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1 Scope

This design report provides the design, function, and performance of the HERSCHEL Extended Payload Module (H-EPLM). The H-EPLM consists of the Cryostat, the Telescope, the Herschel instruments mounted inside and on the outside of the cryostat, the Cryo Control Unit mounted to the SVM, the sunshield/sunshade and the interface struts to the SVM.

The H-EPLM is based on the design heritage of ISO (Infrared Space Observatory, successfully flown in 1995 – 98), various studies performed under ESA contract before the ITT, further definition work done in the proposal phase and the work performed since the kick-off in April 2001. Main emphasis has been laid since the kick-off on the consolidation of the design, verification of system requirements and the performance of trade-off as addressed in the proposal
The description is based on the actual released requirement specification. Known changes to these documents are considered in the trade-off and sensitivity chapter
In summary this design description contains a comprehensive description of the current status and knowledge, The cut-off date for the technical contribution is the
Friday the 13th of July to prepare this document. However major activities, as design consolidation and design optimization are performed in since that time.

2 Applicable Documents and Acronyms

2.1 ESA Documents

Document Number	Iss.	Issue-Date	Document Title
SCI-PT-RS-05991	1/0	31.08.2000	Herschel / System Requirement Specification (SRS)
SCI-PT-IIDA 04624	1/0	01.09.2000	Herschel / Planck IID-Part A (All instruments)
SCI-PT-IIDB/HIFI 02125	1/0	01.09.2000	Herschel IID-Part B HIFI
SCI-PT-IIDB/PACS 02126	1/0	01.09.2000	Herschel IID-Part B PACS
SCI-PT-IIDB/SPIRE 02124	1/0	01.09.2000	Herschel IID-Part B SPIRE

2.2 ASPI Documents

Document Number	Iss.	Issue-Date	Document Title
FP-ASPI-IS-2001	1	28.11.2000	Herschel EPLM Interface Specification
FP-ASPI-RS-1001	2	31.10.2000	General Design & Interface requirement Specification
FP-ASPI-RS-1002	1/1	13.09.2000	Environmental & Test Requirement Specification
FP-ASPI-RS-1003			EMC Requirement Specification

2.3 Acronyms

ABCL	As Built Configuration List
AC	Alternating Current
ACC	Attitude Control Computer
ACM	Attitude Control and Measurement
ACMS	Attitude Control and Measurement Subsystem
ACS	Auto Correlation Spectrometer
AD	Applicable Document
ADC	Analog Digital Converter
ADD	Architectural Design Document
A/D	Analog to Digital Converter
ADP	Acceptance Data Package

ADR	Architectural Design Review
AGN	Active Galactic Nuclei
AIV	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
AM	Alignment Model
AMA	Absolute Measurement Accuracy
AO	Announcement of Opportunity
AOCS	Attitude and Orbit Control System
AOS	Acousto - Optical Spectrometer
APD	Absolute Pointing Drift
APE	Absolute Pointing Error
AR	Acceptance Review
ARE	Absolute Rate Error
AR 5	Ariane 5
ASF	Additional Safety Factor
ASIC	Application Specific Integrated Circuit
ASW	Address and Synchronization Word
ATC	Active Thermal Control
AU	Astronomical Unit
AVM	Avionics model
BAF	Batiment d'Assemlage Final (Final Assembly Building)
BAU	Buffer Amplifier Unit
BCR	Battery Charge Regulator
BDR	Battery Discharge Regulator
BER	Bit Error Rate
BEU	Bach end Unit
BIB	Block Impurity Band
BIT	Built in Test
BMOS	Buckling Margin of Safety
BOL	Begin of Life
BOLA	Bolometer Amplifier (PACS)
Bps	Bits per Second
BRU	Battery Regulater Unit
BSF	Basic Safety Factor
BW	Bandwidth
CaC	Cost at Completion
CC	Configuration Control
CCB	Configuration Control Board
CCI	Cryo Control Instrumentation

CCD	Charged Coupled Device
CCH	Cryo Control Harness
CCSDS	Consultative Committee for Space Data Systems
CDD	Configuration Data Document
CDMS	Command and Data Management Subsystem
CDMU	Central Data Management Unit
CEI	Cryo External Instrumentation
CEU	Cryo - Electronis Unit
CFC	Carbon Fibre Compound
CFRP	Carbon Fibre Reinforced Plastics
CII	Cryo Internal Instrumentation
CMD	Command
CoM	Center of Mass
COP-1	Command operation Procedure number 1
CQM	Cryogenic Qualification Model
CREMA	Consolidated Report on Mission Analysis
CSG	Centre Spatial Guyanais
CTU	Central Terminal Unit
CVCM	Collected volatile Condensable Material
CVV	Cryostat Vacuum Vessel
DACS	Digital Auto Correlator Spectrometer
DBU	Data Bus Unit
DC	Direct Current
DK	Denmark
DLCM	Direct Liquid Content Measurement
DM	Dynamic Model
DMA	Dynamic Memory Access
DML	Declared Material List
DNEL	Disconnect Non Essential Loads
DPC	Data Processing Center
DoD	Depth of Discharge
DoF	Degree of Freedom
DPOP	Daily Prime Operational Phase equivalent to Observation Phase
DRB	Delivery Review Board
DS	Digital Serial
DSN	Deep Space Network
DTCP	Daily Telecommunications Phase equivalent to Telecommunication Phase

DTMM	Detailed Thermal Mathematical Model
ECR	Engineering Change Notice
EDAC	Error Detection and Correction
EDS	Electrostatic Discharge
EED	Electro Explosive Device
EEE	Electro, Electronic, Electromechanical
EEPROM	Electrically Erasable Programmable Read only Memory
EGSE	Electrical Ground Support Equipment
EI	End Items
EIRP	Equivalent Isotropic Radiated Power
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMF	Electro-Motive Force
EMI	Electromagnetic Interference
EoL	End of Life
EoM	End of Mission
EOP	Early Orbit Phase
ESA	European Space Agency
ESD	Electro Static Discharge
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
ESV	An ARIANE 5 launcher version
FAR	Flight Acceptance Review
FD	Flight Dynamics
FEC	Front Error Correction
FEM	Finite Element Model
FINDAS	FIRST Integrated Network and Data Archive System
FIR	Far Infrared
FIRST	Far Infrared and Submillimeter Telescope
FM	Flight Model
FMECA	Failure Modes Effects and Criticality Analysis
FMS	Failure Management System
FOP	Flight Operations Plan
FOR	Field of Regard
FOS	Factor of Safety
FOV	Field of View

FP	Fabry Perot
FPA	Focal Plane Assembly
FPGA	Field Programmable Gate Array
FPLM	FIRST Payload Module
FPU	Focal Plane Unit
FRR	Flight Readiness Review
FS	Flight Spare
FSC	First Science Centre
FSS	Fine Sun Sensor
FSVM	FIRST Service Module
G/S	Ground Station
G/T	Gain to Temperature Ratio
GFC	Glass Fibre Compound
GFRP	Glass Fibre Reinforced Plastics
GMM	Geometrical Mathematical Model
GSE	Ground Support Equipment
GTO	Geostationary Transfer Orbit
H/W	Hardware
HEO	Highly Eccentric Orbit
He II	Helium II (Superfluid Helium)
HFI	High Frequency Instrument (Planck)
HGA	High Gain Antennna
HIFI	Heterodyne Instrument (FIRST)
HK	House Keeping
I/F	Interface
ICC	Instrument Control Centre
ICD	Interface Control Document
ID	Interface Document
IF	Intermediate Frequency
IFAR	Instrument Flight Acceptance Review
IFEM	Instrument Finite Element Model
IID	Instrument Interface Document
IOP	Initial Orbit Phase
IRU	Inertial Reference Unit
ISO	Infrared Space Observatory
ITT	Invitation to Tender
JFET	Junction Field Effect Transistors
J-T	Joule Thomson
LCDA	Launcher Coupled Dynamic Analysis

LCL	Latching Current Limiter
LEOP	Launch and early Orbit Phase
LET	Linear Energy Transfer
LGA	Low Gain Antenna
LO	Local Oscillator
LoS	Line of Sight
LOU	Local Oscillator Unit
LSB	Least Significant Bit
LV	Launch Vehicle
LVDE	Low Vibration Drive Electronics
LW	Launch Window
MAC	Modal Assurance Criterion
MCC	Mission Control Centre
MEOP	Maximum Expected Operating Pressure
MGSE	Mechanical Ground Support Equipment
MLI	Multi Layer Insulation
MOC	Mission Operations Centre
MoI	Moments of Inertia
MoS	Margin of Safety
MPPT	Maximum Power Point Tracking
MTL	Mission Timeline
N/A	Not Applicable
NASA	National Aeronautic and Space Administration
NASTRAN	NASA Structural Analysis Tool
NCR	Non Conformance Report
NRT	Near Real Time
OB	Optical Bench
OBDH	On Board Data Handling
OBT	On Board Time
ODS	Orbital Disconnect Support
OFD	Operations Facility Document
OGSE	Optical Ground Support Equipment
OIRD	Operations Interface Requirements Document
OSR	Optical Solar Reflector
OTF	On Target Flag
P/L	Payload

PA	Product Assurance
PACS	Photoconductor Array Camera Spectrometer (FIRST)
PCM	Pulse Code Modulation
PCS	Power Control Subsystem
PCU	Power Control Unit
PDD	Payload Definition Document
PDE	Pointing Drift Error
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PFM	Proto Flight Model
PI	Principal Investigator
PLL	Phase Lock Loop
PLM	Payload Module
PMD	Propellant Management Device
PPLM	Planck Payload Module
PROM	Programmable Read Only Memory
PSF	Point Spread Function
PSK	Phase Shift Keying
PSVM	Planck Service Module
PT	Product Tree
PUS	Packet Utilization Standard
PWM	Pulse Width Modulation
QSO	Quasi Stellar Object
RAM	Random Access Memory
RCS	Reaction Control Subsystem
RD	Reference Document
RE	Radiated Emission
RF	Radio Frequency
RFI	Radio Frequency Interference
RfW	Request for Waiver
RH	Relative Humidity
RHCP	Right Hand Circular Polarization
RML	Recoverable Mass Loss
ROM	Rough order of Magnitude
RPE	Relative Pointing Error
RS	Radiates Susceptibility
RSS	Root Square Sum
RTA	Real Time Assessment
RTMM	Reduced Thermal Mathematical Model
RTU	Remote Terminal unit

SA	Solar Array
SAA	Solar Aspect Angle
SAS	Sun Acquisition Sensor
SCC	Stress Corrosion Cracking
S/C	Spacecraft
SCOS	Space Control and Operations Centre
SFWK	Spatial Framework
SIH	Scientific Instrument Harness
SIN	Straylight Induced Noise
S/N	Signal to Noise Ratio
S/S	Subsystem
S/W	Software
SCET	Spacecraft Elapsed Time
SCL	Spacecraft Control Language
SDE	Software Development Environment
SDS	System Definition Study
SECDED	Single Error Correction and Double Error Detection
SEL	Spacecraft Event Logic
SEU	Single Event Upset
SF	Safety Factor
SIS	Superconductor Insulator Superconductor
SIS	Spacecraft Interface Simulator
SIV	Software Independent Validation
SM	Structural Model
SOC	Science Operations Centre
SoW	Statement of Work
SPC	Science Programme Committee
SPIRE	Spectral Photometer Imaging Receiver (FIRST)
SPL	Split Phase Level
SRPE	Spatial Relative Pointing Error
SSAC	Space Science Advisory Committee
SSc	Supporting Strap chain
SSM	Second Surface Mirror
SSR	Solid State Recorder
SST	Stainless Steel
STM	Structural/Thermal Model
STMM	Simplified Thermal Mathematical model
STR	Startracker
SVF	Software Validation Facility

SVM	Service Module
TA	Telescope Assembly
TAI	Temps Atomique International
TB	Thermal Balance
TBC	To Be Confirmed
TBD	To Be Defined
TC	Telecommand
TCS	Thermal Control Subsystem
TF	Test Factor
TM	Telemetry
TML	Total Mass Loss
TMM	Thermal Mathematical Model
TOP	Transfer Orbit Phase
TRP	Technological Research Programme
TSMM	Transport Stimuli and Monitoring Unit
TT&C	Tracking Telemetry and Command
TV	Thermal Vacuum
UMOS	Ultimate Margin of Safety
UF	Ultimate Factor of Safety
VFT	Vacuum Feed Through
VMC	Visual Monitoring System
WBS	Work Breakdown Structure
WFE	Wave Front Error
WP	Work Package
WPD	Work Package Description
YMOS	Yield Margin Of Safety
YF	Yield Factor of Safety

3 H-EPLM Design Driving Requirements

3.1 System/Mission Requirements

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

3.1.1 EPLM Functional and Performance Requirements

The following functional and performance requirements apply:

- The EPLM shall provide a suitable environment for instrument operation
- The cryostat lifetime shall be ≥ 3.5 years calculated from launch date.
- 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 PLM environment together with the sun irradiance in L2 shall allow keeping the telescope in a temperature range of 70 - 90 K.
- All in flight performance shall be valid for a solar aspect angle of ≤ 30º in the x-z plane and ± 5º in the z-y plane.
- The ground lifetime (autonomy) shall be 6 days.
- The cooling system shall contain a vacuum vessel, which is evacuated before cool down on ground.
- The heat load to the tank shall be minimized by a thermal insulation subsystem implementing GFRP/CFRP suspension straps for the tank. Thermal Shields covered with MLI shall restrict the radiative heat input to the minimum possible.
- The L2 orbit characteristics shall be used to optimize the CVV radiative performance to bring its surface temperature to the lowest level.

3.1.2 Operational Requirements

The Herschel EPLM shall be designed to support all operations namely

- ground operations, as are
    - AIT (Assembly, Integration, Test)
    - 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 Pre-launch/Launch Operations

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

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 (1 hour, tbc) the residual He in the He I tank shall be rapidly depleted without icing of the external ventline.
- After rapid depletion the He I S/S 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.

3.1.2.2 In Orbit Operations

Following the separation from the launcher, the following applies:

- Cover opening shall be done after desorption 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. once per month initiated by TC. This shall shorten the lifetime by less than 1%.
- 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 Margin Philosophy

Design margins are necessary to cope with the uncertainties during the early definition phase of the project and to provide a buffer for the operational phase of the satellite.
As a major tool to guarantee achievement of all system performance parameters and to have sufficient system resources until end of the development program, a rigorous control of the predetermined system margins is performed.
This is necessary because of the design evolution up to the early phase C/D. Also the subsystem and unit design will evolve during its development and sometimes change in its resource requirements.

3.1.3.1 Mission Life Requirements

SPER 005 For the Herschel missions the spacecraft shall have a nominal lifetime of 3.5 years from launch till the end of the mission. This duration includes a margin of 6 months for the transfer to the L2 Lissajous orbit.
For the solar array and additional year is to be considered for radiation.

SPER 025 The lifetime of items which degrade with time or usage shall be design for 6 years under normal conditions (no additional margin required)

SPLM 035 The cryostat and its internal insulation shall meet the specified nominal lifetime and temperature requirements given in the IIDBs. The amount of cryogen shall be sized accordingly and shall include a margin of 10 %.

SINT 035 The thermal design of the spacecraft shall be able to meet its requirements for the following increases or decreases in the power dissipation of any particular payload unit with respect to the values agreed in the IIDBs at the beginning of the phase B.

3.1.3.2 Mass Margin Requirements

SCMD 080 The total spacecraft mass shall be minimised wherever reasonable and shall include, at the beginning of the phase B a spacecraft element depending on the development status of those elements as follows:

- Complete new development 20%
- New developments derived from existing hardware 15%
- Existing units requiring only minor/medium modifications 10%

- Existing hardware 5%

This requirement is applied in the mass budget, but will not be used in combination with the other requirements e.g. strength requirements. The FEM model contains the nominal mass.

3.1.3.3 Structural Design Margin Requirements

SINT 015 The structural design of the Herschel and Planck spacecraft including the payload interfaces shall be able to meet its requirements if the mass of any particular payload unit is increased by 20 % above the nominal values agreed in the IIDBs at the beginning of the phase B

For the dimensioning the nominal values plus 20% will be used:

SGEN 055 The structural strength dimensioning of the composite shall allow a growth of 10% in total mass of the composite (Herschel and Planck 5310kg

As no allocation between H-EPLM and the total composite is provided, presently the nominal mass of H-EPLM plus a delta mass of 10 % will used for the strength analysis.

SCMD 020 Under worst case combination of mechanical and thermal loads and after application of the relevant safety factors, the margin of safety as determined according to the requirements shall be > 0 %

SCMD 045The following safety factors shall be used:

Item	Yield SF	Ultimate SF	Buckling SF
Conventional metallic material	1.1	1.5	2.0
Unconventional materials	1.4	2.0	2.0
Inserts and Joints	1.5	2.0	na

SCMD 050 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.

SCVE 050 In case of proto flight approach, the various MOS shall be greater than 20%

As the CVV and the suspended mass are following a proto flight approach, the factor is applicable for yield and ultimate strength. In will not be applied for buckling as buckling cases are verified general by analysis

3.1.3.4 Stiffness Margin Requirements

No additional margin on the stiffness requirements is taken. Nominal values for the H-EPLM components in terms of mass, cross section and material data, the Instruments and the Telescope will be used.

3.1.3.5 Power Margin Requirements

The Solar Array shall meet its requirements including all margins after 2 years of ground storage and 4.5 years of in orbit operation including launch and transfer phase. After 6 years in orbit, nominal performance shall be achieved (no margin is required).

3.1.4 Structural Requirements

Stiffness/Eigenfrequency Requirement
The stiffness requirement for the hard mounted H-EPLM is

EPLM Herschel axial eigenfrequency (meff > 5%)	≥ 42 Hz (tbc) 12 Hz
EPLM Herschel lateral eigenfrequency fundamental axial frequency(meff > 5%)	≥ 24 Hz (tbc) 38 Hz

This requirement is valid for a EPLM,. Hard mounted on the SVM

This requirement is changed during the preparation of the document to

The H-EPLM shall achieve the stiffness defined considering the local stiffness of the SVM

SVM local stiffness:

- k circumference > 5.7 E 7 N/m
- k radial > 2.5 E 7 N/m
- k longitudinal (X) > 5 E 7 N/m
- rotational dof are free

H-PLM frequency required

- Lateral frequency (H-PLM+local stiff) 13Hz
- Longitudinal frequency (H-PLM+local stiff) > 35 Hz
-

- Secondary Structure, Subsystem and brackets shall be decoupled from any major frequency of the spacecraft by a factor of 1.4 minimum. As will be shown this requirement in its strict sense will not be fulfilled for some items as sun-shield/sunshade local modes (refer to Section 5.5), where a viable solution is proposed by increasing the design loads for these items.
- The eigenfrequencies of compact equipment and boxes in hardmounted condition shall be above 140 Hz. This is valid for the Cryo Control Electronic, for cryo components like the LHe Valve and will not provide problems, since it was already verified on ISO.

3.1.4.1 Design Loads

The design loads shall envelop the Flight Limit Loads and the qualification loads with a safety factor of 1.25

The design loads of major components are shown in the following table

ELPM Item	Case	Design Loads	Remark
complete EPLM	#1	12.5 axial +- 2 g lateral	
	#2	5 g axial +- 4 g lateral	
Suspended Mass and He II Tank	#1	13 g axial +- 4 g lateral	
	#2	5 g axial +- 6 g lateral	
Optical Bench	#1	15 g axial +- 2 g lateral	
	#2	5 g axial +- 7.5 g lateral	
He I Tank	#1	25 g axial + 2 g lateral	
	#2	5g axial +-7.5 g lateral	
Telescope	#1	16 g axial +- 2 g lateral	Used for Design of Support Structure, Telescope itself not under ASTRIUM responsibility
	#2	4 g axial + 10 g lateral	
Sun Shield/ Sun Shade	#1	15 g axial +(25 g lateral + 5g/m rotation)	rotation which causes 40 g lateral at the top
	#2	100 g locally at top of sun shade	
LOU	#1	tbd	

3.1.4.2 Shock

Shock as specified in Section 3.1.6 of the ARIANE 5 User Manual is applicable at the F/P satellite separation interface. The separation shock of HERSCHEL/PLANCK is considered lower than the F/P satellite separation. The shock propagating through the PLM will experience considerable attenuation. Consequently specific shock specification at the PLM equipment apply.

CCU (Cryo Control Unit)
He-Valves (specifically in the external ventline)

3.1.4.3 Pressure

Many of the cryostat components such as:

- He II Tank
- He I Tank
- He Subsystem components including ventline
- CVV
- Cover

have to be designed for pressure cases determined by nominal operational cases or from the staged safety system implemented in He subsystem (refer to Section 5.2).

3.1.5 Thermal

The solar constant at L2 is:

- 1300 W/m^2 at summer solstice to be used for solar generator sizing
- 1400 W/m^2 at the winter solstice for hot case thermal analysis, e.g. surface temperature of the CVV
- Temperature ranges of equipment will be defined with associated margins according to worst case operating temperature ranges. Specific attention has to be given to the bake out temperature of 353 K (nominal) relevant to all equipment internal to the CVV.
- Other requirements spelt out in the System Specification and ITT´s should not become design drivers. The margin philosophy on .g. FPU´s heat load at various temperature levels should be fixed at begin of Phase B.

3.1.6 Radiation

Radiation requirements are listed in "HERSCHEL L2 Radiation Environment", ESA/ESTEC/Wma/he/HERSCHEL/3.

Radiation Sensitive Items on PLM:

- Solar Generator on the sunshield
- EEE-parts of CCU, parts level to be selected should not provide problems, since the total dose for HERSCHEL is relatively low compared to close earth mission.
- The external cables when using Teflon as an isolation material are more sensitive than e.g. Kapton but in absolute dose values no problem is to be expected.

3.1.7 Humidity

The humidity requirements as per Section 5.5.3 of the System Requirements Specification will be fulfilled per design.

3.1.8 Mass Requirement

The maximum mass of the H-EPLM shall be 1580kg. This mass includes cryostat dry mass, helium and sunshield/sunshade. The instrument masses the telescope mass, the mass of the SVM/CVV struts and the mass of the radiation shield are not included.

Further Mechanical Interfaces:

- The CCU box has to be mounted to the SVM structure, accessibility for connecting the cryostat control harness is required.
- The instrument warm boxes have to be mounted to the SVM structure.

3.1.9 Electrical (Harness / Waveguides/ Bus-Interface)

The following electrical interfaces to the SVM are required:

- CCU interface to SVM (power, signal bus and 4 direct commands originating in AR5 for valve switching before separation)
- Instrument warm units I/F to SVM (power, signal...). These I/Fs and their TCS are considered by the SVM supplier

- I/F brackets SVM/PLM for connection from cryostat control harness to umbilical, NCA and from telescope and solar generator (power and sensors), sunshade
- Scientific Instrument harness I/Fs between cold units and instrument warm boxes arranged in the SVM
- Waveguide I/F between LOU and HIFI warm box arranged in the SVM

3.2 Sunshield/Sunshade Requirements

The main requirements on the Sunshield/Sunshade are:

- shadow the telescope and the CVV from sunlight nominally from +z direction and for a solar aspect angle of ± 30° around y-axis and ± 5° around x-axis.
- fit below the Ariane 5 fairing and keep the Telescope field of view unvignetted
- total mass of 180 kg
- provide a minimum power
  - Minimum End Of Life power 1350 Watts
  - Minimum Begin Of Life power 1500 Watts
- the heatload from the Sunshield/Sunshade to the CVV via the fixation struts shall be minimized

the radiative heatload from the Sunshield/Sunshade to the CVV and to the telescope shall be minimized

Further requirements for the Sunshield/Sunshade will be provided in the subsystem section 5.5.

4 Payload Interface Requirements

4.1 Scientific Instruments Requirements

4.1.1 General

The HERSCHEL payload consists of three instruments, the Heterodyne Instrument for the Far-Infrared (HIFI), the Photoconductor Array Camera and Spectrometer Instrument (PACS), the Spectral and Photometric Imaging Receiver (SPIRE). They will perform astronomical observations in the infrared wavelength range from 80 to 670 micron and their Focal Plane Units (FPUs) have to be cooled to very low temperatures.

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 will be arranged in the HERSCHEL SVM.

The spacecraft performances, capabilities and requirements imposed on the instruments are described in the IIDA. Instrument requirements on the HERSCHEL spacecraft and the instrument capabilities and performances are described in the IID Bs of the SPIRE, PACS and HIFI instruments.

4.1.2 Mechanical/Configuration

4.1.2.1 Focal Plane Units (FPU's)

The cryostat shall accommodate three Focal Plane Units (FPUs) and one JFET box with an allocated total mass of 179 kg kg and an overall dimension envelope of 1240 mm by 1468 mm and a maximum height of 460 mm.

The instrument fixation as given in the IID A is similar for all three instruments. The instrument fixation is still tbd, but a typical example might be for all fixation points a central hole ∅ 12 H7 and a screw pattern of 4 screws M6. All holes on the Optical Bench are fixed, there will be no provisions for compensation of thermal displacements on the EPLM side.

It has to be noted that the instruments' mass and dimensions are increased dramatically compared to the previous studies and the design becomes complex (e.g. Optical Bench design).

SPIRE:

The SPIRE FPU (FSFPU) outer dimensions given in the IID B are 750 x 650 x 455 mm and the nominal mass is 42 kg. It has 3 support interfaces to the Optical Bench.
For the SPIRE JFET box outer dimensions of 300 x 100 x 100 mm and a nominal mass of 6 kg has been given. This box has 4 interfaces (tbc) to the OB, the location is tbd. The provisional outer envelope of the SPIRE FPU and JFET/Filter Box is given in Fig. 3.1-1, the position and size of the JFET box is indicative only).

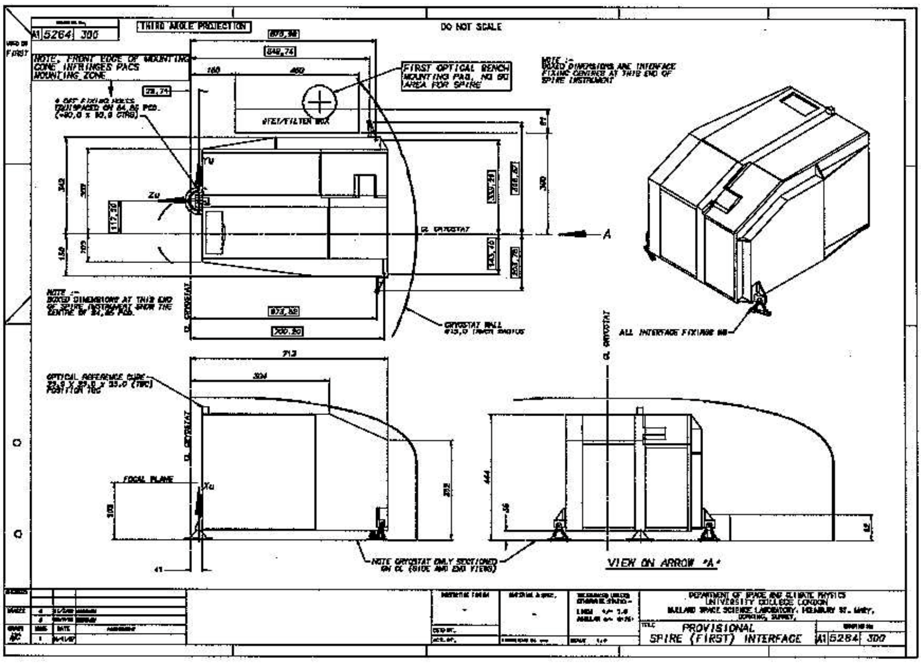


Figure 4.1-1: SPIRE FPU and JFET/Filter Box Outer Envelope

PACS FPU:

The PACS FPU outer dimensions as given in the IID B of PACS are defined by a maximum envelope of 920 x 755 x 460 mm as shown in Fig. 3.1-2, the nominal mass is 60 kg, the maximum mass is 69 kg. It is foreseen that the FPU will have 6 fixation points on the optical bench.

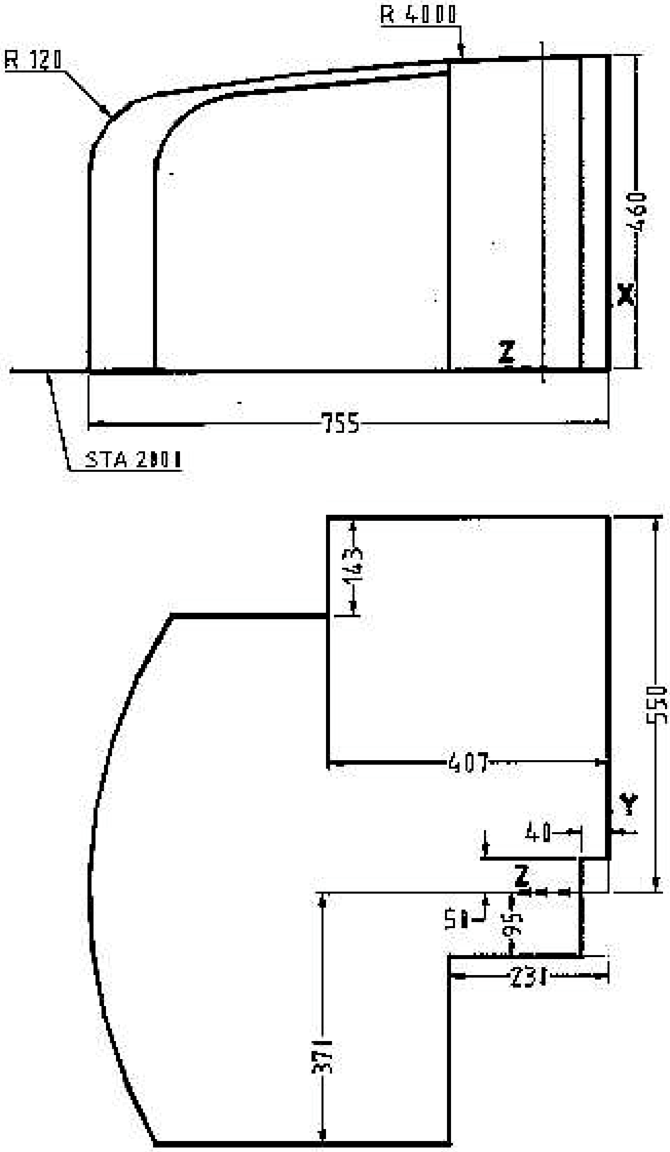


Figure 4.1-3: PACS Maximum Envelope; in the given view in the –x direction the dimension of 143 mm is currently reduced to 90 mm

HIFI:

The HIFI FPU (FHFPU) outer dimensions as given in the IID B are 700 x 555 x 393 mm, the nominal mass is 50 kg. The Focal Plane Unit FHFPU will have 4 fixation points each with 2-4 bolts to the Optical Bench. Fig. 3.1-3 shows the outer envelope of the HIFI FPU.

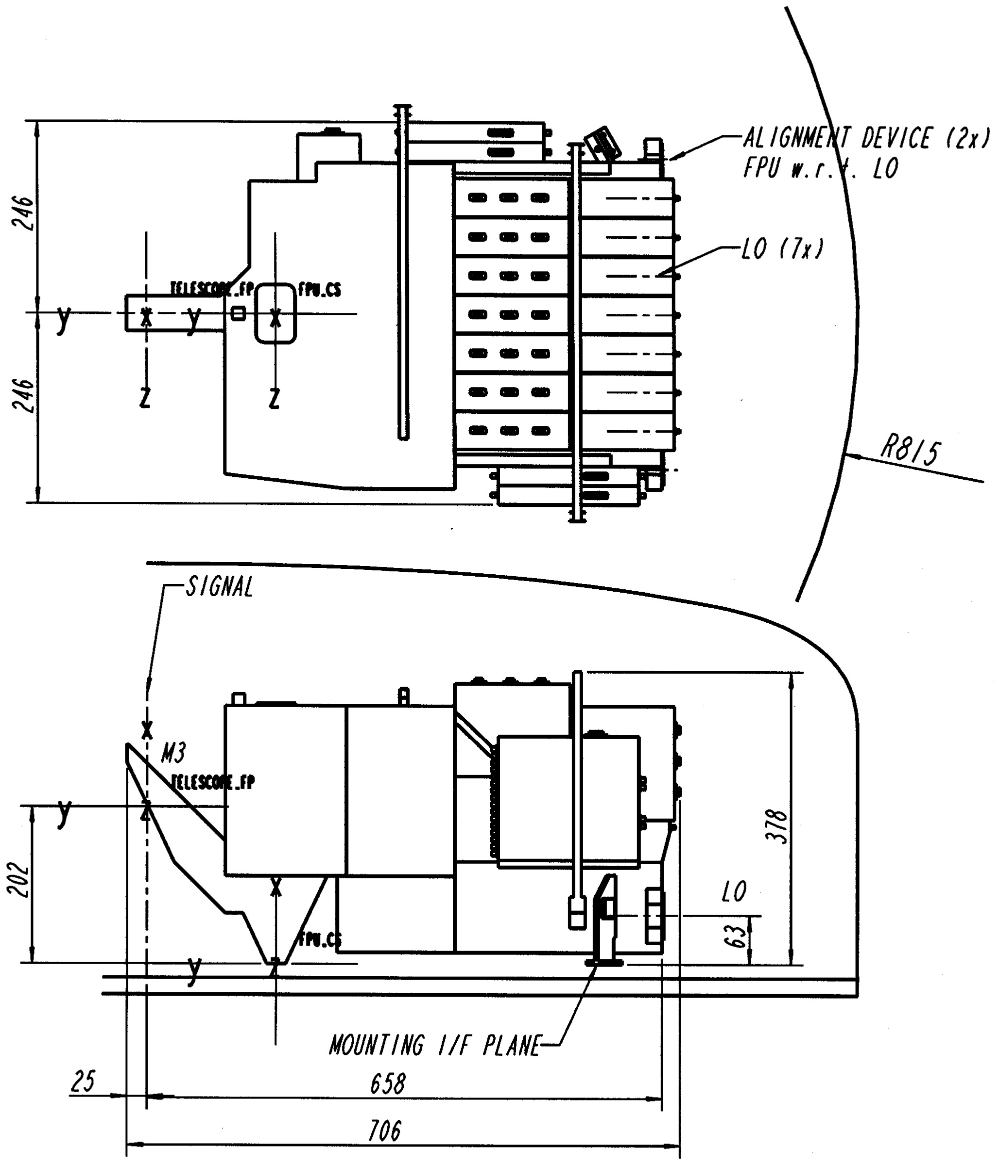


Figure 4.1-5: HIFI Outer Envelope

4.1.2.2 CVV Externally Mounted Units

PACS BOLA:
The PACS BOLA is an amplifier unit with given outer dimensions of 180 x 230 x 100 mm and with 2.5 kg mass, which is mounted with a tbd interface to the CVV.

HIFI Local Oscillator Unit:
For the HIFI LOU in the HIFI IID B outer dimensions of 555 x 492 x 289 mm and an allocated mass of 31 kg incl. radiator and support structures is given. The LOU will have attachment points for the fixation to the CVV via a strut type interface. A mechanical fixation of the wave guide unit FHLWU to the CVV is required.

To maintain the required LOU operating temperature levels a radiator will be implemented between the LOU mounting plate and the LOU base plate. The radiator dimensions are 0.6x0.6m for both sides, thickness 1mm (TBC).

Fig. 4.1-4 shows the external configuration of the Local Oscillator Unit.

