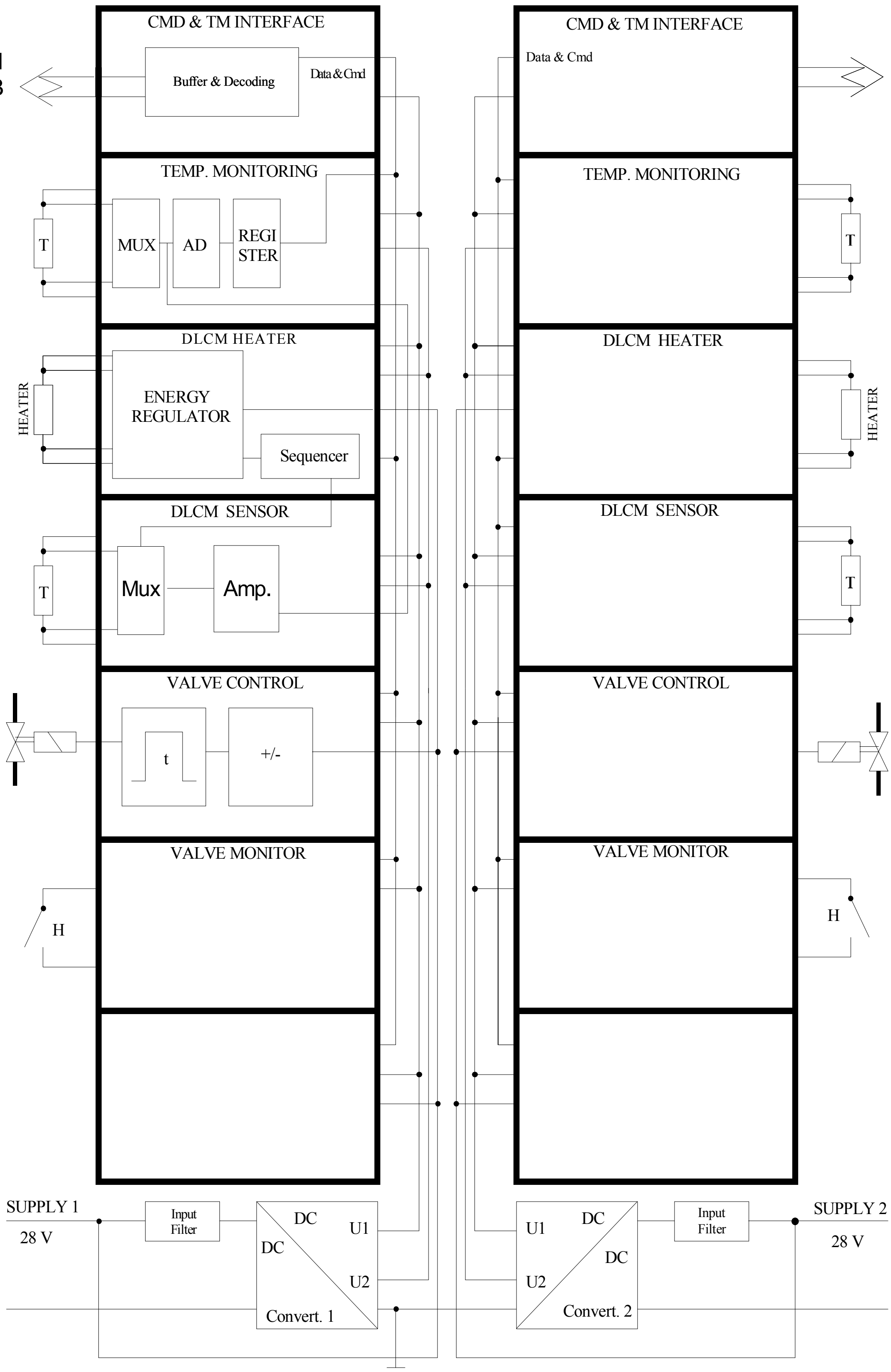


Figure 74: CCU Principle Blockdiagram

For the operation of the cryo system the CCU will provide three major functions:

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

He 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 He valve pair.

Since erroneous He 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 will only be executed when the related arming and switching commands are received in the correct sequence.

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 will be 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 will be able to process and execute the related arming and switching open commands generated by the AR 5 launcher and distributed to the CCU via discrete lines.

Direct liquid content measurement (DLCM)

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. For that purpose the injected current and voltage drop over a heater within the helium bath will be precisely measured every 125 ms for a predefined measurement period of up to 600 seconds (TBC).

The DLCM will be 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 will have a nominal resistance of 50 Ω at 1.8 K (90 Ω at ambient) and will be 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 has to be 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 will be assumed. 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. For the operation in the DLCM these four sensors will be operated in a high precision mode in the temperature range of 1.6 K to 1.8 K with an accuracy of less than ± 0.25 mK.

Since the performance 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 3 seconds (TBC).

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 410 seconds (TBC).
- 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 (TBC) after starting the DLCM monitoring.
  - switch off the DLCM heater after TBD (according to the parameter content in the CMD) seconds.
  - switch off the DLCM monitoring 200 seconds (TBC) after the DLCM heater.
  - 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 will be assembled into a table and is ready for transfer to the CDMU. During the DLCM the nominal cyclic monitoring will be suspended.

Monitoring Function

For the cryo system monitoring the CCU will readout the cryo system temperature, pressure and He valves status sensors.

Six monitoring tables will implement the cryo system monitoring. In the beginning and after a reset each table consists of all monitoring parameters. The monitoring tables can be modified in the following manner:

- one table is fixed with a predefined set and sequence of all monitoring parameters.
- five tables will be configurable with a selectable set and sequence of monitoring parameters.
- within each configurable table the parameter deletion, the setting of the parameter acquisition sequence and the table reset (to the default setting) will be accomplished by command.

Triggered by command sent from the CDMU via the Mil Std 1553 B bus the CCU will sequentially readout all enabled sensors and format the acquired parameters into the selected monitoring table. After completion of this sequential acquisition cycle the monitoring table is ready for transfer to the CDMU. Since a cryo system monitoring parameter can be allocated within one or several acquisition tables and due to the fact that the acquisition cycle for each individual table can be adjusted by CDMU command, the read-out frequency of each monitoring parameter can be set with greatest flexibility. At a minimum the following information will be included in the monitoring tables:

- all (not deleted) cryo control system temperature sensor readouts.
- all (not deleted) cryo control system pressure sensor readouts.
- all (not deleted) cryo system status indicator readouts.

Temperature measurement

Temperature measurement will be accomplished by measuring the voltage drop over a temperature dependent resistor (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. 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 has to be taken into account.

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

Pressure measurement

Pressure measurement will be accomplished by measuring the differential voltage of a resistive bridge with one pressure sensitive resistor (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. 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 has to be taken into account.

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

He valve status

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 digital relay status (DRS) interface.

Since the heat dissipation inside the CVV must be kept to the absolute minimum the valve position sensors will only be 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 will provide 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 will provide the unit’s 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 aspect are covered in Section 5.6.

Electrical Interfaces

SVM power interface

The CCU will have two primary power interfaces (one for CCU A, one for CCU B) via two separate connectors. The average power consumption of the CCU will be 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 will have 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 TBD 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 will correspond to the current drawn during the short peak condition.

SVM data handling interface

Each CCU (the nominal one as well as the redundant one) will provide 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 will be implemented according to the reference standard MIL-STD 1553B Notice 2. The MIL-STD-1553B bus connectors will be dedicated (no sharing of connectors with any other signal) and segregated (one connector for nominal bus and one for redundant bus) on each CCU.

SVW discrete valve command interface

The CCU will have two discrete valve command interfaces (one CCU A, one for CCU B) via two separate connectors. Each discrete valve command interface will comprise two valve-switching commands and two related arming commands. The electrical characteristics of the valve switching and arming command interfaces will comply with the Ariane 5 dry loop command I/F.

Cryo system user interface

The CCU will provide for 4 I/F's (2 within CCU A / 2 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 0 with the following characteristics:

sensor type:	Carbon Resistor C 100 (RCR 07 100 Ω)
temperature range 1:	1.5 K – 2.2 K
meas. accuracy range 1:	≤ ± 0.010 K
temperature range 2:	1.6 K – 1.8 K

meas. accuracy range 2:	≤ ± 0.00025 K
excitation current:	10 µA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for 8 I/F's (4 within CCU A / 4 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 1 with the following characteristics:

sensor type:	Carbon Resistor C 100
temperature range:	1.6 K – 1.8 K
meas. accuracy range:	≤ ± 0.00025 K
excitation current:	10 µA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for 5 I/F's (3 within CCU A / 2 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 2 with the following characteristics:

sensor type	Carbon Resistor C 100
temperature range :	1.5 K – 2.2 K
meas. accuracy range :	≤ ± 0.010 K
excitation current:	10 µA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for 7 I/F's (3 within CCU A / 4 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 3 with the following characteristics:

sensor type	Carbon Resistor C 100
temperature range :	2.0 K – 10.0 K
meas. accuracy range :	≤ ± 0.010 K
excitation current:	10 µA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for 18 I/F's (9 within CCU A / 9 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 4 with the following characteristics:

sensor type	Carbon Resistor C 100
temperature range :	3.0 K – 20.0 K
meas. accuracy range :	≤ ± 0.10 K
excitation current:	10 µA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for 56 I/F's (28 within CCU A / 28 within CCU B) the signal conditioning and acquisition circuitry of the temperature sensor type 5 with the following characteristics:

sensor type	Platinum Resistor Pt 1000
temperature range :	13 K – 370 K
meas. accuracy range :	≤ ± 1.0 K
excitation current:	1.0 mA
excitation time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

Note: The specified measurement accuracy for the temperature, pressure and voltage monitoring channels is an end to end value, where 50 % is consumed by the sensor already. Therefore for the error budget calculation of the temperature, pressure and voltage monitoring channels, ≤ 50 % of the measurement accuracy value will be allocated to the CCU.

The CCU will provide for two I/F's (one within CCU A / one within CCU B) the signal conditioning and acquisition circuitry of the pressure sensor with the following characteristics:

Pressure sensor type:	BHL 4105 – 00 (0 – 35 mbar)
voltage range:	1 – 8mV
voltage accuracy:	≤ ± 0.010 mV
excitation current:	2.5 mA ± 0.1 %
measurement time:	≤ 50 ms
wiring:	4 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide for two I/F's (one within CCU A / one within CCU B) the signal acquisition circuitry of the DLCM heater voltage measurement with the following characteristics:

voltage range:	15 V – 28 V

voltage accuracy:	≤ ± 0.010 V
measurement time:	≤ 10 ms
wiring:	2 wires stainless steel AWG 38 (120 Ω/m)

The CCU will provide (as CCU internal interface) for two I/F's (one within CCU A / one within CCU B) the signal acquisition circuitry of the DLCM heater current measurement with the following characteristics:

current range:	0.4 A – 0.5 A
current accuracy:	≤ ± 0.10 mA
measurement time:	≤ 10 ms
wiring:	CCU internal

The CCU will provide for two I/F's (one within CCU A / one within CCU B) the supply circuitry for the DLCM heaters with the following electrical characteristics:

heater resistance (amb.)	90 Ω
heater resistance (5 K)	50.7 Ω
supply voltage:	26 - 28 VDC primary power (mainbus)
actuation current:	0.4 A – 0.5 A
actuation time:	up to 200 s
wiring:	2 wires brass AWG 30 (2 Ω/m)

The CCU will provide for six I/F's (three within CCU A / three within CCU B) the actuation circuitry for the liquid He valves with the following electrical characteristics:

coil resistance (amb.)	52 Ω ± 5 %
coil resistance (5 K)	TBD Ω
supply voltage:	26 - 28 VDC primary power (mainbus)
actuation current:	0.45 A ± 0.1A
actuation time:	200 ms ± 20 ms
ON command:	current direction forward
OFF command:	current direction reverse
wiring:	2 wires brass AWG 30 (2 Ω/m)

The CCU will provide for six I/F's (three within CCU A / three within CCU B) the acquisition circuitry for the liquid He valves status indicators with the electrical characteristics for the DRS standard interface.

Physical Properties

Mass: The CCU will have a mass of less than 10 kg.

Dimensions: The CCU will have the following dimensions (without feet) :

Length:	370 mm (max)
Width:	250 mm (max)
Height:	250 mm (max)

All unit connectors will be located on the units top face (side opposite to the baseplate) in easily accessible positions. The physical position will be compliant with the minimum distances between connectors.

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

Temperatures: The CCU qualification temperature range will be – 20°C to + 50°C in operating mode.

The CCU qualification temperature range will be – 30°C to + 60°C in non-operating mode.

The CCU qualification minimum switch-on temperature will be – 30°C.

The CCU acceptance temperature range will be – 15°C to + 45°C in operating mode.

The CCU acceptance temperature range will be – 25°C to + 55°C in non-operating mode.

The CCU acceptance minimum switch-on temperature will be – 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 qualification testing.

One Flight Model (FM) will be 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 will be 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 will be subjected to acceptance level testing.

12.5 Optical Bench Assembly (OBA)

The Herschel Instrument Optical Bench Assembly (OBA) serves as mechanical support of the scientific instruments of the Herschel Payload Module at cryogenic temperatures. The three Focal Plane Units (FPU's), HIFI, PACS and SPIRE as well as the SPIRE JFET box are directly bolted to the Optical Bench Plate (OBP), which is fixed upon the He II tank. The principal design of the Optical Bench suspended inside the Cryostat is depicted in the figure below.