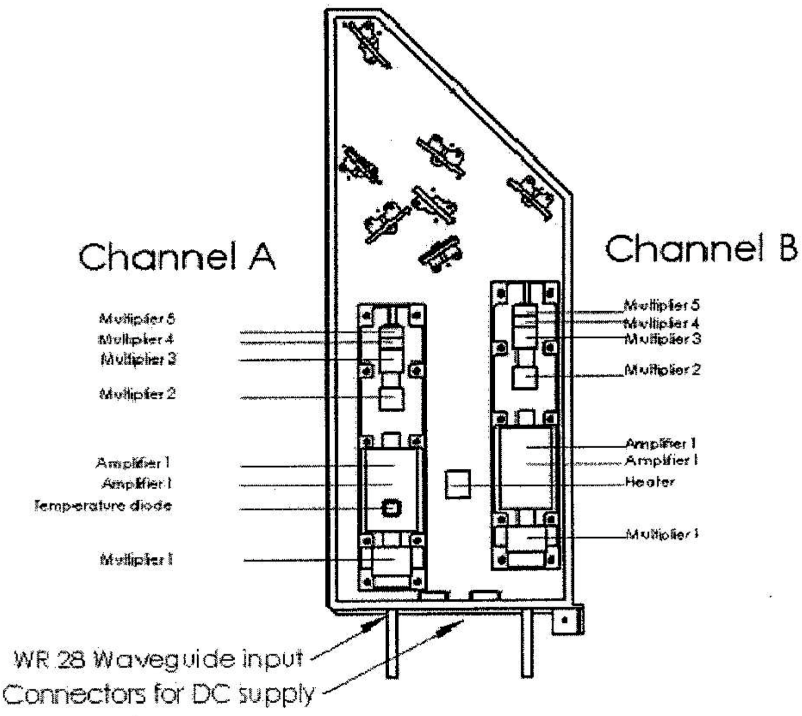


Figure 4.1-7: External Configuration of FHLOU

4.1.2.3 SVM Mounted Units

Mechanical requirements of warm instrument boxes are considered by the HERSCHEL S/C Prime.

4.1.3 Thermal Requirements

The various instrument levels require 3 different temperatures. The required operating temperature levels of each instrument are summarised in Table 4.1.3-1. These temperatures shall be provided by the HERSCHEL cryostat cooling system, which consists of the HeII tank (Level 0) and two interfaces at the ventline of the HeII tank (Level 1 and 2) on the Optical Bench.

The temperatures of the external boxes, which are mounted outside on the CVV, are also listed in Table 4.1.3-1. The boxes are thermally decoupled from the CVV by GFRP struts. Individual radiators reject the heat dissipation, see also section 4.7.2.

Table 4.1-1: Required Instrument Operating Temperatures and Dissipation Excluding Harness Dissipation and Conductive Heat Loads

	Level 0		Level 1		Level 2		outside CVV	
	Temp. [K]	Dissip.* [mW]	Temp. [K]	Dissip. [mW]	Temp. [K]	Dissip. [mW]	Temp. [K]	Dissip. [W]
SPIRE	< 2	3	< 6	5.8 *	< 15	21.2**		
PACS	< 1.75	6.7 / 0	< 5	11.9	N/A			
HIFI	< 2	0.5	< 6	1.2	< 20	34		
BOLA							120-150	2.5
LOU							80-200	12

*) Average (4.1mW for PHOT, 7.4 mW for SPEC)
**) Average (33 mW for PHOT, 9.4 mW for SPEC)

In off mode the dissipation is 0 mW.

Thermal requirements of the warm instrument boxes of SPIRE, PACS and HIFI must be considered by the SVM supplier.

Further instrument specific requirement and constraints:

SPIRE:
Within the SPIRE FPU (FSFPU) further cooling of the detectors is provided by a ^{3}He sorption cooler which is part of the instrument. Thus, in total SPIRE requires 3 separate Level 0 strap interfaces:

- for the ^{3}He cooler evaporator
- for the ^{3}He cooler pump
- for the internal structure of the instrument

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.

The cooler dissipation is not considered critical because of the high heat capacity of the HeII tank, but the high number of straps require several feedthroughs in the Optical Bench.

Further SPIRE consists of a JFET box (FSFTB) which is mounted on the optical bench next to the FPU. The JFET amplifiers operate around 120 K and are thermally insulated inside the enclosure.

PACS:
Also the PACS FPU is equipped with a ^3He sorption cooler which requires recycling every 48 hours. During cryostat warm-up or cool-down phases, the rate of temperature change shall not exceed 5 K/hour above 30 K (tbc).

HIFI:
Temperature stability 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 provides a very stable mass flow rate and the temperature stability is influenced by the instrument internal dissipation changes.

The recommended LOU reference interface temperature is 120 K which can be achieved only by a radiator

4.1.4 Electrical /EMC Requirements

Electrical Requirements

The number of wires connecting the instrument focal plane units with the SVM (via CVV feed-throughs) is given in chapter 5.8.2 of this document.

SPIRE FPU:
The harness from the Units on the OB to the outside of the cryostat is functionally sub-divided in the Housekeeping (H/K) and mechanism harness and the detector signals and control harness. The H/K and mechanism harness runs from the JFET box to the CVV vacuum feedthroughs and then to the warm box in the SVM. The detector signal and control harness leaves the FSFPU and goes via the CVV vacuum feedthroughs to the warm box in the SVM.

PACS FPU:
The PACS Cryo harness is functionally subdivided in

- a cryomechanism harness
- a Ge:Ga detector harness
- Temperature sensors and cooler harness
- a Detector harness from FPU to BOLA

HIFI FPU:
See chapter 5.8.2.

The high number of connections and the necessary cross-sections of these wires lead to a complex harness design and significant thermal heat loads via the harness.

CVV Externally Mounted Units

PACS BOLA:
See chapter 5.8.2.
HIFI LOU:
The LOU is only connected to the SVM with wires (see chapter 5.8.2) and 14 wave guides. A high number of connections with high currents but small daily cycles are given in the IID-B which can only be fulfilled by copper.

SVM Mounted Units

The electrical requirements of the warm instrument boxes of SPIRE, PACS and HIFI to the SVM (power, signal, ...) have to be considered by the HERSCHEL S/C Prime.

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

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

4.1.5 Alignment/ Optical

4.1.5.1 Summary of Alignment Requirements

Proper function of the 3 HERSCHEL instruments HIFI, PACS and SPIRE requires their precise alignment to the HERSCHEL Telescope focus. During the HERSCHEL integration, however, the Telescope, being situated outside and upon the cryostat, is the last optical subsystem to be installed.

The instruments have therefore to be aligned to the CVV w/o telescope, consequently references in the vicinity of the CVV/TEL interface plane must be implemented. The instruments are then aligned to these references without telescope. Later in the HERSCHEL integration sequence when the telescope is integrated it will be aligned to the same references (mirror cubes).

It must be noted that the instruments and the telescope are integrated in warm conditions, but the alignment has to be guaranteed in orbit in cold conditions. Each instrument has to be equipped with a reference mirror cube or mirror flats including reticles which serve as references for the direction of the instrument optical axis (3 rotation angles) and the position of the center of the instrument entrance pupil (3 position coordinates). Using additional sighting marks inside the optical path of each instrument (which for example can be inserted into the ray path by a wheel) would be the safest method for instrument alignment. So approximate alignment could be done by the cubes and fine alignment by the internal marks.

The 3 instruments are mounted on an Optical Bench (OB) and aligned to a reference cube on the OB. Then, the OB with the instruments is aligned to the CVV by the aid of the OB cube and the CVV cubes, such that the instruments are in proper position for the Telescope focus later.

An alignment check within the CVV with direct access to the optical paths of the instruments would be advantageous instead of relying on proper alignment by only the OB cube.

The CVV cover does not incorporate an optical window for alignment measurements on the Optical Bench (OB) or on the instruments (FPUs) with closed cover and in cold cryostat conditions. So no alignment measurements from vertically above (i.e. sighting line in -X), are possible when the cover is closed. However, during the "dark space simulation test" with the instruments looking at a cold plate, which will be inserted on top of the cryostat by the aid of an auxiliary "cavity", a cold alignment measurement on the FPUs can be performed. For this purpose the cold plate device on the cavity is exchanged by an optical window.

The critical alignment for HIFI / OB is the alignment to the LOU-Windows

Allowed tolerances for the alignment of LOU to HIFI given by the HIFI manufacturer						
	ΔX mm	ΔY mm	ΔZ mm	θx deg	θy deg	θz deg
	± 0.75	(± 15)	± 0.75	± 0.038	± 0.11)*	± 0.038
Required tolerances for HIFI to LOU-Windows alignment (RMS)						
	± 0.53	± 5	± 0.53	± 0.027	± 0.076)*	± 0.027

)* derived from ΔX value on 400 mm distance between left and right LOU-alignment window.

In the following table, the required accuracies for Telescope to FPU alignment are sub-divided in FPU to OB alignment and OB to CVV alignment; and CVV to Telescope.

Required Accuracies for FPU to OB Alignment)*						
	ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
SPIRE	± 3 Foc.lateral	± 3 Foc.lateral	± 4.97 **Foc.axial**	± 0.13 Axis	± 0.13 Axis	± 0.5 **Roll**
PACS	± 3 Foc.lateral	± 3 Foc.lateral	± 4.97 **Foc.axial**	± 0.13 Axis	± 0.13 Axis	± 0.5 **Roll**
HIFI	± 3 Foc.lateral	± 4.97 **Foc.axial**	± 3 Foc.lateral	± 0.13 Axis	± 0.13)** **Roll**	± 0.13 Axis
Required Accuracies for OB to CVV Alignment)*						
	± 0.5 Foc.axial	**± 0.5 Foc.lateral**	**± 0.5 Foc.lateral**	**± 0.017 Roll**	**± 0.017 Axis**	**± 0.017 Axis**
Total Accuracy Requirements for FPU to CVV Alignment (see Alignment Plan SCI PT-PI-02220 **)***						
	ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
I.)	**Foc.axial** ± 5	**Foc.lateral** ± 3.04	**Foc.lateral** ± 3.04	**Roll** ± 1	**Axis** ± 0.13 (8 arcmin)	**Axis** ± 0.13 (8 arcmin)
Required Accuracies for TEL to CVV Alignment) (see Alignment Plan SCI PT-PI-02220)						
II.)	±4)***= 9-5 mm orbit variat.	± 1	± 1	± 1	± 0.017 (1 arcmin)	± 0.017 (1 arcmin)
Allowed Internal FPU defocus						
III.)	± 3					

Total Required Accuracies for TEL to FPU Alignment (see Alignment Plan SCI PT-PI-02220)						
(rms from:	**Foc.axial** ± 11 *I), II), III)*	**Foc.lateral** ± 3.2 *I), II)*	**Foc.lateral** ± 3.2 *I), II)*	**Roll** ± 1	**Axis** ± 0.13 (8.1arcmin)	**Axis** ± 0.13 (8.1arc min)

The following observations should be noted:

The assignment of denominations Focus axial, lateral, Roll and Axis are different for the Optical Bench and the different FPUs

)* The alignment requirements of the critical HIFI to LOU-Windows alignment dominate the other alignment requirements so the Optical Bench with the 3 instruments have to be aligned to the CVV using HIFI as a reference.

)** High HIFI Roll alignment accuracy is required because low accuracy would decrease SPIRE and PACS axis alignment values too much when OB is aligned to CVV using HIFI as a reference.

)*** Ref [Alignment Plan SCI PT-Pl- 02220] Tel tolerance: ± 9 mm (including ± 5 mm orbit variation).

PACS BOLA: No alignment requirement.

4.1.5.2 Optical Requirements

SPIRE FPU:
The FPU uses only part of the 260 mm diameter telescope beam area. The beam shape for the cryostat entry hole is given in the following Fig. 4.1-5. It is stated that the 260 mm radius hole in the cryostat is barely large enough, but that effects of diffraction have to be considered. An exact requirement for the cryostat entrance diameter is not yet defined, the 260 mm diameter is used for the baseline design.

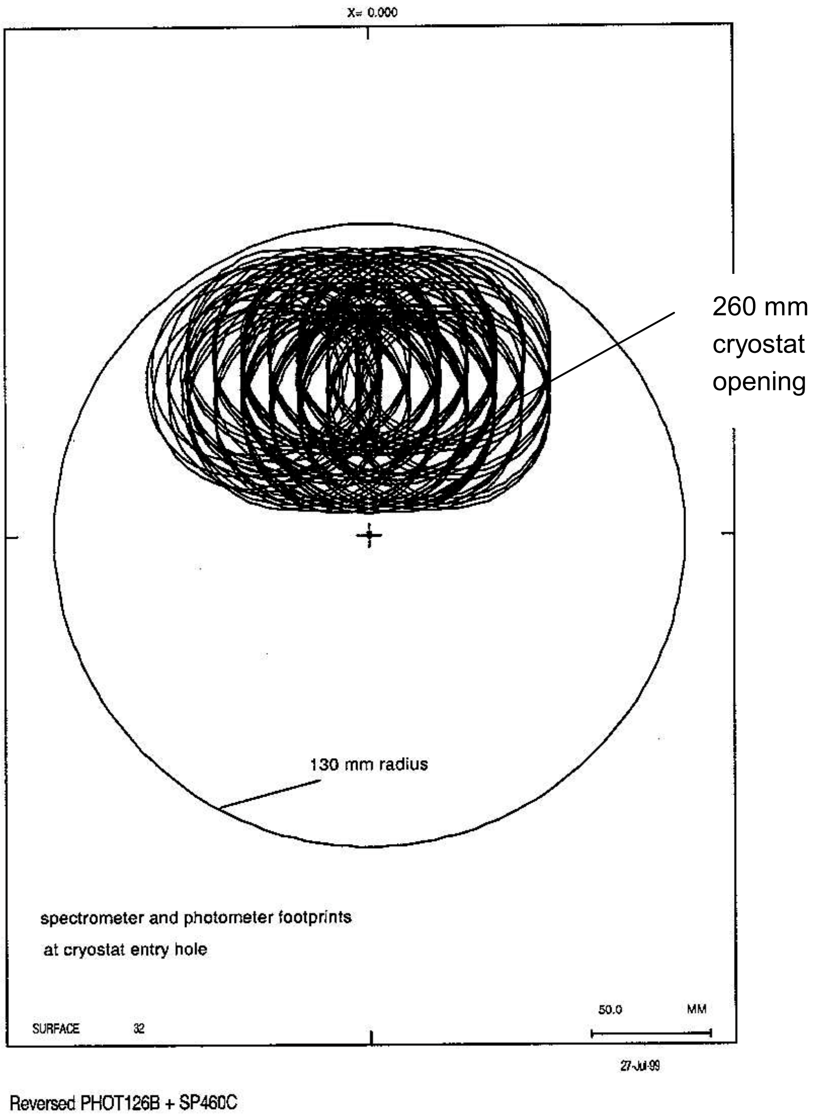


Figure 4.1-9: SPIRE Optical Beam Envelope at the Exit Hole from the HERSCHEL Cryostat

PACS FPU:
There a 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).

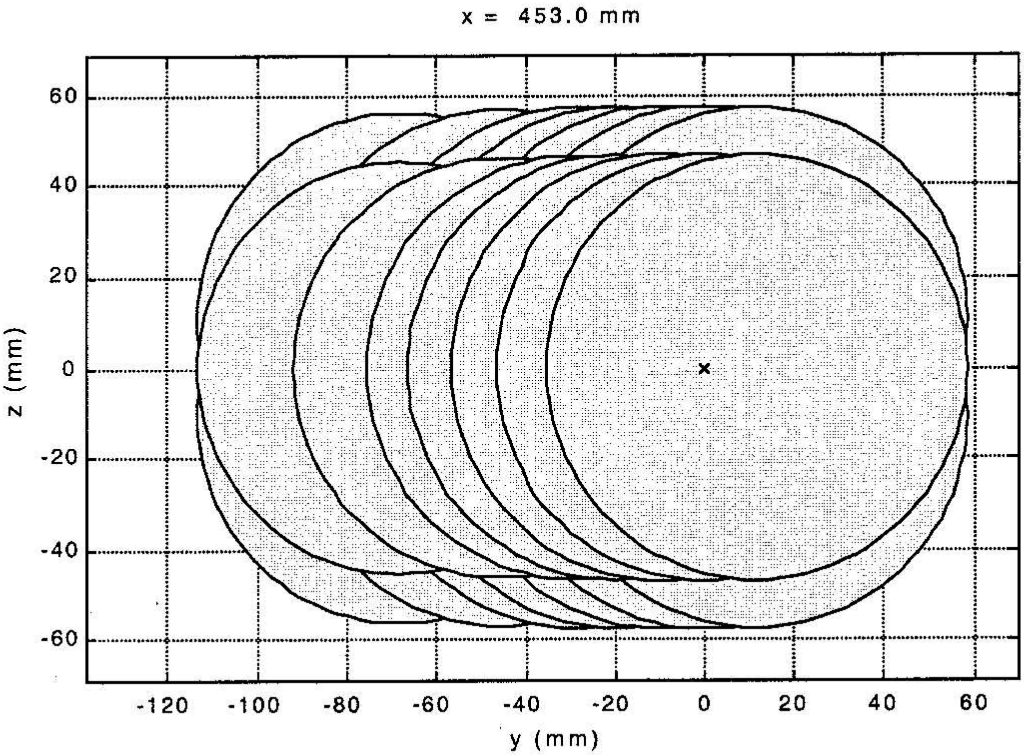


Figure 4.1-11: HIFI Beam Shape at the Height of the Cryostat Opening (from HIFI IID B)

LO Requirements:
Seven LO beams shall enter the cryostat outer vessel along 7 parallel paths from the –y side. A 30 mm free diameter is required for each the window diameter. The inter beam spacing is defined as 50 mm. The windows and filters (if any) 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 LO channels shall have a minimum transmission of 80 % at EOL.

4.1.6 Straylight

According to the HERSCHEL Telescope Specification PT-RS-04671, issue 3/0, there are a total of 3 requirements to be met, for straylight sources outside the field of view (FOV), inside the FOV, and for thermal straylight emission. These requirements are

- Taking into account the worst combination of the Moon and the Earth positions the straylight shall be < 1 % of background radiation induced by self-emission of the telescope.

- Over the entire FOV at angular distances ≥ 3' from the peak of the point-spread-function (PSF), the straylight shall be < $1 * 10^{-4}$ of PSF peak irradiance (in addition to level given by diffraction).

- The straylight level, received at the defined detector element location of the PLM/Focal Plane Unit Straylight model by self emission, not including the self emission of the telescope reflectors alone, shall be ≤ 10 % (tbc) of the background induced by self emission of the telescope reflectors.

4.1.7 Cleanliness

Cleanliness requirements as given in the System Requirements Specifications will be satisfied by design, i.e. composites must be tested for their outgassing properties and special procedures will prevent MLI pieces contaminating the cryostat's interior. The complete cleaning effort of the system will be geared to fulfilling these two requirements.

A molecular contamination of smaller than 2×10^{-7} on ground and a particle contamination of less than 300 ppm on optical surfaces is requested. We will consider an optical element on the optical bench for reference. This requirement can be met in a class 100 cleanroom, which constitutes our baseline. Reasonable budgeting between PLM and Instrument Integration is required. The comparable ISO requirement was for a contamination of 850 ppm. ISO was designed for observations in the near infrared spectral range, which is by far more susceptible to particle contamination than the far infrared range of HERSCHEL. The tightening of this cleanliness specification by a factor of approximately 3 is technically complicated and requires special means.

The IIDA asks for integration to take place in a class 100 cleanroom, similar requirements can be found in the IIDBs (unpacking). This procedure will be followed. An optical surface accumulates particle contamination of 1.5 ppm/day in a class 100 cleanroom (ISO cleanliness Policy). Thus HERSCHEL's optical surfaces could be exposed for a full 200 days before reaching the contamination of 300 ppm. HERSCHEL's optical components are small enough to allow dust covers for most of the time during integration and all other surfaces could be cleaned before closing the cover finally.

An optical subsystem transmission loss of less than 3% during mission lifetime is required. As detailed optical design of the instruments is currently unknown, a budgetary allocation for various mission parts and transformation into suitable surface densities of admissible contaminants is not possible for Astrium GmbH. This requirement can only become effective for PLM integration, after considerable analyses have been performed.

Contamination control of the telescope can only be considered applicable during on ground activities. During and after launch, no feature exists to control contamination. It must be pointed out, in addition, that telescope cleaning in orbit by heating of the telescope dish has to be performed with the CVV cover still closed.

So far, any shielding of the main telescope mirror after launch with the objective of reducing contamination is not part of the HERSCHEL concept. Thus, means of preventing contamination cannot apply to the telescope. Pending analysis, the optical parts inside the cryostat are probably better accommodated, if the aperture to space is only opened after the final orbit is reached. Internal outgassing is assumed to be acceptably low due to the low surface temperatures. Hydrazine decomposition products are assumed not to reach the telescope/cover opening. A system cleanliness analysis has to verify the 3% transmission loss requirement.

The instrument components can be shielded from contamination during installation, but no active means are foreseen during launch and during orbit. Accordingly, this requirement 'in-orbit and during the initial (outgassing) phase and during thruster firings' cannot be met, any necessary mechanisms are not considered for HERSCHEL.

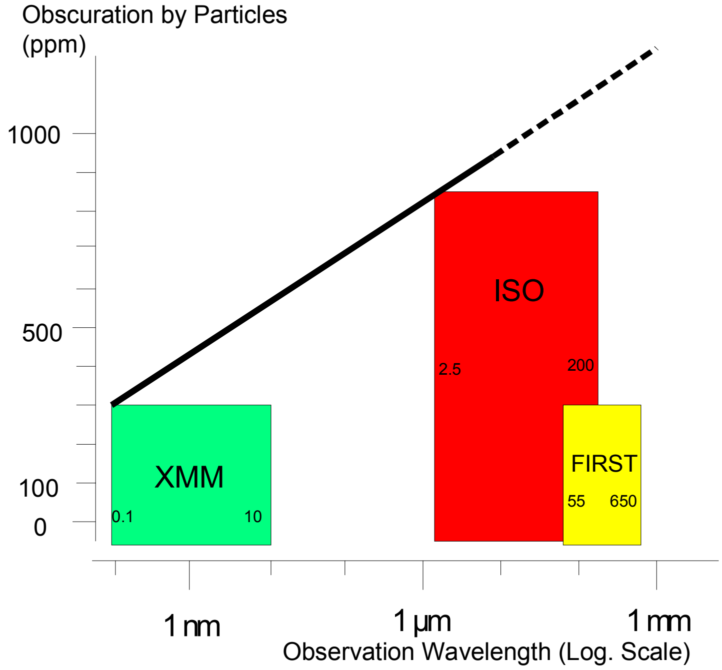


Figure 4.1-13: Comparison of Several Particle Cleanliness Requirements

4.2 Telescope Interface Requirements

The telescope is composed of the primary reflector, a secondary reflector, a reflector support structure and an interface triangle and mechanical fixation devices to the primary reflector. Interface requirements for the Telescope with PLM are described in HERSCHEL Telescope Specification PT-RQ-4671, issue 2/0.

4.2.1 Mechanical /Alignment Requirements

The telescope interface triangle provides for the interface with the telescope support truss structure, which is part of the Payload Module (PLM).

The dimensions and parameters for the mechanical interface of the telescope have been taken from HERSCHEL Telescope Interface Specification document, number “AD2-1”.

TEFU-010 The telescope interfaces mechanically with the PLM interface structure via 3 hard points on the telescope interface triangle which shall allow alignment and mounting of the complete telescope to the PLM.

TEFU-015 One triangle interface point shall be located on the –Z-axis, at a distance of 1.037 mm (tbc) from the X-axis. The other interface points shall be within the Y/Z Plane.

TEFU-020 The structural interface of the telescope and its accessibility shall allow an easy and reproducible assembly and alignment of the complete telescope to the PLM.

TEPE-030 The distance of the primary reflector vertex-best on axis focus shall be t_b =1050 mm ± 10 mm

TEPE-035 The distance of the telescope fixation plane to the primary reflector vertex t_v shall be 250 mm(tbc)

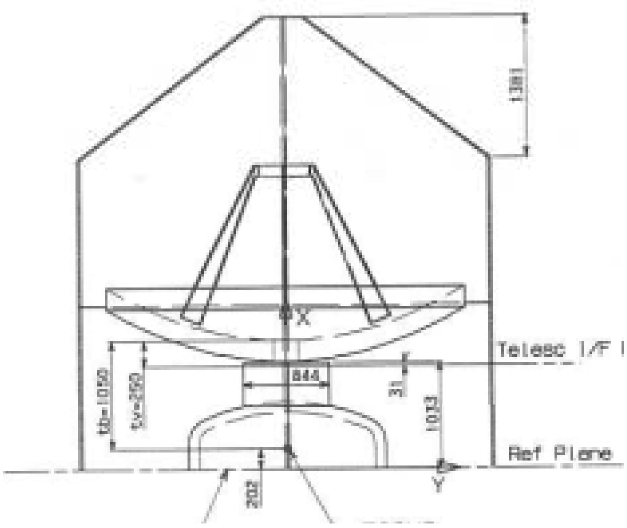


Figure 4.2-1: Interface Telescope/ PLM from HERSCHEL Telescope Interface Specification

The above drawing gives also the I/F PLM cavity to Telescope. Taking the primary mirror thickness of 203 mm as given in the IID A, the remaining distance between cavity upper surface and the telescope lower surface is 16 mm.

- The total mass of the Telescope with the electrical heaters shall not exceed 280 kg.
- The Telescope / PLM Interface when carrying the Telescope with its mass and moments of inertia shall withstand the resulting interface loads from the TEL.

- The flight limit loads as given in RD 20 for the primary reflector are 20 g axial and 15 g lateral.
- Provisions for alignment shall be provided, alignment requirements are given in the HERSCHEL Alignment Plan.

Alignment Requirements

The telescope interface triangle is connected to the PLM interface structure via 3 hard points. It must be possible to perform defined translational telescope movements in the Y/Z plane and to apply stops that allow any previously found alignment position, to be easily found again when the telescope is removed for insertion of new shims.

The translational adjustment along X and the rotational adjustments round Y and Z can be performed by shimming. Rotation round X is uncritical and needs no special adjustment.

Required Accuracies for TEL to CVV Alignment						
	ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
	± 4)*	± 1	± 1	± 1	± 0.017 (1arcmin)	± 0.017 (1arcmin)

)* Ref [Alignment Plan SCI PT-PI- 02220] Tel tolerance: ± 9 mm (including ± 5 mm orbit variation)

4.2.2 Thermal

As thermal interface requirements are identified from the Telescope Specification:

- The average telescope temperature shall be within a temperature range of 70 - 90 K (see TEPE-005).
- The telescope shall be thermally decoupled from the PLM, for the telescope design a total conductance of 5mW/K have been given (see TEFU-050).
- For contamination release the telescope will be heated up to 353 K in orbit for a minimum duration of 3 weeks (tbc) (TEPE –040 and TEEN-090, TEFU-075).

The PLM and sunshield/sunshade interface temperatures and surface properties (TEFU-040, TEFU-045, TEFO-030, TEFU-035) are considered preliminary requirements since:

- Thermal environment
- Telescope (thermal) design
- Telescope temperature range and gradient

are closely interrelated and have to be treated accordingly, i.e. an iterative approach of mechanical/optical design and thermal verification of telescope temperatures within the PLM model.

The Telescope MLI is tbd, it is considered to be part of the telescope

4.2.3 Electrical / Harness

The following electrical I/F requirements are identified:

The electrical interface resistance between the telescope and the S/C grounding system shall be < 1 Ohm.
There will be a heater and sensor harness to the Telescope, the power of the heaters for decontamination is up to 600 W.

4.2.4 Cleanliness

The telescope requirements allow for cleaning (TEEN-075), accordingly mating of the telescope to the PLM will not place stringent requirements on environmental cleanliness, compared to PLM assembly.

Assuming a cleaning of the telescope as close before launch as possible (e.g. before transport to Kourou), particle and molecular contamination is estimated to be well within the specification.

The particle contamination specification is later endangered during launch by sources such as:

- AR5 fairings
- HERSCHEL outside surfaces
- Planck outside surfaces
-

Critically is in the order given above.

Worsening or changing molecular contamination level has to consider

- molecular relations below the fairing during a relatively low duration
- the decontamination heating operation in orbit (temperature level should be carefully considered in Phase B)
- the in orbit vaporisation/condensing mechanisms, which are expected to be fairly low.

5 H-EPLM Design

5.1 H-PLM Overall Configuration

The main parts of the H-EPLM are the:

1. HeII-cryostat
2. The scientific instruments inside and outside the cryostat and in the SVM
3. 3.5 m Telescope
4. HERSCHEL Sunshield/Sunshade (HSS)

The following figure gives an external overview on the H-EPLM.

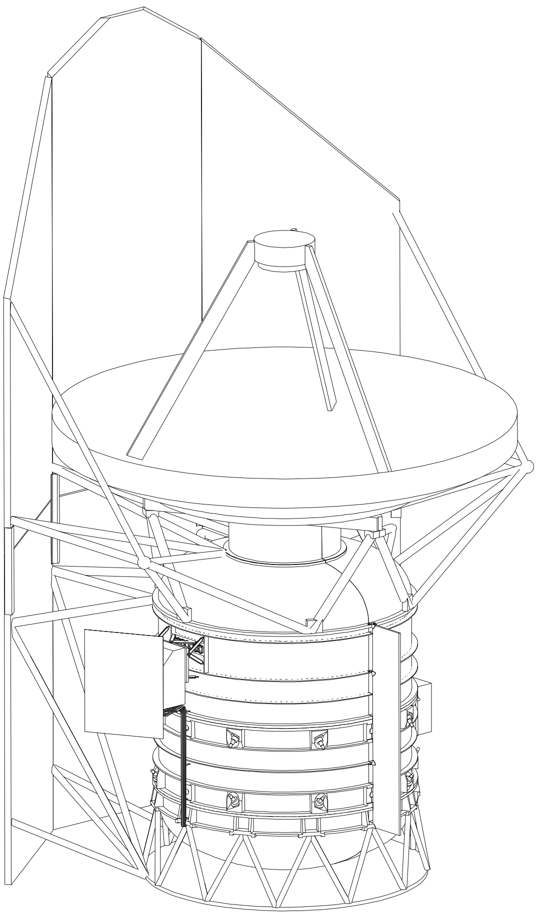


Figure 5.1-1: H-EPLM External View

The H-EPLM is mounted on top of the HERSCHEL-SVM via GFRP-struts
On the outside of the Cryostat Vacuum Vessel the Bolometer Amplifier Unit (BOLA) and the Local Oscillator Unit (LOU) of two of the instruments are arranged. The rear of the Cryostat Vacuum Vessel is used as a radiator to space, which is equipped with an additional radiator area (nose) to improve the radiator performance.
The two individual units Sunshade (SSD) and Sunshield (SSH) are bolted together to form one integral unit. This composed unit requires no frame for lateral stability and is supported via a set of lateral and vertical struts to the CVV and the SVM

The SSD unit consists of 3 different sub panels. The individual panel shape is generated by the Ariane 5 Fairing dimensions, to provide full Telescope shadowing and to fit to the SSH shape. The panels are bonded together by the use of additional doublers and are attached to the SSH via bolts and brackets to allow separate production and verification. The front of the SSD is covered with OSR's.

The SSH consists of 3 unique panels of (2.5 x 1.6) m each carrying the photovoltaic assembly. The integrated SSD/SSH shield is supported by means of struts made of GFRP and are connected to the cryostat. The lower struts are directly connected to the SVM. The whole rear area of the unit is covered with high-efficient MLI.

The 3.5 m HERSCHEL Telescope is mounted upon the Cryostat Vacuum Vessel on 3 GFRP bipods. The following figure gives the view of the H-EPLM.

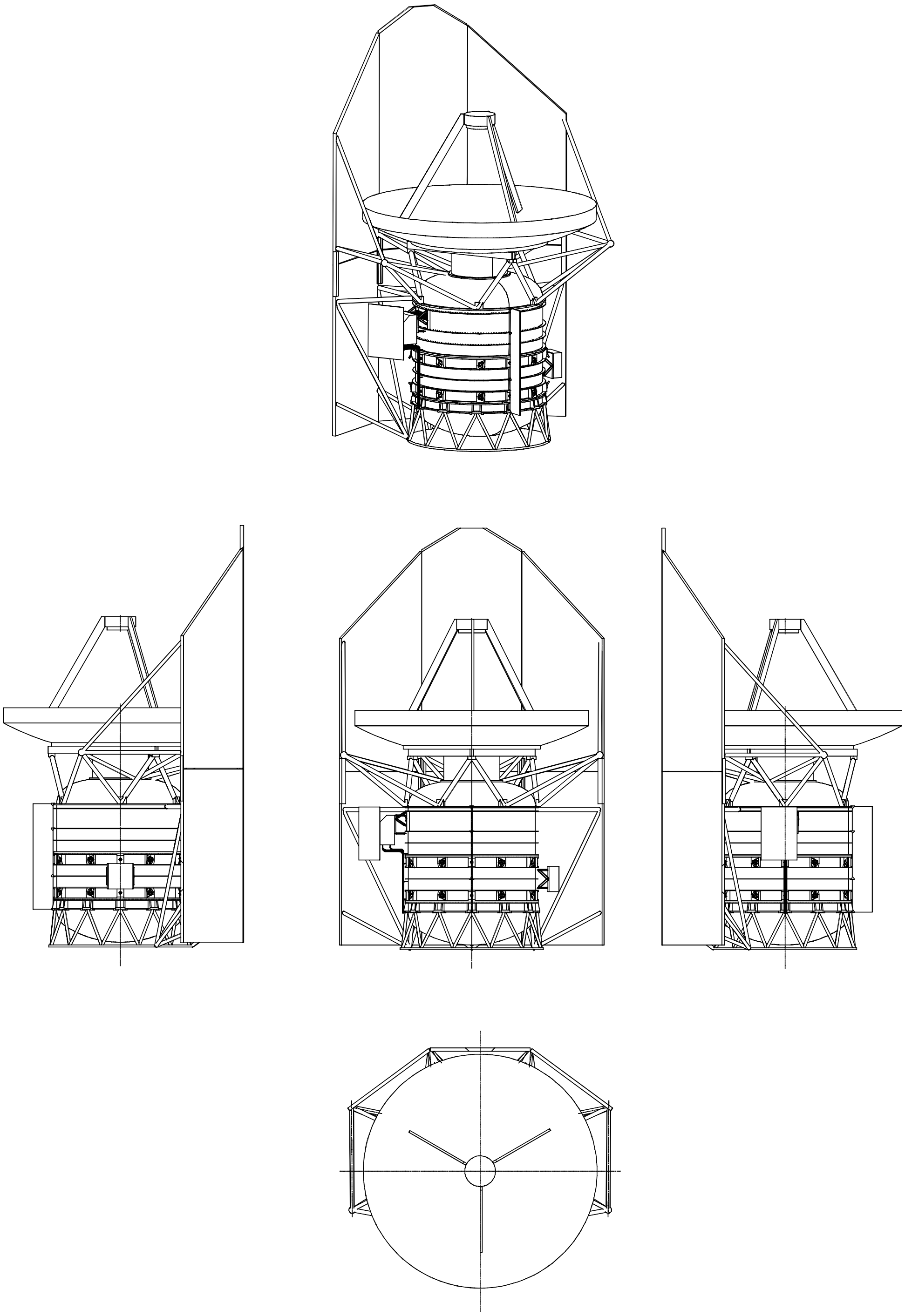


Figure 5.1-2: H-EPLM Overall View

The Cryostat Vacuum Vessel (CVV) provides the vacuum for the instruments and the He S/S on ground. A cover during ground operations and start of the mission closes it.

The segmented 2160-l He II-tank is arranged inside the cryostat. The tank equipment (valves, phase separator, safety devices, sensors, heaters etc.) is similar to the ISO-tank equipment. 16 tank support straps, which are connected to the Upper and Lower Spatial Framework, suspend the tank. The tank support straps consist each of 4 GFRP and 2 CFRP chain loops. Steel bolts, which also act as thermal anchors connect them, and mechanical support of the three vapour cooled heat shields. The tank support straps are pre-tensioned by 16 tank support strap tensioning devices on the outside of the CVV.
A lens-shaped auxiliary LHe-tank for launch autonomy cooling is mounted to the lower spatial framework.

The Optical Bench, which supports the scientific instruments, is mounted on top of the upper spatial framework. A common instrument protection shield surrounds the instruments on the Optical Bench. To provide the cooling level 0 of the instruments they are connected via straps directly to the HeII tank. The He-ventgas leaving the HeII-tank is used for the provision of cooling levels 1 and 2 of the instruments (by connection to the ventline surrounding the instruments) and is then used for cooling of the three cryostat radiation shields. On top of the cryostat a cavity is mounted to suppress straylight incidence.

A half section of the cryostat with the important dimensions is given in the following .