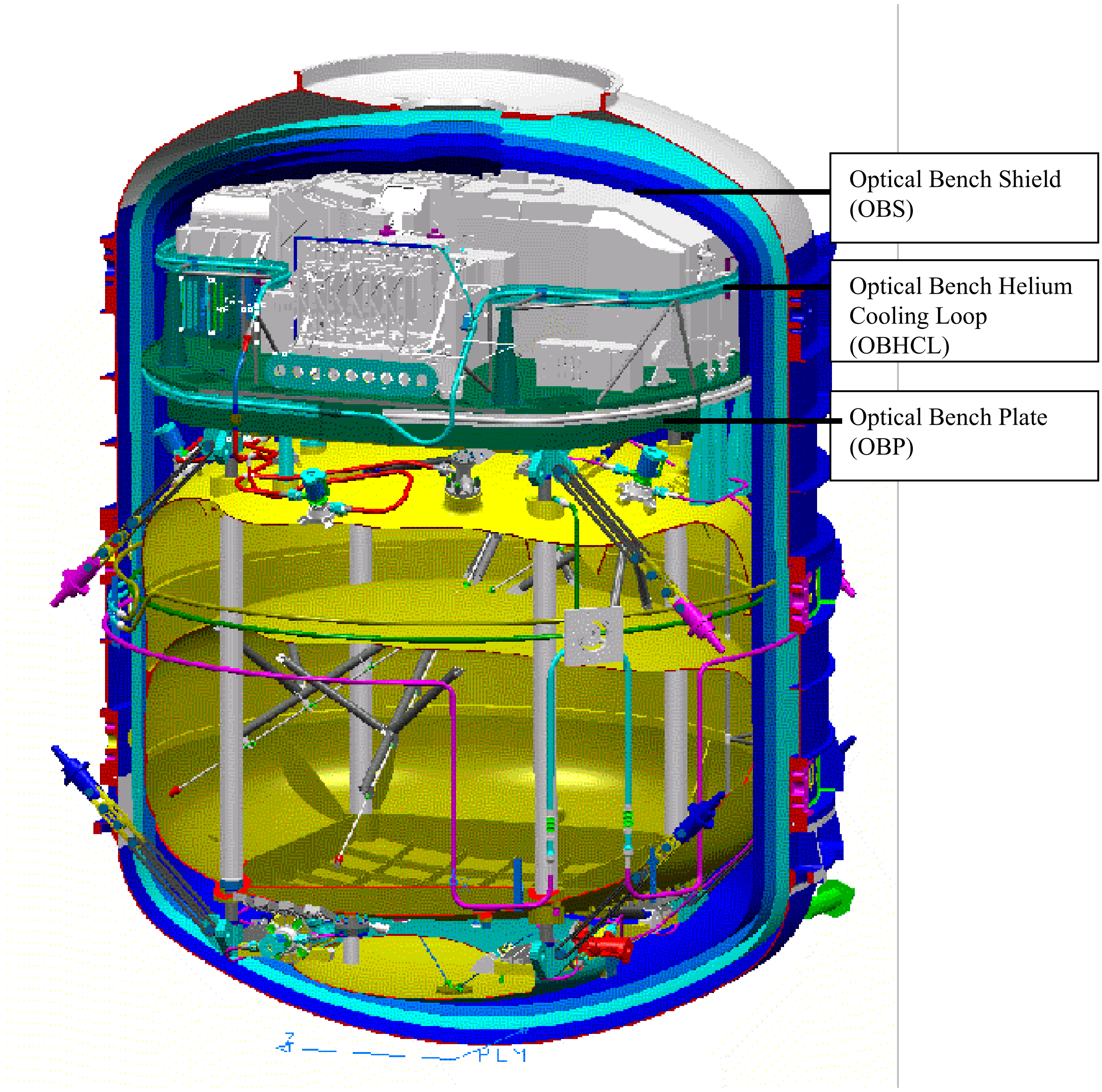


Figure 75: Overview, Optical Bench Assembly suspended inside the Cryostat

The Optical Bench Assembly consists of the following components:

- Optical Bench Plate (OBP) with mounting brackets and fasteners to the Spatial Framework (SFW),
- Optical Bench Shield (OBS), including entrance baffle and LOU baffle,
- Optical Bench Helium Cooling Loops, including mounting brackets (OBHCL),
- Thermal Interface Links to Scientific Instruments (OBTL),
- Associated screws/bolts for mounting of OBS and OBHCL to OBP and fasteners to attach the OBA to the Spatial Framework
- Mass Dummies of OBP mounted instrument units
- Optical Bench Instrumentation interfaces
- Scientific Instrument and Cryostat Instrumentation Harness interfaces

The basic function of the optical bench assembly is to provide a solid and alignment stable support of the instruments within the 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, instrument thermal links, to the He II Tank (HTT) and the OBS. The instruments on the OBP as well as OBP itself will be cooled by the OBHCL, which is routed around the rim of the plate and which is bolted to the OBP via brackets.

The OBP together with the OBS shall act as a light tight cavity when the entrance baffle and the LOU baffle are shut by test covers. This requires light tight feed throughs for all cut-outs in the OBP and in the OBS.

The OBA has to provide interfaces for harness attachment and instrumentation sensors attachment. The cryo harness and the instrumentation is not part of the OBA.

Main design drivers for the design/construction of the OBA are:

- Form stability due to cooling down from room temperature to 10 Kelvin,
- Eigenfrequency/stiffness requirements of 70 Hz out of plane,
- Strength compatibility against launch/interface loads.
- Supporting of straylight requirements

Different views of the OBA and their interfaces are shown in Figure 15 to Figure 19 in the instrument section 5.3. An OBA overview is provided in Figure 76.

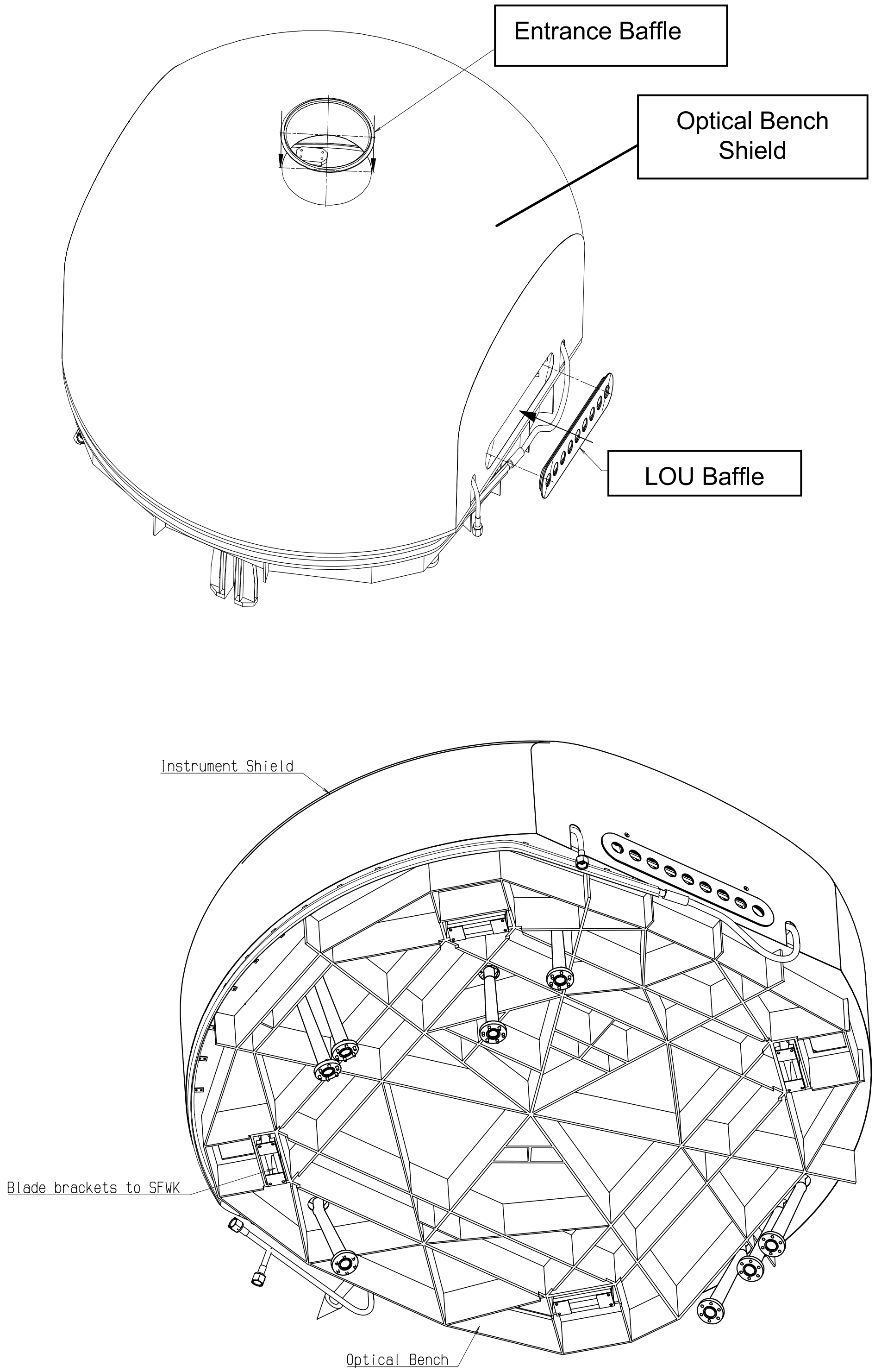


Figure 76: OBA Overview

12.6 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 approximately 14 days (tbc). 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 70-80 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
- 73 (tbc) 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
- Mounting basis for 6 Telescope support struts
- Mounting bases for 24 PLM/SVM struts
- Mounting basis for 8 LOU-struts
- Mounting basis for BOLA I/F bracket
- Mounting basis for 8 Sunshield/Sunshade-struts
- Mounting basis for Cryostat Cover (to be opened on orbit)
- Mounting basis for Cryostat Baffle resp. CTA
- Mounting basis for Radiators
- Mechanical support for external He-ventline and He-heater/filter, external harness 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

12.6.1 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
- 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 (tbc) 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 (tbc).

12.6.2 CVV Radiators

The CVV Radiators (“Nose” and “Ears”) are located on the –z-side respectively on the +y and –y-side of the CVV. Both sides of the –z-radiator are black anodised (tbc) to provide a high emissivity surface, whereas for the +y and –y-radiators only the frontside facing deep-space will be black anodised (tbc); the backside (i.e. the side facing +z-direction) is covered with MLI. All radiators are attached to the CVV by at least 6 brackets onto the CVV rings to ensure sufficient thermal connection. The design baseline is a integral milled panel with high ribs for better emissivity. As an option, an open honeycomb panel is under evaluation.

12.6.3 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 vacuum feed throughs 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 32 to 34 mm (tbc) to provide the required 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 (tbc).

The following figures provide an overview of the CVV baseline configuration:

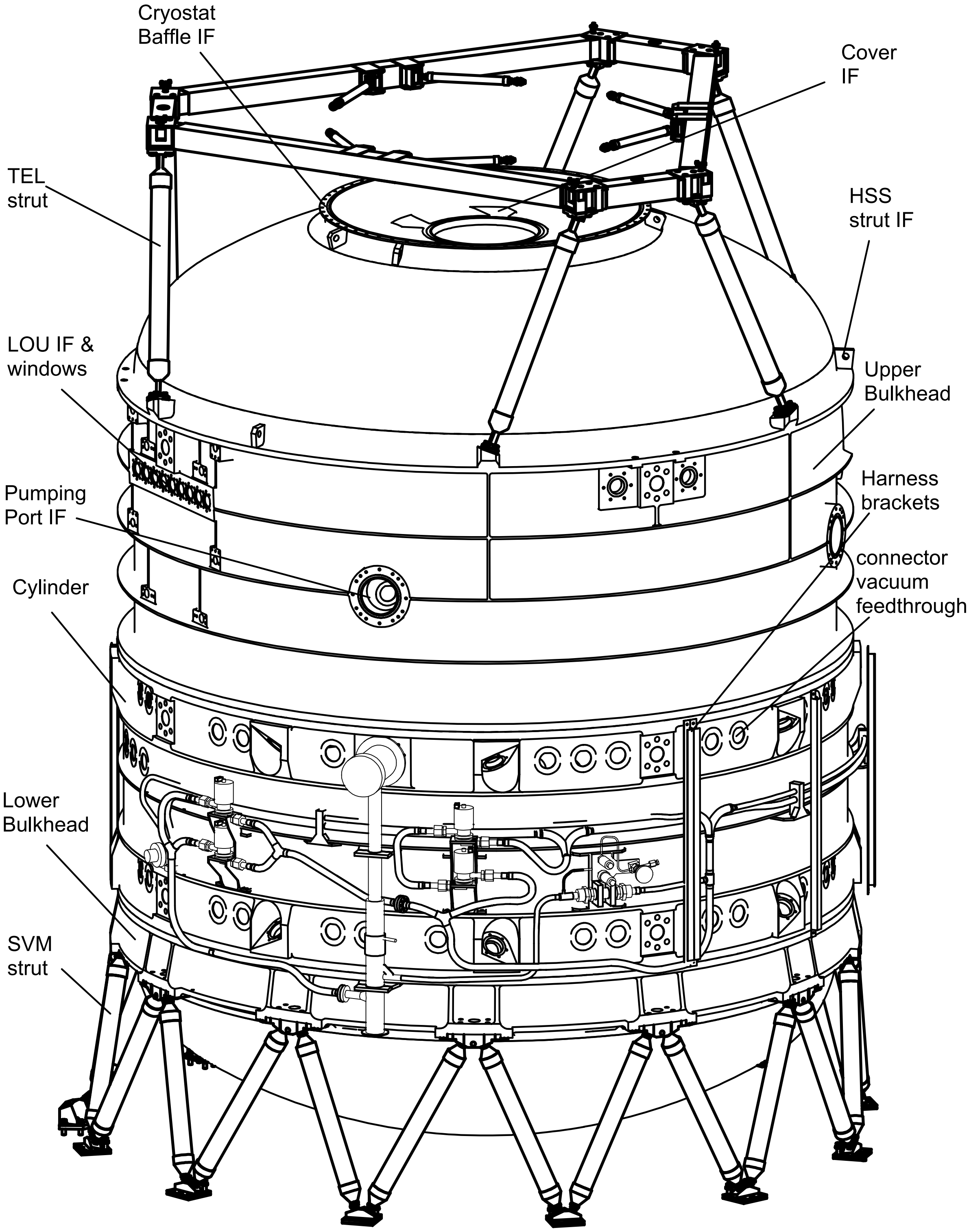


Figure 77: CVV overview

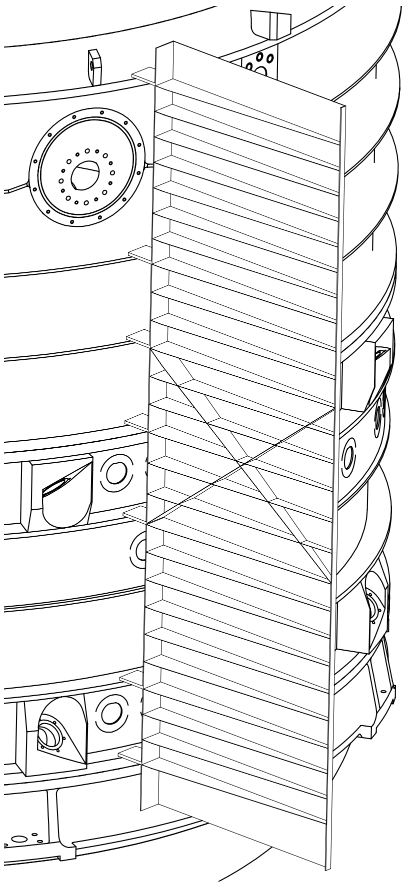


Figure 78: CVV radiator (draft)

12.7 Helium – II Tank (HTT)

The HTT will provide a cold volume of at least 2160 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 L0 thermal links to FPU's
- DLCM 1/2 with T101/102 and H101/102
- Level Probe L101/102
- Fluid Thermometer T104/105 (tbc)
- Surface Thermometer T103 (Pt500) T106/ T107 (CX)
- Rupture Disc RD124
- External Heaters H103/104
- Several He-valves and SV123
- Pressure Sensor P101/P102

- Adsorber
- 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 (SFWK).