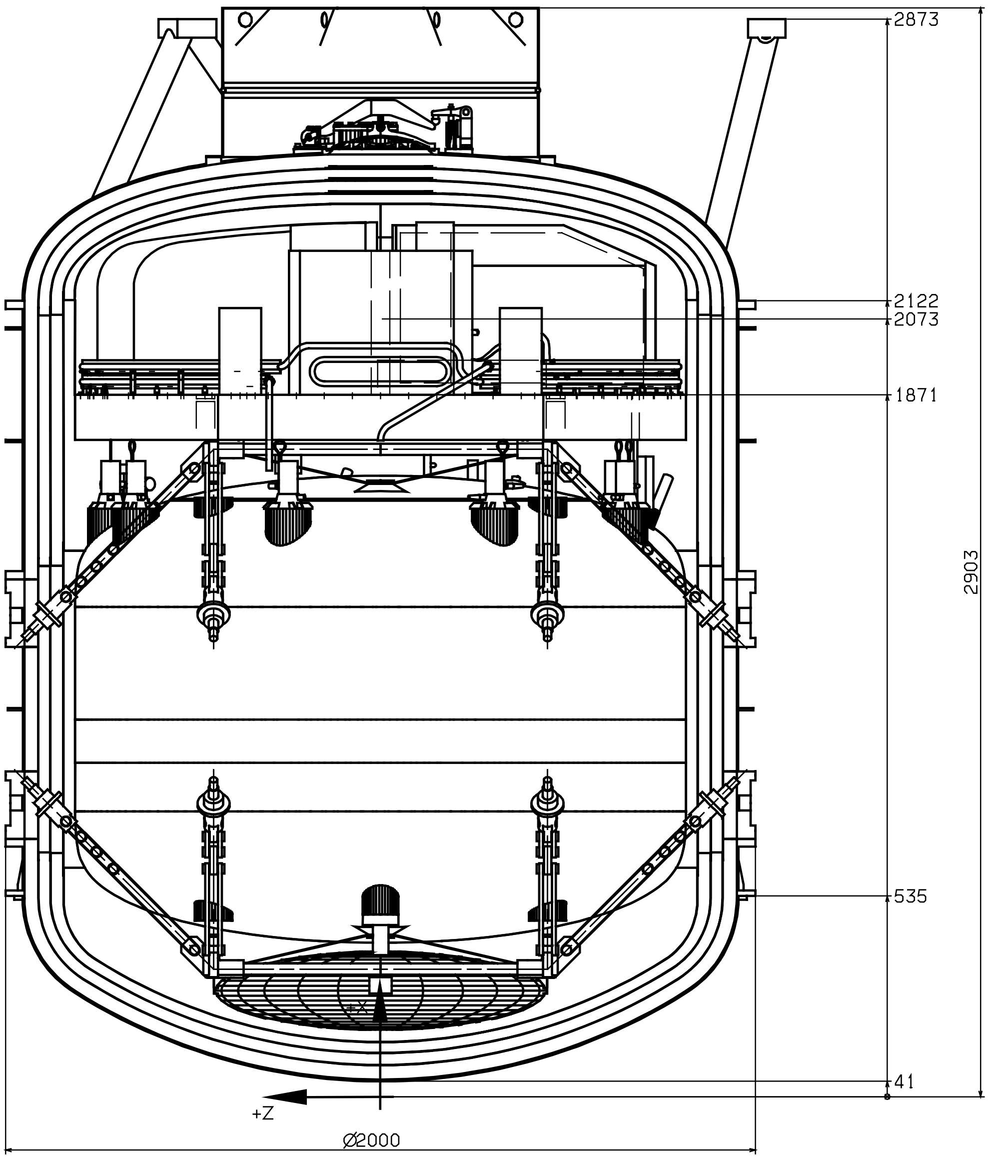


Figure 5.1-3: Half-Section of Cryostat

The H-PLM consists of the following subsystems (SS):

- Structure SS
- Helium SS (He SS)
- Insulation SS
- Electrical SS
- HERSCHEL Sunshield/Sunshade (HSS)

The main components of the Subsystems are:

- Structure SS
  - CVV, Cryostat Cover, Tank support system, Spatial Framework, Optical Bench, External Structures, Optical Feedthroughs, CVV cavity
- Structure SS
  - HeII tank assembly, HeI tank assembly, OB tubing, Ventline on shields, external ventline assembly, CVV mounted safety equipment
- Insulation SS
  - Radiation shields, MLI
- Electrical SS
  - Cryoelectronic, Instrumentation, Harness
- FSS
  - Sunshield/Sunshade Structure, Solar Generator, MLI, Sunshade radiator

Chapters 6 describe the subsystems in detail and the Instrument Accommodation is described in chapter 5.4

5.2 H-PLM Functional Description

The overall function of the H-PLM is to provide a suitable environment for the scientific instruments and the telescope on ground, during launch and in orbit, for the required lifetime.

The structure SS comprises mainly the CVV and OB and provides the mounting base for the scientific instruments, the telescope and the sunshield/sunshade. It supports the He SS (HeII tank, ventline), the Insulation SS (radiation shields and MLI) and the instrumentation and harness of the Electrical SS. The CVV provides the insulation vacuum for the He SS during ground operations and early phase after launch. It is equipped with a cryostat cover which is opened after telescope decontamination to provide the instruments with the telescope beam.

The He SS provides the cooling of the scientific instruments inside the CVV on ground, during launch and in orbit. The HeII tank is the reservoir that provides the cooling over the lifetime of the H-PLM in orbit and for ground testing. The HeI-tank is used as a cooling reservoir during launch preparation.

The Insulation SS (radiation shields and MLI) enables the cryostat to provide the required temperatures and the lifetime. It protects the CVV from external radiative heat input (e.g. from SVM and Sunshield) and the HeII tank from radiative heat input from the CVV.

The Cryostat Electronic, Instrumentation and the Cryostat Control Harness of the Electrical SS enable the proper function of the cryostat on ground, during launch and in orbit (housekeeping). The scientific instrument harness provides the electrical connection between the instrument cold units inside and outside the cryostat and the instrument warm boxes in the SVM.

The FSS shadows the Cryostat and the Telescope from sun illumination, the solar generator provides the electrical power for operation of the satellite

5.3 Sensitivities

5.3.1 Influence of Design Parameters on Life Time and Telescope Temperature

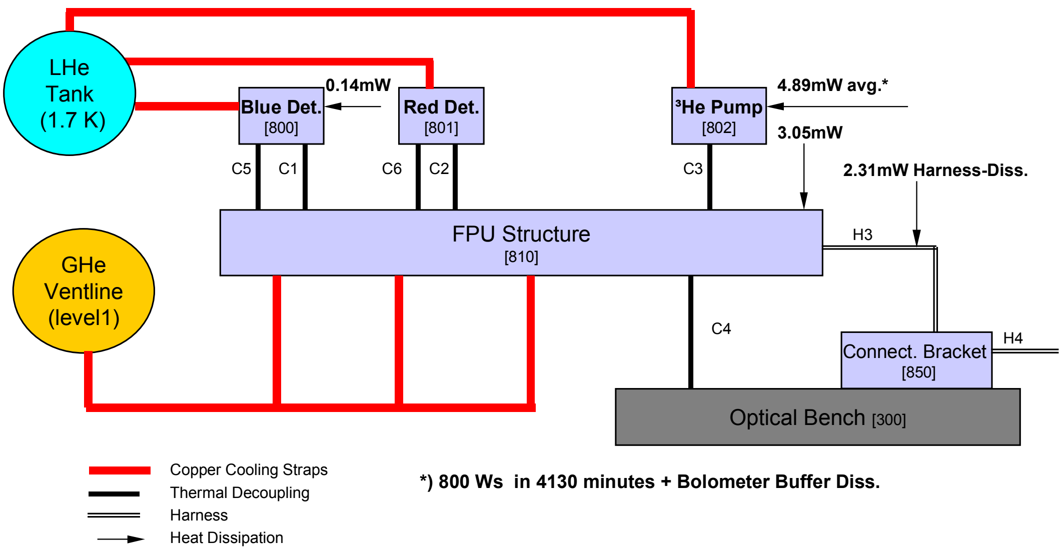
5.3.1.1 Sensitivity to Mechanical Connections and Temperatures

Item	Baseline design data	Lifetime Sensitivity	Ref.
SVM / CVV struts	25.32 mm A/l* GFRP	22 days per 20%	
HSS / CVV struts	5 mm A/l* GFRP	10 days per 20%	
Telescope / CVV	7.6 mm A/l* GFRP	small due to small temperature gradient	
Tank suspension straps	172.5 mm² per strap	55 days per 20%	
Tank / SFWK	14.45 mm A/l* CFRP	14 days per 20%	
Tank Temperature	1.6 K ± 0.1K (tbc)	15 days per 0.1K	
CVV Temperature	71 K ± 5 K (tbc)	-105 days for +5 K +119 days for -5 K	
Sunshield Temperature	109°C max (center panel)	~15 days per 10 K	
Sunshade	276 K max (center panel)	~2.5 days per 10 K, see also sect. 5.3.1.5	

*) A/l = cross-section to length ratio of mechanical fixation device

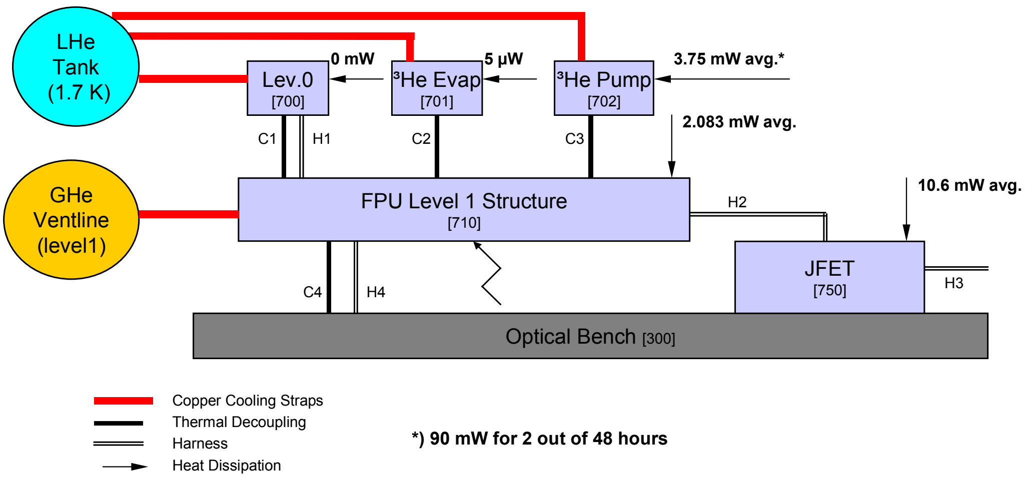
5.3.1.2 Influence of Instruments on Life Time

- PACS update (T300 blades): -36 days for Issue
- PACS update (stainless steel blades): -10 days in addition (Option)
- SPIRE update (Issue 2/0): -32 days in addition
- HIFI Box on SVM top (10 W to SVM shield): -20 days



C1: Kevlar struts with 156 mm^2 cross section and 40 mm length
C2: Kevlar struts with 156 mm^2 cross section and 40 mm length
C3: Stainless steel tubes with 67.5 mm^2 cross section and 60 mm length
C4: CFRP struts (T300) with 600 mm^2 cross section and 30 mm length (baseline)
alternative: Stainless steel struts with 350 mm^2 cross section and 70 mm length
C5: 0.31 mm² stainl.steel, 5 mm length + 16.83 mm cross section to length ratio of Kapton
C6: 0.31 mm² stainl.steel, 5 mm length + 16.83 mm cross section to length ratio of Kapton
H3: 35.244 mm² steel + 5.148 mm² brass + 295 mm² Teflon, 0.5 m length

Figure 5.3-1: PACS reduced TMM with average dissipation values /1,2/



C1: Stainless Steel blades with 68.1 mm² cross section and 27.5 mm length
C2: Ti6Al4V structure with 11.6 mm² crosss section and 27.5 mm length
C3: Ti6Al4V structure with 11.6 mm² crosss section and 27.5 mm length
C4: Stainless steel blades with 106 mm² cross section and 40 mm length (tbc)
H1: 5.088 mm² manganin + 39.6 mm² Teflon, 0.025 m length
H2: 11.895 mm² steel + 5.088 mm² manganin + 39.6 mm² Teflon, 0.1 m length
H4: 7.222 mm² steel + 2.01 mm² brass + 222 mm² Teflon, 0.1 m length

Figure 5.3-3: SPIRE reduced TMM with average dissipation values (data derived from /3/)

5.3.1.3 Influence of Harness on Life Time

Following harness sensitivity analyses have been performed:

- Variation of harness cross section : 60 days per 20%
- Harness length between CVV and HS1 (0.25 m): 45 days per 20%
- Harness acc. to IID-A, Issue 1/1: tba

An increase of the Harness thermal insulation length between CVV and inner heat shield (HS1) to at least 0.3 m should be emphasized and worked-out. Thermal insulation length means the "free" length between the end of the harness thermalisation section at the CVV and the begin of the thermalization section at the HS 1. To increase the "free" harness length the length of the thermalization section on HS1 may be reduced. A good thermal contact conductance between harness and HS1 could be kept using adhesive bonding with e.g. STYCAST to special "thermalization brackets", similar as done by ISO.

5.3.1.4 Influence of Solar Generator Design on Lifetime

BOL case: 300 W excessive electrical power dissipated additionally on center Solar Panel due to higher cell efficiency of Solar Generator at BOL (actual electrical power demand at BOL is provided by ALCATEL).
Result: Solar Generator center panel temperature increases from 109°C to 116°C, which lead to a lifetime reduction of 4 days (only). Thus, a "Dumper" radiator located e.g. at the SVM for dissipating the excessive electrical power seems not to be necessary (TBC).

Option: 30% OSR coverage on Solar Generator (feasibility tbc):
Max temperature (center solar panel) reduced from 109°C to 83°C, lifetime increased by **36 days**. In addition, the efficiency of the solar cells may be better at lower temperature. OSR coverage may be feasible due to the reduced EOL power requirement to 1300 W and due to possible extension of the Solar Generator at the SVM end.

5.3.1.5 Influence of Sunshade Performance on Telescope Temperature

The main task of the sunshade is to provide a telescope temperature of less than 90 K. Following influence of the sunshade radiator solar absorptivity α have been calculated:

The solar absorptivity α=0.2 is assumed as baseline for the OSR coating at EOL and the IR emissivity is set to 0.84. This yield a telescope temperature of 76 K.

5.3.1.6 References

/1/ PACS-KT-AN-003, Issue 3 DRAFT; Thermal Analysis
/2/ Lutz Morgenroth, email answer: PACS reduced TMM_200601.ppt, 21/06/01
/3/ SPIRE-RAL-PRJ-000728, Issue. 1/0, 20.06.01, not approved

5.4 Instrument Accommodation

5.4.1 Optical Bench

The three FPUs of PACS, SPIRE and HIFI and the SPIRE JFET box are arranged on the Optical Bench (OB) which is fixed upon the HeII-tank. The OB will be made of aluminium. Figure 5.4-1 shows the principal arrangement of the instruments on the OB. The OB is currently under design, which will yield also the final dimensions (see configuration drawings).

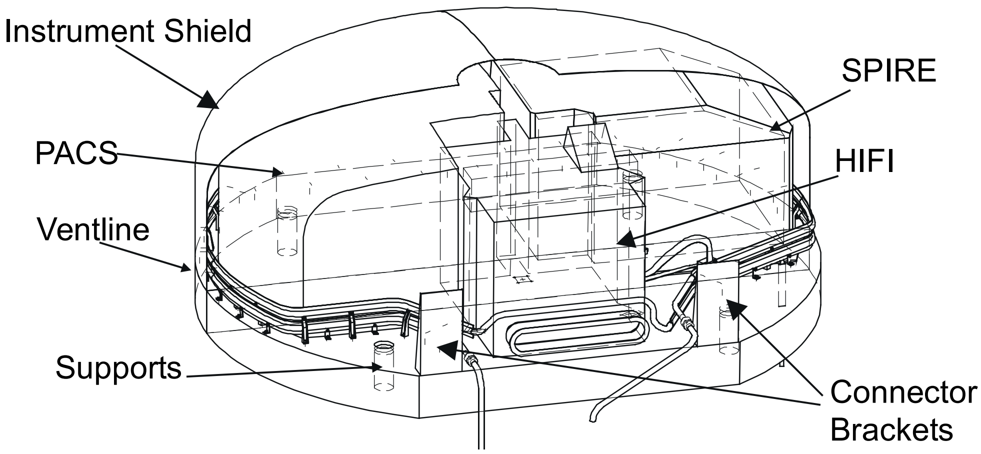


Figure 5.4-1: Arrangement of FPU´s – Overall View

5.4.1.1 Mechanical Interfaces

The following Figure 5.4-3 shows the OB on which the FPUs and the SPIRE JFET box will be mounted. The diameter of the OB is 1630 mm (tbc) and is cut-off laterally. It is mounted at 4 I/F points to the Spatial Framework.

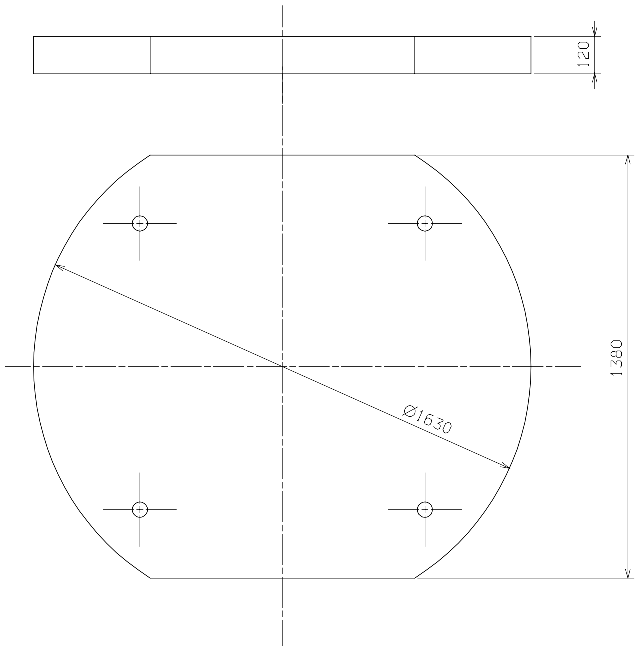


Figure 5.4-3: Optical Bench dimensions (tbc)

The FPUs are covered by a common instrument shield (see figure 5.4-3) which is mechanically fixed to the Optical Bench. The minimum distance between instruments to instruments, and instruments to OB shield shall be 10 mm (tbc).

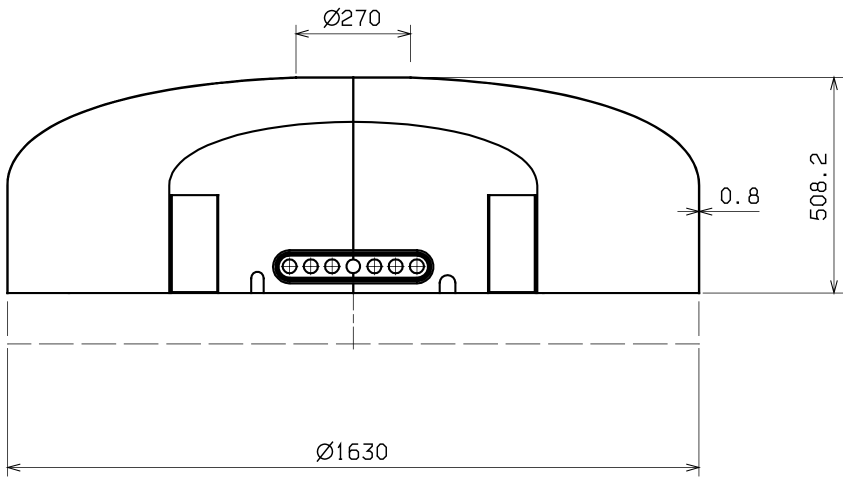


Figure 5.4-5: Instrument Shield

Instrument Fixation on the OB

The number of fixation points is different for each instrument: 3 for PACS FPU, 3 for HIFI FPU, 3 for SPIRE FPU. The SPIRE JFET boxes are directliy mounted to the OB via four attachment points. tbc).. For each instrument, one mounting reference hole has to be defined from y=0 and z=0. It is recommended that the reference holes are as close as possible to the centre of the OB (y=0, z=0) and to the y or z-axis. All other fixation points shall be defined w.r.t. the instrument reference point.
The concept of instrument adjustment was successfully applied on ISO FPU mounting interfaces and shall also be applied for Herschel.

5.4.1.2 Thermal Interfaces

The ventline surrounds the instruments twice and provides the temperature levels 1 and 2 to the instruments. To achieve a low temperature, the level 1 ventline is thermally insulated from the OB by CFRP brackets. The level 2 ventline is thermally well connected to the Optical Bench. The instrument level 2 interface is then provided either via the mounting feet directly to the OB structure or via cooling straps directly to the level 2 ventline. Direct strapping provides the level 0 to the HeII-tank.

For connection of the instruments to levels 0, 1 and 2, copper straps with 20 mm x 1mm cross-section are used. For the connection between instrument and Cu-strap the standard ISO mounting concept (see figure 5.4-5) is proposed. The strap to the HeII-tank (level 0) is routed through holes in the Optical Bench. It is either mechanically fixed but thermally insulated from the Optical Bench or directly strapped. (Depending from the interface location on the instrument.)

To keep a small temperature gradient between the instrument and the He-gas in the ventline, the use of the ISO copper quality for levels 1 and 2 seems sufficient. However, for connection to the He II-tank, the use of copper with a higher conductivity and an increase of the contact area may be necessary. SPIRE requires three (tbc) cooling straps to level 0, PACS and HIFI need one strap. For level 1, one strap per instrument is foreseen. Cooling to level 2 is required by the SPIRE JFET box(es) and HIFI FPU structures only.
The numbers of straps as given here may have to be changed, since the instrument developments in the recent months shows the necessity to implement changes in this respect. The consequences of potential changes wrt. lifetime are investigated in detail in Chapter 5.3.

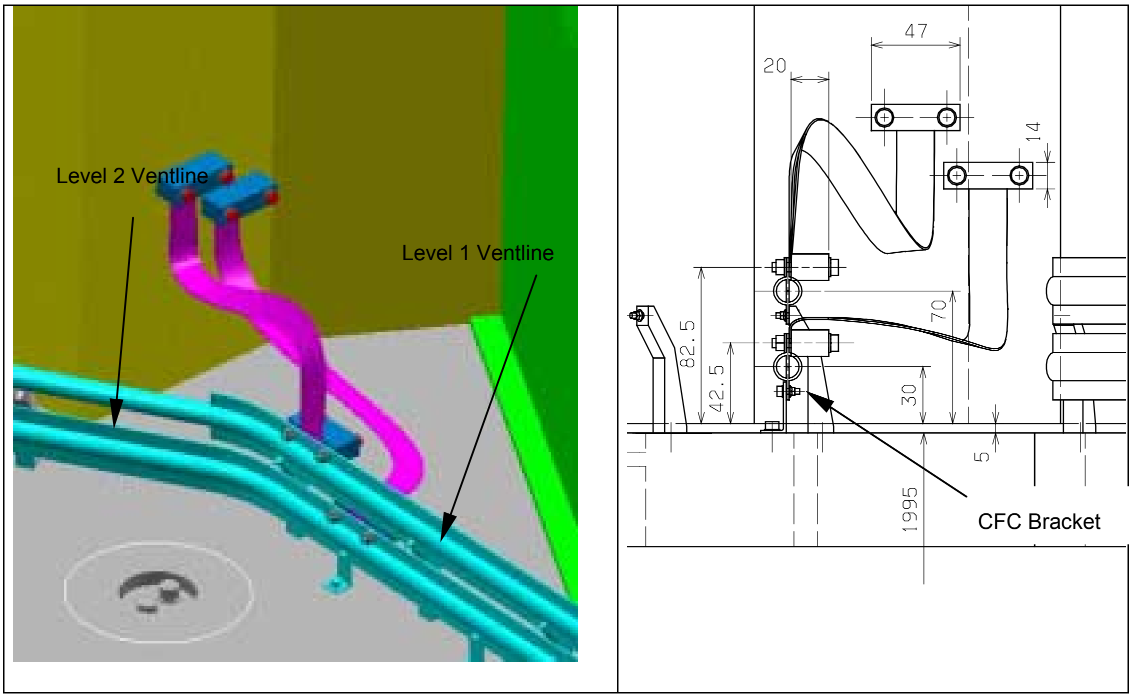


Figure 5.4-7: Connection of the Instruments to the He-ventline (level 1 and level 2)

The nominal lifetime have been calculated with the TMM using the simplified instrument thermal models shown in chapter 5.3The average dissipation is included in the simplified instrument TMM's assuming 1/3 operation time of each instrument. A margin of 20% is also included in the average dissipation values.

5.4.1.3 Electrical Interfaces

The interfaces on the instrument boxes and the harness to the OB connector brackets are briefly described, more details on the harness are given in chapter 5.8.2 (Cryo-Harness).

The electrical I/Fs for PACS are on two sides of the FPUs (about 60 connectors), which are not yet finally defined. It is assumed that they are arranged on the + y-side or – y-side of the FPU. The electrical I/Fs for SPIRE are partly at the FPU and partly at the JFET box, the position of the connectors is tbd. It is assumed they are all on the +y side of the JFET box and the FPU. The electrical I/Fs for HIFI are at the FPU, most of the HIFI connectors are situated on the –y-side and on top of the instrument (tbc). It is assumed that all instrument connectors are MDM connectors with a maximum of 37 pins and 2 rows.

The design of the harness on the Optical Bench is complex due to the high number of connections and limited space. Therefore network harness bundles (spider harness) have to be avoided.

Deatils of the cryo-harness design are compiled in Ch. 5.8

5.4.1.4 Optical Interfaces and Alignment

The three FPUs are not using the full telescope beam of 260 mm diameter. A view of the used parts of the beam and a section at x = 304 mm above the focus, which is at the height of the instrument shield is shown in figure 5.4-10. Taking into account some additional space (5 mm tbc) around the beam patterns, a baffle can be introduced at the level of the instrument shield which reduces the radiation from the heat shield baffles, the CVV and the cavity to the cold FPUs and the Optical Bench. At the height of the CVV the SPIRE pattern is close to the 260 mm clear diameter opening (approximately 4 mm), the other two beams have more distance. It is assumed that the 260 mm diameter is still sufficient and the opening diameter can be kept.

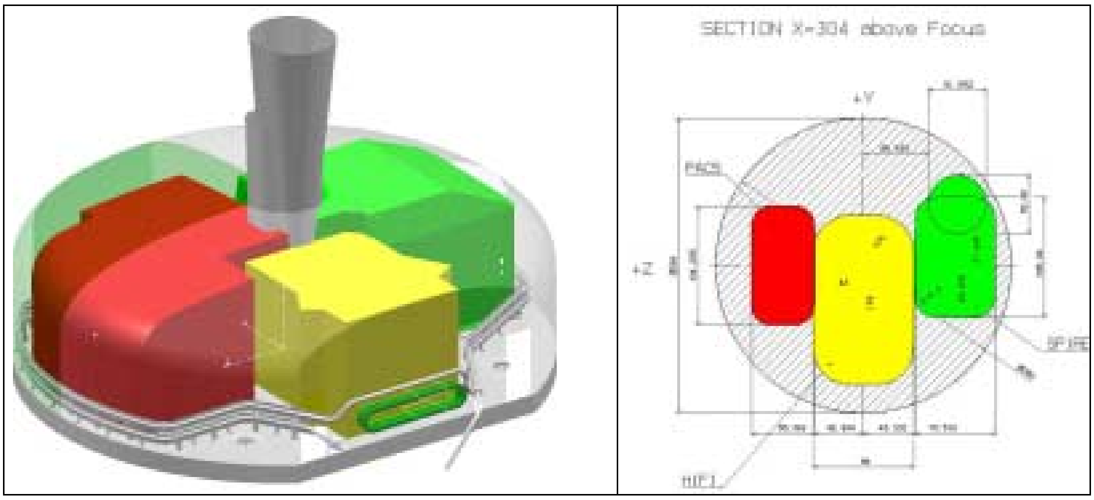


Figure 5.4-9 Beam Pattern for the three instruments

In the Thermal Mathematical Model (TMM) the effect of this instrument shield baffle on the instrument temperatures is considered by a rectangular baffle of similar opening area. The fig. 5.4-10 shows the implementation of this baffle in the TMM.

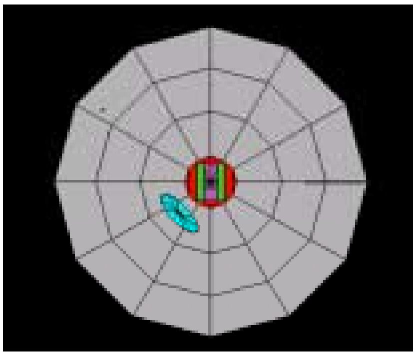


Figure 5.4-11: Top view in the TMM on the CVV Opening and the Rect. Baffle on the Instrument Shield

There is a second optical interface to the instrument, the HIFI LO interface. To protect the PACS and SPIRE instrument from stray radiation of the LO reference signals, a baffle between the HIFI instrument and the instrument shield is foreseen. It shall consist of two parts, one mounted to the HIFI instrument and one mounted to the instrument shield, overlapping each other to generate a labyrinth (Fig. 5.4-12).

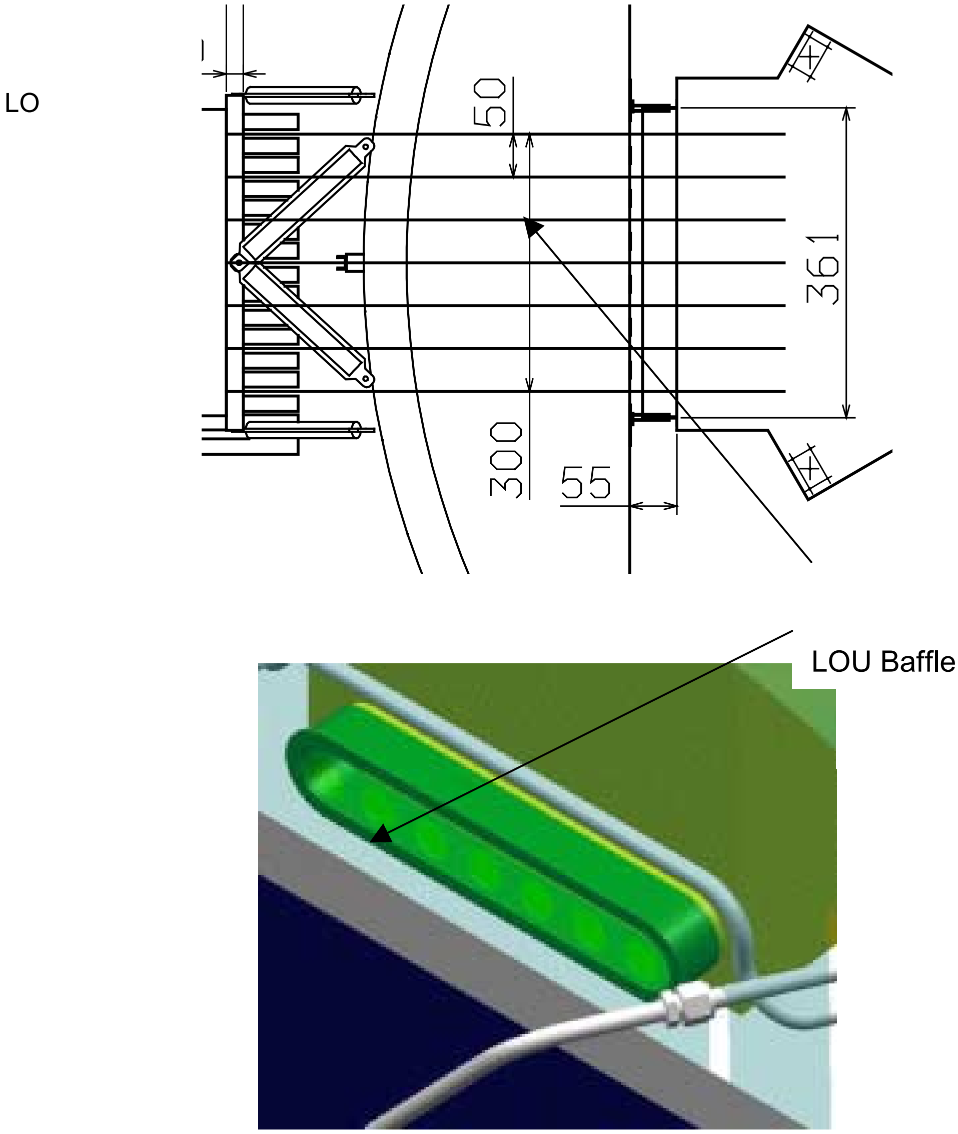


Figure 5.4-13: Baffle between HIFI Instrument and Instrument Shield

Alignment of Instruments on the Optical Bench (OB)

Each instrument FPU has to be equipped with an external reference mirror cube (or with flats) with reticles representing its optical axis (position and direction of optical axis). HIFI has to be equipped with two additional alignment dvices for LOU alignment. The OB incorporates a central alignment cube with reticles, which represents the OB coordinate

axes for instruments to OB alignment and OB to CVV alignment. An auxiliary alignment cube on the OB which is visible from –z through a CVV window has to be used (tbc). Details of alignment are described in chapter 5.4.4.4.
REMARK: A detailed description of the payload alignment is given in "Herschel Alignment Concept", Doc.-No.: HP-2-ASED-TN-0002.

5.4.1.5 Straylight

The straylight considerations are described in chapter 5.13.

5.4.2 Local Oscillator Accommodation

The Local Oscillator Unit provides the HIFI FPU with seven reference signal beams, which are coupled via windows into the CVV.

5.4.2.1 Mechanical Interfaces/ Fixation of Local Oscillator Unit

Fig. 5.4-13 shows the fixation of the Local Oscillator Unit (LOU). The LOU is mounted by means of eight GFRP struts onto the CVV. They are optimised w.r.t. reduction of thermal load to the CVV. The LOU is equipped with a radiator which allows most of the internal dissipation to radiate to space. This radiator is part of the LOU. Part of the LOU box serves as an additional radiator.

The waveguides are mechanically attached to the CVV. For thermal decoupling the fixations are GFRP brackets. It is assumed that the waveguides themselves include flexible elements which allow for the differential shrinkage during cool down as well as for the mechanical loads during vibrations. (An optimisation of the design wrt. stiffness and thermal insulation is currently being performed.)

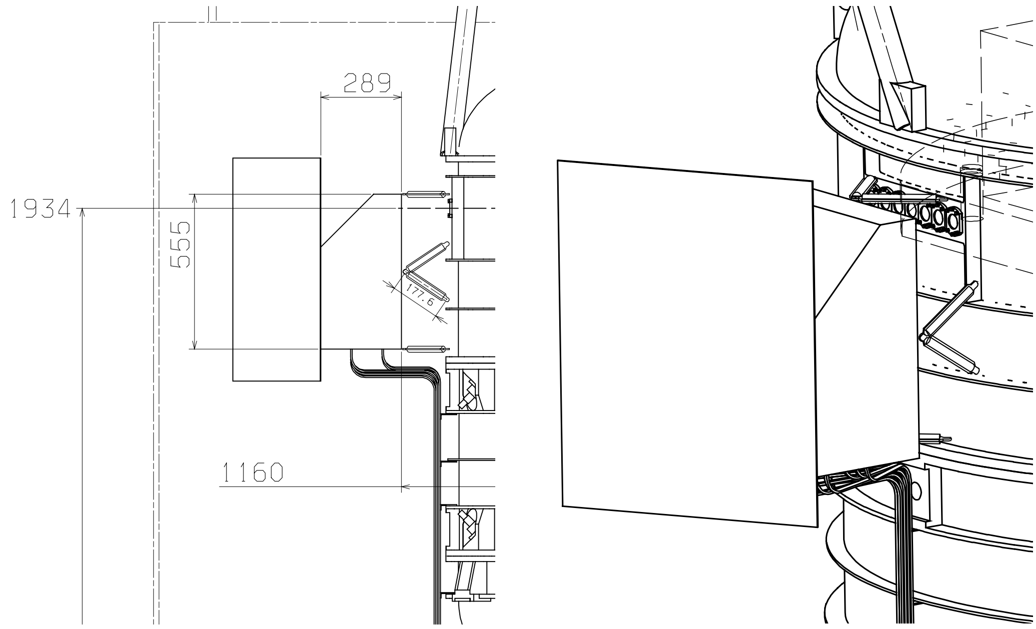


Figure 5.4-15 LOU Installation Layout

5.4.2.2 Thermal Interfaces

For the baseline configuration, the given LOU is equipped with a 0.5 m² radiator to reduce its temperature as far as possible. The radiator is tilted to avoid coupling of the warm sunshade rear side to the LOU radiator. The following assumptions for LOU thermal calculations have been taken:

- LOU box:	0.555 x 0.492 x 0.289 m
- Dissipation:	12 Watt
- emissivity of box MLI external layer:	0.15
- emissivity of radiator rear side MLI ext. layer:	0.05
- emissivity of radiative areas:	0.9
- thermal conductance between LOU box and radiator:	1 W/K (assumption)

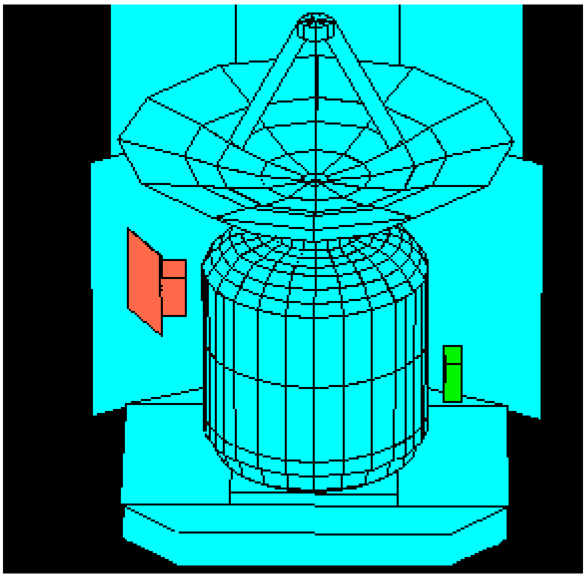


Figure 5.4-17: 0.5 m² LOU Radiator in TMM

The calculated temperature of the LO is tbd K. In the FIRST Instrument I/F study it was shown that the outside of the LOU box can also be used as a effective radiator to space. This possibility should be investigated in more detail in phase B, it may reduce the need for a special radiator.