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
- 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 reducing 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 must have 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 below:

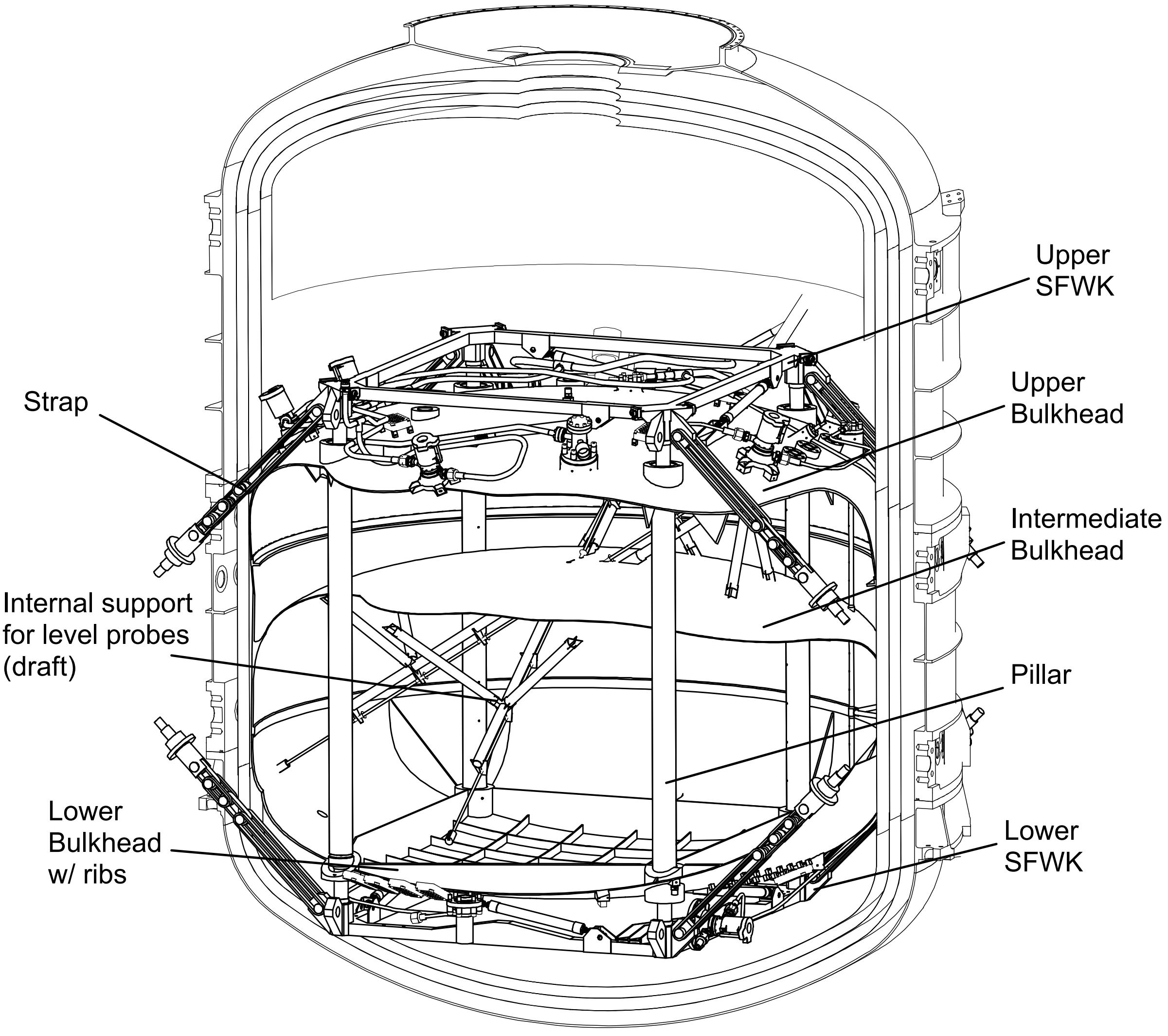


Figure 79: HTT design and fixation in the SFWK

12.8 Helium – I Tank (HOT)

The He I tank provides a cold volume of at least 78.4 l for normal liquid helium (LHe) for cooling the cryostat during some ground tests and pre-launch operations ("launch autonomy", i.e. 6 days after the last filling (tbc) and thermal conditioning of the He II tank). Especially during the pre-launch operations the He I tank 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 He I tank is electrically heated. Several He I tank refillings with LHe, even through the Ariane 5 payload fairing, will be necessary to actually guarantee the required launch autonomy time. The He I tank will be completely emptied just before lift-off by electrical heating and shall 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

The main design drivers for the design, construction and operation of the He I tank are:

- Tightness to LHe condition at $\approx$ 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 SFWK using four brackets with low radial stiffness to minimise thermomechanical loads during cool-down. The design baseline for the He I tank is an ellipsoid shape which is manufactured from two segments with a weld seam on the equator. However, design optimisation studies currently performed at the HOT subcontractor indicate that a bulkhead shape similar to the HTT leads to lower wall thickness and a better compatibility of the weld geometry with HTT and CVV. Therefore, a change of HOT geometry is anticipated.

Design and fixation of the baseline design HOT is shown below:

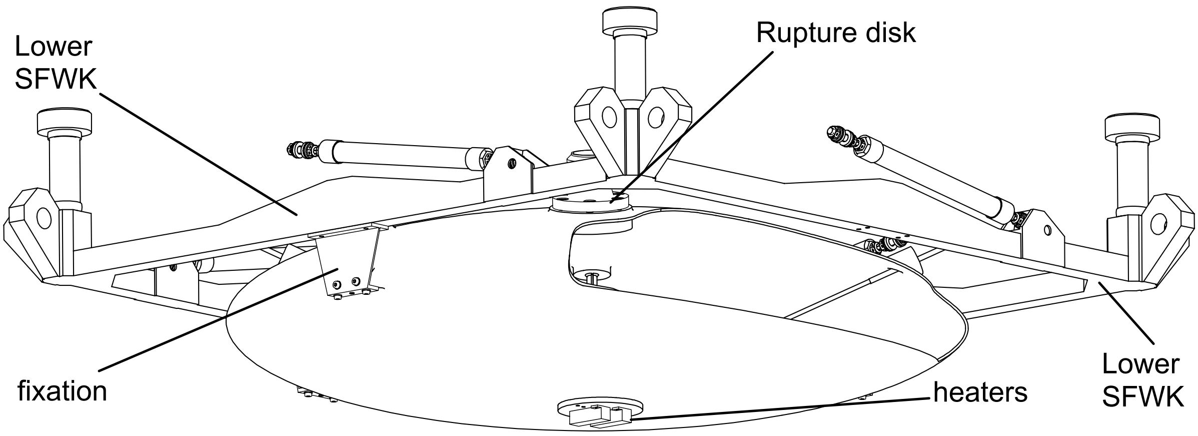


Figure 80: HOT design and fixation to lower spatial framework

12.9 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.

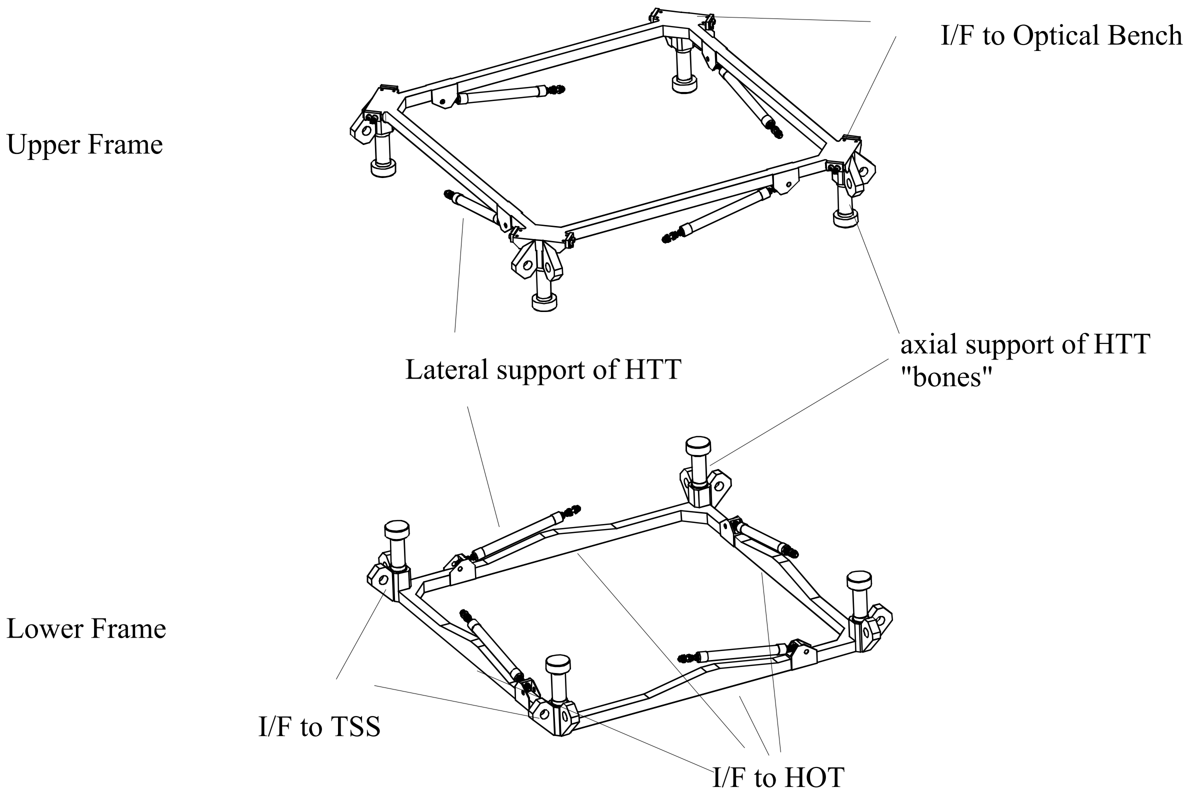


Figure 81: Spatial Framework

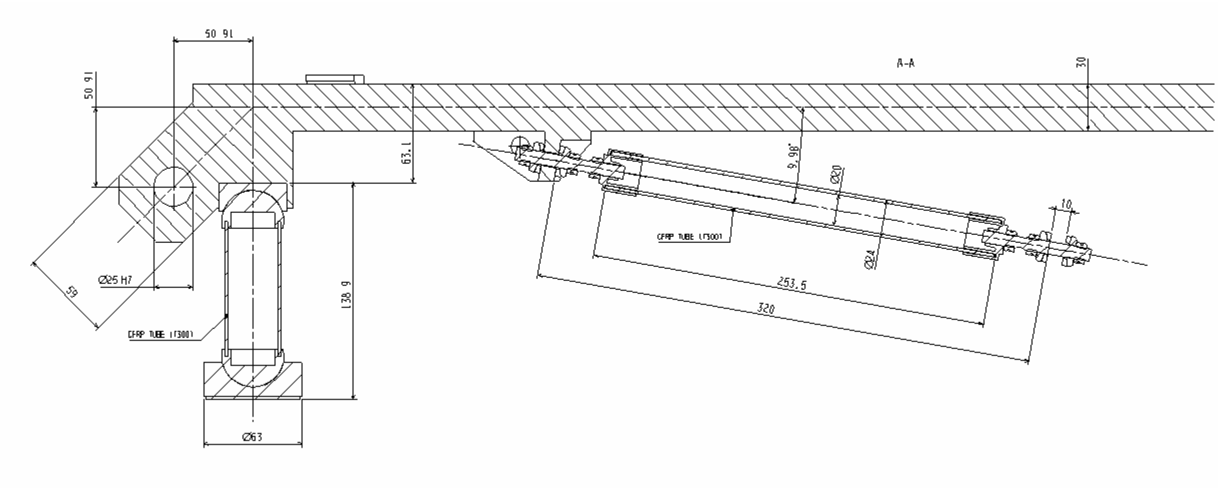


Figure 82: Design of lateral struts and bones

As shown in Figure 81 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 strats, 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 SFW is has to be designed for cryogenic temperatures. The following table summarises the main design drives.

Item	***Design Driver***	***Solution***
Aluminium fame	Tension stiffness	Aluminium cross: section 30 x 30
	Bending Stiffness of Lower frame	Reinforcments on the frame
Bone	Compression Load of 55 KN	T300 CFRP, cross section is 256 mm^2
	Thermal conductance	Material selection T300
	Possibility to compensate differential expansion between HTT and SFW frame.	“bone” design which allows rotation
Lateral struts	Stress/Strength to take the lateral loads of 8900 N	Adequate cross section A =
	Possibility to compensate the rotation of the due to thermal distortion.	Adequate Design

12.10 Tank Support Suspension (TSS)

The suspended mass of the Herschel cryostat are supported by the Tank Support Suspension (TSS). The TSS consists of the 8 upper and the 8 lower 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 below.