The material and size/thickness of the waveguides are important for the heat input on the CVV. The thermal impact of Al and SST waveguides have been investigated. Thin SST waveguides show the lowest impact on the cryostat. To reduce shadowing of the CVV radiator, the waveguides might be fixed in a position slightly shifted in +z-direction on the CVV. (An optimisation of the design wrt. stiffness and thermal insulation is currently being performed.)

5.4.2.3 Electrical Interfaces (Harness, waveguides)

The LOU is connected with the warm electronics in the SVM via waveguides and the LOU to SVM harness. The waveguides (WR-28) are bundled together below the level of the LOU box. They are mechanically fixed to, but thermally insulated from the CVV and routed along the CVV, then via the H-PLM/SVM struts to the warm electronic in the SVM. The same is considered for the power cables of the LOU (which have to be made from copper according to present requirements) to limit the heat load to the CVV.

5.4.2.4 Optical Interfaces (LOU Optical Windows)

For the seven LO beams seven flanges for mounting of the LOU Optical Windows are foreseen (Figure 5.4-14). The spacing between the beam centres is 50 mm. By taking into account alignment considerations the inner diameter is 34 mm to provide the required 30 mm optically free diameter required by the instrument. The post-assembly position (i.e. tilt) of the LOU Optical Windows will be defined by the window support at the CVV. On both sides of the LO window row, two alignment windows are arranged (not shown in Figure 5.4-14.

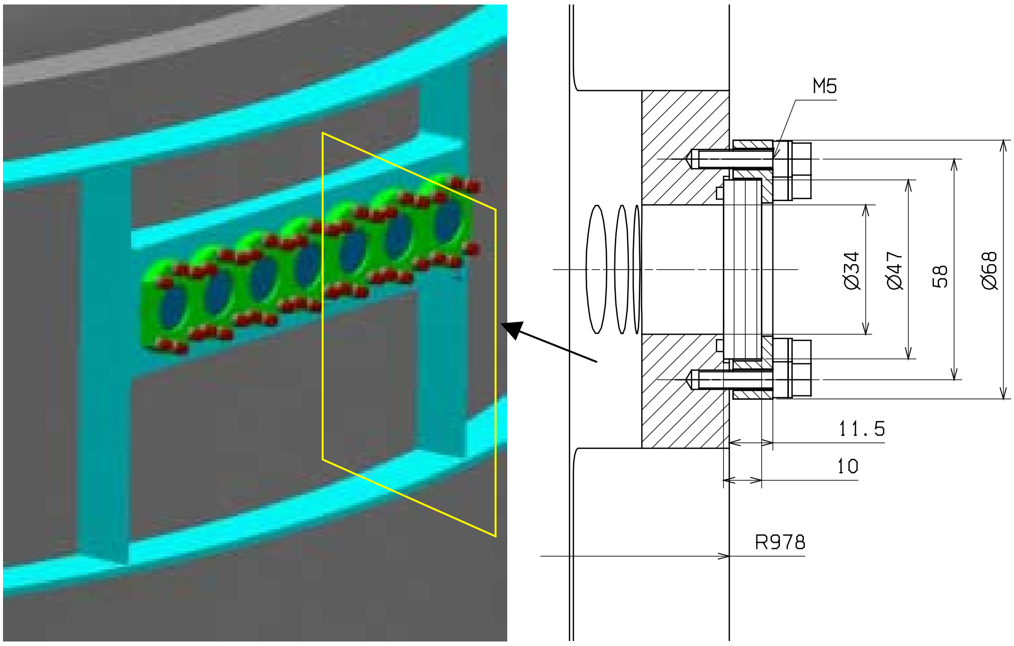


Figure 5.4-19: LO vacuum feedthroughs

LOU Optical Window Transmissions :

For the baseline configuration the following concept has been selected (tbc):

- one crystal quartz window (z-cut crystal quartz) in outer cryostat vessel (about 80K in orbit) without any thermal filter at the inner shield (about 30K in orbit)
- use of poly-ethylene anti-reflection coatings on crystal quartz ($\lambda/4$ coating optimised for each LOU channel)
- window surfaces are parallel within 5 arcsec
- windows are tilted by 2° to avoid reflections

The calculated transmission is higher than 80%.

5.4.2.5 HIFI/LOU Alignment

LOU to HIFI alignment requires at least 2 visible-light alignment windows at each side of the line of the 7 LOU IR-windows (at the CVV -Y side). The size of these 2 windows may be identical with the LOU-windows (i.e. 34 mm free diameter) or bigger.

At the +Z and -Z sides of HIFI 2, alignment devices (such as cubes) are mounted as close as possible to the LOU-windows such, so their -Y faces can be sighted by theodolite in autocollimation through the alignment windows. The cubes are equipped with plane reflectors and crosshairs.

The alignment windows are also equipped with cross hairs and are adjusted such, that they can be used as a reference for the CVV coordinate system. i.e. their (weak) autocollimation figures indicate the direction of the CVV-Y axis and allow the angular alignment of HIFI to CVV round X and Z.

The positions of the crosshairs in CVV co-ordinates are known. They allow the position alignment of HIFI along X and Z. The connecting line through the crosshairs of the left and right alignment window defines a reference line for the angular alignment of HIFI to CVV round Y. It is compared with the connecting line through the crosshairs on the left and right HIFI cube.

It should be noted here, that the instrument supplier is currently proposing an alignment system, which allows to perform the HIFI/LOU alignment in the same manner as described above. However, the envisaged devices shall be usable also within a thermal vacuum chamber, therefore, these devices could also be used for alignment monitoring during testing, where direct human acces is not possible.

Alignment Means on LO

At positions which correspond to the HIFI cubes i.e. at the +Z and -Z sides of LOU two semitransparent alignment cubes (or flats) with crosshairs are fixed. They can be sighted from +Y as well as from -Y and it is also possible to perform a sighting from -Y through the cubes and through the alignment windows onto the HIFI cubes.

With these cubes, LOU alignment to HIFI and to the LOU alignment windows can be performed by theodolite. The alignment can also be checked after mounting of the LOU.

The possibility of continuous LOU to HIFI alignment monitoring - even during TV tests - will be given by two pairs of special alignment cameras with auxiliary optics, which will be temporarily fixed on LOU - one camera pair for each of the 2 alignment windows. Camera no.1 - the tilt recording camera, comprises an autocollimation device; camera no.2, the offset recording camera, is focused on the HIFI-cube crosshairs and LOU-cube crosshairs which are illuminated by an appropriate light source. Again, here the alignment device as envidsaged by the instrument supplier could be used instead of the set up described above.

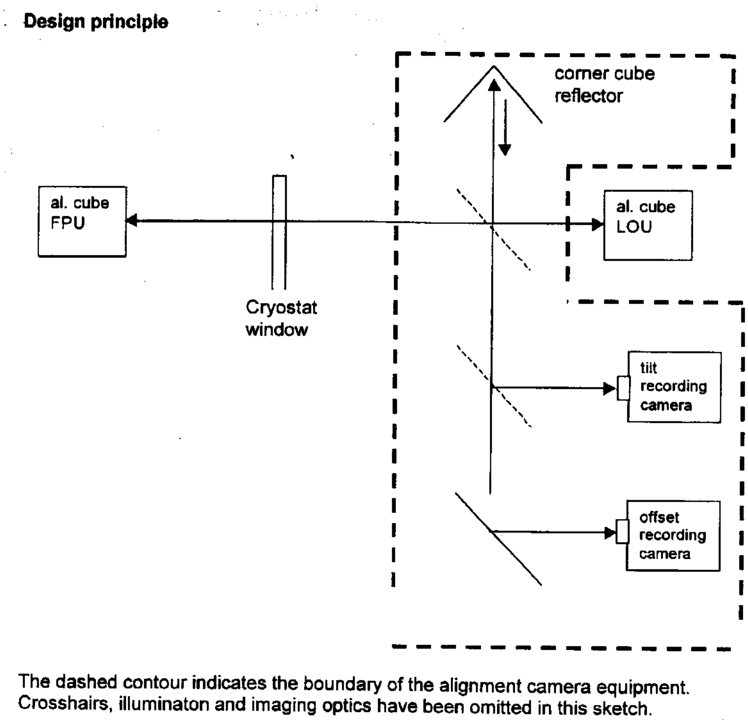


Figure 5.4-21: Alignment Camera (to be provided by HIFI)

5.4.2.6 Straylight

See chapter 5.13 Straylight.

5.4.3 Bolometer Buffer Amplifier Unit

5.4.3.1 Mechanical Interfaces

For the Bolometer Buffer Amplifier Unit (BOLA) the same fixation as for the Local Oscillator is used. It is mounted with 8 GFRP struts to the CVV. The box is fixed at the height of the electrical vacuum feedthroughs, on the +y side of the cryostat. The location depends on the location of the connectors on the PACS FPU, which is still to be defined.

5.4.3.2 Thermal Interfaces

The BOLA box surface serves as radiator area to space (tbc). The calculated BOLA temperature is 110 K for 0.2 W dissipation and for the present box size and position.

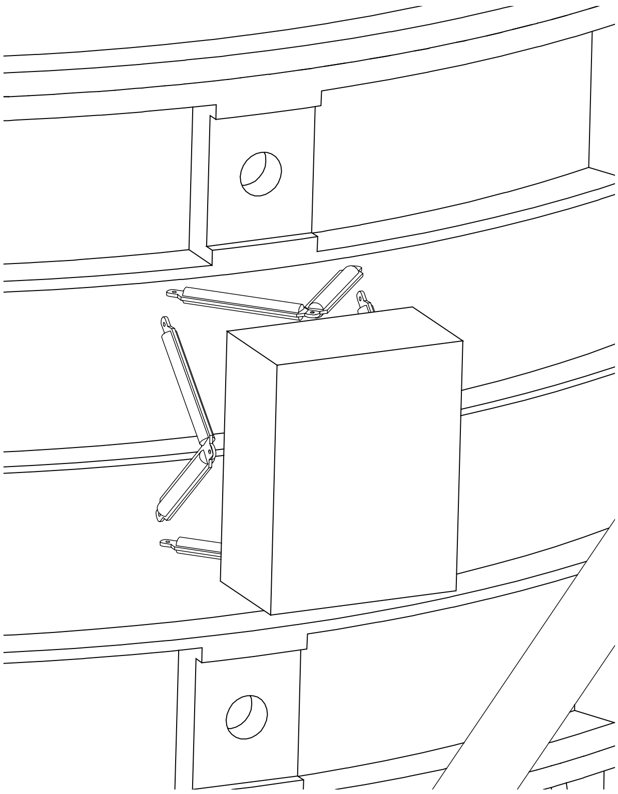


Figure 5.4-23: Bolometer Buffer Amplifier Unit Fixation

5.4.3.3 Electrical Interfaces

The position of the connectors on the BOLA is tbd. The harness from the CVV feedthroughs will be routed via the GFRP struts to the BOLA connectors and from the BOLA connectors back via the GFRP struts back to the CVV and down to the SVM.

5.5 H-PLM – Telescope Accommodation

5.5.1 Mechanical/ Configuration

The mechanical I/F between H-PLM struts and Telescope triangle is tbd. The six (6) telescope struts form three triangular strut arrangements with three I/F brackets on top of them. The struts are made of GFRP to achieve the required strength and stiffness with a low thermal conductivity. The preliminary strut cross-section is 794 mm^2
The distance between the cavity upper side (for a 260 mm diameter cover) and the lower side of the Telescope is 16 mm.

5.5.2 Thermal

The HSS is the main heat source for the Telescope, therefore, the rear of the HSS is covered with high efficient MLI and the external MLI surface has a low emissivity of 0.05. The resulting telescope temperature is predicted to 76 K.

5.5.3 Electrical

A connector bracket mounted on the top of the cryostat will be used as the electrical I/F between the telescope and H-PLM. Details are tbd. 16 wires of Cu AWG 24 (8 lines and 8 return) will be used (tbc) for the telescope heater harness on the H-PLM side. The sensor harness is tbd.

5.5.4 Alignment

The CVV Reference Coordinate System for the alignment measurements is defined by a mechanical CVV diameter (Z-axis) and the normal of the CVV flange plane running through the centre of the CVV diameter. This diameter is visualised by marks on the outer circumference of the CVV.

The normal on the CVV flange plane is initially visualised by a flat reference mirror upon an auxiliary CVV flange plate. Two CVV reference cubes which are situated at stable places on the circumference of the CVV are calibrated with this intermediate reference which is then removed. All alignment measurements at CVV level refer to the CVV co-ordinate system which is now incorporated in the two CVV reference cubes.

It should be noted that one CVV cube would be sufficient to characterise the CVV reference co-ordinate system. Two cubes, however, are more convenient for accessibility and give also a higher alignment security due to redundancy at this vital interface.

Alignment Means

The H-PLM interface structure must incorporate auxiliary (removable) adjustment devices in order to perform defined translational telescope movements in the Y/Z plane. These devices shall comprise stops which allow easy telescope readjustment after telescope removal for change of the shims. The translational adjustment along X and the rotational adjustments round Y and Z can be performed by shimming.

Alignment Measurement Means

Baseline for the alignment measurements is to use high precision theodolites with autocollimation devices. The theodolites are situated upon linear mounts which include position measurement capabilities. They can be applied for measurement of tilt angles of optical axes (cube normals) and for lateral position measurements of reticles.

The telescope is equipped with optical alignment references (mirror cube and pinball or mirror cube with reticles) which will probably be fixed at the telescope interface triangle, must have appropriate counterparts at the CVV. All references must be visible even after completion of telescope integration on H-PLM.

The CVV references can be two alignment mirror cubes which are equipped with reticles and which are mounted at opposite and well protected positions on a CVV diameter (e.g. Z-diameter). Additional auxiliary cubes on the CVV as well as on the telescope which could simplify the alignment can also be used.

It is crucial for the proper alignment of telescope to instruments to select mechanically stable fixation positions for the CVV cubes.

The alignment mirror cubes shall be metallic optics devices (aluminium) with the following characteristics:

- can be made without application of any glue.
- incorporate a metallic flange with fixation holes
- can be exposed to deep temperatures without problems
- size of the cubes shall not be smaller than 14 mm edge length
- equipped with 5 reflecting faces including a thin reticle in their centres

5.6 Mechanical and Thermal Design

5.6.1 Mechanical design

The structural design is driven by stiffness requirements and stress/strength considerations.

The key parameters for the stiffness are:

SVM/PLM I/F struts
Stiffness of suspensions
Sunshield/Sunshade fixation

These parameters are also the key parameters for the thermal control and the life time of the system.

For stress analysis the pressure load cases and the pretension of the suspensions are the most important. These loads are the driving factor for the design of the
He II tank and the
CVV
and are driving for the total force.

The general rule is therefore, that the load assumptions, safety factors and other factors to be applied on the stress analysis are is driving for the masses. The margins to be applied on the stiffness requirement is driving for the life time on the system.

The investigation of needed cross sections are based on the mathematical model shown in the following figure.

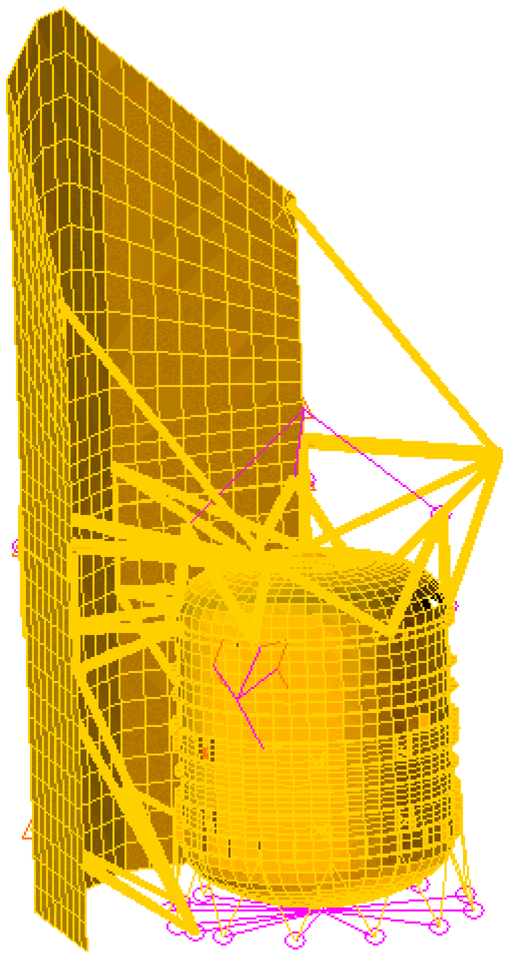


Figure 5.6-1: FIRST H-PLM Mathematical Model

A summary of the model status is given in the following table:

Item	Status	Remark	Ongoing Work
He II Tank and load introduction	New model	details see section 7	
Helium II	considered as lumped mass	details see section 7	
Optical Bench	Plate with smeared stiffness	see section 7	detailed analysis ongoing
Spatial Framework Suspensions	as in proposal	Based on ISO heritage	
CVV	New model		mass reduction to be performed
SSD	update of model	additional support struts at SSD	Further optimization planed

Analysis Results :

Dynamics

The dynamic behaviour can be summarised as follows:

- The suspended mass has a lateral natural frequency of 32 Hz and a global axial load of 50 Hz
- The SSD has a first mode at 31 Hz the mode with an effective mass above 10% is at 49 Hz

It si the aim to separate the global H-EPLM modes from the SSD and suspended mass.. The detailed results are shown the following effective mass table and the mode shapes, shown in the following figures.

EPLM Hard Mounted Frequencies:

Mode No.	frequency [Hz]	m_eff T1	(relative) T2	[%] T3	R1	R2	R3
1	18.58	0.1	0	**85.6**	0.1	**95.8**	0
2	19.59	0	**88**	0	0.3	0	**92.7**
3	30.52	0	0	3.6	0.6	1.4	0

Mode No.	frequency [Hz]	m_eff T1	(relative) T2	[%] T3	R1	R2	R3
4	31.17	0	0.7	0	10.1	0	3.3
5	31.23	0.2	0	0	0	1.2	0
6	32.16	0	1.2	0.1	34.2	0	0.5
7	34.45	0	0	0.1	10.5	0	0.8
8	38.37	0.1	0	0.2	0.1	0	0
9	38.8	0	0.2	0	7.6	0	0.2
10	40.77	**14.9**	0	0	0.1	0.1	0
11	41.78	0.8	0.3	0	16.2	0	0.4
12	42.35	**52.3**	0	0	0	0	0

Table 5.6-1: Effective masses of the H-EPLM hard mounted

EPLM Soft Mounted Frequencies

To simulate the stiffness of the SVM the following springs, with the following stiffness, are used:

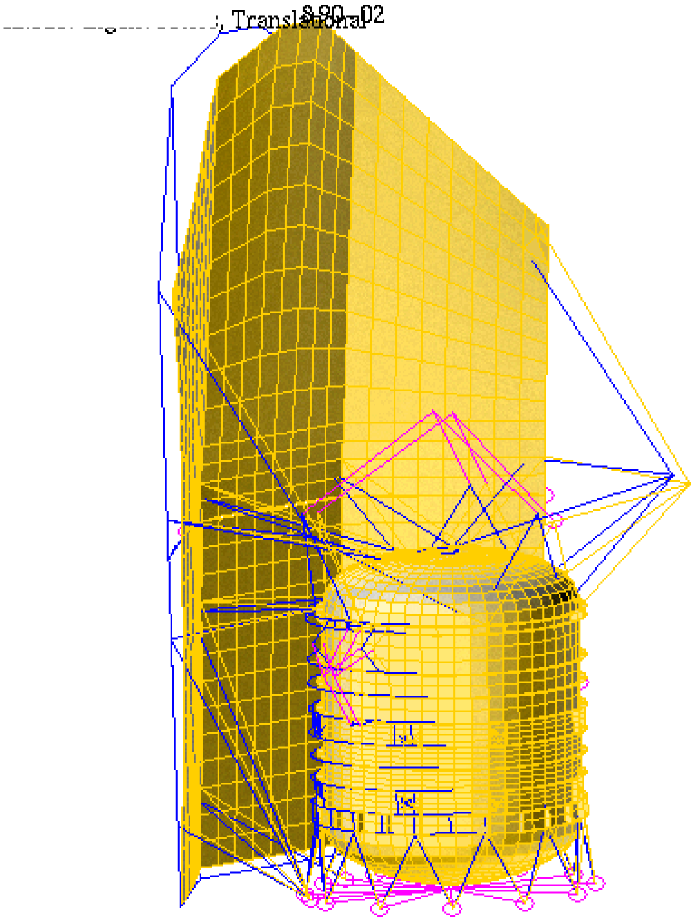
direction	**spring stiffness in N/m**
circumference	5.7 E 7
radial	2.5 E 7
longitudinal	5 E 7
rotational	no rotational stiffness

Table 5.6-2: Stiffness of SVM

mode no.	Frequency [Hz]	m_eff T1	(relative) T2	[%] T3	R1	R2	R3
1	15.8	0.1	0	**81.3**	0.1	**98.3**	0
2	16.77	0	**83.9**	0	0.6	0	**97.2**
3	29.36	0	0	8.1	0.5	0.3	0
4	29.73	0.1	4.7	0	4.3	0	0.8
5	30.76	0.5	0	0.1	0	0.2	0
6	31.47	0	1.4	0.1	51.6	0	0
7	33.04	0	0.1	0	13.5	0	0.5
8	37.93	0.1	0.2	0.1	9.3	0	0.2
9	38.14	**49.3**	0	0.1	0	0	0
10	38.26	**16.8**	0	0.1	0.1	0	0

mode	Frequency	m_eff (relative) [%]					
no.	[Hz]	T1	T2	T3	R1	R2	R3
11	40.45	0.4	0.1	0	6.6	0	0.1
12	40.85	**10.1**	0	0	0.2	0	0

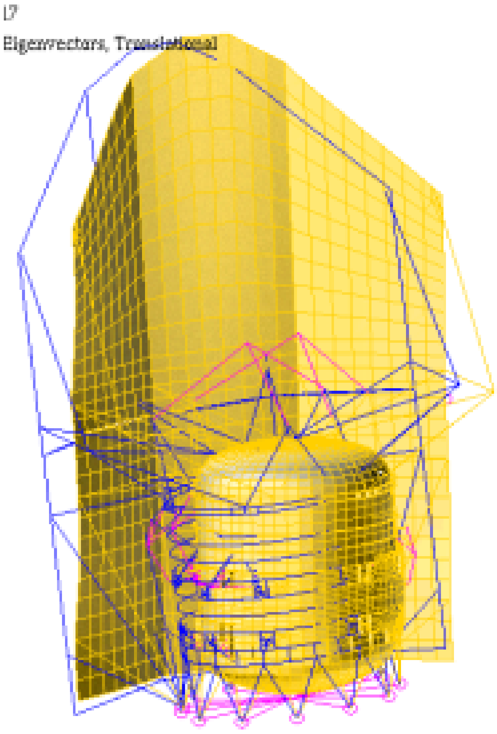
Table 5.6-3: Effective masses of the H-EPLM hart mounted

Figure 5.6-7 Mode 1, f = 18.58 Hz Global Mode in z-direction	

EPLM
Bending Mode
y bending

Figure 5.6-9

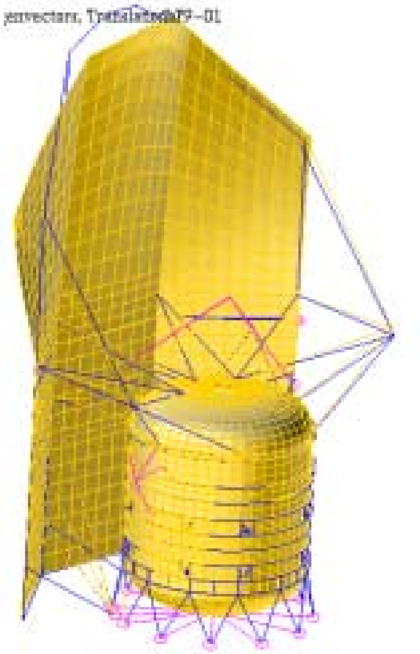
Mode 2, f = 19.6 Hz

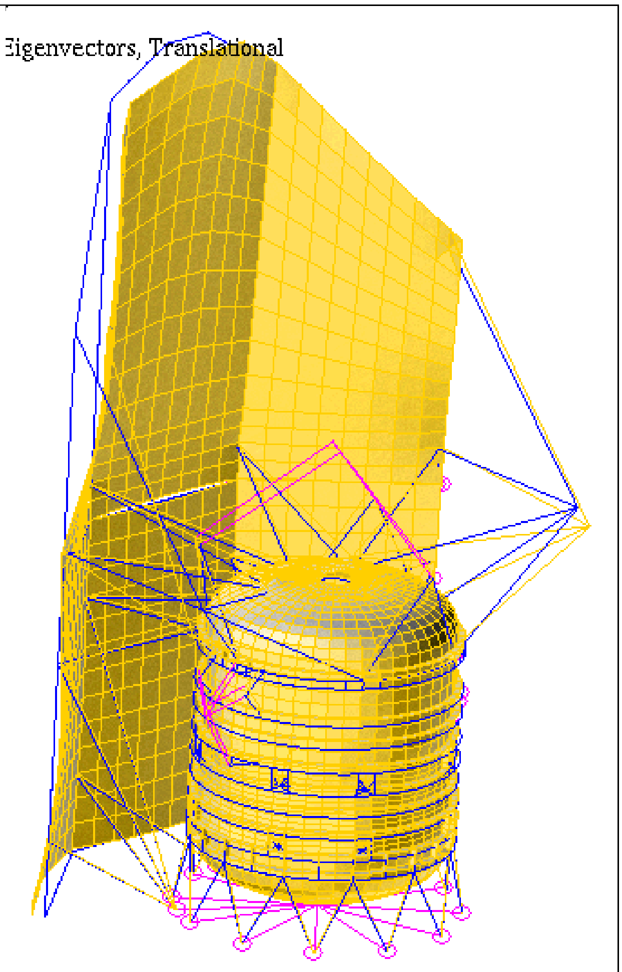


SSD
Mode

Figure 5.6-11

Mode 3, f =30.5 Hz



f = 42.6 Hz global axial mode	

Stress Analysis/Fatigue Analysis

The mechanical environment of the cryostat consists of vibration at launch, several pressure loading conditions and thermal load cases. As a protoflight approach is planned, fatigue aspects must be covered by analysis.

The ISO heritage covers the stress analysis of many parts. The FEM provides information about load levels in e.g. the CVV. The maximum stress of about 40 MPa in the launch load case shows, that the load levels are uncritical.

Figure 5.6-13 Stresses in the CVV wrt. 12 g Axial and 5 g Lateral (TBC

5.6.2 Thermal Design

To investigate the feasibility of the baseline design, the thermal mathematical model (TMM) shown below has been established. All relevant material properties are implemented as temperature dependent functions. As far as applicable, ISO test data are considered for calculating thermal couplings. The instruments are implemented using simplified models as described in section 5.4.

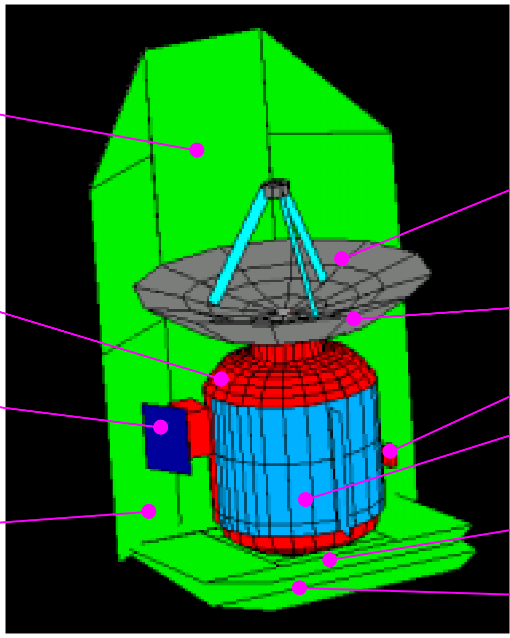


Figure 5.6-15: Geometry Model of the HERSCHEL TMM

The CVV equilibrium temperature depends on the heat input from the environment (e.g. conduction from SV, radiation from SVM shield) and the possibility of removing heat (mainly via radiation to space). The CVV temperature should be as low as possible to reduce heat input to the cryostat interior.

One of the main tasks is to minimize the parasitic heat loads into the HeII tank satisfying the contrary mechanical requirements. As presented in the thermal budget diagram the total heat load in the HeII tank is about 50 mW, whereas the contribution directly from the instruments is about 7mW, i.e. 14%. The main parasitic contributors are the tank suspension straps via the Spatial Framework and radiation via the tank MLI. A further, indirect contributor is the internal harness which is thermalized on the Heat Shield 1 and thus increases the temperature of this shield. The He vapour takes about 92 mW further heat load from the instruments via the He ventline and the Optical Bench. The absorbed heat load from the heat shields totals about 520 mW, i.e. the contribution of the instruments into the ventline is about 15%.

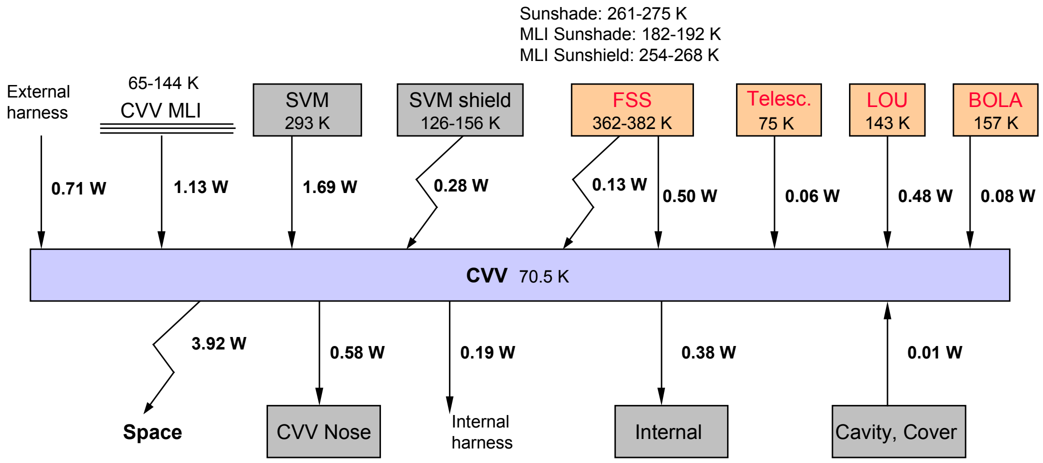


Figure 5.6-17: CVV Heat-Flow Diagram and Temperatures

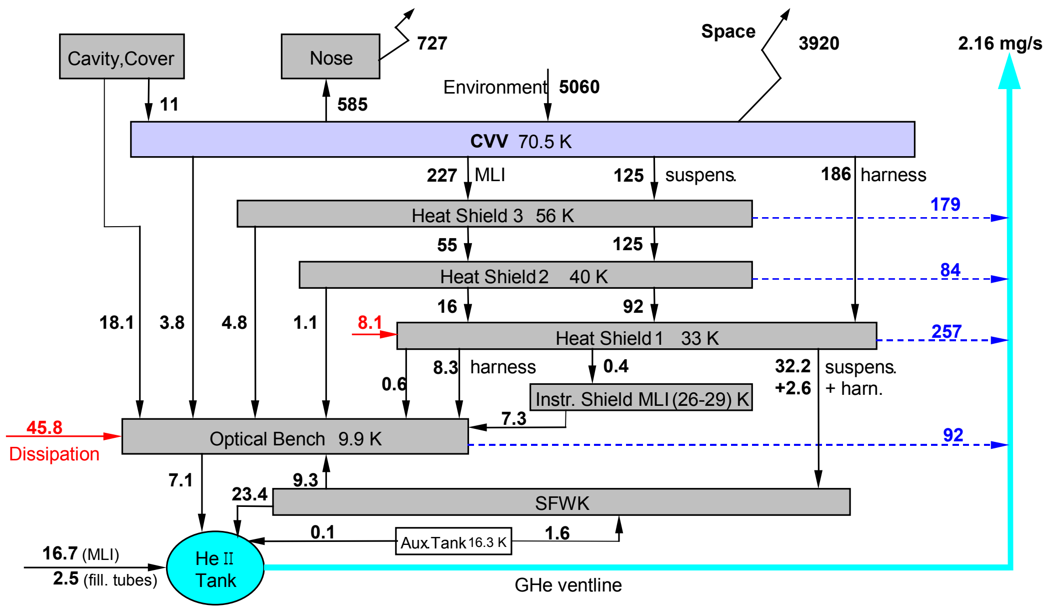


Figure 5.6-19: Cryostat Internal Heat Flow Chart in mW

5.7 Cryo System

A detailed description of the Cryo System components is given in Chapter 6.2 of the current document. The following sections comprise a brief overview of the system, its main requirements and functions.

The Herschel Cryo subsystem is strongly based on ISO heritage, with the main differences as listed in Figure 5.7-1: below.

Figure 5.7-1: Differences between ISO and Herschel He subsystems

Item	ISO	Herschel	Expected impact on
Location of He I tank	above HeII tank	below HeII tank	Ground Operations? length of filling lines, thermo-acoustic oscillations
Mass flow rate through PPS (in orbit) (on ground)	4.2 mg/s to 18 mg/s 27 mg/s	2 mg/s to ? 32 mg/s	Vent line pressure drop PPS layout, feasibility
Launch sequence / thrust phases	continuous until 3rd stage cut-of	coast phase after lower stage cut-off	Time available for HeI tank evacuation and PPS start-up
He II tank temperature	1.8 K	1.7K	Vent line pressure drop
He I tank volume	60 l	80 l	HeI tank evacuation time
Inlet / outlet filters on external valves	no	yes	Vent line pressure drop
LHe valves improved wrt force margins	no	yes	
Nominal life time	1.5 yrs	3.5 yrs	
Temperature sensors	C10 / C100	selection ongoing	

The C10 / C100 temperature sensors which were manufactured by Linde and used in the ISO programme are no longer available. A possible candidate for replacement are Cernox sensors. The sensors will be selected when the benchmarking is finished.

5.7.1 Cryo System Overview

The He S/S provides the cooling of the scientific instruments inside the CVV on ground, during launch and in orbit. The He II tank is the reservoir for the superfluid Helium which evaporates and heats up in the heat exchangers of the vent line along the optical bench and the heat shields and thus provides the cooling over the lifetime of the PLM in orbit and for ground testing. The He I tank is used as the cooling reservoir during launch preparation (launch autonomy), when no further access to the He II tank is possible.

An overview of the cryostat temperature levels is given in chapter 5.6 of this document.

The He S/S can be subdivided in the following parts:

- He II tank assembly which contains:
  - He II tank,
  - Passive Phase Separator PPS 111 with T111and T112
  - Direct Liquid Content Measurement DLCM 1/2 with T101,102 and H101/102
  - Level Probe L101/102
  - Fluid Thermometer T104/105
  - Surface Thermometers T103 (Pt500), T106/ T107 (selection ongoing)
  - Rupture Disc RD124
  - Heater H103/104
  - Safety Valve SV123
  - Internal He-valves V102,103,104,105,106,701
  - Pressure Sensor P101
  - Adsorbers
  - Filling port with Safety Valve SV121, Oscillation Damper OD101, Filter S101
  - He II tank tubing
- The He I tank assembly which contains
  - He I tank
  - Level Probe L701/702
  - Heaters H701/702
  - Surface ThermometersT701 (Pt 500) T702/ T703 (selection ongoing)
- The Optical Bench tubing and fixation/thermal hardware
- Internal vent line / heat exchangers on shields
- External ventline assembly which contains
  - Heater H501 with Filter S501, Thermometer T502 and Valve V502
  - Heater H502 (heater foil)
  - Thermometers T501/T503 Pt-500 sensors glued on ext. ventline
  - Safety Valve SV521

- Valve V506
- Pressure Sensor P501/502
- External Valves V501/503/504/505
- Nozzles N511/N512 and N513/N514
- Tubing

- CVV mounted safety equipment SV921/922

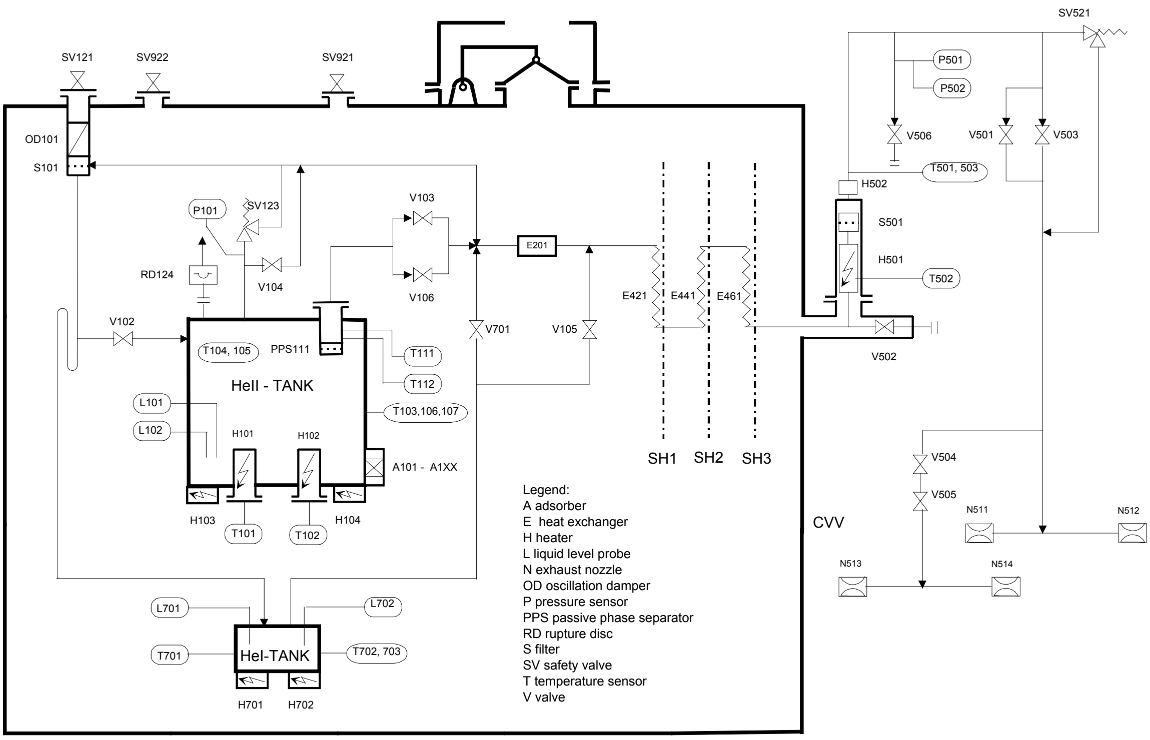


Figure 5.7-3: Herschel He Flow Schematic

5.7.2 S/S main requirements

The He S/S as part of the Herschel PLM shall provide the cooling of the FPUs of the scientific instruments.

- The He S/S shall be designed to compensate the heat dissipated by the FPUs and by the housekeeping instrumentation as well as the heat load by thermal conduction and radiation through the insulation system and all parasitic heat loads.
- To provide the cooling level 0, 1 and 2 for the instruments the following temperatures shall be achieved:

He II tank	≤ 1.7 K
Helium Ventline on OB (level 1)	< 5 K
Helium Ventline on OB (level 2)	< 15 K

- The lifetime in orbit shall be 3.5 years (calculated from launch date).
- The He S/S shall provide a cryogenic autonomy on ground staying in the superfluid state in the He II tank for 6 days. For this purpose a LHe tank shall be implemented.
- During the cryogenic autonomy period the FPUs, the OB and the Shields shall be cooled by GHe evaporated in the He I tank, if necessary intensified by using the heaters H701/H702.

- During evacuation and bake-out the He S/S and all integrated parts shall withstand a max. temperature of T ≤ 363K for a time of t ≤ 100h.

- Leak rates for all parts of the He S/S:

  He-volumes:

against insulation vacuum	L ≤ 10^{-8} mbar l s^{-1}

  Valves seat tightness:

of cold valves	L ≤ 5*10^{-2} mbar l s^{-1}
of warm valves	L ≤ 10^{-4} mbar l s^{-1}

- Leak rate of each fully equipped He tank (He II tank incl. He II tank piping / He I tank)

at RT	L ≤ 10^{-8} mbar l s^{-1}
at He I temperature	L ≤ 10^{-6} mbar l s^{-1}
at He II temperature	L ≤ 10^{-6} mbar l s^{-1}

- The tank pressures against vacuum shall be:
  - maximum expected operating pressure (MEOP) 1.46 bar
  - maximum allowable working pressure (MAWP) 1.76 bar
  - proof pressure (PP) (MEOP x 1.5) 2.20 bar
  - ultimate pressure (UP) (3.06 + 0.3) 3.36 bar
  - min. required burst pressure (BP) ≥ 6.72 bar

- Mechanical stability of the tanks against static and dynamic loads.
- Dynamic loads to tank mounted equipment: 15g
- The design pressure of all components which are in contact with the process Helium shall be (set pressure of RD 124 + tolerance = 2.8 + 0.26 bar) ≥ 3.06 bar

- The He II tank temperature control in orbit shall be performed passively by the pressure drop layout of the passive phase separator PPS 111 and the internal and external vent line (including components and nozzles).
- The design of the vent pipes shall allow a nominal mass flow
  on ground ~ 30 mg/s
  in orbit ~ 2.5 mg/s
  a maximum flow during cooldown of 2 g/s
- The pressure drop in orbit (equilibrium) shall be <11.3 mbar
  (T = 1.7K, incl. PPS 111, internal and external ventline)
- Pressure drop Δp during cool-down on ground: > 200 mbar
- The design of the ventline shall allow the post-launch evacuation of the ventline downstream V103/106 after fairing jettisoning before the onset of the first zero gravity phase to guarantee safe starting conditions for the phase separator.

5.7.3 He S/S Operations Overview

The main operation modes of the He S/S are the following:

1) Bake out
2) Test Operations
3) Cool-down and Filling/Refilling Operations
4) Pre-Launch and Launch Operations
5) Transfer to and final steady state orbital operation

1) Bake out

During bake-out the He subsystem will be purged with gaseous He at 90°C.

2) Test Operations

During on Ground Testing the Cryostat will be operated either under superfluid or normal Liquid Helium conditions. The cryostat will be in the superfluid stage during experiment testing to provide a flight representative thermal environment. For mechanical testing the cryostat is filled with liquid helium. During the Thermal/Vacuum Test the cryostat will be operated with the main tank filled with superfluid helium.
The corresponding operations are described in the paragraphs below.

3) Cool-down and Filling/Refilling Operations

The He II tank is initially cooled down and filled with He I via the filling port SV121 with the filling valve V102 in open position. The vent gas is leaving the He II tank via V104. Valves V701 and V105 are open to conduct the main mass flow via the bypass and not through the heat exchanger E201 which consists of the Herschel 4.3 K and 15 K level stages. The vent gas is the cooling the radiation shields SH1, SH2 and SH3 before leaving the cryostat via the manual valve V502 and an exhaust line attached to it.

For He II production the He II tank filling valve V102 is closed and the gaseous He is evacuated through valve V104 by two He service pumps via the filling port (SV121 open) and valve V502.

For He II top up the He II tank fill valve V102 is opened again and the LHe coming from a supply dewar via a specific transfer line is throttled inside the filling port in a Joule-Thompson valve. All GHe produced during He II top up is pumped away again through the filling port and the specific He II transfer line outer counterflow channel and valve V502.

After the He II top-up all He II tank valves are closed to prepare the launch autonomy phase.

4) Pre-Launch and Launch Operations:

After the final He II top up, all He II tank valves are closed and the auxiliary LHe tank (He I tank) is filled with normal LHe for launch autonomy via the filling port and valve V105 open.

At the start of launch autonomy, the filling port is closed by inserting SV121 through the airlock, valve V105 is closed and valve V701 is opened. Dedicated heating of the He I tank by heaters H701/702 provides sufficient cold GHe flow via the open valve V701 to cool the scientific instruments and the cryostat insulation system during launch autonomy. It shall be possible to interrupt the autonomy phase for refilling the He I tank and to continue after refilling. To avoid the release of very cold GHe into the fairing and the condensation or freezing of moisture at the external vent pipe and the nozzles, heater H501 is used to heat the GHe to ambient temperature at the beginning of the external vent line.

At launch autonomy end, shortly before launch, when the He I tank is empty, valve V701 is closed and valve V105 is opened again in order to prevent heating of the scientific instruments by warm GHe. The He I tank is heated to ≥ 30K before lift-off using heaters H701 and H702 to reduce the cold gas mass in it. After the launch autonomy and the He I tank heating, valves V501/503 are closed.

During launch these valves are opened again shortly after jettisoning the payload fairing to allow the cryostat He-ventline system and the He I tank to be evacuated to a pressure significantly below the absolute pressure inside the He II tank. Shortly before the beginning of the first zero gravity phase, the valves V103/106 downstream of the porous plug phase separator are opened to start its operation before the liquid He can penetrate the PPS and fill the downstream tubing up to the valves with the onset of zero-g conditions. The pressure in the piping shall be below the actual pressure in the He II tank to avoid a back flow over the phase separator.

5) Transfer to an final steady state orbital operations

At the start of the orbit phase the system has to cool down to its nominal orbit temperatures. This cool-down is achieved by an increased gaseous helium mass flow rate from the He II tank which vents to space through nozzles N511/N512 and N513/N514 (V501/V503 and V504/V505 are open).

When the nominal temperature levels have been reached and the mass flow rate is close to its steady-state value, the redundant valves V504/V505 shall be closed to use the normal way of venting via nozzles N511/N512 only.

The monitoring of essential values shall be performed.

The Direct Liquid Content Measurement shall be performed as necessary.

The valve states during the detailed operations are shown in the following table:

	Operation	electically operated							manually operated	
		internal valves					external valves			
		V102	V104	V103 / V106	V105	V701	V501 / V503	V504 / V505	V502	filling port / SV121
1	Cooldown and filling with LHe	open	open	closed	open	open	closed	closed	open	open
2	He II production	closed	open	closed	open	open	closed	closed	open	open
3	He II topup	open	open	closed	open	open	closed	closed	open	open
4	Testing incl. ext. vent line w/o operation of PPS	closed	open	closed	open	closed	open	closed / open	closed	closed
5	Testing incl. ext. vent line with operation of PPS	closed	closed	open	open	closed	open	closed / open	closed	closed
6	He I tank filling / refilling	closed	closed	closed	open	closed	open	open	closed	open
7	Launch autonomy	closed	closed	closed	closed	open	open	open	closed	closed
8	He I tank heating	closed	closed	closed	open	closed	open	open	closed	closed
9	Launch	closed	closed	closed	open	closed	closed	closed	closed	closed
10	after payload fairing jettisoning	closed	closed	closed	open	closed	open	open	closed	closed
11	before termination of 2nd stage burn	closed	closed	open	open	closed	open	open	closed	closed
12	nominal orbit operation	closed	closed	open	open	closed	open	closed	closed	closed

Table 5.7-1: Valve states for main operations

5.7.4 Critical Aspects

5.7.4.1 Thermo-acoustic oscillations

During ISO ground operations, thermo-acoustic oscillations (TAO) occurred frequently with the interaction of the He I tank, see “ISO Lessons Learned”. Due to the longer filling line for the Herschel He I tank (which is located below the He II tank) connecting cold and warm elements the susceptability of the Herschel tubing system to TAOs is considered more critical than for ISO. The risk of TAOs shall be assessed during Phase B.

5.7.4.2 PPS start-up and launch sequence

For safe start-up of the phase separator it is essential that

- the pressure in the external vent line is lower than in the He II tank and that
- the vent line downstream of the PPS is not filled with liquid.

Therefore the evacuation of the He I tank and the external vent line has to be carried out before the PPS is started which in the current baseline is done by opening the external valves V501, V503, V504 and V505 after the payload fairing jettisoning.

Since the He II flow impedance of the porous plug is very small as long as no evaporation takes place, the PPS must not be immersed in the liquid phase before the internal valves V103 and V106 are opened and the pressure downstream of the PPS is less than the vapor pressure in the He II tank.

This means that the GHe evacuation and the start-up of the phase separator have to take place between the payload fairing jettisoning and the beginning of the first zero gravity phase, i.e. in the current baseline the cut-off of the Ariane V lower stage engine. In the ISO launch sequence, the time frame for these operations was 876 s whereas for the Herschel baseline only 343 s are available.

5.7.4.3 Launch Autonomy

A certain time before lift-off there is no further possibility for He II top up because the fairing is installed and no access via the fairing doors is possible. The He I tank enables achievement of the required launch autonomy period (up to 6 days with one refilling) by evaporation of the LHe in this tank and cooling of the instruments and the radiation shields.
Additional sub-cooling with a high GHe mass flow rate (60 mg/s) before the final filling of the He I tank can be taken into account to get colder initial conditions.

The nominal (i.e. without additional heating) mass flow from the He I tank during launch autonomy is 23.2mg/s according to the TMM. This leads to a cryogenic hold time of approx. 4 days. Optimizing all parameters this time could probably be extended to 4.5 to 5 days.
With respect to safety issues it is desired to avoid the He refilling under the fairing via the access holes. With respect to cryo performance and cryo operations it is desirable to refill the He I and He II tanks as late as possible.
Thermal analysis of the LEOP scenario and further discussions with Arianespace will reveal the necessity and feasibility of He I tank cryo-servicing via the access holes of the Ariane 5 fairing.

5.8 Functional and Electrical design

5.8.1 Electrical Design Overview

The electrical design of the EPLM is driven by it's physical configuration in particular due to the accommodation of the instrument cold units, located on optical bench within the Cryo Vacuum Vessel whereas the associated warm units sit on the service module.
The payload instruments warm units are interconnected with their related cold units by the Scientific Instrument Harness (SIH), especially designed for minimizing thermal losses which have adverse effects on the cryostat lifetime. 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.
It will be ensured by analysis, design requirements and design control 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 verified by adequate testing.
In order to allow for the proper operation of the EPLM, the payload module is equipped with a set of electrical devices which provide operational access to the cryostat control instrumentation (CCI) via the Cryostat Control electronic Unit (CCU)and the Cryostat Control Harness (CCH).
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.
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 Electronic Unit (CCU)
  - The Cryostat Control Instrumentation (CCI)

- The Solar Generator (SG) Subsystem mounted on the Sunshield (SSH)

5.8.2 CRYO Harness

5.8.2.1 General Description

The cryostat harness consists of the following two main harness parts:

- Scientific Instrument Harness SIH
- Cryo Control Harness CCH

The two harness parts will distribute the power and signal lines between the warm units allocated within the SVM and the units mounted externally on the cryostat or installed on the optical bench.

Harness interconnections and interface brackets will be kept to a minimum, to cover the manufacturing schedule, the instrument and PLM AIT requirements and the handling access.

Main interface connector-brackets are foreseen with the following functions:

SVM Interface connector bracket (SVM-IF-CB)
Separation of warm units from the SVM external harness;
Separation of copper-wire harness branches (TBC) from the SST one
Test and unit health check SKIN interface connector-brackets
With respect to the Cryo harness and AIT handling requirements, it might be preferable to have an SVM IF-connector-bracket. Detailed investigations are in progress.

Cryo Vacuum Vessel interface connector bracket (CVV IF-CB)
separation of cryo internal and external harness branches
Separation of different harness wire materials
Minimize harness feedtroughs through the CVV
Interconnection of cryo internal and external attached instrument units

Optical Bench interface connector bracket ((I)OB IF-CB)
additional interconnection on the optical bench, to separate the individual SIH units and CCH end-items (e.g. temperature sensors).

Note: According to the latest design, it is prefered to reduce the amount of interface connector-brackets (IF-CB`s) and interface connectors.

In the following figures Figure 5.8-1 to Figure 5.8-2:, cryo harness overviews are defined.

In Figure 5.8-1 the cryo harness schematic of the interface cables is defined for the major harness sections. The identified numbers specify the quantity of core lines and shielded lines (SH).
Interface connector brackets (IF-CB`S) shown in “dotted lines“ are currently under investigation aimed at reducing the amount of interface connectors. Necessary functional

interface connectors of CCH and SIH will be designed during the ongoing harness lay-out design, to shorten the harness manufacturing expense too.

Figure 5.8-2: provides some more details of the wiring list connector allocation code. Since the harness connects two and more structural items and units etc., all harness connector positions will be identified for harness manufacturing, the EICD and for PLM AIT use.

The complete harness connector identification code will be defined in the cryo harness specification in close relation to the harness EICD. Harness lines as shown in Figure 5.8-2: identify the SIH interconnection units as defined within the current, reviewed IIDB`s.

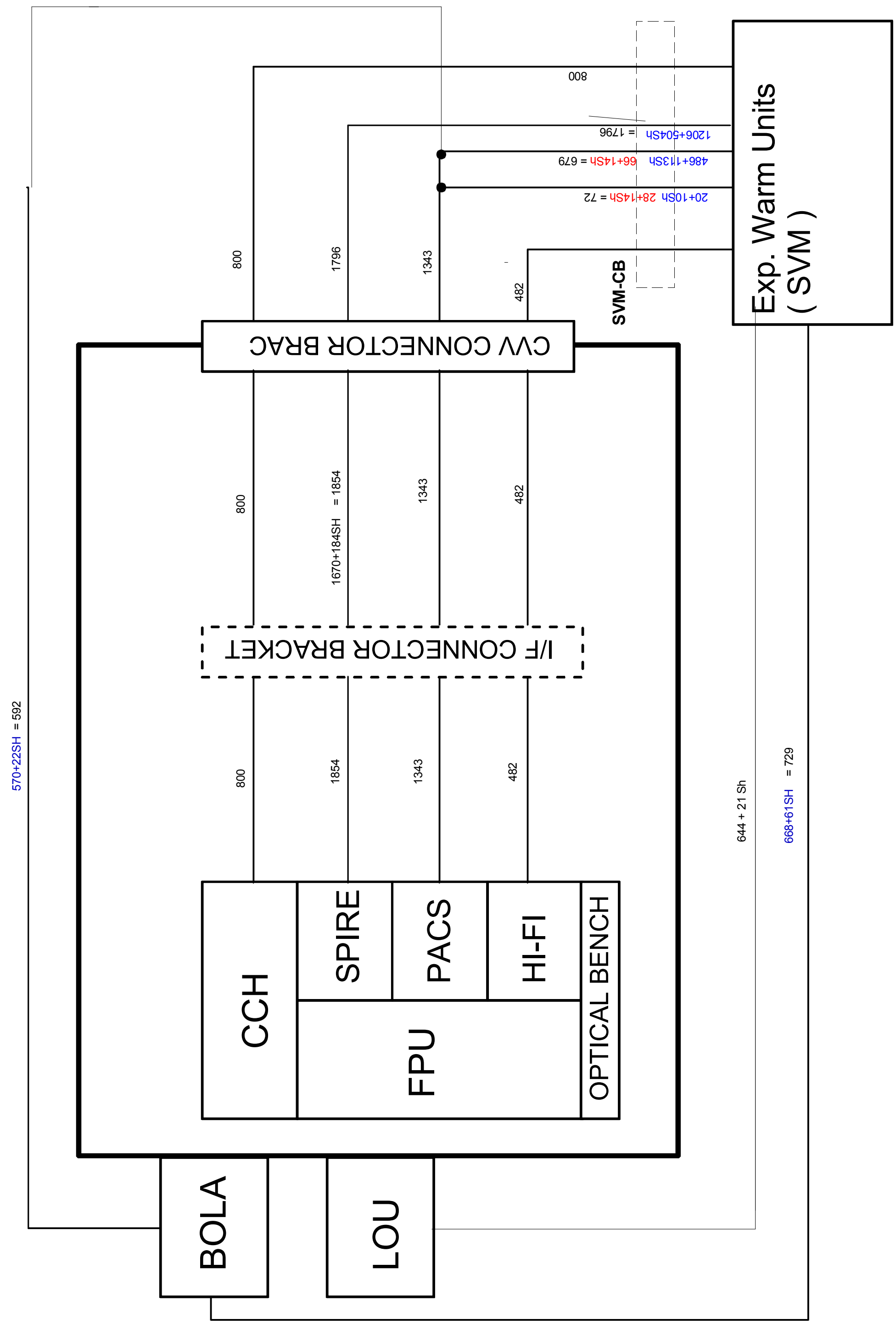


Figure 5.8-1: HERSCHEL PLM Cryosat Harness Interface Connector-Bracket Schematic

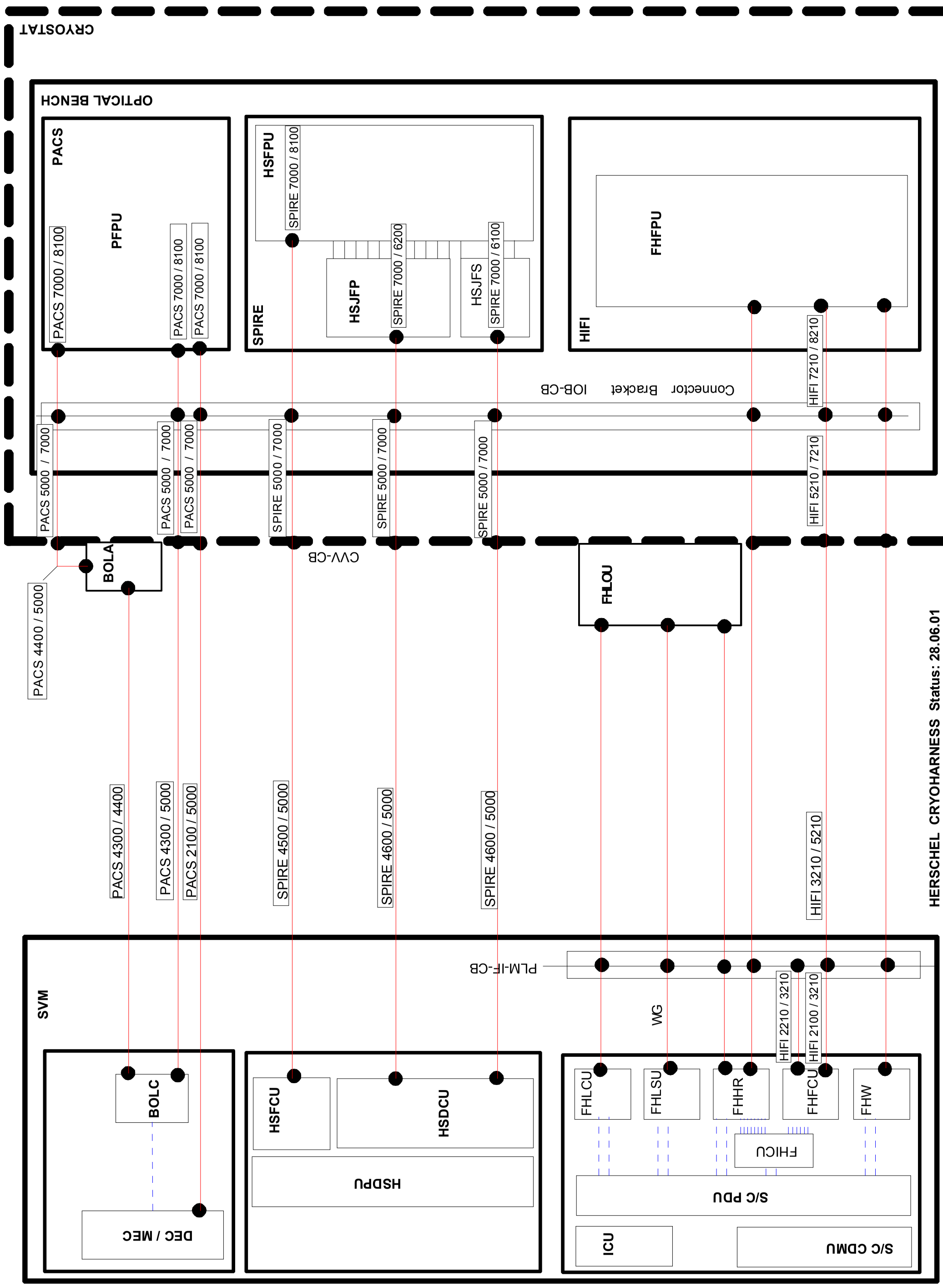


Figure 5.8-2: HERSCHEL PLM Cryosat Harness Advanced Overview of Identification Code for EICD

5.8.2.2 SIH Cryo Scientific Instrument Harness

The 3 instrument harnesses will be distributed between warm units within the SVM, the CVV external and internal units on the optical bench.

An overview of the Scientific instrument harnesses (SIH) covering the major and optional interface connector brackets is provided in Figure 5.8-3 and Figure 5.8-4 for PACS and SPIRE, respectively.

SIH definition for HIFI is not yet available.

MPIA MAX-PLANCK-INSTITUT FÜR ASTRONOMIE Heidelberg	PACS Cryo Harness Specification	Project PACS Doc.ref :PACS-MA-SP-001 Issue :Draft Date :12/03/2001 Sheet : 6 of 80

3 Harness Diagrams

3.1 Overview PACS Harness

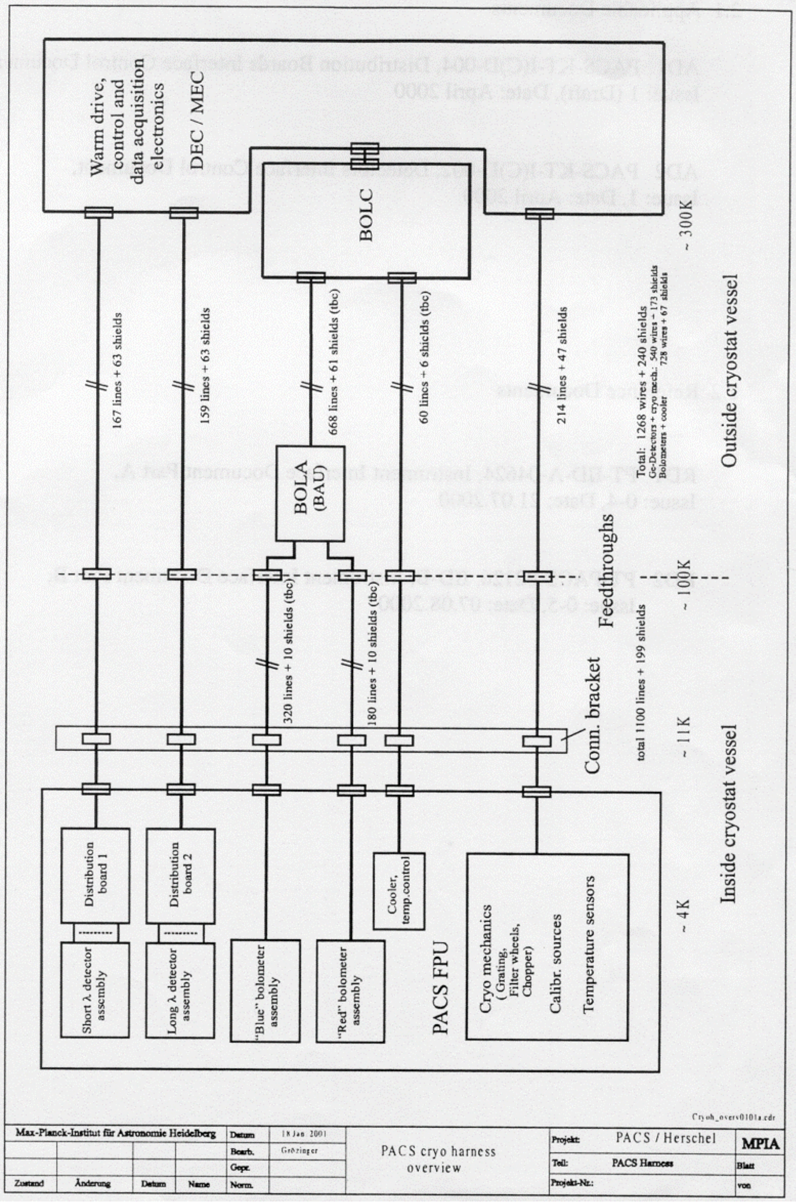


Figure 5.8-3: SIH PACS overview

CLRC	SPIRE HARNESS DEFINITION	Doc #: SPIRE-RAL-PRJ-000608 Issue: 0.3 Date: 30/5/01 5:34 PM Page 7 of 124

3 INTRODUCTION

The overall HERSCHEL SPIRE harnesses are configured as shown:

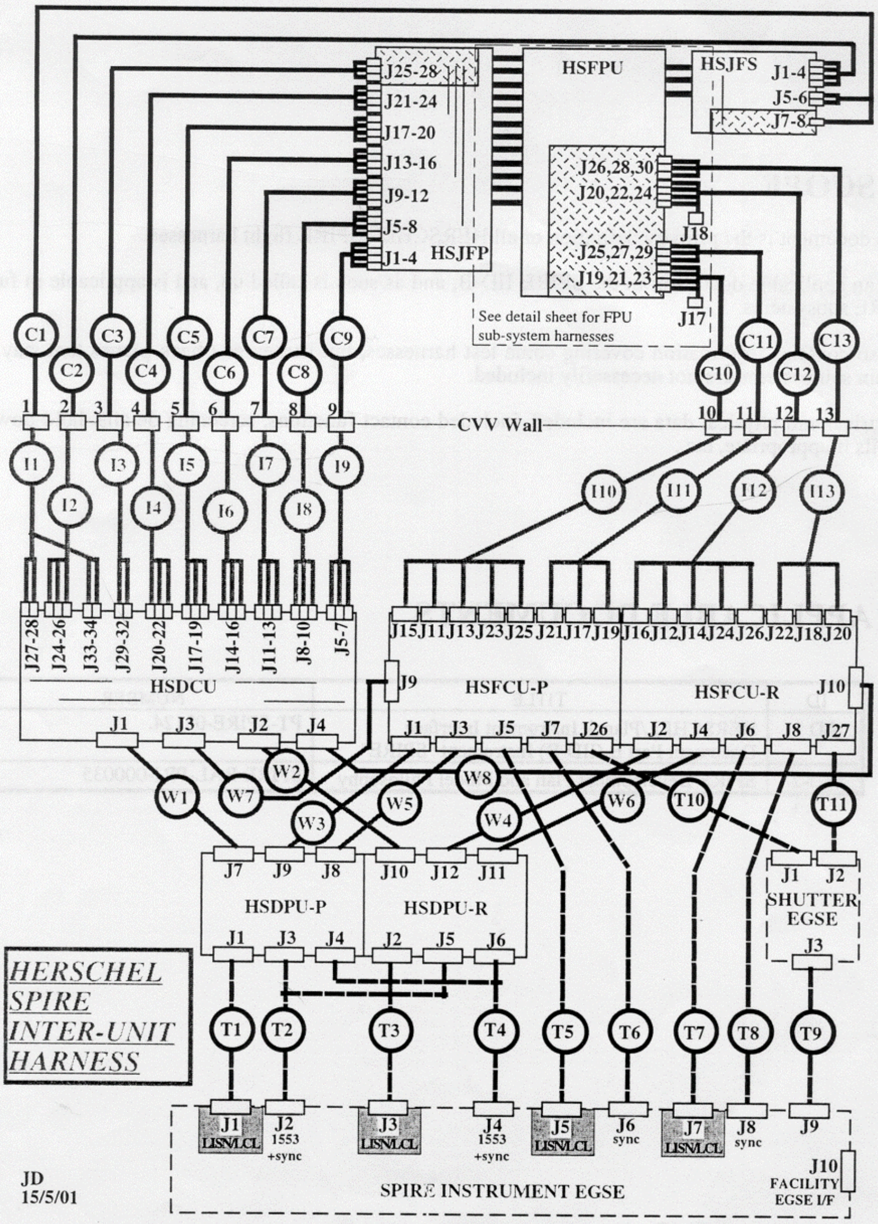


Figure 5.8-4: SIH SPIRE overview

5.8.2.3 CCH Cryo Control Harness

The CCH will be distributed between the SVM warm units, the CCU and the optical bench internal and external units, up to the individual end items as e.g. thermistors and heaters. A small amount of cables will be distributed from other SVM sources and interface connector brackets.

An overview of the CCH showing the major and optional interface connector brackets is provided in Figure 5.8-1.

5.8.2.4 Harness Models and Responsibility

The following harness models will be designed and manufactured:

Harness	Model	Responsibility of	Supplier
SIH	EQM	Cryo Harness	
SIH	PFM	Cryo Harness	
CCH	EQM	Cryo Harness	
CCH	PFM	Cryo Harness	

5.8.2.5 Relationship to other Cryo Programs

Harness experiences and progress made in the frame of programs ISO, ISOPHOT Testharness and GIRL will be adopted on the Herschel cryo harness design and manufacturing.
The harness design criteria as detailed below will show the advantages and disadvantages of one and the other interconnection approach.

5.8.2.6 Main Cryo Harness Design Criteria

For the detailed cryo harness design the main design criteria are listed below:

- Final definition of interfaces
- Review of instrument documents, selection of cable types
- Definition of the Herschel necessary instrumentation and relevant harness
- Necessity of Optical Bench Harness, e.g. location of I/F brackets on OB

- Transition of harness bundles from optical bench to spatial framework
- Bundle separation, routing and fixation on the chains
- Thermal connection of bundles to innermost shield
- Location of Vacuum feed-throughs (access to the connectors, forbidden areas)
- Accommodation of Vacuum feed-throughs on CVV (current estimation 63 connectors)
- Traction relief and routing of cables on CVV inside up to the chains
- bundle separation, routing and fixation on CVV and struts (telescope, struts between CVV-SVM)
- Location of SVM units (opposite side SVM – CVV)
- Design of CCH depending of SIH, routing of complete CCH via lower chains only
- Consideration of other harnesses via CVV

5.8.2.7 Necessity of Optical Bench Harness

For the above defined main design criteria the following summary shows which main tasks have to be performed before the necessity of the optical bench harness and the additional interface connector bracket will be decided upon:

- Harness design of the Instruments (bundle separation, spiders)
- mechanical properties of the FPU's
- location of the FPU interface connectors
- Integration Flow
- mechanical properties of the optical bench
- Routing of vent line on the optical bench
- Design of the Instrument Shield
- mechanical interface to the spatial framework and to the chains

5.8.2.8 Cryo Control Harness EQM CCH

The ISO EQM Cryostat will be refurbished to the Herschel EQM.