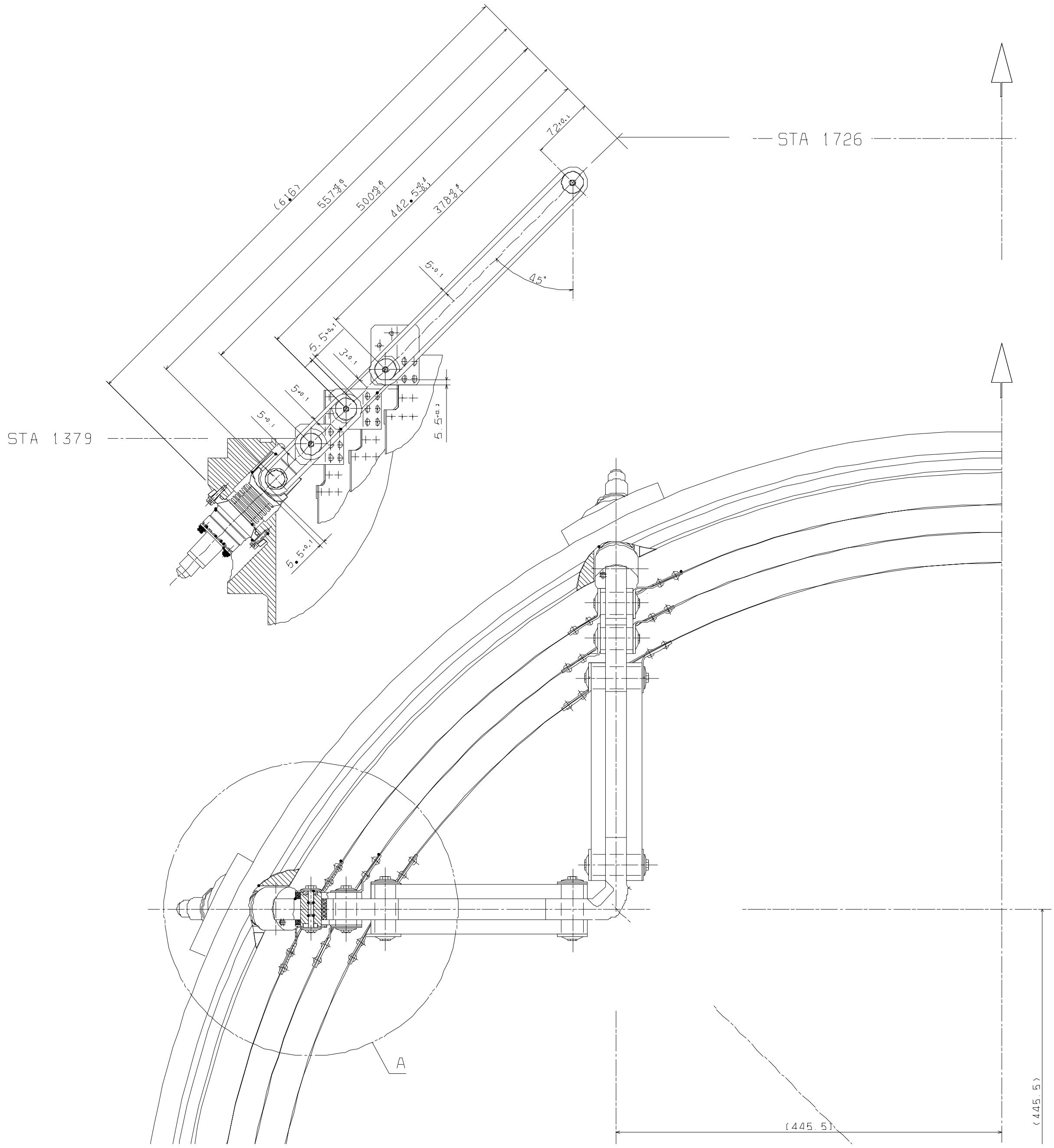


Figure 83: Tank Support System

Strap	Material	Cross section in mm^2
1	T300	172.5 (TBC)
2	S2 –Glas (TBC)	172.5 (TBC)
3	S2 -Glas	172.5 (TBC)
4	S2 -Glas	172.5 (TBC)

Table 26: Material definition of the straps

Part of the chains are the pre-tensioning device which allows to apply the needed preload of 25 KN to the TSS and which allows to align the OBA.

As the stiffness and strength requirements are more stringent in axial direction, the lower and upper tank chain are identical. An optimisation of the cross section is foreseen.

The TSS has a I/F to the CVV, to the SFW has to provide the I/F to the Thermal Shields. The I/F are identical to the ISO I/F.

From mechanical and thermal requirements (stiffness, loads, conductivity) the TSS is quite similar to the ISO upper chains.

12.11 Herschel Sunshield/Sunshade (HSS)

12.11.1 Introduction

The design of the HSS plus support struts assembly, which is the basis for the HSS and HSS support structure ITT's, is shown in Figure 84.

The HSS is mounted on the CVV and the SVM via 12 struts plus two attachment brackets. The mounting concept is as follows:

The upper end of the SSH 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 SSH in circumferential direction. Two additional struts from the SSH upper end to the CVV help the two axial tripod struts to carry the axial loads.

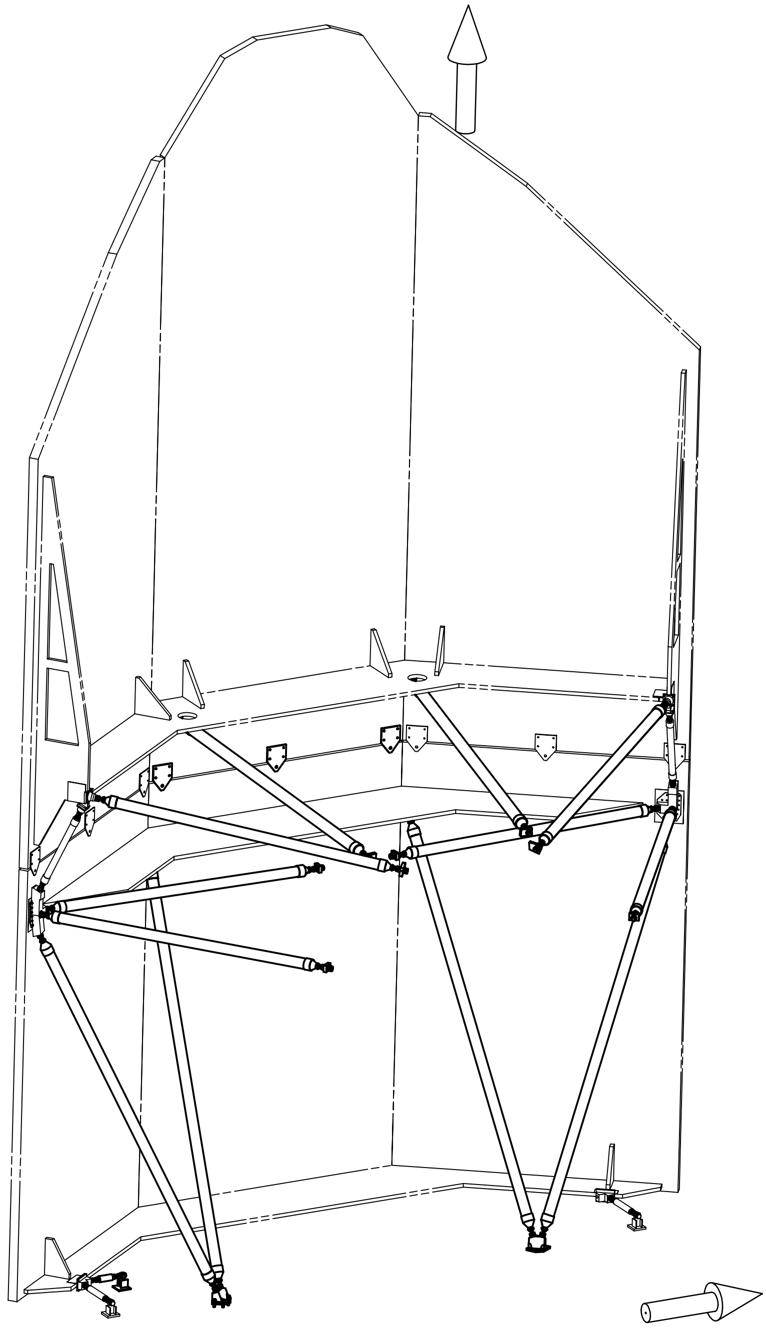


Figure 84: HSS and HSS Support Struts

The lower end of the SSH is horizontally linked to the SVM shear panels via two attachment brackets to transfer lateral HSS loads. These attachment brackets are part of the HSS. A stiffening element links the two attachment brackets on the SSH in circumferential direction.

The SSD is mounted onto the SSH via 9 GFRP blades (thermal isolation required, mechanical load transfer).

In addition the SSD is horizontally attached to the CVV via 4 GFRP struts. The strut points on the SSD are linked via a stiffening element in circumferential direction.

For stiffness increase of the SSD ears vertical stiffening ribs are placed on the +Y and –Y edge of the SSD.

A detailed design description for the HSS is given in document HP-2-ASED-RP-0025, 'Herschel Sunshield and Sunshade (HSS) Design Development'.

12.11.2 Physical Properties

12.11.2.1 Mass

The actual nominal mass of the HSS including its fixation struts is 169.4 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. For a detailed mass breakdown refer to HP-2-ASED-RP-0025.

12.11.2.2 Dimensions and Mechanical Interfaces

The HSS and its fixation struts have the dimensions and mechanical interfaces toward SVM and CVV as shown in HP-2-ASED-RP-0025.

12.11.3 Mechanical Design

12.11.3.1 Mechanical Properties

The HSS baseline design assumes CFRP M55J panels and stiffening ribs with the mechanical properties as presented in Table 27:. The HSS support strut properties are defined in Table 28:.

Sunshield/Sunshade		**Panels**	**Profile T300**	**Strut CFK**	**Strut GFK**
Density Fibre		1.93	1.78	1.93	2.55
Density Resin		1.3	1.3	1.3	1.3
Fibre Volume		0.6	0.6	0.6	0.6
Density Laminate		1.678	1.588	1.678	2.050
	Panel	Rib			
Sandwich Type	A	B			
Sandwich Height (mm)	50.00	20.00			

Sunshield/Sunshade		Panels	Profile T300	Strut CFK	Strut GFK
Face Sheet Thickness (mm)	0.2500	0.375			
Core (kg/m³)	16.00	32.00			
Adhesive (g/m²)	150.00	150.00			
Face Sheet Mass (kg/m²)	0.839	1.259			
Adhesive (kg/m²)	0.300	0.300			
Core (kg/m²)	0.792	0.616			
Mass (kg/m²)	1.931	2.175			
Density (kg/m³)	38.62	108.73			

Table 27: HSS Mechanical Properties

<table>
<tr><th>StrutNo,</th><th>from</th><th>to</th><th>Cross section [mm²]</th><th>Young's modulus [N/mm²]</th><th>Thermal conductivity [W/m K]</th></tr>
<tr><td>1 thru 4</td><td>SVM I/F</td><td>SSH I/F</td><td>500</td><td>323000</td><td>28.5 (200-300K)</td></tr>
<tr><td>5 thru 8</td><td>CVV I/F</td><td>SSH I/F</td><td>785</td><td rowspan="3">48000</td><td rowspan="3">0.347(50K)
0.477(120K)</td></tr>
<tr><td>9, 12</td><td rowspan="2">CVV I/F</td><td rowspan="2">SSD I/F</td><td>785</td></tr>
<tr><td>10, 11</td><td>864</td></tr>
</table>

Note: Brackets and tube end-fittings are not considered in this table. End-fittings have reduced cross section (16 mm DIA, Length 60 mm)

Table 28: HSS Support Strut Mechanical Properties

12.11.3.2 Stiffness

The HSS including fixation struts has minimum resonance frequencies of

- 24.9 Hz (local mode, SSD ears)
- 26 Hz for the first global bending mode (minimum of 24 Hz specified)
- 71 Hz for the first X mode

with the struts hard-mounted at their external interfaces.

The first HSS bending mode natural frequency stays at 26 Hz with the HSS integrated in the S/C (soft-mounted frequency). The second global lateral S/C bending mode lies at 27.3Hz, i.e. very close to the main HSS bending mode.

12.11.3.3 Dynamic Response

The loads on the optical bench and He2 Tank analysed with the Herschel S/C are as listed in Table 29:.

	2nd global Herschel bending mode F = 27.3 Hz	1st HSS bending mode F = 25.9 Hz
	Y-response	**Z-response**
Optical Bench	5.9	5.4
He2 Tank	10.9	7.3

Table 29: Dynamic Amplifications on E-PLM from Response Analysis with 1g Input

With an input of 1 g accelerations on the Optical Bench lie within the specified limits (7.5 g specified) for the two most critical modes listed in Table 29:. Amplifications on the He2 Tank exceed the specified limits (5 g specified) for the two most critical modes listed in Table 29:. On the other hand the second global Herschel bending mode will certainly be notched and thus accelerations on the He2 tank will be reduced.

12.11.4 Thermal Design

12.11.4.1 Sunshield Thermal Design

The sunshield is the lower part of the HERSCHEL Sunshield/Sunshade. The SSH serves as solar generator and shall shadow the PLM from solar radiation. The external surface is therefore covered with Solar Cells and on the remaining area at the top end of the sunshield with OSR's. The inner (rear) side is covered with highly efficiency MLI.

As a conservative approach for the solar cell design and performance prediction, an adiabatic sunshield rear side is assumed.

The SSH with bonded solar cells and the OSR elements experience the temperature range –100°C (TBC) to 136°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 Sunshield temperature is very important for the lifetime of the Herschel cryostat. The temperature is minimised by coverage of the upper rim of the sunshield area with OSR’s.

The Sunshield is thermally isolated from the SVM by using GFRP attachment brackets at the SSH lower edge. The axial struts between SSH upper edge and SVM have to made from CFRP to carry the axial HSS loads.

The Sunshield is thermally isolated from the CVV by using GFRP struts between SSH upper rim and CVV.

12.11.4.2 Sunshade Thermal Design

The sunshade is the upper part of the HSS. The SSD 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 +25°C is expected 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 Sunshield through connecting the two parts by GFRP blades.

The Sunshade is thermally isolated from the CVV by using GFRP struts between SSD lower rim and CVV.