Main tasks for reconfiguration of the ISO EQM Harness are given below:

- identification of ISO EQM instrumentation usage and availability for HERSCHEL EQM

- definition of necessary free areas for new HERSCHEL (SIH & CCH) harness parts
- re-routing of remaining ISO CCH from these free areas
- removing of no longer used ISO EQM (SIH & CCH) harnesses
- check of possibility to reuse
  - external CCH harness
  - ISO Cryo Electronic
  - testharness and I/F's to EGSE (HERSCHEL parts)
- definition of new HERSCHEL harness parts (CCH) installed on ISO EQM for
  - upper cone instrumentation
  - shields instrumentation
  - test cavity instrumentation
  - Optical Bench CCH (FM representative)
  - new auxiliary tank (option)
- necessary tasks for SIH (FM representative) installed in ISO EQM
  - routing of internal harness
  - thermal coupling of internal harness to innermost shield
  - routing of external harness
  - location of vacuum feed-throughs and prohibited areas
  - new connector ring for SIH
  - using of old connector ring for HERSCHEL SIH

5.8.2.9 Cryo Harness components

5.8.2.9.1 Cables

The Herschel Harness will use wire materials as defined in the frame of ISO, ISOPHOT Testcable and GIRL. The basic harness procurement spec ISO-K-101 will be taken as baseline.
Other cables as defined therein will be approved either by similarity or will be asked for ESA approval.
In case of new cable configurations and/or wire materials, a procurement spec. will be provided.
On the Cryo harness the same wire and cable materials will be used as on the former programs Cryo programs.

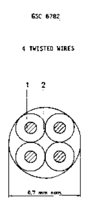
5.8.2.9.2 Cable and Wire characteristcs:

- conductor material: Stainless Steel (SST) and Brass
- shield material: Stainless Steel (SST)
- Isolation material: PTFE, GORE-Tex and Polymide Tape
- Designed [AWG sizes]:
  - conductor SST AWG-38 (diameter = 0,1mm)
  - conductor Brass AWG-38 (diameter = 0,1mm)
  - conductor Brass AWG-30 (diameter = 0,25mm)
  - Shield SST AWG-44 (diameter = 0,05mm)

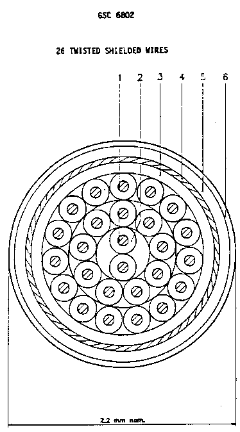
Procurement of the above described raw materials has been started with the ESA approved supplier GORE. As a baseline from the former cryo programs, existing cable configurations (e.g. GSC6802) will be preferably used. Other cables configurations, as requested e.g. on the SIH have to be correlated, subject to their electrical requirements, to the requirement of “ISO-K-101” and the manufacturing process.
As alternative a “drain-wire cable” configuration is under investigation, to simplify the cable shield termination with regard to soldering and welding process. With a drain-wire cable, the treatment with flux of cable-shields will be avoided. The thermal impacts have to be investigated. Drain-wire configurations similar to SCC 3901-021 (copper wire cables, supplier GORE) will be investigated in case of shielded SST and Brass cables.

Typical CCH cable configurations

Temperature sensor cable



Signal line cable



For special applications (e.g. high power, ventline heater) standard copper wires will be used outside of cryostat.

Table 5.8-1: ISO-K-101 cable type characteristics

ISO-K-101_variant_no	01	02	05	07	08	10	11	12	13	15	16	03	06	09	14	17	04	18		
GSE_No_Rev	6775_2	6777	6782	6786_3	6788_3	6790_3	6792_4	6793_4	6795_3	6802	7525	6770_3	6783_3	6789	6796	6778_3	6779_3	6779_3	6802_3	7525_0
shd_and_jacked_1	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes		no			
shd_and_unjacked_2	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no		
shd_qty	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0		
no-shd_jacked_1	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no		
no-shd_unjacked_2	no	yes	yes	yes	no	no	no	no	no	no	no	yes	yes	no	no	yes	yes	yes		
core_qty	1	2	4	2	3	7	11	19	4	29	(3+1)	2	4	2	4	2	2	2		
C_AWG	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	30	30		
C_dia-max_mm	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.26	0.26		
C_Section-nom_qmm	0.008		0.008					0.008									0.051	0.051		
C_material	SST	SST	SST	SST	SST	SST	SST	SST	SST	SST	SST	Brass	Brass	Brass	Brass	Brass	Brass	Brass		
C_R_Ω-p-m	130	130	130	130	130	130	130	130	130	130	130	10	10	10	10	10	2	2		
Dia_fine_wire	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.52	0.55	0.71		
Insul-Section-nom_qmm	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.106	0.079	0.173		
Insul-Section-color	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	blue	red	red	red	red	[illegible]	yel	yel+[illegible]		
shd-Section-nom_qmm	0.020			0.060	0.070	0.080	0.110	0.136	0.070	0.106	[illegible]			0.070	0.070					
shd-AWG	44			44	44	44	44	44	44	44	44			44	44					
Cab-Dia-nom_mm	0.7	0.5	0.7	1.2	1.2	1.4	1.6	1.9	1.9	2.2	4.5	0.5	0.7	1.2	1.3	0.7	1	1.2		
Twisted-wire_Length-of-lay-nom_mm		7	9	7	9	10	14	19	9	27	10	7	9	8	9	7	14	11		
Jacket_polimid_Section-nom_qmm				0.207	0.214	0.295	0.315	0.352	0.226	0.401	0.885			0.214	0.236					
Jacket_polimid_color	natural			natural	natural	natural	natural	natural	natural	natural	natural			natural	natural					
R-max_tol-10%_Ω-p-m	140	140	140	140	140	140	140	140	140	140	140	12	12	12	12	12	2.2	2.2		
Cab-capacity_max_pF-p-m_conductor-conductor	120	65	65	60	65	60	65	60	60	60	60	50	55	65	40	50	65	65		
Cab-capacity_max_pF-p-m_conductor-shd				100	100	100	100	100	100	100	100			105	100					
Cab-weight_gram-p-m	0.750	0.360	0.720	1.760	2.800	3.600	4.200	5.100	2.220	8.250	25.000	0.370	0.740	2.000	2.280	0.630	1.380	1.720		
Voltage_max_V/rim	150																			
Current_max_mA	70	70	70	70	70	70	70	70	70	70	70	230	230	230	230	230	800	800		
Frequency_range_KHz	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100		
Operation_Temperatur-min_Kelvin	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
Operation_Temperatur-max_Kelvin	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473		
Storage_Temperatur-range_min	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
Storage_Temperatur-range_max	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473	473		
conductor_Elongation_factor	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.00086	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.00110		

5.8.2.9.2 Cryo Harness cables and estimated Distances

The CCH and SIH cable summaries have been taken for a first worse-case mass analysis. In Table 5.8-2 these mass figures are provided.

Table 5.8-2: CCH and SIH Cryo Harness cables and estimated Distances

	Proposal Length [m]					6.0	3.0	1.0		4.0	1.4	0.5			
Instrument		SST core	SST Shd	Bi-core	Bi-shd	Warm Units - SVM	SVM BOLA	BOLA-CVV	SVM LOU	SVM CVV	CVV opt. Bench	on opt Bench	Length	SST cable_L	Bi-cable_L
	IF Harness	awg 30	awg 44	awg 38	awg 38	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
		Qty	Qty	Qty	Qty	1.0	5.5	2.5	2.5	6.0	2.5	1.0			
PACS	BOLC to BOLA	668	61			1.0	5.5						6.5	4342.0	
PACS	BOLC to CVV	20	10	28	14	1.0	5.5			6.0			12.5	250.0	350.0
PACS	BOLA to CVV	570	22					2.5					2.5	1425.0	
PACS	DECMEC to CVV	488	113	66	14	1.0				6.0			7.0	3452.0	462.0
PACS	"Dec/Mec Dist. B 1+2	328	77	10	1										
PACS	Dec/Mec Mechanism	100	35	58	13										
PACS	W-Units CVV to FPU	1070									2.5	1.0	3.5	3745.0	
PACS	W-Units CVV to FPU		145								2.5	1.0	3.5		
PACS	W-Units CVV to FPU			94							2.5	1.0	3.5		329.0
PACS	W-Units CVV to FPU				28						2.5	1.0	3.5		
SPIRE	HSDCU to CVV	924	434			1.0				6.0			7.0	6468.0	
SPIRE	HSFCU to CVV	368	70			1.0				6.0			7.0	2576.0	
SPIRE	CVV to HSJFS	288	24								2.5	1.0	3.5	1008.0	
SPIRE	CVV to HSJFP	1032	86								2.5	1.0	3.5	3612.0	
SPIRE	CVV to HSFPU	350	74								2.5	1.0	3.5	1225.0	
SPIRE	W-Units SVM to CVV	1202	604			1.0				6.0			7.0		
SPIRE	CVV to opt Bench	1670	164								2.5	1.0	3.5		
HIFI	FCU to CVV	448	34			1.0				6.0			7.0	3136.0	
HIFI	CVV to FHFPU	448	34								2.5	1.0	3.5	1568.0	
HIFI	W-Units SVM to LOU	644	21			1.0			2.5				3.5	2254.0	
Option HIFI	FCU to CVV	287	23	102	11	1.0				6.0			7.0	2009.0	714.0
Option HIFI	CVV to FHFPU	287	23	102	11						2.5	1.0	3.5	1004.5	357.0
CCH	SVM internal	100	20	60	10	1.0									
CCH	SVM to CVV	800	40			1.0				6.0			7.0	5600.0	
CCH	CVV to opt Bench	800	40								2.5	1.0	3.5	2800.0	
				estimated, but not calculated										38946.5	2212.0

In Table 5.8-3 the CCH and SIH wires and cables have been summarized for a first harness mass figure. The data have been collected from the IIDB´s and latest amendments for the current worse-case analysis. Uncertainties are based on less precise harness data, available from the instruments and CCH harness design, recommendation of
non ISO-K-101 type of cables and TBD connections on SIH.

Table 5.8-3: Cryo Harness cable mass

HERSCHEL CRYO - HARNESS						
Cable-Types	UNIT / HARNESS					
	PACS	SPIRE (ouside CVV)	SPIRE (inside CVV)	HI - FI	CCH	TOTAL-Qty
SL1C		76	56			132
T2C		18				18
T4C		20	12			32
T1S2C38S	184	454	22	4	100	764
T1S3C38S		8	6	2		16
T1S4C38S	38	42	46	2	150	278
T1S6C38S	5					5
T1S8C38S	4			2		6
T1S11C38S	4					4
T1S12C38S	6		110	6		122
T1S13C38S	4					4
T1S15C38S				2		2
T1S16C38S	1			2		3
T1S23C38S	6					6
T1S24C38S	3					3
T1S26C38S	2					2
T2S1C38S	50					50
T1S2C30B	16					16
T1S4C30B	8					8
T1S6C30B	3					3
T1S9C30B	1					1
Harness Weight / g	7446,4	6909	2004,6	3600,6	2775	22735,6

Special Harness abbreviations:

Cable code definition: „ This code will be used for correlation only"

a) unshielded cables:
- n 1C38 = n* single line AWG 38
- 1 T2C = 1 twisted 2 cores
- 1 T26C36 = 1 cable with 26 cores AWG 36

b) shielded cables:
- 5 T1S37C = 5 cables with 1 Shield and 37 cores each
- 5 T2S37C = 5 cables with 2 Shields and 37 cores each

c) coaxial cables:
- 3 CX1C36 = 3 Coaxkabel with 1 core AWG 36
- 1 CX2C36 = 1 Twin-Coaxialkabel with 2 cores AWG 36
- 1 CX3C38 = 1 Triax-cable with 3 cores AWG 38

d) Wave-Guide:
- 1 WG15 WR112= 1 Waveguide with Flange-size and dia. square

5.8.2.9.3 Cable selection flow

The selection of the Herschel Harness requested and necessary cables is in progress and will be performed in the way as given in the following flow chart.

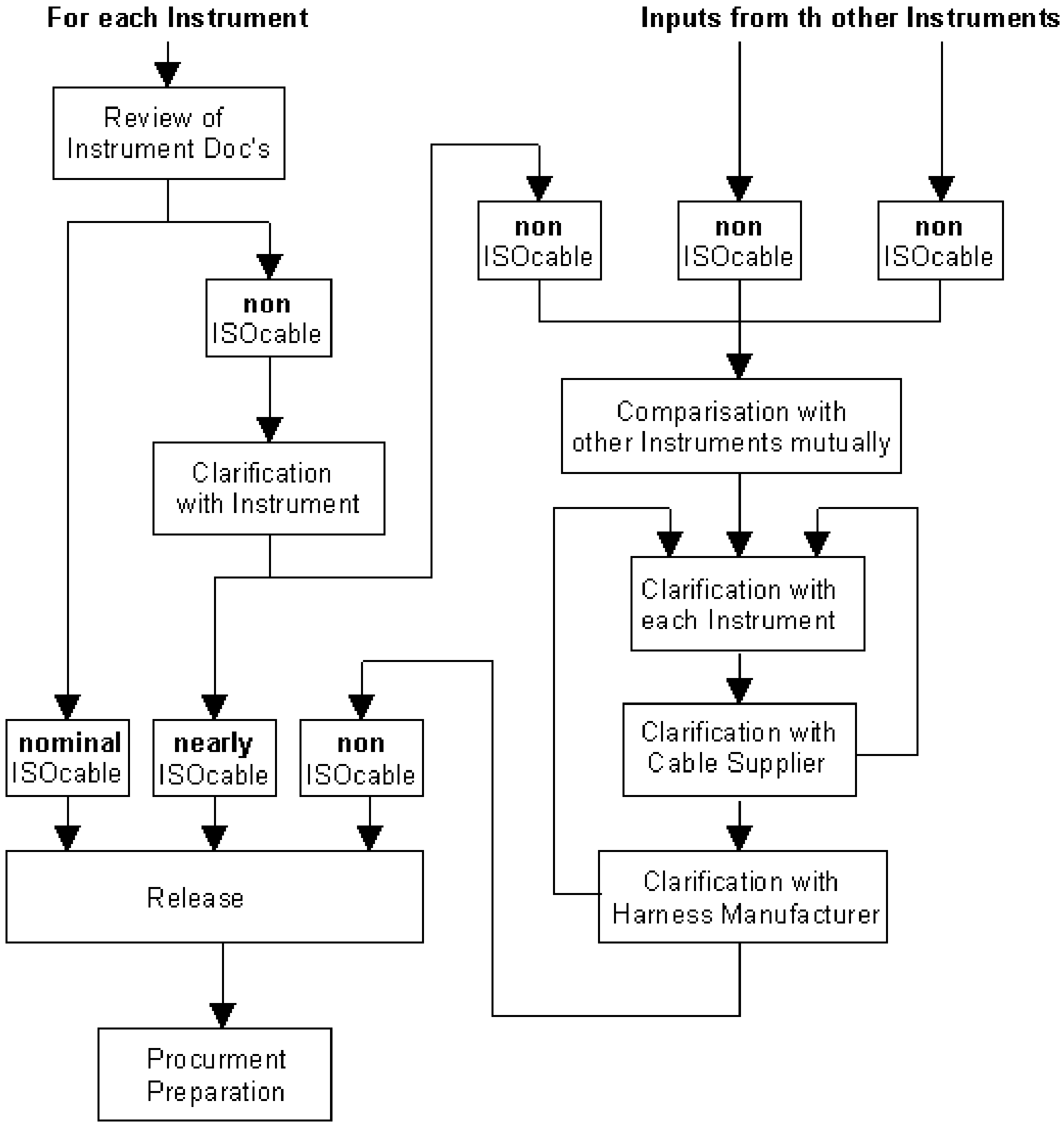


Figure 5.8-5: Cable Selection Flow Chart

Main tasks

Review of instrument documents

review of current instrument IID B's and/or Specifications considering the requirements to the cables (electrical characteristics like resistance, current . . . . , thermal aspects, screens, bundle configuration, CVV I/F, pin function, integration and so on) ⇒ Output

nominal ISOcable | **non** ISOcable

Clarification with instruments

compare the non ISO cable configurations with the existing ISO cable configurations (e.g. two cables in parallel) ⇒ Output

nearly ISOcable | **non** ISOcable

Comparison with other instruments mutually

Put together the - non ISO cables - from all three instruments and compare it to minimise the number of cable types. (for example: HIFI cable conversion table nominal ISO and nearly ISO cables) .

Table 5.8-4: ISO cables and nearly ISO cables

			Requested Cable 15.03.2001					adaptable ISO Cable							
No.	Connector No.	Signal name	type	# of wires	twisted groups	# of Shields	Sum. of connect.	No. of Cable	type	# of wires	twisted groups	# of Shields	Sum. of Shields	Summary of v all	used
	FPU														
	FCU-J16	Chopper, calibrator and therm.	TWS	4	1x4	1	5	1	6795	4	1x4	1	1	4	4
	FCU-J16	Chopper, calibrator and therm.	TWS	3	1x3	1	4	1	6788	3	1x3	1	1	3	3
	FCU-J16	Chopper, calibrator and therm.	TWS	2	1x2	1	3	1	6786	2	1x2	1	1	2	2
	FCU-J16	Chopper, calibrator and therm.	TWS	12	1x12	1	13	2	6790	7	1x7	2	4	14	12
	FCU-J16	Chopper, calibrator and therm.	TWS	2	1x2	1	3	1	6786	2	1x2	1	1	2	2
	FCU-J16	Chopper, calibrator and therm.	TWS	8	1x8	1	9	2	6795	4	1x4	1	2	8	8
	FCU-J17	Diplexer actuator	TWS	12	1X12	1	13	2	6790	7	1X7	1	2	14	12
	FCU-J11	Mixer bias	TWS	20	4x5	1	21	4	6790	7	1x7	1	4	28	20
	FCU-J11		TWS	15	3x5	1	16	3	6790	7	1x7	1	3	21	15

Note: electrical characteristics not considered in this table

Following an overview of the actual status of number of wires/shields and the difference to the proposal.

Table 5.8-5: Comparison between Proposal and current status of cables

Scientific Instrument	Number of Wires/Shields		Remark
	Proposal	Current	
- SPIRE			
housekeeping and mechanisms harness	224/34	368/70	
Detector signal and control	848/424 + 36 common shields	924/434 ext. 1320/110 int.	number of wires differs between external and internal harness
- PACS			
cryo-mechanisms harness	178/35	160/36	
Ge:Ga detector harness	424/138	326/77	
detector harness FPU-BOLA	500/20	570/22	
detector harness BOLA-SVM	668/81	668/61	
temperature sensors and cooler harness	60/6	48/24	
- HIFI			
cryo harness FPU-CVV	552/32	448/34	
cryo harness Coax	4	4	
cryo harness LOU-CVV	644/12	644/21	

5.8.2.9.4 Connectors

As described in the proposal in general, the following types of connectors will be used :

- On SVM connector types (nominal D-Sub and HD Connectors) as required in the applicable Documents:
  - IID-B for the Scientific Instruments
  - SVM Design and Requirement Specification
- Cryostat Vacuum Vessel (CVV), Hermetic Connectors as jack’s installed in the CVV wall and Straight connectors for Plugs
- Cryostat Internal connector types as required in the IID-B for the Scientific Instruments and MDM connectors with soldering pins for cryostat internal interfaces.

Differences in the material compositions between the actual MDM connectors from Cannon and the MDM connectors used in ISO (Cannon) will be clarified. A second source for MDM connectors is the supplier Glenair, these material compostions will be analysed too.

The Vacuum Feed-through connectors used in ISO with solder cups will be replaced by connectors with solid wire contact.

Alternatively a Cu-wire adapter (pig tail) can be used, but the distance between the two solder joints , to avoid melting of one joint during soldering of the other, must be considered in design of backshell and CVV (distance between Cylinder wall and third shield).

For Herschel, Harness Connectors with solid wire contacts should be preferred

- **Advantage of solid wire contact**
  - only one type of contact for all connection joints for SST and brass wires
  - good manufacturing control after soldering and welding process
  - extracting of gold and pre-tinning simplified
  - better access to the contacts
  - simplified manufacturing flow and quality control (no additional Cu-wire follower necessary)
  - better traction relief (longer shrinking tube)

In Table 5.8-6 the present CCH and SIH CRYO harness connectors have been summarized .

Table 5.8-6: Cryo Harness connector summary

HERSCHEL CRYO Harness connector Summary

	D*MA										HD*MA				MDM												VCC-Conn.		Round Conn. ML C 3000	
Unit	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Fxx 100P	Jxx 100S	30-30P	26-26S
PACS						2	10	8						2	2	2	2	2	4	12	10	0	15	15	26	26	18	18	15	15
SPIRE	2		6				10	8	2	10												34			6	8	25	25	13	13
HIFI				4			4	4			4	4	4	4													7	7	7	7
CCH																											13	13		
CVV-CB																											63	63		
OB-CB (SVM-CB)																													35	35
Summe	2	8	6	4	8	2	24	18	2	10	4	4	4	6	2	2	2	2	4	12	10	34	15	15	32	34	63	63	36	36
454	74										18				164												126		72	

Table 5.8-7: CRYO Harness connector summary details

O Harness connector summary

	D*MA										HD				MDM												CVV-Conn.		MIL-C-38999		quantity
PACS	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S	
Unit																															
DEC/MEC															2		2		4		8		15								
BOLC						2	10	9						2																	
BOLA																					2				19	16					
Distr.-Board 1																				4				5							
Distr.-Board 2																				4				5							
Bolom. Blue																									6	3					
Bolom. Red																									2	4					
Cryo - Cooler																										2					
Calibr. Source 1+2																		2													
T1 + T2																1															
Copper																								1							
Filterwheel 1																								2							
Filterwheel 2																								2							
T3 + T4																1															
Grating																				4											
PACS / CVV-CB																											18	18			
PACS / SVM-CB																													15	15	
Summe	0	0	0	0	0	2	10	9	0	0	0	0	0	2	2	2	2	2	4	12	10	0	15	15	27	25	18	18	15	15	204
	D*MA										HD				MDM												CVV-Conn.		MIL-C-38999		quantity
SPIRE	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S	
HSDCU							4	5		18																					
HSFCH-P	1		3				3		1																						
HSFCH-R	1		3				3		1																						
HSJFP																						26									
HSJFS																						8				2					
HSFPU																									5	6					
SPIRE/CVV-CB																											26	26			
SPIRE / SVM-CB																													13	13	
Summe	2	0	6	0	0	0	10	5	2	18	0	0	0	0	0	0	0	0	0	0	0	34	0	0	5	8	26	26	13	13	170
	D*MA										HD				MDM												CVV-Conn.		MIL-C-38999		quantity
HI - FI	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S	
LOU = TBD																															
FCU				2			2	2			2	2	2	2																	
FHPPU				2			2	2			2	2	2	2																	
HI-FI/CVV-CB																											7	7			
HI-FI / SVM-CB																													7	7	
Summe	0	0	0	4	0	0	4	4	0	0	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7	7	60
	D*MA										HD				MDM												CVV-Conn.		MIL-C-38999		quantity
CCH	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S	
Summe																											12	12			24
	D*MA										HD				MDM												CVV-Conn.		MIL-C-38999		quantity
TOTAL	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S	
Summe	2	0	6	4	0	2	24	18	2	18	4	4	4	6	2	2	2	2	4	12	10	34	15	15	32	34	63	63	35	35	454

Connector incl. Backshell mass																														
	D*MA										HD*MA				MDM												KJ*		Round Conn. MIL-C-38999	
TOTAL	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S
mass [g] / connector + backshell	36	35	44	42	45	44	71	70	75	73	71	70	75	73	23	23	25	25	27	27	33	33	39	39	46	46	150	150	150	150
no of connectors	2	0	6	4	0	2	20	10	2	0	4	4	4	6	2	2	2	2	4	12	10	34	15	15	32	34	63	63	35	35
mass [g]	72	0	264	168	0	88	1420	700	150	0	284	280	300	438	46	46	50	50	108	324	330	1122	585	585	1472	1564	9450	9450	5250	5250
Total mass [g]	39846																													

In the connector mass figures inclusive backshels, but exclusive harness attachment and cooling hardware have been calculated on data summarized in Table 5.8-6.

Table 5.8-8: Current mass summary of SIH , CCH and delta estimation of connectors

Connector incl. Backshell mass																														
	D*MA										HD*MA				MDM												KJ*		Round Conn. MIL-C-38999	
TOTAL	9S	9P	15S	15P	25S	25P	37S	37P	50S	50P	44S	44P	62S	62P	9S	9P	15S	15P	21S	21P	25S	25P	31S	31P	37S	37P	Pxx 100P	Jxx 100S	25-35P	25-35S
mass [g] / connector + backshell	36	35	44	42	45	44	71	70	75	73	71	70	75	73	23	23	25	25	27	27	33	33	39	39	46	46	150	150	150	150
no of connectors	2	0	6	4	0	2	20	10	2	0	4	4	4	6	2	2	2	2	4	12	10	34	15	15	32	34	63	63	35	35
mass [g]	72	0	264	168	0	88	1420	700	150	0	284	280	300	438	46	46	50	50	108	324	330	1122	585	585	1472	1564	9450	9450	5250	5250
Total mass [g]	39846																													

Table 5.8-9 and Table 5.8-10 provide the comparison of the ISO and HERSCHEL CRYO Harness connectors.

Table 5.8-9: ISO Connector Overview

Interface	Jack				Plug				Remark
	connector	Type of Contact	Connection	Supplier	connector	Type of Contact	Connection	Supplier	
FPU	N/A	N/A	N/A		MDM	solid wire	Ni-Form	Cannon	Used for all FPU connectors
Spatial Framework	MDM	solid wire	Ni-Form	Cannon	MDM	solid wire	Ni-Form	Cannon	Used for all Spatial Framework connectors
CVV	KJ7	solder cup	Ni-Tube	Cannon	KJ6	crimp + Cu wire	Ni-Form	Souriau	changed, Cannon connectors used before, also Crimp with Ni-Form
CVV Unit	N/A	N/A	N/A	N/A	MDM	solid wire	Ni-Form	Cannon	
SVM	N/A	N/A	N/A		D-Sub	crimp + Cu wire	Ni-Form	Cannon	changed, Cannon connectors with solder cup used before, connection of SST via Ni-Tube
on SVM and CVV outside additionally different types of connectors used (e.g. for H501)									

Table 5.8-10: Herschel Connector type Overview

Interface	Jack				Plug				Remark
	connector	Type of Contact	Connection	Supplier	connector	Type of Contact	Connection	Supplier	
FPU	N/A	N/A	N/A		MDM	solid wire	Ni-Form		as used for ISO
Optical Bench	MDM	solid wire	Ni-Form		MDM	solid wire	Ni-Form		as used for ISO
Spatial Framework	MDM	solid wire	Ni-Form		MDM	solid wire	Ni-Form		as used for ISO, CCH only
CVV Unit									
CVV	KJ7	solid wire	Ni-Form		KJ6	crimp + Cu wire	Ni-Form		alternative solid wire for plug
SVM	N/A	N/A	N/A		D-Sub	crimp + CU wire	Ni-Form		alternative solid wire contact
on SVM and CVV outside probably also additionally different types of connectors necessary, type TBD (e.g. for H501) brass wires will be soldered directly to the solid wires according to ISO, or alternative with additional silver tube Connectors for other harnesses not considered									

Connectors procurement with solid wire contacts

- MDM connectors with solid wire back-end can be procured, same type as used on ISO will be used for HERSCHEL, but changed material compositions have to be verified.
- In principal Vacuum Feed-throughs connectors with solid wires can be procured, Samples procured from the supplier Glenair, qualification status must be checked,.

The boundary conditions for delta qualification or similarity analysis will be clarified with ESA next .

- CVV straight plugs: baseline are connectors with crimp contacts as used in ISO, alternative solid wire contact instead of crimp contacts can be procured in principle, manufacturing flow simplified, solid wire contact delta qualification or similarity analysis have to be clarified with ESA.
- D-Sub connectors: baseline are connectors with crimp contacts of normal density, as used on ISO and former cryo harness programs and high density connectors. The alternative solid wire contacts, will have the same contact front-end and retention (clip mechanism), but with a solid cylindrical contact end instead, necessity of delta qualification will be evaluated, standard solid wire end sizes (e.g. AWG 25/26 as available on the MDM connectors) will simplify the manufacturing flow.

5.9 Operations

5.9.1 Launch Preparation Operations

The final cryo operations activities during the launch preparation phase will start at HO- 7 days [RD-1] (TBC) and will include:

- He filling lines and equipment setup
- final He II filling of main tank
- LHe filling of auxiliary tank
- re-subcooling of main tank
- removal of vacuum gauge magnets and cables

In the current baseline scenario the He filling of both tanks (main and auxiliary) will continue until HO-4 (TBC), when the vacuum pump is disconnected and the ground autonomy phase starts.
Ground Autonomy Phase will incorporate the following operations:

- all He II tank valves shall be closed. Only electrical links shall be available via the umbilical and via CCU (TM/TC data)
- the He-flow necessary to cool the FPU´s and the insulation system shall be evaporated from the He I tank controlled by the He I tank heaters
- the He I tank shall be rapidly depleted just before launch and warmed up to about 30K. Before the start of rapid depletion, the mass flow has to bypass the OB. During

cooling of the H-PLM via the He I tank the external heater H501 shall prevent freezing of humidity at the ventline

The last operation in this phase shall be the closing of external ventline valves V501/V503 and V504/V505.

As an option LHe re-filling of the auxiliary tank may be possible via the launcher fairing doors until HO-2 days (TBC). This would ensure that the ground autonomy phase is extended by approximately 48 hours (TBC).

During the ground autonomy phase (and the initial launch phase described in the following section) the temperature of the He II tank shall not increase above TBD K.
The diagram shows that with the current assumptions a ground autonomy of 6 six days can be achieved.

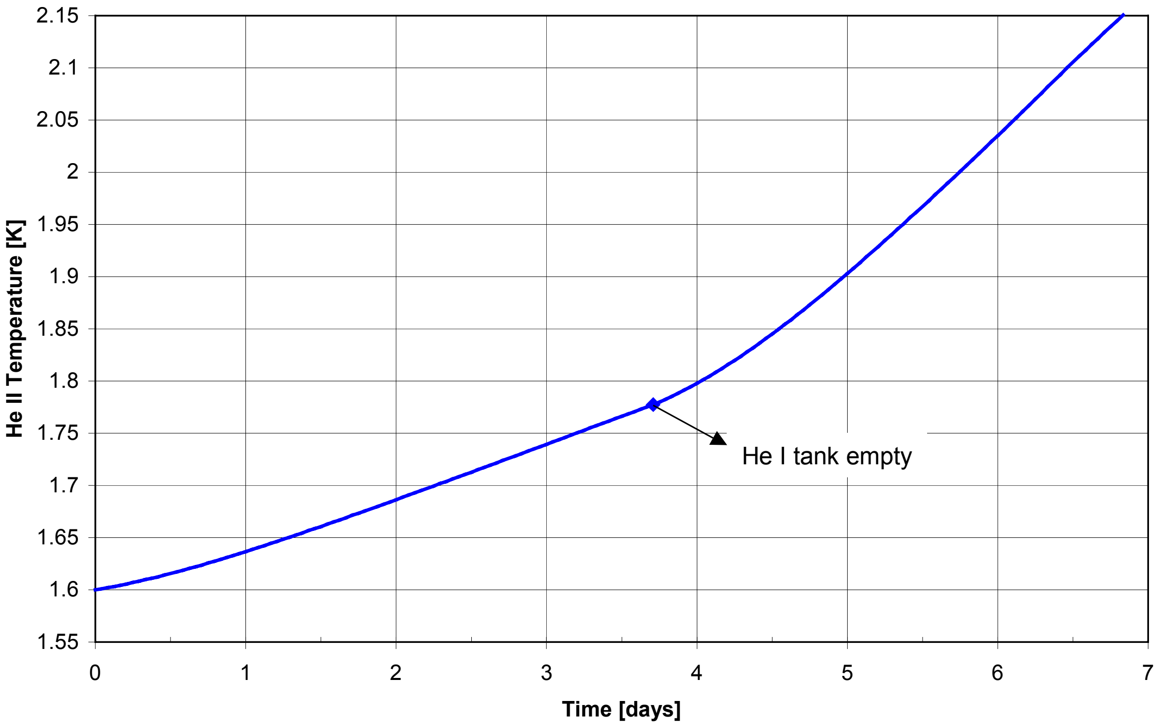


Figure 5.9-1: Temperature increase of He II tank during launch autonomy phase

The temperature curve is calculated based on following parameters:

- 60 mg/s He mass flow for HPLM pre-cooling (Auxiliary Tank)
- 30 mg/s He mass flow after final Auxiliary Tank filling

- Start temperature of He II at 1.6 K
- CVV temperature at 293 K

5.9.2 Launch Operations

During launch, the following H-PLM operations, commanded from the launcher, are to be performed:

- opening of external valves V501/V503 and V504/V505 shortly after the payload fairing jettisoning to evacuate the ventline
- opening of internal valves V103 and V106 during Ariane-5 upper stage boost phase to start phase separator

This starts the phase separator operations and initiates the in-orbit cool-down to the nominal temperature level.

5.9.3 In Orbit Operations

After separation from the launcher, the following H-PLM operations shall be performed:

- Telescope Heating (TBC)

  The telescope shall be heated to a temperature of tbd K. With the current telescope design assumptions heating may not be required.

- 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).

Furthermore, the following will be performed:

- Close Valves V504 and V505

  V504 and V505 shall be closed by telecommand to stabilise the He II tank to a certain temperature for proper operation of the He S/S

- Direct Liquid Content Measurement (DLCM)

  The remaining He II mass in the He II tank shall be measured in orbit by use of the DLCM. Applying a well-defined heat pulse to the He II bath allows the calculation of the actual He II mass content in the tank.

- H-PLM Monitoring

  The monitoring of all relevant cryostat temperature, pressure and status measurements is performed. The monitoring data are collected and prepared for further processing and ground transmission within the OBDH.

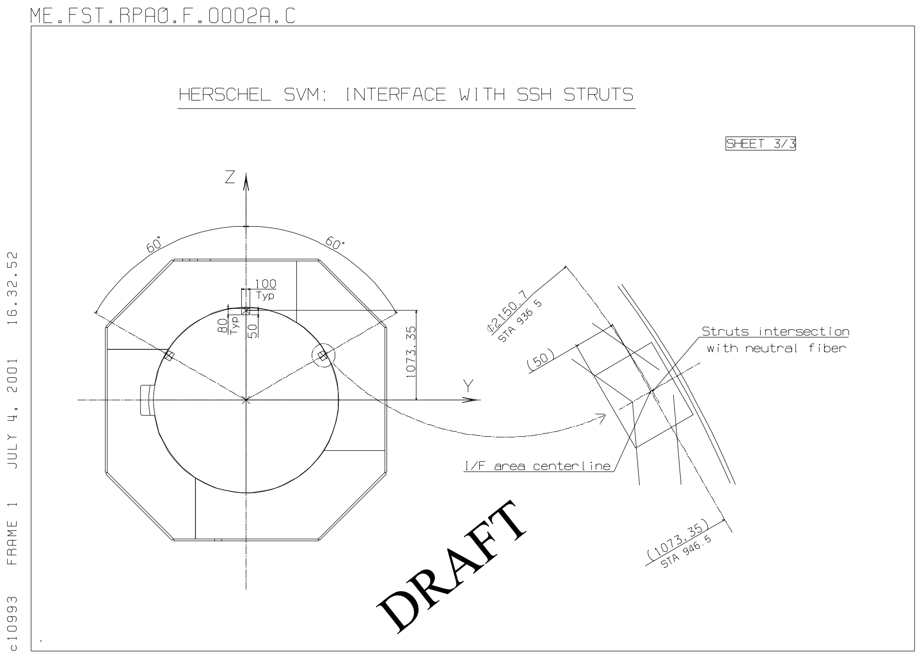
Reference Documents:

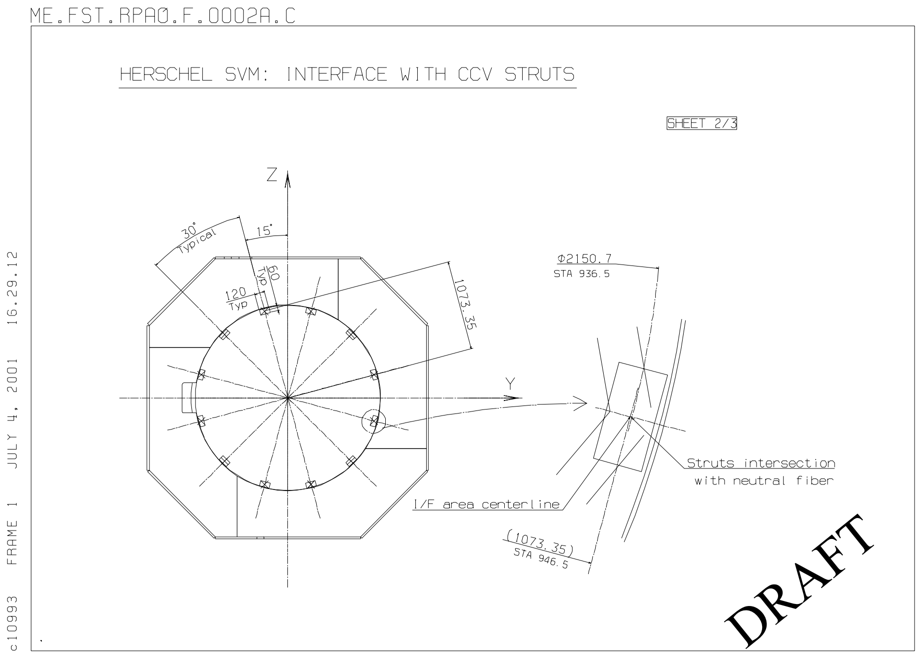
RD[1] Arianespace, Operations Herschel/Planck feasibility, Minutes-of-Meeting, AE/DC/P/N-2001-285 PG/MB, 15/06/2001

5.10 External Interfaces H-PLM-SVM

5.10.1 Mechanical / Configuration

- H-PLM-SVM strut interface (I/F) similar as ISO interface shall be used.
- The H-EPLM is supported by 24 struts at the SVM
- The strut design is similar to theI SO interface struts
- The neutral axis of the struts interfaces the SVM at a height of x =936.5 mm at a diameter of 2150.7mm. The contact area is at x= 945.5 mm from the S/C separation plane





5.10.2 Thermal

- The H-PLM-SVM struts isolates the cold CVV from the warm SVM. Thermal control of the warm instruments and the cold CCU is part of the warm SVM.
- T-anchor and lacing cord fix the external harness to the I/F struts by lacing cord and to the SVM. The thermal coupling from the Harness to the SVM structure will be low. The harness is thermally coupled to the relevant instrument warm boxes, the CCU or the SVM/H-PLM I/F bracket. For the external harness, suitable material (stainless steel or brass) is used to reduce the parasitic heat onto the H-PLM.
- A radiation shield shall minimise direct radiation from the warm SVM to the cold H-PLM. Furthermore; the lower bulkhead of the H-PLM is covered with MLI to reduce heat radiation from the radiation shield top surface.
- The use of low conductive material (e.g. stainless steel, titanium, GFRP etc.) for the waveguides between SVM and LOU is mandatory to reduce the thermal heat input onto the H-PLM (waveguides are part of the HIFI Instrument).

5.10.3 Electrical / Harness

- The CCU has an interface to power, the MIL 1553 Bus and to 4 direct commands from the launcher for valve switching
- The instrument warm units have electrical I/Fs to the SVM (power, signal etc.) The accommodation of these I/Fs will be (defined/developed) performed by the SVM supplier.

5.11 Cleanliness

The applicable cleanliness requirements for the Herschel satellite system are defined in the Herschel / PLANK Cleanliness Requirements Specification, H-P-1-ASPI-SP-0035. The particle and molecular contamination requirements for the a.m. document have been derived with the help of the Contamination Working Group which was led by ESA and which was supported by all involved parties inclusive the instrument representatives.

For Herschel a specific EPLM Cleanliness Requirements Specification will be issued to cover the special needs of a cryogenic system. This document is based on the ASPI Herschel / PLANK Cleanliness Requirements Specification.

5.11.1 Basic Cleanliness Definitions for the Herschel H-PLM

There are three distinctly different areas where cleanliness has to be well defined to individual 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-PLM, together with transport conditions and test chamber environments.

5.11.2 He Subsystem Cleanliness

The subject of this chapter is the inside of He tubing and tanks only, 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.

5.11.2.1 Particle Contamination of the HERSCHEL 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 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 should 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.

5.11.2.2 Molecular Contamination of the HERSCHEL 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 more or less 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.

5.11.3 Cryostat Vacuum Vessel (CVV) Cleanliness

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

5.11.3.1 ISO Experience

Contamination of the experiments by particles was the main driver for extensive use of the class 100 cleanroom during H-PLM Integration. A detailed justification is given in ISO document ISO AS 1300 TN 0429 (ISO Cleanliness Policy) which will be considered for the establishing of the Herschel EPLM Contamination Control Plan.

5.11.3.2 Proposed Particle Contamination Policy

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. 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 155 working days during 7 months. Refurbishment after qualification takes another 64 working days during 3.5 months. Assuming the system to be covered during all inactivity periods (½ day per workday) leads to an effective exposure duration of 110 days. In a class 100 cleanroom the particle deposition rate is 1.5 ppm/day (ISO Cleanliness Policy, p. 33), resulting in an optical obscuration of 165 ppm at the end of all integration procedures. This total contamination could be improved by suitable cleaning procedures.

5.11.3.3 Molecular Contamination

The most likely 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 vapor 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 vapor 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
- 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. Outgassing measurements (VBQC tests) on actually used samples are suggested. A budget for all materials used inside the CVV has to be established. ISO experience resulted in two necessary procedures: Plastic components had to be vacuum 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 suitable bake out period and temperature profile has to be derived for HERSCHEL from the above mentioned budgets.

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 and analysed in more detail, 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 manoeuvering 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.

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

5.11.4 Outside Cleanliness

The outside cleanliness also encompasses the cleanliness of the telescope mirrors. The recommended approach is to clean the outside as close as possible to the launch, e.g. by vacuum cleaning. Particle contamination of the outside will be mainly accumulate on the launch pad and the journey to L2. Special cleaning procedures before launch for selected 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, comparable to launch conditions, additional efforts for selected areas will be discussed.

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

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

5.12 Alignment

5.12.1 Set Up Requirements

5.12.1.1 CVV Configuration for Alignment Measurements

CVV Cover

The CVV Cover does not incorporate an optical window for alignment measurements on the Optical Baseplate (OB) or on the instruments (FPUs) with closed cover and in cold cryostat conditions. So no alignment measurements from vertically above (i.e. sighting line in -X) and into the cryostat are possible when the cover is closed and therefore also no end-to-end test. However, in the EQM programme it is possible to switch on the LOU and determine the signal strength at HIFI which will verify correct alignment of the LOU w.r.t. HIFI.

Lateral CVV windows

1. Arrangement of Lateral Alignment Windows.

Without "cavity" only horizontal, lateral measurements (i.e. sighting lines in Y and Z) will be performed when the cryostat is closed. This method basically requires two lateral windows in the CVV at 90 deg to each other. One of these can be one of the already planned 2 LOU alignment windows at -Y, the second is an additional one at -Z .

(REMARK: Omission of the possibility to look into the FPUs optical paths with closed cryostat means the omission of a convenient method for instrument recognition and analysis of failure,!)

2. Special Arrangement of Lateral Alignment Windows (Baseline).

A further restriction of the number of the lateral alignment windows i.e. omission of the -Z window is basically possible if both LOU alignment windows are used. The special alignment camera as proposed by HIFI will be used for the alignment of the LOU w.r.t.

HIFI and also for alignment monitoring during the whole AIV programme. With this arrangement, however, it is not possible to measure distances in y direction. In course of phase B it will be clarified with the help of a thermal mechanical model which takes into account the in-orbit effects if we can rely here on mechanical tolerances.

Remark: Alignment windows in the CVV wall represent an additional risk in view of the possibility that such a window might break. Therefore, the number of alignment windows has to be restricted to the absolute minimum. This means, that the alignment cheks after closing the CVV has to rely to the extent possible on inevitably available windows, such as the LOU alignment windows. Other windows will probably not be acceptable (failure risk, technical complexity, lifetime . . .)

Table 5.12-2 Possible Arrangement of Lateral CVV Windows for Alignment Measurements with Closed CVV

No	Required Cubes on OB	Number of additional)* Alignment Windows	Measurement of	Missing Value	Remark
01	2 OB cubes	2 (at +Y; -Z)	Xpos, Ypos, Zpos; Xrot, Yrot, Zrot	none	complete measurement
02	1 OB cube 1 HIFI cube and 1 LOU -Y window	1 (at -Z)	Xpos, Ypos, Zpos; Xrot, Yrot, Zrot	none	complete measurement (baseline method)
03	2 HIFI cubes and 2 LOU-Y windows	**none**	**Xpos, Zpos, Xrot, Zrot, Yrot** derived from Xpos on the 2 LOU-windows	Ypos	**Ypos** to be measured on HIFI with laser distance metre /decreased Ypos and Yrot accuracy

)* additional alignment window means additional to the already existing 2 LOU-alignment windows

5.12.1.2 Required Alignment References and Devices on CVV, OB and Instruments

Optical Bench (OB)

The OB forms a common baseplate for the three instruments and incorporates a central alignment cube (OBC1) with reticles. It represents the OB coordinate axes for instrument to OB alignment and OB to CVV alignment.

If the CVV is closed, sighting is of course only possible through the two additional LOU alignment windows.

Instruments (Focal Plane Units, FPU)

Each instrument has to be equipped with a reference mirror cube (or with flats) with reticles representing its optical axis (position and direction of optical axis). HIFI has to be equipped with two additional alignment mirrors for LOU alignment.

CVV

The CVV is equipped with at least two alignment cubes mounted at opposite positions on the circumference of the CVV cylinders upper part. They serve as references for the later telescope accommodation. The cubes mirror faces indicate the direction of the CVV cylinders axis of symmetry.

For the nominal case this axis shall coincide with the direction of the telescopes optical axis. The reticles on the cube faces are located at known distances from the position of the CVV cylinders axis of symmetry and serve as references for the required position of the telescope optical axis.

For fine alignment of OB/HIFI to CVV the two LOU alignment windows on the -Y side of the CVV upper dome must be equipped with reticles in their centres for position measurements and their autocollimation figures shall be usable as references for the direction of the CVV coordinate axes.

5.12.2 Alignment / Measurement Plan

5.12.2.1 Alignment at OB Level

At the beginning of the STM programme, Instrument Dummies are integrated on the Optical Bench (OB). By the aid of their own alignment references and an alignment reference which is directly fixed on the OB they are aligned to the OB. This alignment can be performed on an optical set up outside the CVV. Afterwards the OB is mounted within the CVV and aligned to the CVV using the OB reference and the CVV references. For the PFM programme the dummies are later exchanged with the real instruments without removing the OB from the CVV. Instrument to OB alignment has therefore to be performed within the CVV (with CVV Upper Dome removed).

5.12.2.2 Alignment at CVV Level

Figures to be measured:

1. Axial defocus: Linear deviation of Instrument focus position from nominal Telescope focus position along TEL X-axis.
2. Lateral deviation: Linear deviation of Instrument FOV centre (centre of Instrument focus) from nominal Telescope FOV centre (centre of TEL focus) measured perpendicular to TEL X-axis i.e. along TEL Y- and Z-axis.

It should be noted that as each instrument FOV cuts out only a part of the whole TEL FOV, a dedicated nominal lateral defocus value is given for each instrument. (It is correlated with the "Tilt" number beneath – but it is not the same!). If the actual lateral defocus value is compared to this nominal value a lateral defocus error can be derived.

3. Tilt (or axis alignment): Angular deviation round TEL Y- and Z-axis of Instrument optical axis from connecting line between Telescope Secondary Mirror (=TEL exit pupil) centre and each individual Instrument FOV centre.

Note: As each instrument FOV cuts out only a part of the whole TEL FOV, this line includes a dedicated nominal tilt angle with the connecting line between Telescope Secondary Mirror centre and TEL FOV centre (=Telescope back optical axis (TELBO)). If the actual Tilt value is compared to this nominal value a Tilt error can be derived.

4. Roll alignment: angular deviation of each instrument round its optical axis from its nominal rotational position. For the OB roll alignment means rotational alignment of the OB round X relative to the Telescope.

Note: that OB Roll alignment is not critical for PACS and SPIRE but is crucial for HIFI because of the HIFI to LOU-window alignment.

Alignment measurements of the above figures will be performed by sighting the optical reference cubes of the instruments, the OB cube and the HIFI reference mirrors which are used for the LOU alignment

5.12.2.3 Alignment Methods / Set Ups

General

The Herschel PLM alignment applies two different kind of measurements:

- **Autocollimation for all angular measurements.**
- **Axial and lateral (i.e. vertical and horizontal) linear translations.**

The equipment used to perform these measurements is:

- **Theodolites with autocollimation capability for angular rotations.**
- **Linear measurement device plus theodolite for distance measurements.**

CVV Cubes

The CVV coordinate system is initially defined as follows:

1. Direction of X-axis is given by the normal of the CVV flange plane for the upper dome. It is visualised by a flat reference mirror upon an auxiliary CVV flange plate which is removed after CVV cube calibration. Position of the X-axis is given by the centre of a mechanical CVV diameter visualised by marks on the outer circumference of the CVV which can be sighted from above.

2. X-rotation of Z-axis is also given by the mechanical CVV diameter marks i.e. Z-axis runs perpendicular to X-axis and through the CVV marks.

3. Y-axis is perpendicular on X and Z.

The lateral positions w.r.t. the CVV Cube can be measured via the CVV cube reticles. Rotations w.r.t. the CVV cube can be measured via autocollimation w.r.t. the CVV cube faces.

Optical Bench with Instruments on CVV

This alignment step will be performed using the CVV cube and the OB cube as references for rotational axial and lateral alignment. It must be noted that HIFI / OB has to be aligned to the TEL interface as well as to the LOU- windows. The HIFI to LOU-window alignment is considered to be the more critical one. To fulfil both conditions at the same time, the size of the LOU windows must have some margin.

LOU to HIFI

The LOU alignment w.r.t. the HIFI FPU will be performed using the dedicated alignment cameras as proposed by HIFI. These cameras are capable of detecting rotational and lateral deviations except in y direction (which is, however, rather uncritical) TBC.

Note:
For all alignment work a verification of the influence of gravity on alignment should be considered. LOU to HIFI is especially critical in this respect.

Alignment measurements shall be performed:

- at ambient conditions taking into account the in-orbit effects
- at cryoconditions in laboratory
- before and after vibration tests
- before and after TV tests.

5.12.2.4 Flow Chart of HERSCHEL Alignment for STM and PFM

Adjustment of OB Cubes to OB	Incoming Inspection of FPUs

Integration and Alignment of FPU Dummies to OB for STM	Integration and Adjustment of CVV Cubes to CVV

Integration of OB into CVV and alignment of OB to CVV	Adjustment of 7 LOU IR windows and 2 LOU Alignment windows to CVV Upper Dome

Mounting of Upper Dome on CVV and adjustment to CVV cylinder

Alignment Check of LOU windows to CVV Cubes and to HIFI

Alignment of LOU w.r.t HIFI dummy-FPU

Integration of Cover and Cold tests with FPU Dummies incl. Alignment Measurements for STM

Dismounting of Cover and Upper Dome

Exchange of FPU Dummies with real FPUs and FPU Alignment to OB for PFM

Remounting of Upper Dome and readjustment to CVV

Fine Alignment of HIFI/OB to LOU windows and to CVV Cubes using the tank straps

Integration of LOU on CVV and Alignment of LOU to LOU windows and HIFI

Alignment Check in cold conditions using the HIFI alignment cameras

Telescope Integration and Alignment

5.12.3 Alignment Budget

5.12.3.1 HIFI and LOU to LOU-windows

The following alignment budget still represents the status of the proposal. An update is in preparation which may lead to certain modifications which are not included in the tables following hereunder. Similarly the spectrum of the in-orbit effects is not yet complete. The full spectrum of these effects will be considered in detail within the next update.

Requirements

The LOU/HIFI Alignment Sequence will be as follows.

1. Alignment of HIFI to the 7 LOU IR-windows on the CVV Upper Dome by the aid of the 2 LOU-alignment windows.
2. Alignment of LOU to the 2 LOU-alignment windows.
3. Alignment Check of LOU to HIFI.

Allowed tolerances for the alignment of LOU to HIFI given by the HIFI manufacturer					
ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
± 0.75	± 15 (uncritical)	± 0.75	± 0.038	± 0.11)*	± 0.038
)* derived from ΔX value on 400mm distance between left and right LOU-alignment window.					
Alignment stability of LOU to HIFI (100 sec)[for information]					
± 0.075mm	*± 0.003mm (critical)*	*± 0.075mm*	*± 0.003deg*	*± 0.04 deg*	*± 0.003deg*

Due to the transfer of the satellite from ground into orbit the following parameters will change:

1. outer CVV temperature and as a consequence CVV dimensions and straps pretension
2. gravity 1g → 0g
3. atmospheric pressure 1bar → 0bar

These effects have to be pre-compensated by a corresponding off-set alignment of the LOU on ground.

From these values the alignment requirements for HIFI to LOU-windows and LOU to LOU- windows can be derived:

Required tolerances for HIFI to LOU-Windows alignment (RMS values)					
ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
± 0.53 *Foc.lat.*	± 5)* *Foc.axial*	± 0.53 *Foc.lat.*	± 0.027 *Tilt*	± 0.076deg)** *Roll*	± 0.027 *Tilt*
Required tolerances for LOU to LOU-Windows alignment (RMS values)					
ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
± 0.53	(uncritical)	± 0.53	± 0.027	± 0.076deg)**	± 0.027

(designation of coordinates i.e. Foc.axial, lateral, roll tilt refer to HIFI Instrument plane)
)* FPU to TEL requirement on H-PLM level for Focus axial
)** derived from ΔX value on 400mm distance between left and right LOU-alignment window

Achievable Alignment Accuracies

A detailed analysis leads to the following alignment uncertainties.

HIFI to LOU Windows Alignment

Rotational uncertainties round X and Z: ± 0.0022deg (rms)
(This corresponds to a linear error at the LOU-window position of ±0.013 mm)
Rotational uncertainty round Y: ±0.04 deg
Position uncertainties along X and Z (Ypos is uncritical): ±0.25mm (rms)

LOU to LOU Windows Alignment

Rotational uncertainties round X and Z: ±0.0022deg (rms)
(This corresponds to a linear error at the LOU window position of ±0.013 mm)
[The corresponding worst case values would be ±0.005deg and ±0.03 mm]

Rotational uncertainty round Y: ±0.04 deg
Position Uncertainties along X and Z (Ypos is uncritical): ±0.25 mm (rms)
[Corresponding worst case value ±0.6 mm]

Structural Experience from Project ISO (LOU to HIFI derived from ISO STR to instrument effects)

	Item	Rot.	Pos.
1	Expected rotational ground to orbit transition effect on LOU (Zrot only)	+ 0.015deg)*	
2	Settling effects derived from TV test (Xrot, Yrot, Zrot)	0.02deg	
	Zrot = Sum 1 + 2 (worst case)	± 0.035deg)**	^0.2mm
	Xrot, Yrot	± 0.02 deg	^0.12mm
3	Expected position ground to orbit transition effect on LOU (assessment)		0.2mm)*
4	Uncertainty of shrinking effect of vacuum vessel		±0.2mm)***
	Total position uncertainty <u>(RMS)</u> (from Zrot): Total position uncertainty <u>(RMS)</u> (from Xrot, Yrot):	Zpos= Xpos; Ypos =	±0.35 mm ±0.31 mm
	Total position uncertainty <u>(worst case)</u> (from Zrot): *Total position uncertainty <u>(worst case)</u> (from Xrot, Yrot):*	*Zpos=* *Xpos; Ypos =*	*± 0.6 mm* *± 0.52 mm*

)* due to in orbit change of: 1.) outer CVV temperature and straps pretension, 2.) gravity, 3.) atmospheric pressure (can be compensated to some extent by pre-compensation)
)** leads to a linear offset at the LOU windows of 0.2mm (~330mm distance) [for determination of the required LOU window diameters the linear LOU beam offset (translation value) is the important figure!]
)***shrinking effect of Al for the expected ΔT: 0.004 (4 ‰) is known with an accuracy of 5%; assumed length: 900mm; shrinking consequently: 3,6mm; shrinking uncertainty: 5% of 3,6mm = 0.2mm

Summary LOU / HIFI

Allowed Tolerances for LOU to HIFI Alignment					
ΔX mm	ΔY mm	ΔZ mm	θx deg	θy deg	θz deg
± 0.75	(± 15)	± 0.75	± 0.038	± 0.11	± 0.038

1. Required Tolerances for HIFI to LOU-Windows and LOU to LOU-Windows Alignment					
ΔX mm	ΔY mm	ΔZ mm	θx deg	θy deg	θz deg
± 0.53 *Foc.lat.*	± 5)* *Foc.axial*	± 0.53 *Foc.lat.*	± 0.027 *Tilt*	± 0.076 *Roll*	± 0.027 *Tilt*

)* Telescope Focus axial requirement for HIFI

2.) Expected alignment accuracy of HIFI to LOU-window alignment					
ΔX mm	ΔY mm	ΔZ mm	Θx deg	θy deg	θz deg
±0.26		±0.26	±0.0022	±0.037	±0.0022
3.) Expected alignment accuracy of LOU to LOU-window alignment					
ΔX mm	ΔY mm	ΔZ mm	Θx deg	θy deg	θz deg
±0.26		±0.26	±0.0022	±0.037	±0.0022
4.) Structural uncertainty (derived from ISO STR)					
±0.31	±0.31	±0.26)*	±0.02	±0.02	±0.02)**

5.) RMS values from 2.) and 3.) and 4.) to be compared with the allowed tolerances for LOU to HIFI alignment					
±0.48		±0.45)*	±0.02	±0.056	±0.02)**

)* pre-compensation of 0.1mm applied!)** pre-compensation of 0.015deg applied!

The above table shows that the required tolerances can be achieved.

Required Size of LOU Windows

The really needed free LOU-IR windows diameters for LOU beams with 30 mm diameter which must not be vignetted is 34 mm. This value has been derived by considering the worst case position uncertainties (Xpos, Zpos) of the LOU beams at the LOU windows.

5.12.3.2 Instrument to CVV Alignment

Requirements

Required Accuracies for FPU to OB Alignment)*						
	ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
SPIRE	± 3 Foc.lateral	± 3 Foc.lateral	± 4.97 Foc.axial	± 0.13 Axis	± 0.13 Axis	± 0.5 Roll
PACS	± 3 Foc.lateral	± 3 Foc.lateral	± 4.97 Foc.axial	± 0.13 Axis	± 0.13 Axis	± 0.5 Roll
HIFI	± 3 Foc.lateral	± 4.97 Foc.axial	± 3 Foc.lateral	± 0.13 Axis	± 0.13)** Roll	± 0.13 Axis
Required Accuracies for OB to CVV Alignment)*						
	± 0.5 Foc.axial	± 0.5 Foc.lateral	± 0.5 Foc.lateral	± 0.017 Roll	± 0.017 Axis	± 0.017 Axis
Total Accuracy Requirements for FPU to CVV Alignment (see Alignment Plan SCI Pt-Pl- 02220)*						
	ΔX mm	**ΔY mm**	**ΔZ mm**	**θx deg**	**θy deg**	**θz deg**
	Foc.axial ± 5	Foc.lateral ± 3.04	Foc.lateral ± 3.04	Roll ± 1	Axis ± 0.13 (8 arcmin)	Axis ± 0.13 (8 arcmin)

Note that the assignment of denominations Focus axial, lateral, Roll and Tilt are different for the Optical Bench and the different FPUs.

)* The alignment requirements of the FPUs to OB are not stringent enough for the critical HIFI to LOU-Windows alignment (LOU-windows are situated in the CVV wall). Therefore the Optical Bench with the 3 instruments has to be aligned to the CVV using HIFI as a reference such, that the HIFI to LOU-window alignment requirements are fulfilled.

)** high HIFI Roll alignment accuracy required because low accuracy would decrease SPIRE and PACS tilt alignment values too much when OB is aligned to CVV using HIFI as a reference.

Achievable Alignment Accuracies

Achievable Accuracies for FPU to CVV Alignment

	ΔX mm	ΔY mm	ΔZ mm	θx deg	θy deg	θz deg
	± 1	± 0.4)*	± 0.4)*	± 0.005)**	± 0.005)**	± 0.005)**

)* FPU cube uncertainty (0.1mm) + measurement uncertainties on: FPU cube (OB level:0.1mm) +OB cube (OB level:0.1mm) + adjustment resolution (OB level:0.1mm)+ OB cube (CVVlevel:0.2mm) + CVV cube (CVV level:0.2mm) + adjustment resolution (CVV level:0.2mm) = ± 0.4mm RMS
)** FPU cube uncertainty (2mdeg) + measurement uncertainties on: FPU cube (OB level:1mdeg) + OB cube (OB level:1mdeg) + adjustment resolution (OB level:1mdeg)+ OB cube (CVV level:2mdeg) + CVV cube (CVV level:2mdeg) + adjustment resolution (CVV level:2mdeg) = ± 4,4mdeg RMS
Note: Due to FPU arrangement upon OB a rotation round any axis influences a Tilt angle of an Instrument. Therefore high alignment accuracy is required round all axes.

The required alignment accuracies can be achieved.

5.12.3.3 TEL to CVV Alignment

Required Accuracies

	ΔX mm	ΔY mm	ΔZ mm	θx deg	θy deg	θz deg
TEL	± 4)*	± 1	± 1	± 1	± 0.017 (1arcmin)	± 0.017 (1arcmin)

Achievable Accuracies

	± 1	± 0.3	± 0.3	± 0.008	± 0.008)**	± 0.008)**

)* Ref [Alignment Plan SCI Pt-Pl- 02220] Tel tolerance: ± 9mm (including ± 5mm orbit variation)
)**Knowledge of CVV cube: ± 0.003°; knowledge of TEL cube: ± 0.003°; measurement accuracy on each cube: ± 0.001°; shimming increments: ± 0.006° (0.1mm on 1m) Total (rms): ± 0.0075°.

REMARK: A detailed description of the payload alignment is given in "Herschel Alignment Concept", Doc.-No.: HP-2-ASED-TN-0002.

5.12.4 Figures

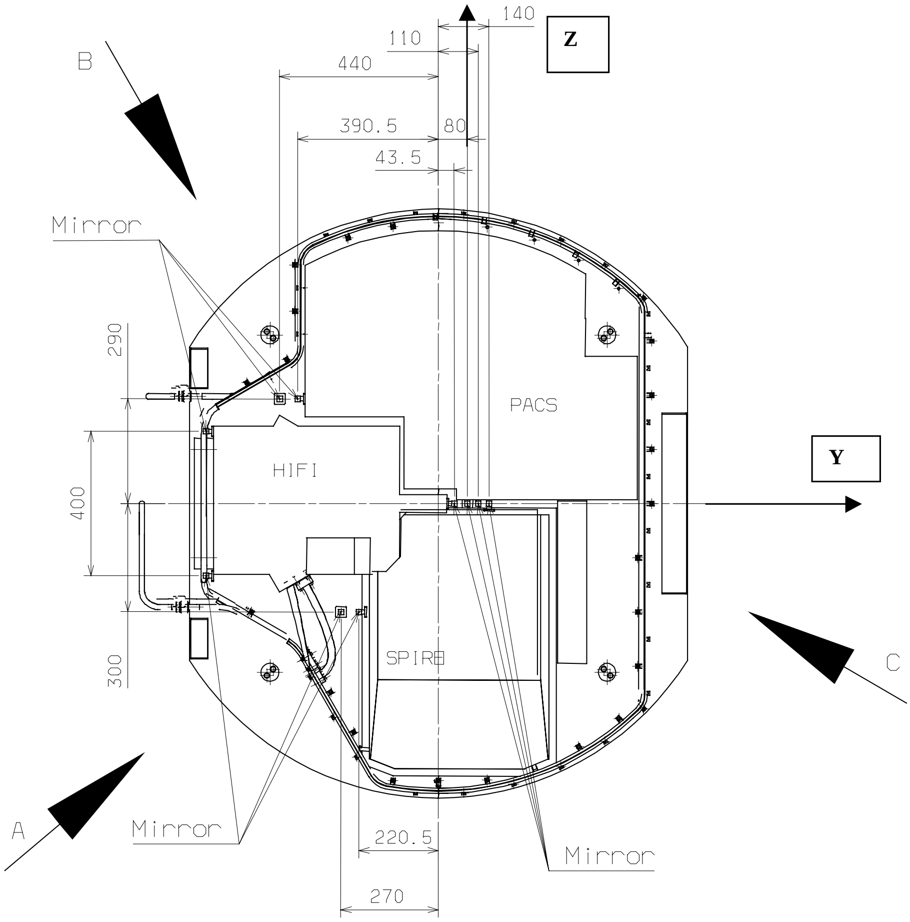


Figure 1.1-1 Optical Bench (OB) on CVV [Perspective View]

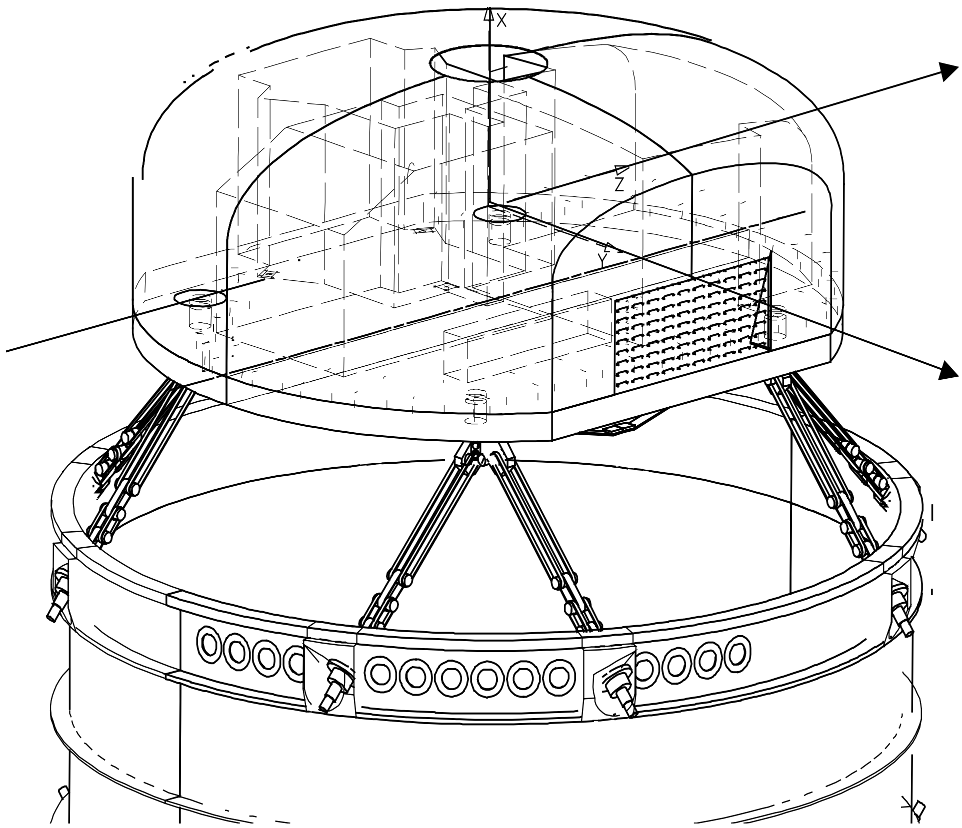


Figure 1.1-2 Optical Bench (OB) on CVV [Perspective View]

5.13

5.13 Straylight

5.13.1 General

A number of straylight analyses have already been performed in the past with the APART/PADE software. It was performed for old S/C and instrument configuration and old orbital conditions of the S/C.

These preliminary analyses only considered the wavelength range of 85-320 µm. At least one of the instruments is sensitive up to a wavelength of 670 µm. New straylight calculations therefore will consider additional wavelength bands, where it is necessary. This mainly is the case for all phenomena where diffraction plays a major role. In the other cases, calculations performed for one worst case wavelength band could be sufficient.

For straylight calculations, the ASAP straylight program will be used. ASAP does not have the intrinsic (wide-angle) diffraction function, which APART has. Nevertheless, ASAP´s programming language is general enough so that simple wide-angle diffraction phenomena can be calculated too. In spite of this (user programmed) function needs considerable programming and calculation effort, ASAP is much more user friendly than APART.

In the FIRST Telescope Specification, PT-RS-04671, issue 3/0, it is said that "*the definition of the optical components and properties between the Primary reflector and the detector element, as far as relevant for the straylight verification, is called the PLM/Focal Plane Unit Straylight model and will be provided by ESA*". It is understood that ESA or instruments will supply straylight models containing the telescope geometry and the instruments internal geometry (written in ASAP, 3 different sub-models for the 3 different experiments). This then has to be completed by us for the cryostat internal geometry, and all necessary calculations to be done by us.

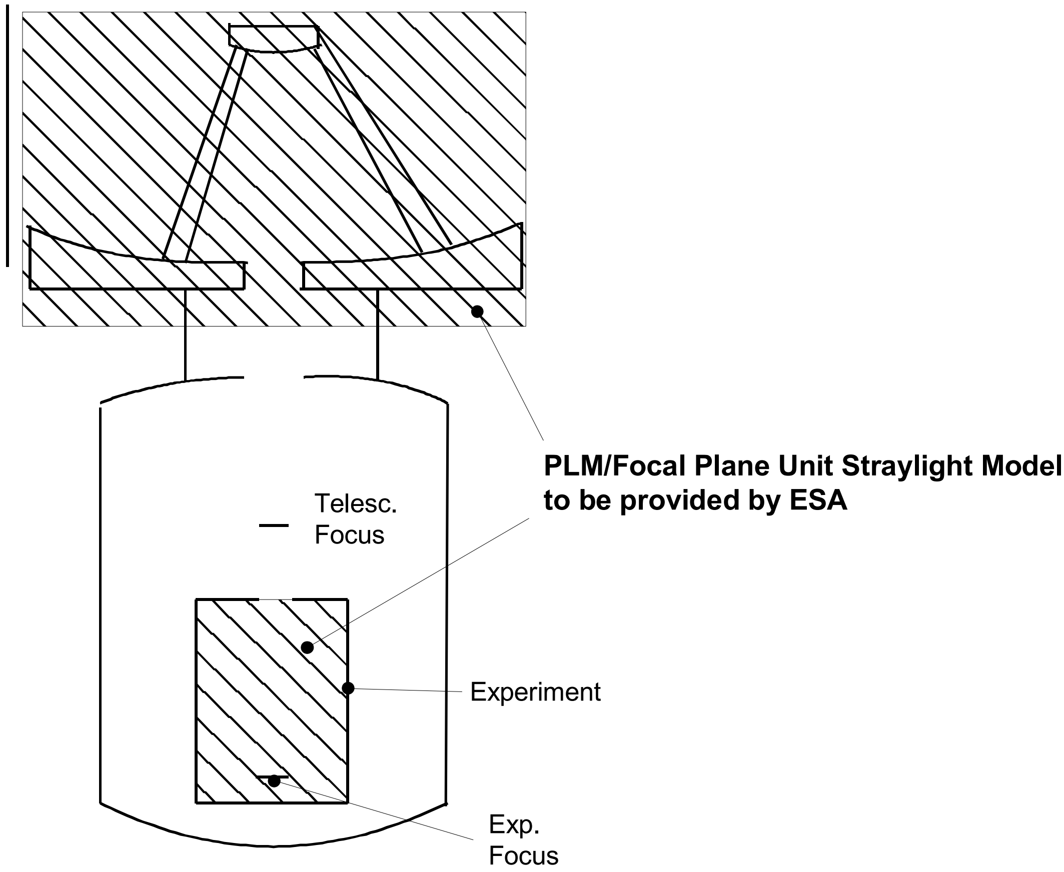


Figure 5.13-1: PLM/Focal Plane Unit Straylight Model

5.13.2 Straylight Cases

Straylight has to be considered in the wavelength range between 80 µm and 670 µm. It can occur from several different sources:

1. **Straylight from bright external sources such as sun, earth and moon, outside the telescope FOV.**

Requirement (TEPE-090 of FIRST Telescope Specification, PT-RS-04671, issue 3/0): *Taking into account the worst combination of the Moon and the Earth positions ... the straylight shall be < 1 % of background radiation induced by self-emission of the telescope.* It shall be verified by analysis.

An update of the former analysis will be given, and extended for additional wavelength bands. This update will be necessary due to changed S/C configurations, changed worst case positions of the straylight sources and changed wavelength range.