12.11.5 Photo-Voltaic Assembly (PVA) Design

The sunshield (SSH), consisting of three hard-mounted panels with identical area caries on its outer, sun-exposed surface the solar cells of the photovoltaic assembly. Due to mechanical reasons, the three panels form a structural entity, which cannot be disassembled after manufacturing completion. 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 1500 W (Option 2: 1600 W) at the begin of the nominal mission lifetime under the following conditions:

- Mismatching loss factor : 0.97
- Calibration loss factor : 0.98
- Micrometeoroid and ultraviolet degradation loss factor : -
- Random failure losses : -
- Sun aspect angle around the S/C Y-axis : ± 0°
- Sun aspect angle around the S/C X-axis : ± 0°
- Solar flux (summer solstice at LEOP) : 1328 W/m²
- Radiation fluence (1 MeV e^- equivalent particles) : -
- Cover-glass loss factor : TBD by contractor

- Thermal mismatch factor : TBD by contractor

The PVA shall provide a minimum power of 1350 W (Option 2: 1400 W) at the end of the nominal mission lifetime (after 3.5 years in orbit) under the following conditions:

- Mismatching loss factor : 0.97
- Calibration loss factor : 0.98
- Micrometeoroid and ultraviolet degradation loss factor : 0.992
- Random failure losses : 1 string
- Sun aspect angle around the S/C Y-axis : ± 30°
- Sun aspect angle around the S/C X-axis : ± 1°
- Solar flux (summer solstice at L2 max.) : 1287 W/m²
- or Solar flux (winter solstice at L2 max.) : 1405 W/m²
- Radiation fluence (1 MeV e^- equivalent particles)* : 0.91×10^{14}
- Cover-glass loss factor : TBD by contractor
- Thermal mismatch factor : TBD by contractor

*Radiation fluence calculated for Ga As cells and a cover-glass thickness of 100µm and includes an uncertainty factor of 1.3 . To be scaled if material / dimensions are chosen differently.

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 the following conditions:

- Mismatching loss factor : 0.97
- Calibration loss factor : 0.98
- Micrometeoroid and ultraviolet degradation loss factor : 0.985
- Random failure losses : 1 string
- Sun aspect angle around the S/C Y-axis : ± 30°
- Sun aspect angle around the S/C X-axis : ± 1°
- Solar flux (summer solstice at L2 max.) : 1287 W/m²
- Radiation fluence (1 MeV e^- equivalent particles)* : 1.56×10^{14}
- Cover-glass loss factor : TBD by contractor
- Thermal mismatch factor : TBD by contractor

*Radiation fluence calculated for Ga As cells and a cover-glass thickness of 100µm and includes an uncertainty factor of 1.3 . To be scaled if material / dimensions are chosen differently.

For the power calculations the related SCA temperatures (as obtained from the thermal analysis)shall be increased by 5°C.

The PVA shall provide it's specified powers at the SVM interface connector, i.e. already considering worst case harness and blocking diode losses.

The PVA shall provide it's specified powers at a minimum voltage of 30.0 V at the SVM interface connector throughout the nominal and extended mission life time.

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 > 25% (under normal conditions) is needed to guarantee the required performance. Presently such a high efficiency can only be achieved with a triple junction Ga As cell, which is qualified and available in mass production only from US manufacturers.

Therefore for the reference design (used as long no subcontractor information is available) the data sheet of the Improved Triple Junction (ITJ) solar cell from Spectrolab with the following characteristics is used:

Features

- High efficiency n/p design (28°C, AM0)

  BOL: 26.8% min. average efficiency @ maximum power

  26.5% @ load voltage)

  EOL: 22.5% min. average efficiency @ maximum power

  (22.3% @ load voltage), 1 MeV 1E15 e/cm²
- Integral bypass diode protection

Description

Substrate	Germanium
Solar Cell Structure	GaInP2/GaAs/Ge
Method of GaAs Growth	Metal Organic Vapor Phase Epitaxy
Device Design	Monolithic, two terminal triple junction.
	n/p GaInP2, GaAs, and Ge solar cells interconnected with two tunnel junctions
Size	24.5 cm² (70 x 35 mm²)
Assembly Method	Multiple techniques including soldering,welding,thermocompression, orultrasonic wire bonding
Integral Diode	Si diode integrated into recess on back side

Typical Electrical Parameters	(AM0 (135.3 mW/cm²) 28°C, Bare Cell)
Jsc =	16.90 mA/cm²
Jmp =	16.00 mA/cm²
Jload min avg =	16.10 mA/cm²
Voc =	2.565 V
Vmp =	2.270 V
Vload =	2.230 V
Cff =	0.84
Effload =	26.5%
Effmp =	26.8%

Radiation Degradation	(Fluence 1MeV Electrons/cm²)		
Parameters	**1x10^{14}**	**5x10^{14}**	**1x10^{15}**
Imp/Impo	1.00	0.98	0.96
Vmp/Vmpo	0.94	0.90	0.88
Pmp/Pmpo	0.94	0.88	0.84

Thermal Properties

Solar Absorptance = 0.92 (Ceria Doped Microsheet)

Emittance (Normal) = 0.85 (Ceria Doped Microsheet)

Weight

84 mg/ cm² (Bare) @ 140 µm (5.5 mil) Thickness

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 reference design was envisaged:

Panels:	3 identical panels with 10 el. sections per panel
Sections:	30 identical el. sections with 6 strings per section
Strings:	180 identical strings with 21 solar cells per string

That results in a PVA with an effective surface of 9.261 m² with an area usage factor of 87 % evenly distributed on the three panels.

Each string is coupled to the related section via its blocking diode. Six strings, wired in parallel to one section, are connected individually to the PCDU via two TP AWG 20 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 center panel
- Solar aspect angles (0 / 30 deg.) as required above for the related case
- Solar cell (Spectrolab ITJ) performance as described above
- Blocking diode losses of 0.8 V
- Harness losses (2 x 6.5 m TP AWG 20 per sect.) up to the SVM I/F connectors
- Sun irradiation intensities as required above for the related case

The results of the PVA reference design performance prediction is given in Section 6.

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 20 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 will be isolated from the electrically conductive SSH 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 SSH panel structure will be isolated from the spacecraft structure by more than 10 MΩ. By means of the redundant bleeding resistors, the conductive SSH panel structure

will be bonded to the spacecraft structure by about 10 to 100 kΩ for each panel individually.

12.12 SVM Thermal Shield

The complete SVM thermal shield subsystem including fixations is shown in Figure 85.

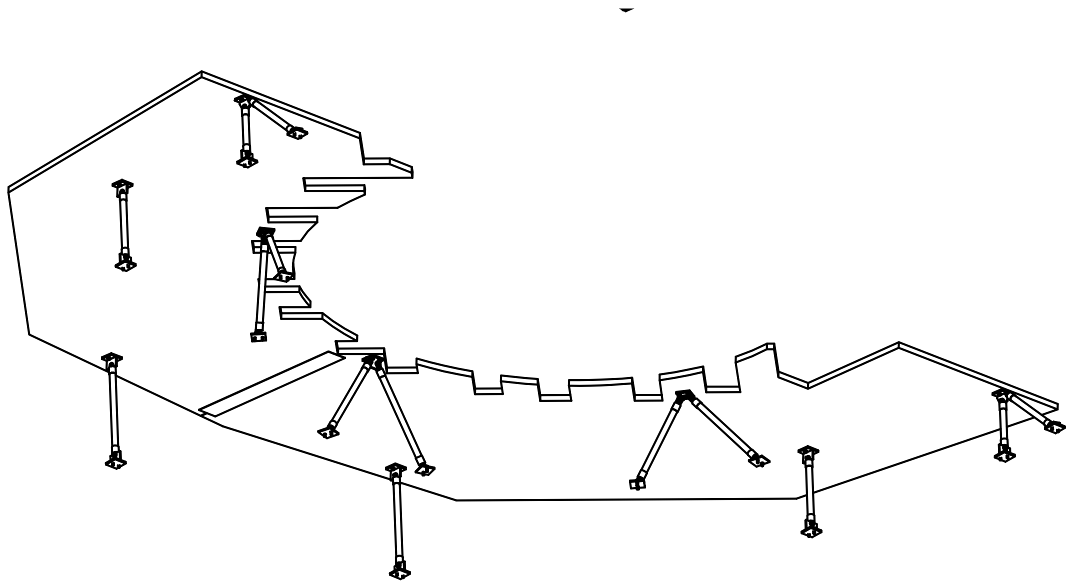


Figure 85: SVM Thermal Shield Subsystem Definition

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 ($\varepsilon<0.045$ required, goal: $\varepsilon<0.04$). 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.

12.12.1 Physical Properties

12.12.1.1 Mass

The actual mass of the SVM thermal shield is 14.4 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.

3.3 kg are needed for MLI of SVM thermal shield and fixation struts.

12.12.1.2 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.

12.12.2 Mechanical Design

12.12.2.1 Stiffness

The SVM thermal shield including fixation struts has a minimum resonance frequency for global modes of

- 26.8 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.

12.12.2.2 Quasi-Static Design Loads

The SVM thermal shield is designed against the quasi-static design loads as stated in Table 30.

SVM thermal shield	#1	50 g axial +/-35 g (TBC) lateral

Table 30: Quasi-static Design Loads SVM Thermal Shield

12.12.2.3 Low Frequency Sinusoidal Vibrations

The SVM thermal shield is designed against the low frequency sinusoidal design loads defined in Table 31 on SVM thermal shield S/S level.

Axis	Frequency range (Hz)	Qualification level (0-peak) (g)
Longitudinal	5 - 11.2 11.2 - 100	+/-10 mm 5 g (TBC)
Lateral	5 - 15.8 15.8 - 100	+/-10 mm 10 g (TBC)

Table 31: Envelope of SVM Thermal Shield S/S Sinusoidal Vibrations – Qualification Level

12.12.2.4 Acoustic Noise

The SVM thermal shield shall be designed against the acoustic environment.

12.12.3 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.

The IR emissivity on 90% (TBC) of the SVM thermal shield -X surface is minimised. An $\varepsilon < 0.045$ is achieved by covering the shield surface by gold plated kapton foil. An $\varepsilon < 0.04$ shall be aimed for.

On 10% (TBC) of the SVM thermal shield-X surface edges (exact location is TBD) an $\alpha/\varepsilon < 0.15$ (TBC) is required during early orbit phase.

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 (TBC).

The SVM thermal shield provides interfaces for the attachment of 6 (TBC) temperature sensors PT1000. Positions are TBD.

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.

12.13 Cryostat Cover and Cryostat Baffle

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, sunshield and telescope rear sides. It shall be able to carry the loads induced by the telescope support.

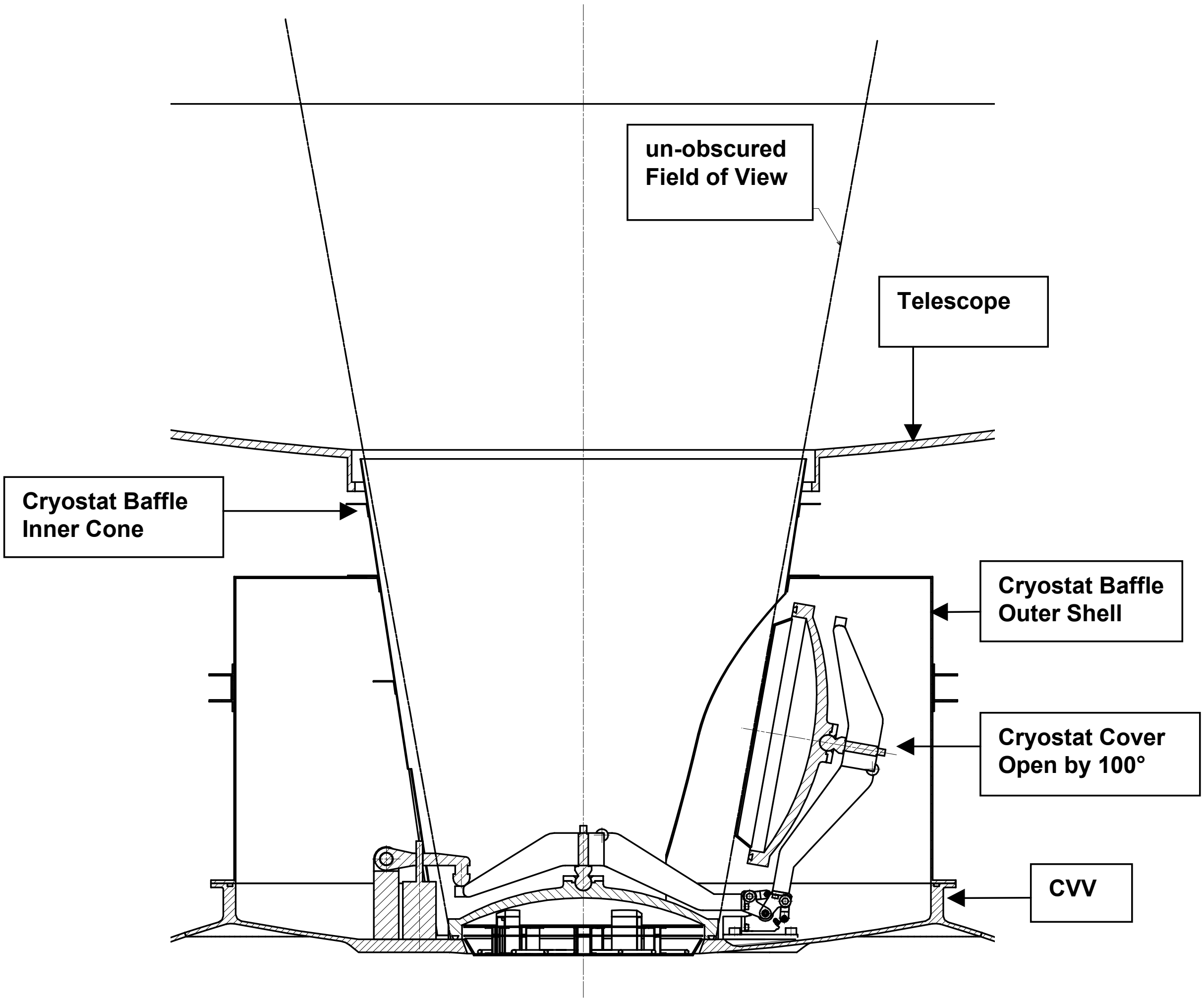


Figure 86: Cryostat Cover and Cryostat Baffle, General Arrangement

12.13.1 Cryostat Cover (CC)

The CC for vacuum tight closure of the cryostat, includes the hinges, the hold-down and release mechanism (HRM), a latch mechanism or an end stop, as well as temperature sensors and end switches with associated harness. The harness shall be routed to a common connector bracket, which shall be fixed to outer wall of the cryostat baffle.

A vacuum seal shall close the cryostat during all operational cases.

The cover shall provide the following main functions:

- Close and tighten CVV during ground and launch operations for insulation vacuum.
- Opening in orbit by a drive device using for release a Non Explosive Device (NED) with redundant release coils. The opening angle of the cover shall be 100°(TBC) including an amount of 3° for latching. Safe single opening on orbit for start of scientific mission without unintended closure
- Provide sufficient free entrance (ø288 mm) for telescope beam into cryostat when open
- Provide a cover shield temperature which allows operation of instruments on ground

In order to be able to operate the instruments on ground, the CC is equipped with a Helium/Liquid Nitrogen cooling system to achieve a temperature range at the Cover Heat Shield (CHS) from 10K to 90K pending on the used medium.

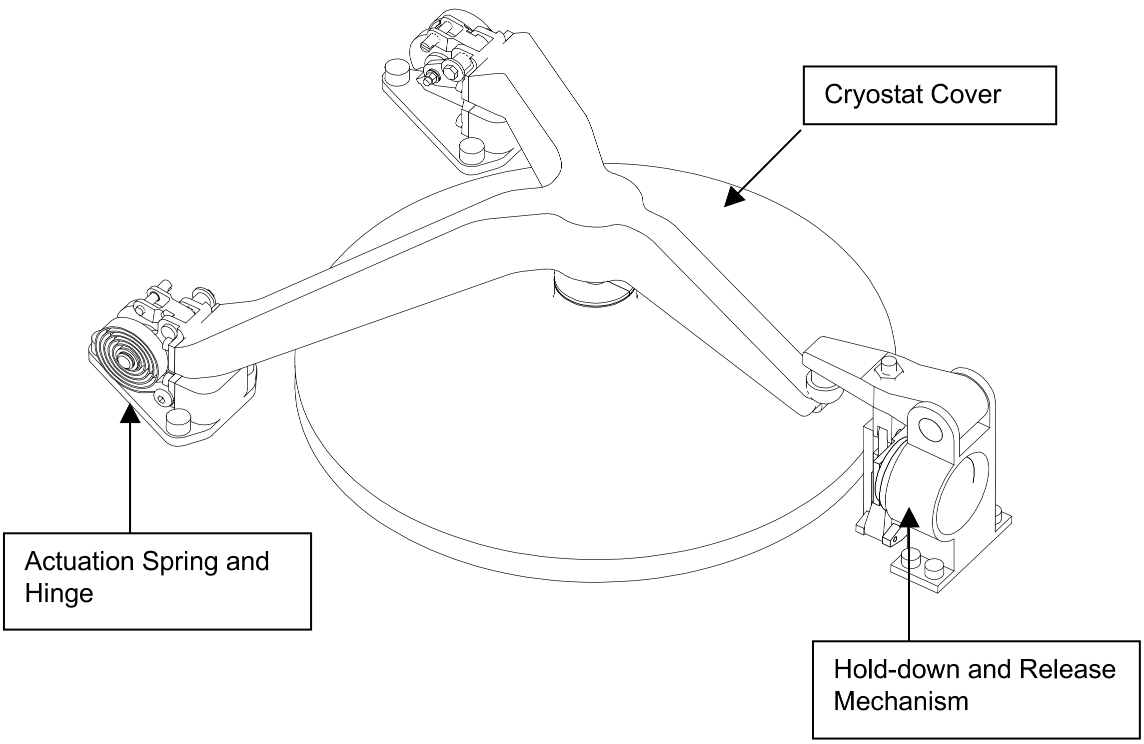


Figure 87: Cryostat Cover Overview

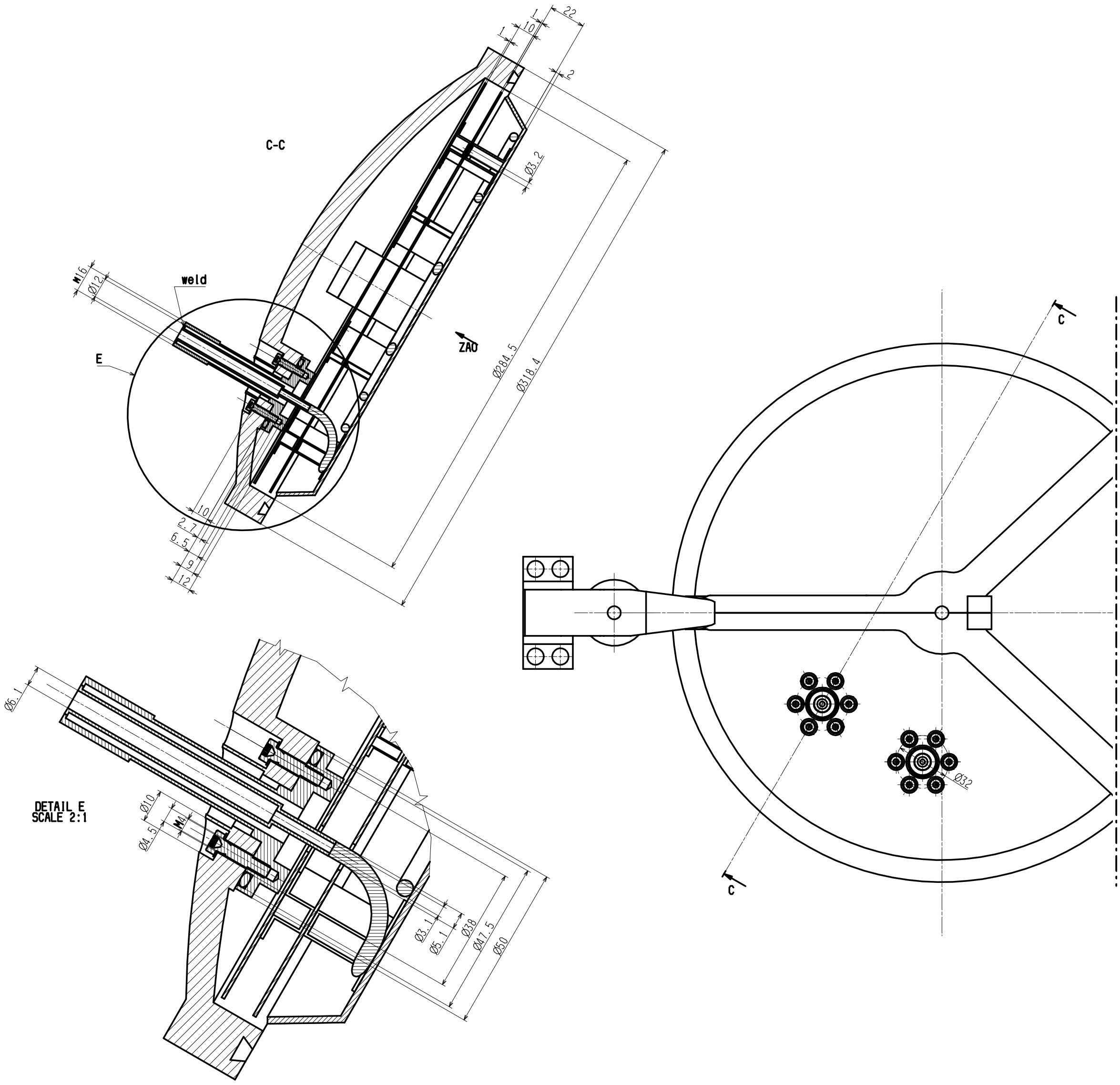


Figure 88: Cryostat Cover Active Cooling Loop

12.13.2 Cryostat Baffle (CB)

The CB shall protect the instruments from radiation from sunshade, sunshield and telescope rear sides. The CB shall be a light weight design.

The cryostat baffle shall carry the lateral loads introduced by six struts into the telescope support structure I/F ring, in order to prevent the telescope mounting structure frame from dynamic movement.

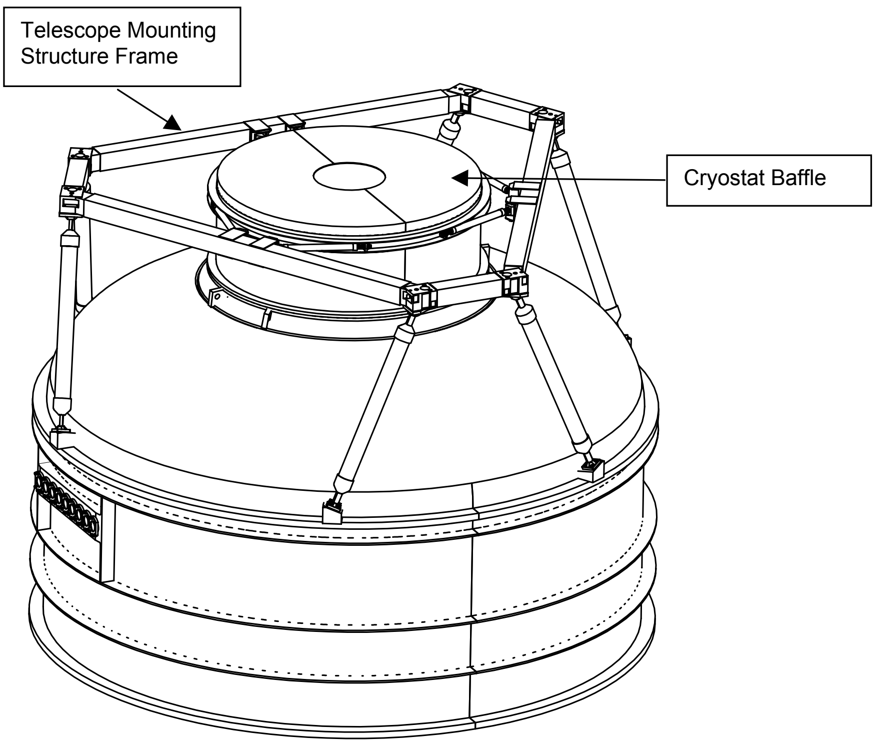


Figure 89: Interface of CB to Telescope Mounting Structure Frame (General View)

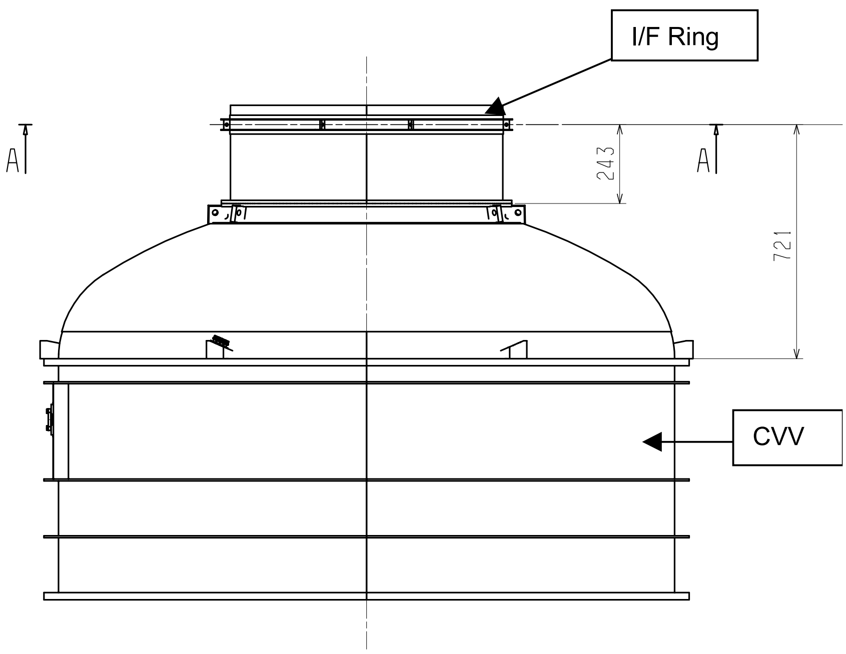


Figure 90: I/F of Cryo Baffle to Telescope Mounting Structure Frame (side view)

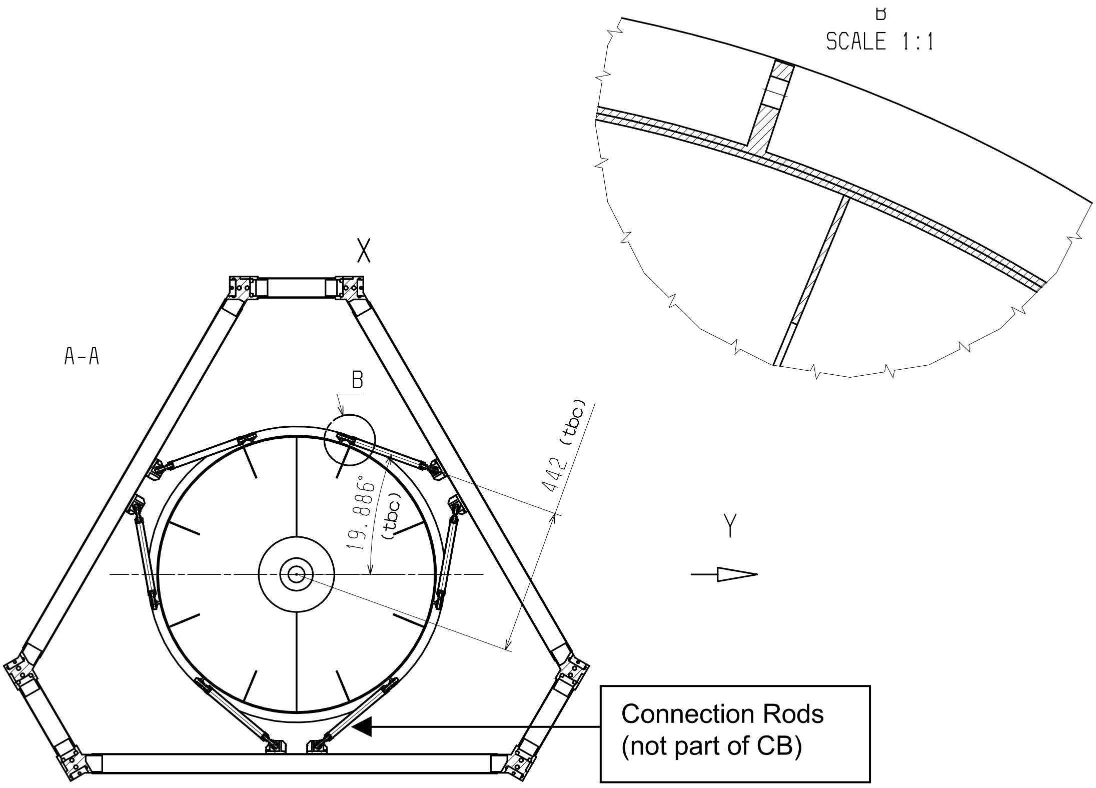


Figure 91: I/F of Cryo Baffle to Telescope Structure Mounting Frame (top view)

12.14 Herschel Support Structures (HSS, SVM Interface, Telescope, LOU)

12.14.1 Introduction

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 92: .

The SSH and SSD support struts are shown in Figure 93. The SSH is supported by the SVM via four struts linking the upper end of the SSH to the SVM central cone (CFRP struts for high mechanical loads). Four further struts laterally attach the upper end of the SSH 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 two attachment brackets. The SSD is mounted on top of the SSH. Four lateral attachment struts link the SSD to the CVV (GFRP struts for good thermal isolation). Two struts connect SSD to SSH (GFRP struts for good thermal isolation). The total number of SSH/SSD struts is twelve included in the Herschel support structures S/S and six included in HSS S/S.

The telescope is mounted on top of the CVV via the Telescope Mounting Structure (TMS) as shown in Figure 94. 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 95. The LOU has very stringent alignment requirement. In plane translations and any rotations must be minimised.

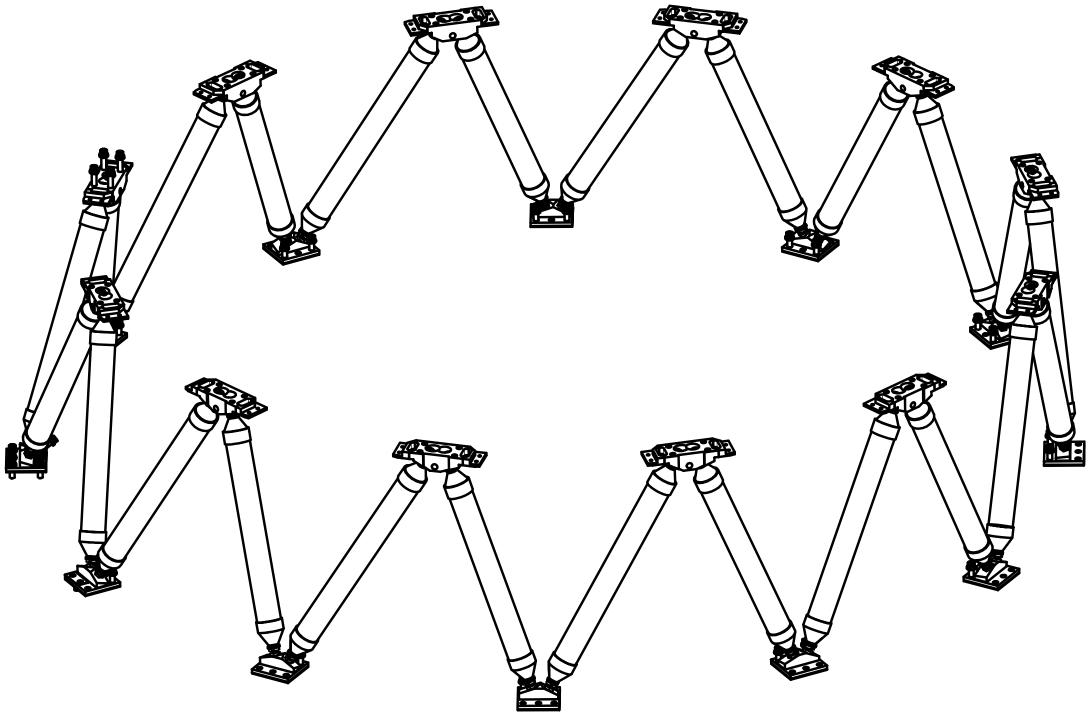
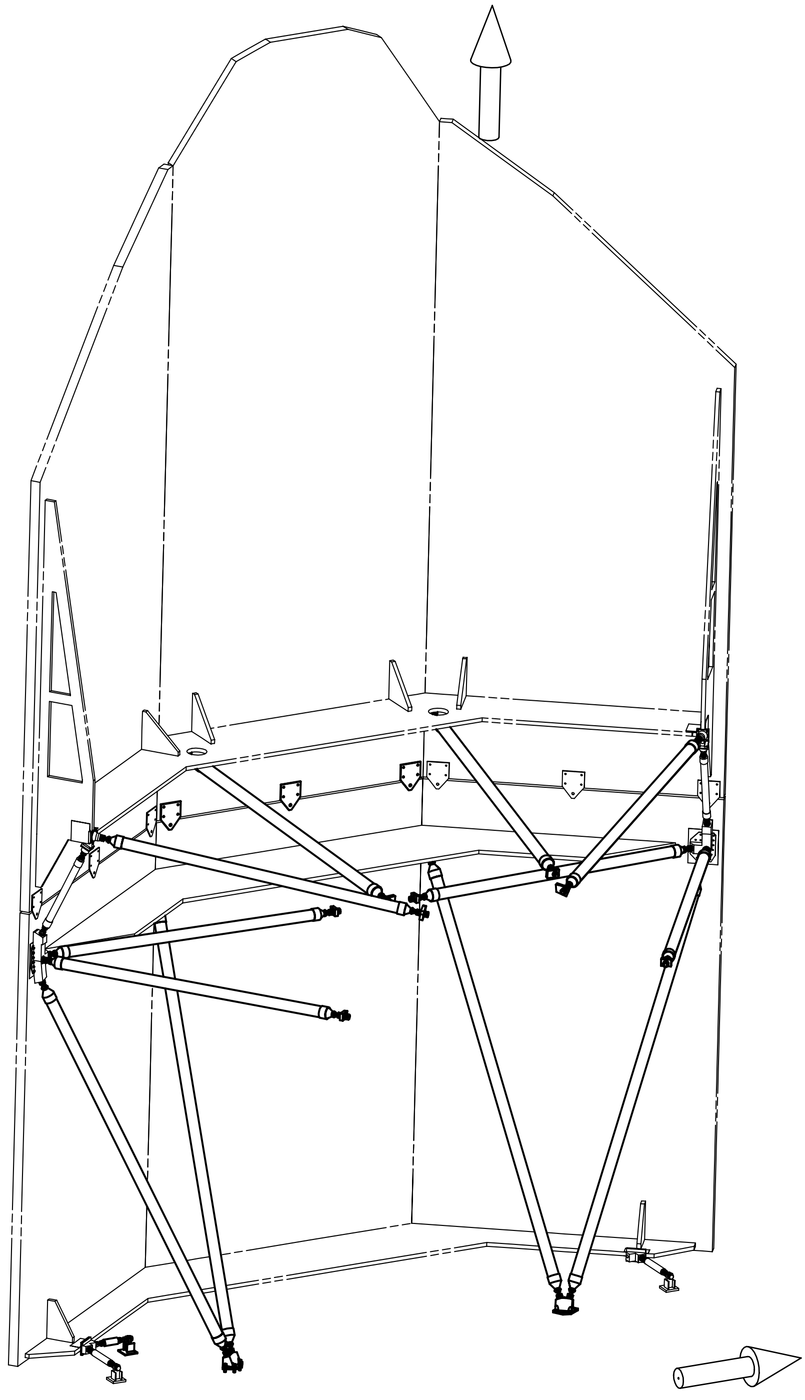
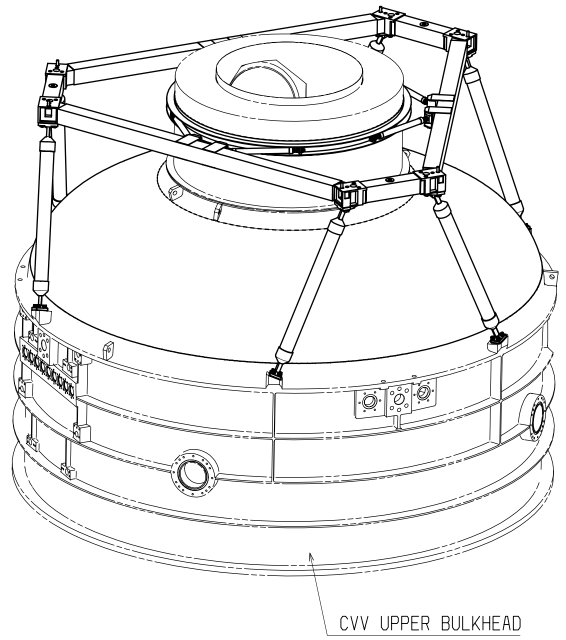


Figure 92: PLM/SVM Interface Struts Subsystem Definition



Note: Panels, stiffening ribs and brackets on panel side are not part of HSS support struts

Figure 93: HSS Support Structure Subsystem Definition



Note: CVV upper bulkhead and cryostat baffle are not part of TMS

Figure 94: Telescope Mounting Structure Subsystem Definition

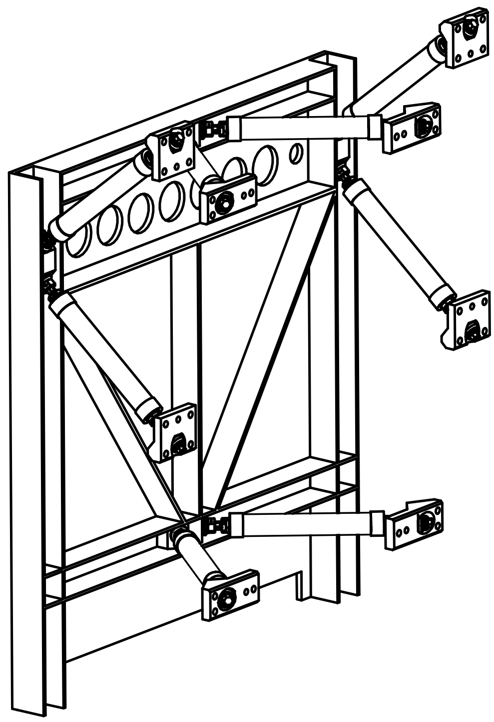


Figure 95: LOU Support Structure Subsystem Definition

12.14.2 Physical Properties

12.14.2.1 Mass

The mass of the PLM/SVM interface struts is 26.5 kg for a strut diameter of 50 mm and a wall thickness of 1.4 mm. The mass contains all support structure parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc. The mass of the HSS support struts is 28.8 kg. The mass contains all support structure parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc. The mass of the telescope mounting structure is 32.5 kg. The mass contains all support structure parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc.

The mass of the LOU support structure is 8 kg, i.e. 2.5 kg for the eight struts and 5.5 kg for the support frame. The mass contains all support structure parts including interface and fixation elements, such as brackets, shims, bolts, washers, etc.

12.14.2.2 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, HP-2-ASED-0002. Geometrical properties are listed in Table 32. The TMS/telescope interface planarity of 0.08 mm shall be guaranteed in orbital environment (moisture, temperature)

12.14.3 Mechanical Design

12.14.3.1 Stiffness

The support strut axial stiffnesses are listed in Table 32.

Item	**A [mm^2]**	**L [mm]**	**EA/L *) [N/mm]**
PLM/SVM Struts	214	615	17378
SSH/SVM Struts	500	2417 / 2526	63861 / 66743
SSH/CVV Struts	785	1683	22397
SSD/CVV Struts	785 / 864	1649 / 1873	22861 / 22137
TMS/CVV Struts	180 (blades) 707 (strut)	35 (blades) 592 (strut)	83960
TMS/CB Struts			6500
LOU Support Struts	36.6	215	8419
*) at RT			

Table 32: Support Structure Geometry and Axial Stiffness

The HSS Support Struts Bending Stiffness including end fittings and attachment brackets (if applicable) are

77 Hz to 84 Hz for HSS strut 1 through 4
52 Hz to 55 Hz for HSS strut 5 through 12.

The TMS including telescope has a first resonance frequency of 36.5 Hz in lateral direction (Y/Z) with the three TMS bi-pods hard-mounted at their external interfaces and considering the ASEF CDR telescope model.

12.14.3.2 Static Design Loads

The Herschel support structure struts has interface loads and moments as stated in Table 33.

Item	**Load** **[kN]**	**Bending moment** **[Nm]**
PLM/SVM Struts	35	TBD
SSH/SVM Struts	46	300 (TBC)
SSH/CVV Struts	9.5	250(TBC)
SSD/CVV Struts No. 9, 12	9.5	250(TBC)
SSD/CVV Struts No. 10, 11	21	300(TBC)
TMS/CVV Struts	26	TBD
TMS/Cryostat Baffle Struts	1	TBD
LOU Support Struts	6	

Table 33: Struts Interface Loads under Static Design Loads

12.14.3.3 Quasi-Static Design Loads on TMS S/S

The TMS is designed against the quasi-static design loads as stated in Table 34:

Item	**Loadcase**	**Axial load**	**Lateral load**
TMS	#1	16 g	+/- 3 g
	#2	1 g	+/- 11 g

Table 34: Quasi-static Design Loads on TMS

12.14.3.4 Low Frequency Sinusoidal Vibrations on TMS S/S

The TMS is designed against the low frequency sinusoidal design loads defined in Table 35 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 (TBC)
	40 - 100	3 (TBC)
Lateral	5 - 16.6	+/- 10 mm
	16.6 - 30	11 (TBC)
	30 - 100	2 (TBC)

Table 35: Envelope of TMS S/S Sinusoidal Vibrations – Qualification Level

12.14.3.5 Interface Loads

The lateral load applied to the cryostat baffle interface is less than 3000 N for all six struts. The load per strut lies between -1090 N and 1090 N.

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.

12.14.3.6 Thermo-elastic Loads

In orbit the PLM will have the temperatures stated in Table 36 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.

12.14.4 Thermal Design

The individual parts of the support structure have the operational temperature range and the interface heat flow at the cold side as stated in Table 36.

Item	From (warm side)	Temperature [K]	To (cold side)	Temperature [K]	I/F Heat Flow at Cold Side 4) [W]
PLM/SVM Struts	SVM	300	CVV	70	1.3 (TBC)
SSH/SVM Struts	SSH	415	SVM	270	1.9
SSH/CVV Struts	SSH	415	CVV	70	0.4
SSD/CVV Struts	SSD	300	CVV	70	0.25
TMS(CVV and CB struts)	Telescope	320 1)	CVV	70	4.0 (TBC)
	Telescope	60	CVV	70	n./a.
LOU Support Struts	LOU	300 2)	CVV	70	n./a.
LOU Support Struts	LOU	150 3)	CVV	70	0.09

1) during decontamination phase in orbit
2) maximum temperature during transient test case
3) nominal operating temperature
4) under vacuum conditions and assuming adiabatic outer surface for each individual strut (i.e. each strut wrapped in MLI)

Table 36: Support Structure Operational Temperature Range and 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 Eccofoam.

The support structures are designed to withstand a depressurisation rate of TBD mbar/sec. Venting holes are foreseen to evacuate interior of struts during TB/TV test and in orbit.

13 Compliance Statement and Open Points

13.1 Compliance Statement

A general statement of compliance can be given at this stage only, as two major requirements specification (i.e. AD-6 and AD-7) have been issued only recently. Therefore no compliance matrix could be provided in the data package. A review for the applicable requirement specification shows, that the H-EPLM design is compliant, with a few exceptions, detailed in the following.

13.2 Non Compliance

Requirement HERS-0380

The maximum mass of the H-EPLM shall not exceed 1653 Kg. This includes cryostat dry mass, Helium and Sunshield/Sunshade and the CCU. Not included are the instrument masses and the telescope mass.

Discrepancy:

The actual mass is 1767 kg (including a margin of 9% on the calculated dry mass). As the criticality of this requirement is recognised since the beginning of the phase B, high attention has been given to this requirement. The TN Impact Assessment of Design, Safety and Test Requirements on CVV and He-Tanks Mass; HP-2-ASED-TH-0028, has been raised to identify the mass driving requirements and critical margins philosophy and to investigate the consequences on the design. The mass optimisation was a continuous process thought the entire phase B.

Measures and Actions

Establish an independent tiger team

Identify mass critical requirements

Stringent control of the mass at the supplier

Requirement HERS-0400

The nominal position of the H-EPLM Centre of Gravity (CoG) shall be located:

- in the range of 0 to –35 mm on Y axis
- in the range of 0 to + 70 mm on Z axis

Discrepancy:

The actual CoG is at

- - 41 mm in y direction

- 58 mm in z direction

The off set is mainly driven by asymmetric location of the LOU on the –y side. There are only very limited measures for the H-EPLM to fulfil this requirement. A radical measure would to shift the entire H-EPLM in +y direction. As the CoG of entire S/C is presently not critical, a waiver will be raised by ASED.

Measures and Actions

ASED will raise a waiver

Requirement GDGE 210 (**Lifetime)**

Herschel shall have a nominal life time of 3.5 years.

Discrepancy:

The calculated nominal lifetime is **3.44 years** taking into account the IID-A heat load allocations, a margin of 10% in the amount of helium and taking into account a launch delay of 25 hours (after HOT is emptied).

Explanation:

A nominal launch scenario without launch delay leads to only 18 kg He consumption during the first 40 days, resulting in a lifetime of **3.52 years**. This means that the current baseline design is compliant with the lifetime requirement when the nominal launch scenario is considered.

More detail about launch scenarios are described in /He System Description, HP-2-ASED-RP-0034/.

Measures and Actions:

- Alternative coax cable designs for HIFI FPU will be investigated
- Optimise the thermal coupling of the harness to the thermal heat shields
- Increase the radiation area of the CVV to space
- Enhance the thermo-optical properties of the outer surface of the CVV

HIFI L1 Requirement Interface temperature (HIFI IID-B, Section 5.7)

Discrepancy:

The HIFI L1 interface temperature can reach 6.6 K in the worst case, which is above the requirement of <6.0 K.

Explanation:

It is considered to be not critical for HIFI operation, because L1 is only a pre-cooling stage for the L0 interface, see also / HIFI-FPU heat load sensitivity to Level 1 temperature, Doc. No.FPSS-00236, dated 23.April 2002/. Main contributor to the high L1 temperature are also the coax cables and the HIFI harness dissipation.

Measures and Actions:

- Alternative coax cable designs for HIFI FPU will be investigated or raise waiver

Requirement HERS-0600

The straylight level received at the detector element location of the H-EPLM/Focal Plane Unit by self emission (including telescope - PLM and instrument contribution), not including the self-emission of the telescope optically active surfaces, shall be less than 10% of the background induced by the self emission of the telescope optically active surfaces.

Discrepancy:

The value achieved is 17%.

Measures and Actions

- Optimised shape of cryogenic baffle, interface to telescope
- minimised gap between telescope and sunshade

Requirement HERS-0580

The parasitic light in the focal plane shall be below 1% of the background induced by self emission of the optical system for Sun, Earth, Moon at worst case locations corresponding to the aspect angle limits as specified in Section 4.2.7 for the Herschel observation mission phase.

Discrepancy:

The value achieved is 16.4% (only at some directions allowed for the moon, but the requirement is fulfilled for most of the directions)

Measures and Actions

- Rounding of the hexapod structure of the telescope

Requirement HERS-0700

During observation phase, the alignment stability of the Instruments LOS w.r.t. the SVM/PLM interface plane as defined in § 4.1.2 shall be better than:

- 0.2 arcsec (0.05 arcsec goal)
- 0.1 arcsec on 1 minute (0.02 arcsec goal)

around each axis taking into account worst case Sun Aspect Angle variation, season effects and temperature gradient at SVM/PLM interface (temperature maps provided in AD04). The PLM/SVM is assumed to be perfect.

Discrepancy:

The actual value is 0.87 arcsec. ASED as only very limited measures to influence the thermal distortion behaviour of the H-EPLM

Measures and Actions

Discuss the definition of the requirement with ASPI

Re-perform thermal distortion analysis and discuss results with ASPI

Requirement HERS-2210

It shall be possible to fill the main tank with superfluid helium at 1.6 K to no less than 98% of full capacity.

Statement

The Herschel cryostat design concerning piping length and diameter is close to the ISO design. For the CVSE more or less the refurbished ISO equipment is foreseen. From the ISO heritage it is known that due to pressure drop and pumping capacity the tank could be filled to ~ 1.8K and 98% after several days. It is ASEDs opinion that the lifetime requirement and the thermal requirements for the instruments cover the above requirement of a temperature together with a degree of filling. Anyhow could a temperature of 1.6 K be achieved by pumping on ground and even in orbit.

Measures and Actions

ASED will raise a waiver

Requirement HERS-2220

In orbit helium exhaust shall be made such that the resulting torque (around all axes) is less than 0.1 x 10-5 Nm and shall minimise orbit disturbances.

Discrepancy:

The actual design achieves 1.5 10^{-4} Nm . The ISO requirement was 0.16 10^{-5} Nm and a waiver was raised. Instead of a new calculated value, the Helium exhaust nozzle definition was given for justification. Due to numerous asymmetric extensions outside the Herschel CVV (Lou, Bola, waveguides, radiators, …) it seems not feasible to achieve the theoretical quality of the ISO nozzles design.

Measures and Actions

ASED proposes two different approaches which are to be discussed with ASPI. One uses the exhaust helium for additional attitude control, by compensating the momentum induced by solar pressure. The other is an advanced nearly momentum free device located below the SVM.

Requirement HERS-1580

The HTT volume shall be such as to be compliant with the lifetime requirement.

Discrepancy:

The calculated lifetime is 3.44 years (considering a margin of 10% of the Helium).

Measures and Actions

An increase of the HTT volume of 5 %, which is necessary to achieve the required life time, without improving the thermal behaviour will require a delta mass of approximately 30 kg. Conflict with the mass requirement

13.3 Open Points

13.3.1 Instrument Interfaces

The following major issues are currently open concerning the instrument interfaces:

- PACS instrument alignment requirements

New instrument alignment error requirements have been raised in Change Request (ref. H-P-PACS-CR-0005). The initial alignment requirements, i.e. 11mm overall in x-direction and 8mm overall lateral have been decreased. The new requirements will be evaluated following the consolidation and clarification of the apportionment of the alignment error.

- SPIRE thermal interface requirements

During Phase B new thermal interface requirements have been raised by SPIRE (ref. HR-SP-RAL-ECR-009). The thermal analysis at Herschel EPLM level revealed, that they could not be accepted without major design changes, although some thermal interface have already been improved. This issue will be followed up and it is planned to be resolved until the co-location period.

13.3.2 Instrument Testing EQM

The environment provided to the instruments is given in He Control System Description HP-2-ASED-RP-0034. The baseline concept is described in Trade Off for the Herschel Cryogenic Test Adapter; HP-2-ASED-TN-0055. The results are to be discussed with the instruments.

13.3.3 Instrument Testing PFM

The environment provided to the instruments is to be discussed with the instruments.

13.3.4 Straylight

The finalisation of the straylight analysis is required to confirm the design of the beam entrance baffle and cryostat baffle. Furthermore, the interface compliance with the telescope has to be established.

13.3.5 Cleanliness

The most stringent cleanliness requirements are currently those of the HIFI instrument, namely

- 1200 ppm and $6x10^{-6}$ g/cm^2 for HIFI FPU (instruments outside)
- 4650 ppm and $4x10^{-6}$ g/cm^2 for the telescope M1
- 4300 ppm and $4x10^{-6}$ g/cm^2 for the telescope M2

To meet these requirements two open points need further clarification:

- For the lift off phase Arianespace guarantees a particle fall out of max. 5000 ppm. This value would violate the requirement for the telescope. Negotiations will be initiated to improve the particle fall out (PFO) during the lift off phase, the goal is a rate of better than 1000 ppm.
- The amount of molecular contamination (ice) on the FPUs caused by air permeation through the CVV sealings has to be re-calculated.

The Cleanliness Team established a bottom up contamination budget. Considering certain cleaning operations in Europe and in Kourou and provided that a PFO of lower than 1000 ppm can be realised during launch and neglecting the air permeation, the contamination budgets reveal following EOL values (for details see budget-chapter 6.10 Cleanliness):

≤ 500 ppm and $5.6x10^{-6}$ g/cm^2 for Optical Bench Assembly incl. FPUs

≤ 3900 ppm and $1x10^{-6}$ g/cm^2 for the telescope M1 and M2

≤ 4000 ppm and $3.3x10^{-6}$ g/cm^2 for the S/C outside (except telescope)

Above values are within the requirements.

13.3.6 Coax HiFi

Alternative coax cable designs will be investigated, as the main consumer of lifetime is the Scientific Harness. Especially, the 4 HIFI Coax cables with a copper cross-section of 0.522 mm² (assumed in the TMM) consume about 2 months of lifetime.

13.3.7 Performance of Phase Separator

A minimal mass flow rate is needed to achieve the required instrument temperatures at the different heat exchanger levels. Due to the hysteresis of the passive phase separator and the heat load variation to the tank, e. g. from sorption cooler recycling it is possible that this minimal mass flow cannot be guaranteed continuously. The behaviour of the phase separator is currently under investigation at Linde. The behaviour of the phase separator has a significant influence on the performance of the temperature requirements of the instruments and on the lifetime.
In general it should be mentioned that the Herschel cryostat has requirements for minimal mass flow rates (required from the instruments) and a maximal flow rate (resulting from helium mass and lifetime requirements).

13.3.8 Pressure Drop Accuracy

The accuracy of the predicted pressure drop of the vent line system in orbit, which defines the HTT tank temperature, probably cannot be achieved from the ISO heritage. The solution approach is to improve the thermal models to achieve higher accuracy in prediction of the orbital behaviour. The pressure drop will be verified during the TB/TV test.

13.3.9 Launch Scenario

In the Helium Subsystem Description different launch scenarios are given. Both the nominal launch scenario and the launch scenario with launch delay of 25 hours assume a He II top up temperature of T = 1.8 K based on the ISO experience. An additional analysis has been performed to define the maximum allowed He II temperature at the event of the launch resulting in 1.93 K. The achievable He II temperature after top up will be determined in the first cryogenic system tests.

E N D O F D O C U M E N T

Quantity	Name	Dep./Comp.	Quantity	Name	Dep./Comp.
	Alberti von Mathias Dr.	ED 544		Runge Axel	OTN/TN 94
	Barlage Bernhard	ED 62		Sachsse Bernt	EC 34
	Bayer Thomas	ED 532		Sagner Udo	OTN/TN 64
	Faas Horst	ED 516		Schäffler Johannes	OTN/TN 64
	Grasl Andreas	OTN/TN 64		Schink Dietmar	ED 522
	Grasshoff Brigitte	ED 511		Schlosser Christian	OTN/TN 64
	Hartmann Hans Dr.	ED 172		Schweickert Gunn	ED 544
	Hauser Armin	ED 541		Steininger Eric	ED 522
	Hinger Jürgen	ED 541		Stritter Rene	ED 61
	Hohn Rüdiger	ED 531		Tenhaeff Dieter	ED 544
	Hölzle Edgar	ED 171		Thörmer Klaus-Horst Dr.	OTN/ED 37
	Huber Johann	ED 532		Wagner Adalbert	OTN/IP 35
	Hund Walter	ED 556		Wagner Klaus	ED 541
	Idler Siegmund	ED 521		Wietbrock, Walter	ED 511
	Ivády von András	EC 32		Wilz Eberhard	OTN/ED 37
	Jahn Gerd Dr.	ED 541		Wöhler Hans	ED 544
	Kalde Clemens	ED 513		Ziegler Fred	OTN/ED 522
	Kameter Rudolf	OTN/TN 64		Zipf Ludwig	EC 32
	Knoblauch August	ED 51			
	Koelle Markus	ED 533			
	Kroeker Jürgen	ED 515			
	Lamprecht Ernst	OTN/TN 72			
	Lang Jürgen	ED 556			
	Langfermann Michael	ED 531			
	Mack Paul	OTN/TN 64		Pastorino Michel	ASPI Resid.
	Maier Hans-Ulrich	ED 61			
	Mauch Alfred	ED 544		Alcatel (on FTP-Server)	
	Moritz Konrad Dr.	ED 37		ESTEC (on FTP-Server)	
	Müller Lutz	OTN/TN 64			
	Muhl Eckhard	OTN/TN 64			
	Peitzker Helmut	ED 37		APCO	
	Peltz Heinz-Willi	ED 515		MPGE	
	Peters, Gerhard	ED 533		RALA	
	Pietroboni Karin	ED 37		SRON	
	Puttlitz Joachim	OTN/ED 37			
	Raupp Helmut	ED 543			
	Rebholz Reinhold	ED 531			
	Reuß Friedhelm	ED 7			
	Rühe Wolfgang	ED 3			