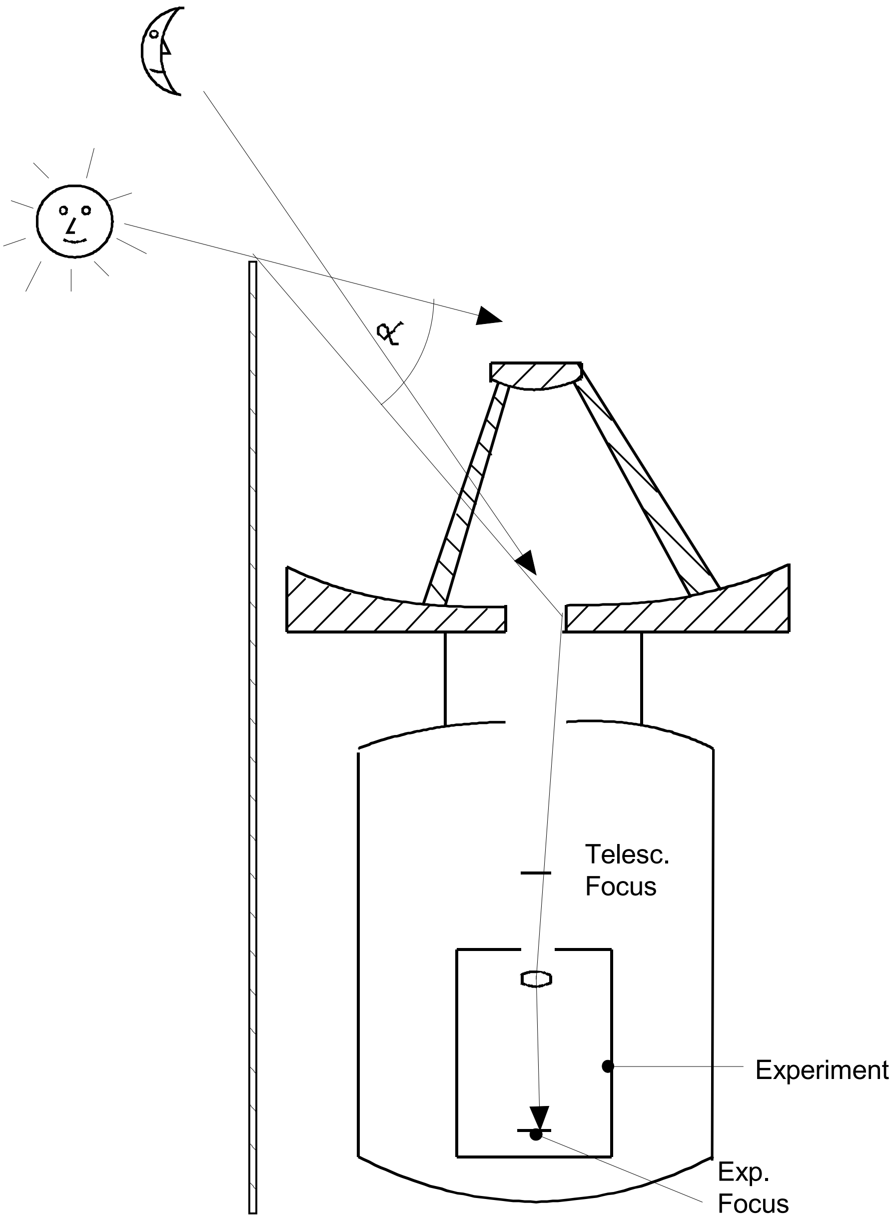


Figure 5.13-2: Worst Case Positions for Sun, Earth and Moon

2. Sources inside the FOV

Requirement (TEPE-095 of FIRST Telescope Specification, PT-RS-04671, issue 3/0): *Over the entire FOV at angular distances ≥ 3' from the peak of the point-spread-function (PSF), the straylight shall be < $1*10^{-4}$ of PSF peak irradiance (in addition to level given by diffraction)*. It shall be verified by analysis.

In meeting this requirement the question of the surface roughness and cleanliness of the primary and secondary telescope mirrors must be considered. An estimate of the irradiance at 3' worst case position from the peak of the PSF in the centre of the FOV will be made for the expected mirror surface roughness, and contaminated by up to 300 ppm particles (case a, tbc).

Secondly, sources inside the FOV may generate reflected ghost images. This mainly could occur because of reflection at the tripod struts and other tripod structures, if their surfaces can reflect specular into -X direction (which therefore should be avoided by design as much as possible). It is supposed that the sunshade inner surfaces are sufficiently far away in Z-direction from the main mirror outer rim, not to generate additional ghost images. The peak irradiance of such ghost images in relation to the direct image will be calculated for a few relevant cases within the FOV (case b).

Because of the effect of surface roughness and cleanliness, the short wavelength is considered the worst case, and the generation of ghost images is considered more or less independent of wavelength, these calculations will be made for one wavelength band only.

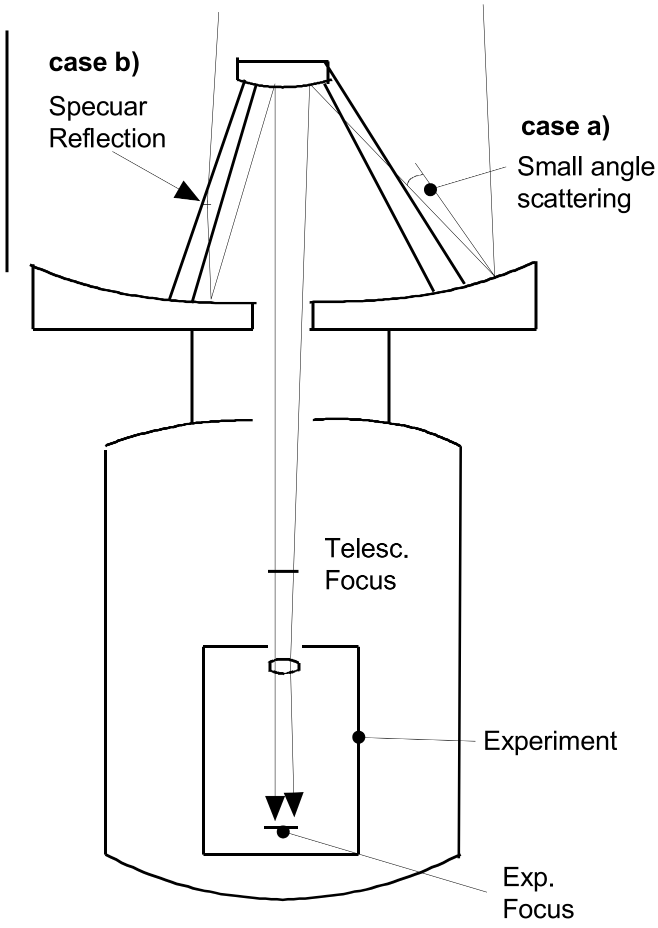


Figure 5.13-3: Sources inside FOV

3. Thermal self-emission from the telescope primary and secondary mirror and its support structure.

As these elements are in the detector's direct FOV, their contribution cannot be suppressed further. It therefore serves as a basis for the definition of the other straylight requirements. All other straylight contributions shall not exceed a certain percentage of this unavoidable contribution.

Nevertheless, this straylight contribution has to be re-calculated due to changed temperatures of the mirrors and to the changed diameter of the primary mirror. These calculations also have to be extended to the other wavelength bands not yet considered in previous analyses.

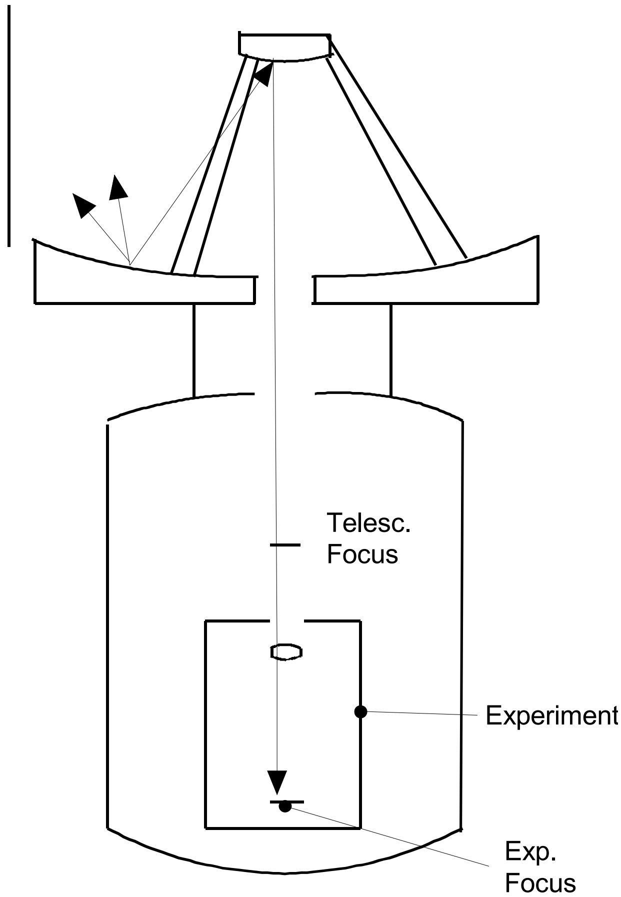


Figure 5.13-4: Thermal Self-emission from Telescope

4. Thermal self-emission from other structures (sunshade and structures inside the Cryostat cavity and the Cryostat Vacuum Vessel).

Requirement (TEPE-100 of FIRST Telescope Specification, PT-RS-04671, issue 3/0): *The straylight level, received at the defined detector element location of the PLM/Focal Plane Unit Straylight model by self emission, not including the self emission of the telescope reflectors alone, shall be ≤ 10 % (tbc) of the background induced by self emission of the telescope reflectors.* This straylight contribution shall also be verified by analysis.

An update of the former analysis will be given for the straylight levels in the PACS detector element location, and additionally the straylight levels in the detector element locations of HIFI and SPIRE will be calculated.

The calculations will again be made for the different wavelength bands, as far as relevant for the different instruments.

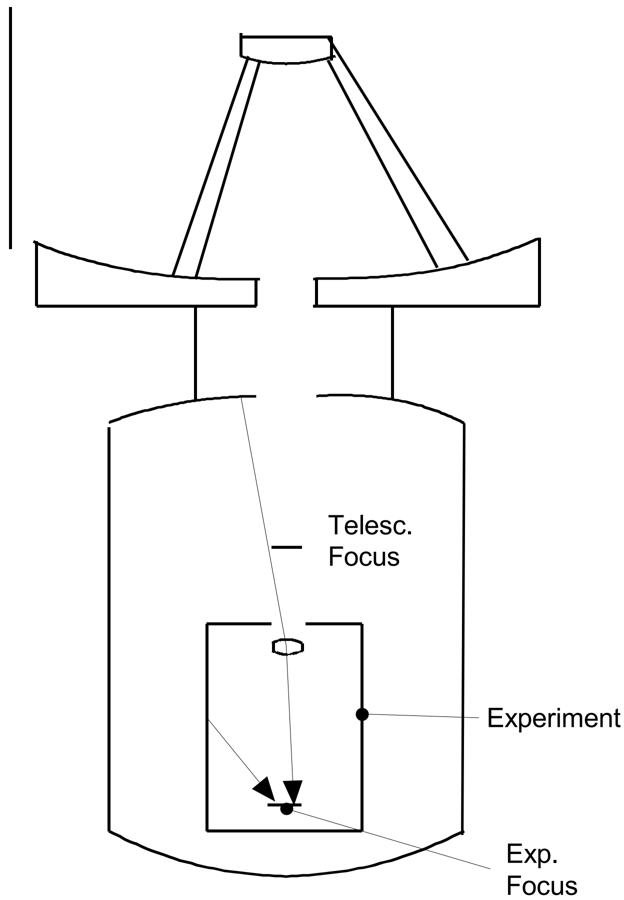


Figure 5.13-5: Thermal Self-emission from Other Structures

5. Straylight from the Local Oscillator.

Although there is no requirement yet, the mixer of the HIFI instrument could also suffer from straylight originating from the LO path. A rough estimate of straylight levels will be given, whether this is a significant contribution to total straylight or not (tbc).

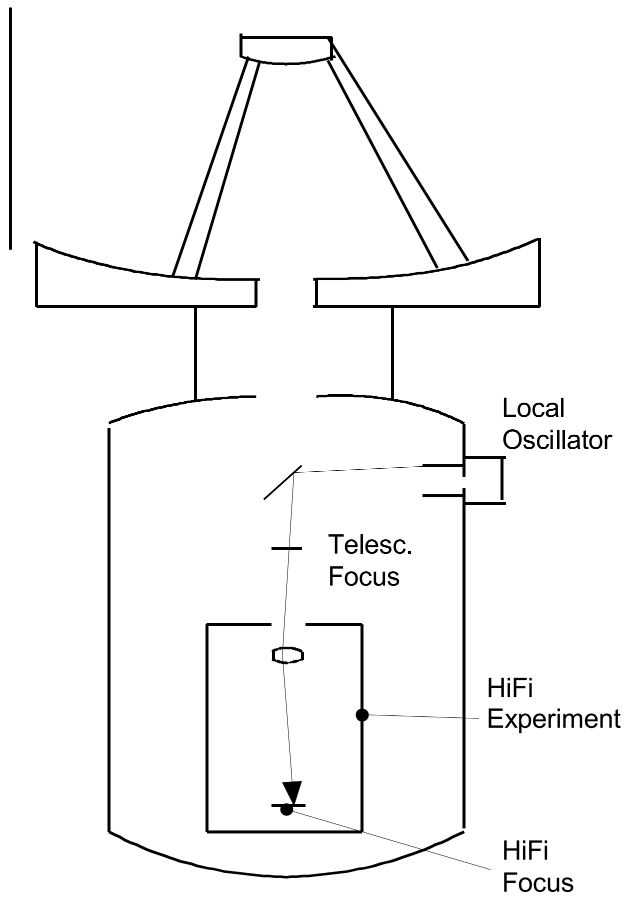


Figure 5.13-6: Straylight from LOU

5.13.3 Summary

The various straylight contributions will be considered with focus on the most important contributions, which appear to be the thermal self-emissions from the cryostat and from the instrument interiors.

5.14 Reliability and Safety Aspects

5.14.1 Objectives

The objective of the following chapters is to introduce the reliability and safety concepts, which are currently implemented in the EPLM design. The more PA related aspects about safety and reliability are provided in the PA Plan.

The reliability and safety aspects as introduced hereafter based on the design and experiences from the ISO program.

5.14.2 Reliability and Fault Tolerance

For the Cryo-Control-Electronics CCE design a reliability analysis will be performed to demonstrate that all reliability requirements are met.

The design principle of the CCE is based on the ISO CCU and consists of two hot redundant unit branches, both providing identical functions, with a metallic separation between them. Redundant temperature sensors connected to the CCE will be arranged thermal symmetrically but at different locations in the CVV design. 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 CCE.

FMECA

Failure mode, effect and criticality analysis is in preparation for the EPLM, 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 EPLM system design.

  - Single Point Failure Identification
    The identification and elimination of single point failures will be the prime objective of the FMECA effort.

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

  - internal leakage by valves
  - unwanted opening of valves
  - unwanted closing of valves
  - loss of Phase Separator function

A harness connector containing main and redundant leads within one connector housing, e.g. due to the small available space for all the connectors at the CVV, will be treated as a potential single point failure and as a minimum, one free pin between main and redundant will be provided. A new distribution of the signal and power lines is recommended.

The hold-down and release mechanism of the cryostat cover contains a further potential single point failure that is the release actuator, which provides the hold-down and release of the cover. A redundant design for the HDRM hold down can not be provided and therefore, this single point failure will be treated as a Waiver. A redundant actuator and opening drive will be implemented.

- Redundancy Concept

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

Following the ISO redundancy concept, 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.

All equipment and components including the test measurement equipment applied inside the CVV, e.g. the DCLM, heaters, thermistors, pressure sensors and accelerometers, are as far as possible, designed in a redundant configuration.

5.14.3 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 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 is in preparation 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 procedures defining quality 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.

EPLM Safety Concept

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

Cryostat Safety Philosophy

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 II tank and consequently a burst of the CVV is in the end prevented by a rupture disc (RD) flanged directly to the He II tank and by the corresponding safety relief valves at the CVV.

The rupture disc is designed to burst far below the burst pressure of the He II tank, 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 tank failure mode rupture appears by handling error, i.e. unintentional closure of valves
- Internal piping including the He I tank failure modes appear by handling errors as above and/or blockage of the system 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 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 including the He I tank - 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 - covered by “He-leak” case
- Air-Leak - covered by “He-leak” case
- 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 <u>worst case failure mode,</u> air will penetrate through a leak into the CVV and will condense on the walls of the He tanks. Due to the large

latent heat and the heat of condensation of air, the He II tank will worm up and consequently the He evaporation rate becomes high.

6 Subsystem Design

6.1 Structure Subsystem

6.1.1 Structure S/S Configuration and Components Overview

The structure S/S consists of the Cryostat Vacuum Vessel, the Optical bench, the Cryostat Cover, the Tank support system, the external structures and the Optical Feedthroughs.

6.1.2 Structure Components Description

6.1.2.1 Cryostat Vacuum Vessel

As its name indicates, the prime CVV-function is to provide a highly tight high-vacuum environment for the He-subsystem and thermal insulation system for the FIRST-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) shall act as a thermal radiator to reduce its temperature to approximately 70-80 K, and is therefore painted black.

As an essential cryostat component the CVV shall provide the following functions and penetrations/feedthroughs:

- Mechanical support for the internally suspended He-subsystem, thermal insulation system (heat shields), Optical Bench with Scientific Instruments on it.
- Two evacuation ports for high vacuum generation, both equipped with internal pressure safety relief valves.
- One LHe-filling port.
- One GHe-exit port.
- Mechanical support for external He-ventline and He-heater/filter
- One opening for the telescope beam (closed on ground, during launch and early orbit).
- A large number (number tbd) of electrical connector feedthroughs for scientific instruments and cryostat housekeeping functions.

- 7 + 2optical windows for the LOU-beams and alignment beams to the OB.

Additionally the CVV shall provide 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 6 or 8 BOLA-struts
- Mounting basis for ??14 (12) Sunshield/Sunshade-struts
- Mounting basis for cryostat cover (to be opened on orbit)
- Mounting basis for Cavity
- Radiator/Nose
- External Harness
- External MLI

The figure below shows an overview of the FIRST-CVV.

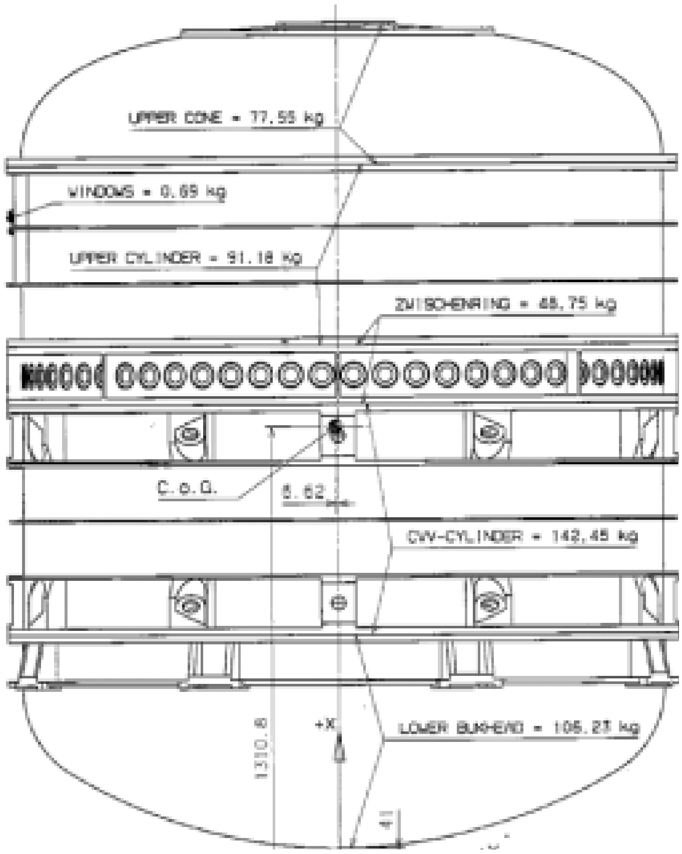


Figure 6.1-1 Cryostat Vacuum Vessel

The FIRST-CVV shall be principally designed in the same manner as ISO.
Due to the higher number of cryo harnes lines an additional ring in needed for the connectors.

- Lower Bulkhead, identical with the corresponding ISO-part. (Note: It may become evident during Phase B-design definitions that some mechanical support bases for the sunshield/sunshade may be necessary on the lower bulkhead).
- Main Cylinder, very similar to the ISO-CVV cylinder but 500 mm shorter.
- Upper Bulkhead and Skirt, different from the ISO-Upper Cone, but with the same connection flange to the main cylinder.

The CVV-parts shall be fixed to each other via their interface flanges by a total of 64 (TBC) high-strength Ti-alloy screws or bolts with nuts, respectively, for each of the two flange connections.

6.1.2.2 Cryostat Cover

The cryostat cover design shall be directly derived from the previously successfully flown IBSS-cover. The active IBSS-motor opening and closing mechanism will be replaced by a spring loaded swing-open device with hinges from successfully flown solar array panel hinges.

The opening release mechanism shall be a non explosive device (NED) with redundant release coils. The cover will swing open inside the cavity upon ground command and kept in an open position by a catching mechanism.

The Cover Subsystem shall provide the following main functions:

- Close and tighten CVV during ground and launch operations for insulation vacuum
- Safe single opening on orbit for start of scientific mission without unintended closure
- Ability to be reclosed on ground during operation with GSE Cavity
- Provide sufficient free entrance (260mm) for telescope beam into cryostat when open
- Provide an internal temperature as low as possible on ground, by a passive shielding

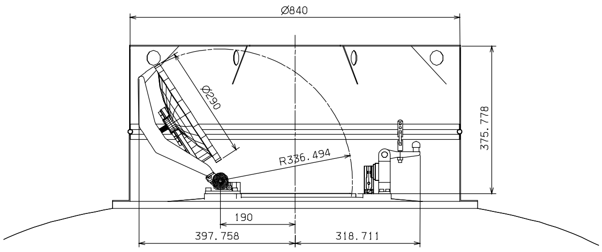


Figure 6.1-3: Cryostat Cover

6.1.2.3 Tank Support System

The tank support system form the load distributing structure between the Cryostat Vacuum Vessel and the main Hell-tank.

The tank support system consists of 2 Spatial Frameworks (SFWK), which are almost identical and 16 suspension chains with tension devices. The cross section suspension chains will be adapted to the stiffness and strength
needs.

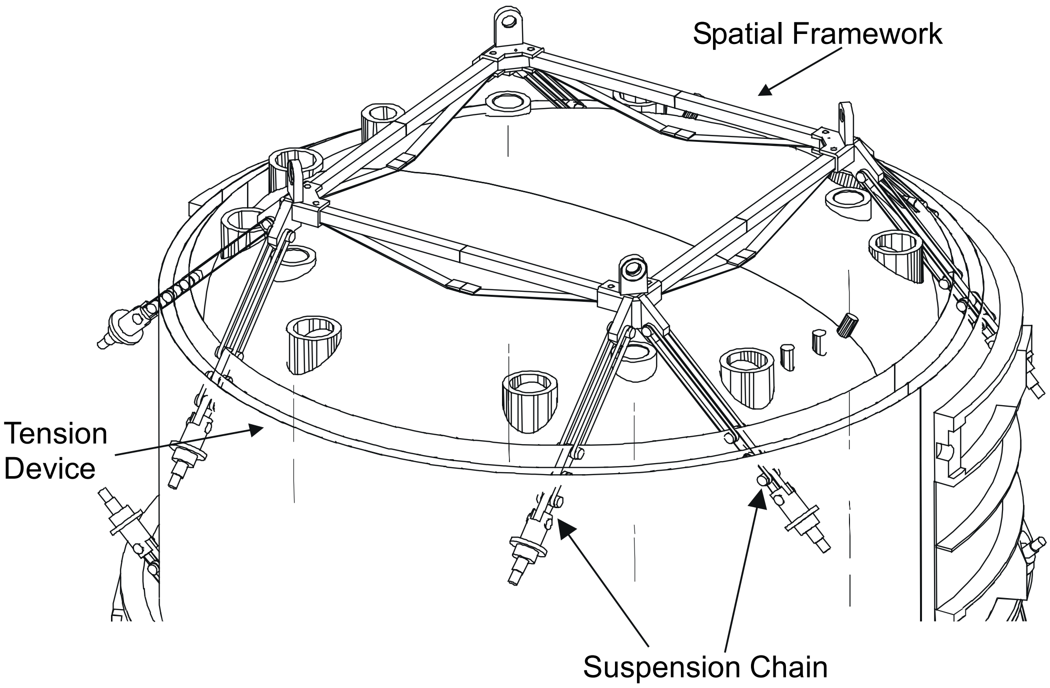


Figure 6.1-5: FIRST Suspension System

Suspension System

The suspension system consists of 16 tank suspension chains with tension devices. It is the load transferring element between the cryostat vacuum vessel (CVV) and the SFWK. The typical layout of the main HeII-tank suspension, the pretension device and the fixation of the vapour-cooled shields to the support straps shall comply with the figure below.

For thermal conductance reasons the inner strap loops from the innermost shield to the spatial framework are made from CFRP. The outer strap loops between the shields and between the shield 3 and the CVV are made from GFRP.

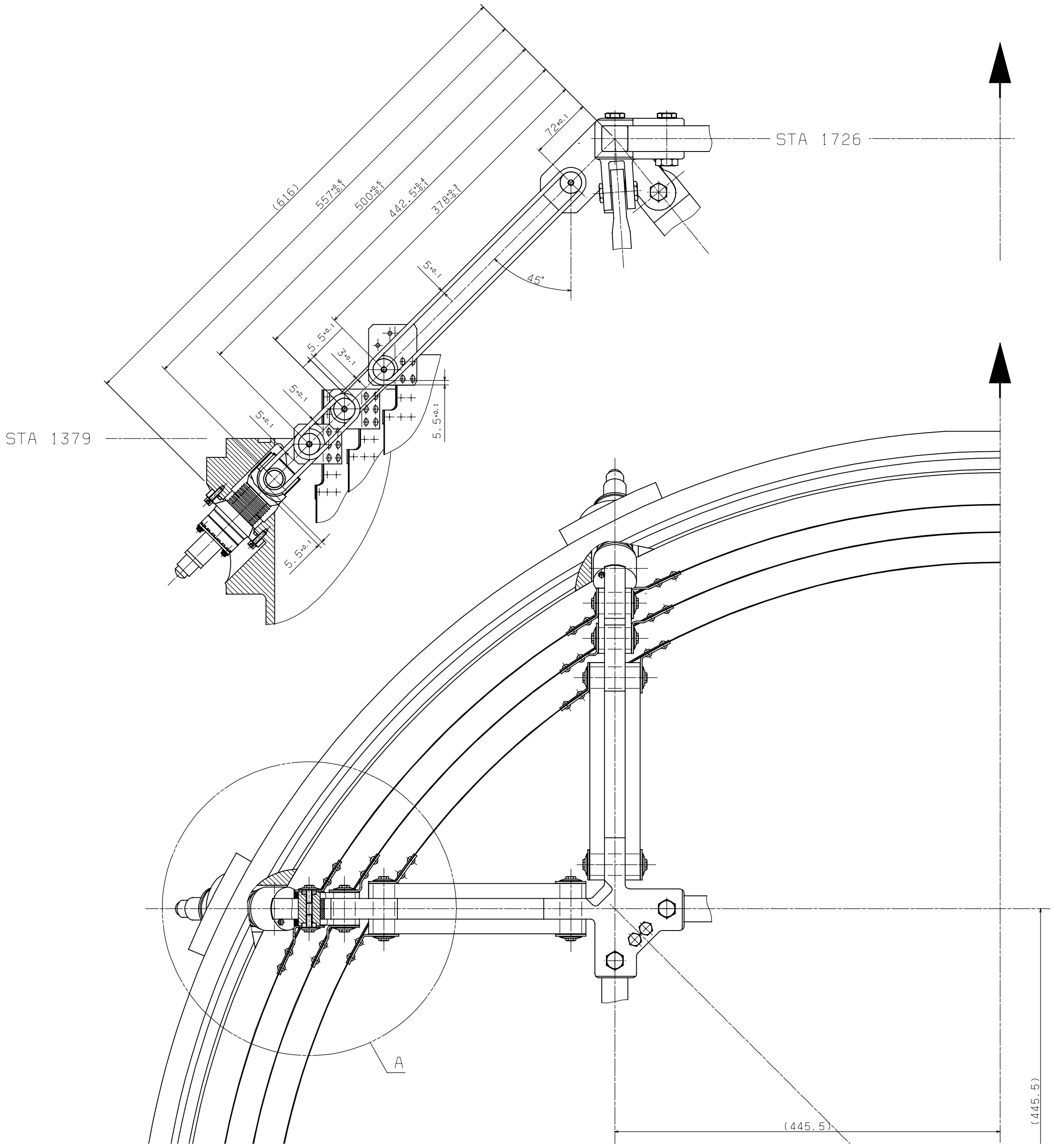


Figure 6.1-7: Tank Strap Design and Fixation of Shields

Spatial Framework

The lower SFWK is mounted to the lower HeII-tank mounting interface, the upper SFWK is mounted in an identical manner to the upper HeII-tank mounting interface. The only difference between the two SFWK 's is that the upper SFWK shall carry at its 4 corner brackets the Optical Bench assembly and the lower SFWK shall provide the mounting interface for the auxiliary HeI-tank.

The SFWK shall have, in top-view, the form of a square (main frame) with a side length (corner center to corner center) of 891 mm.

The nearly identical upper and lower frameworks shall form the load distributing structures between the 16 tank suspension straps and the main Helium II tank. According to the figures below, the Spatial Framework shall comprise the quadratic main frame, the corner brackets, 4 "tank bones" connecting the corner brackets with the HeII-tank and 4 lateral struts between the tank and the corner brackets

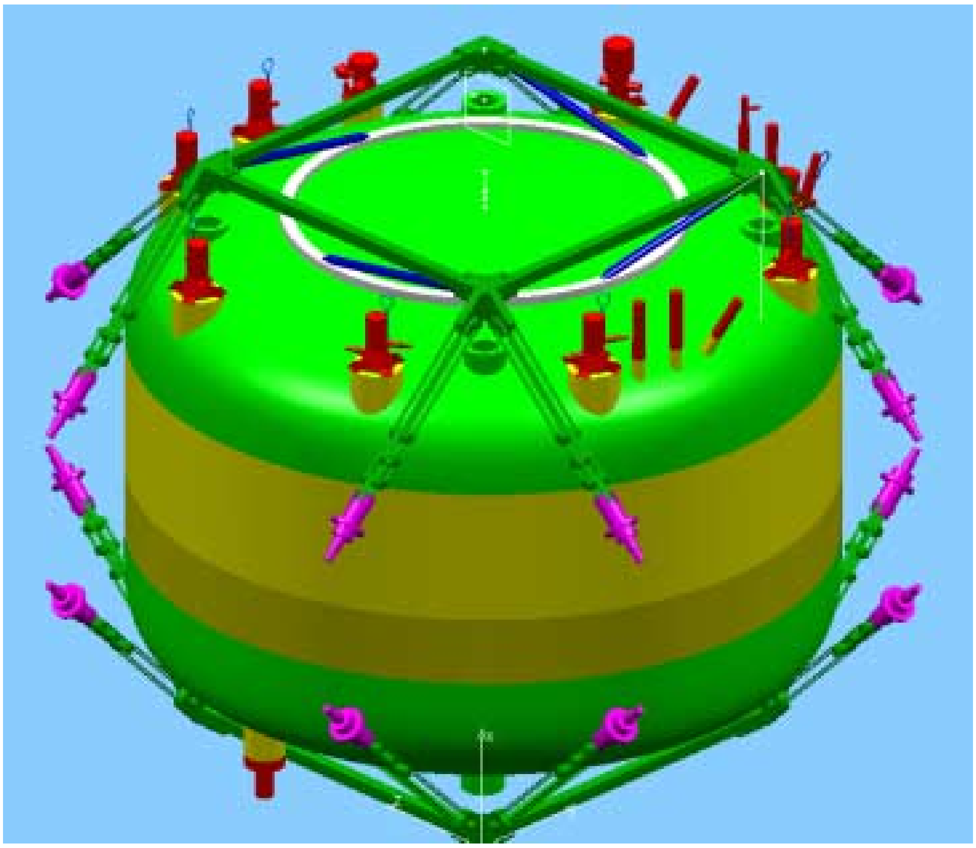


Figure 6.1-9: Upper Spatial Framework

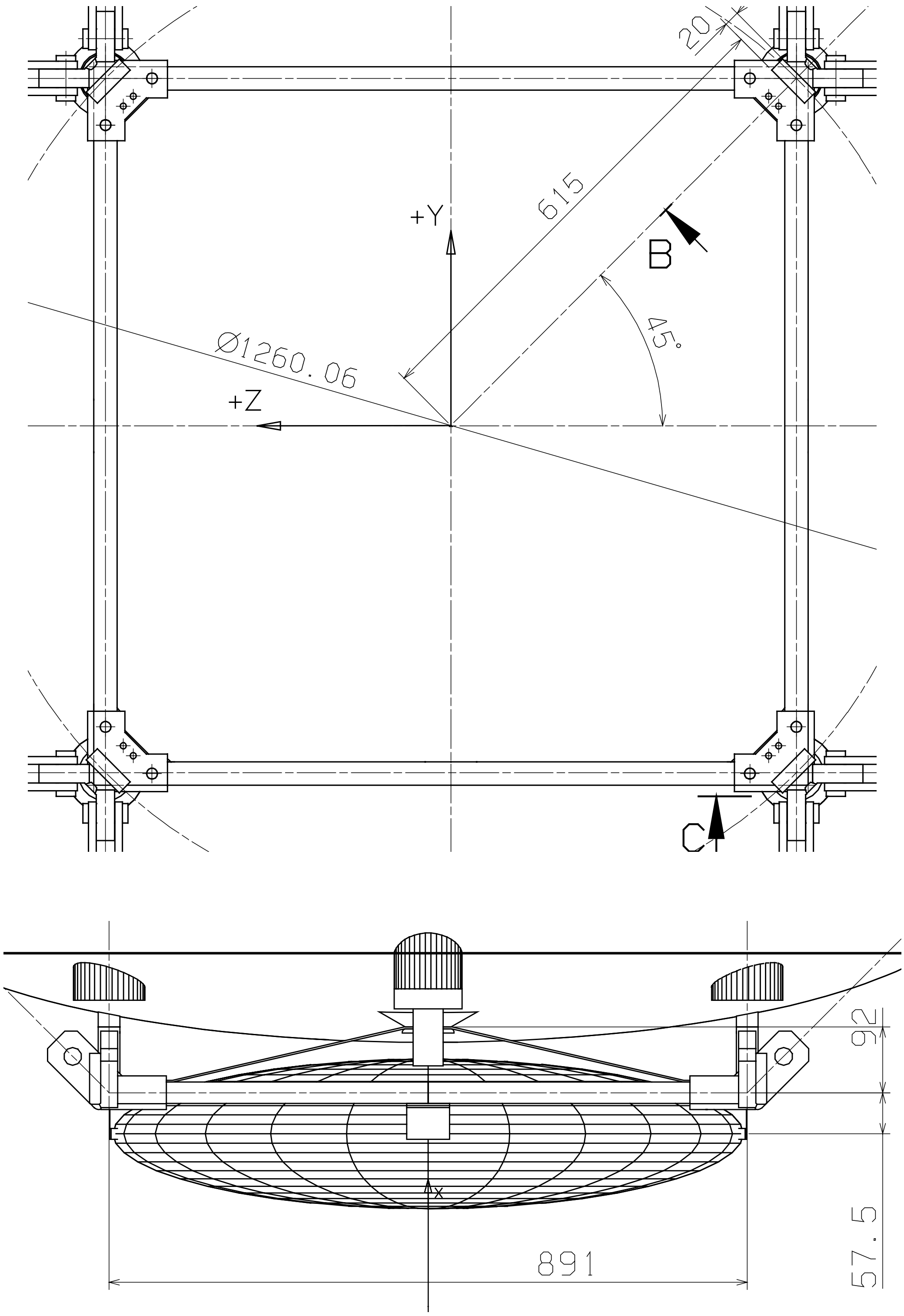
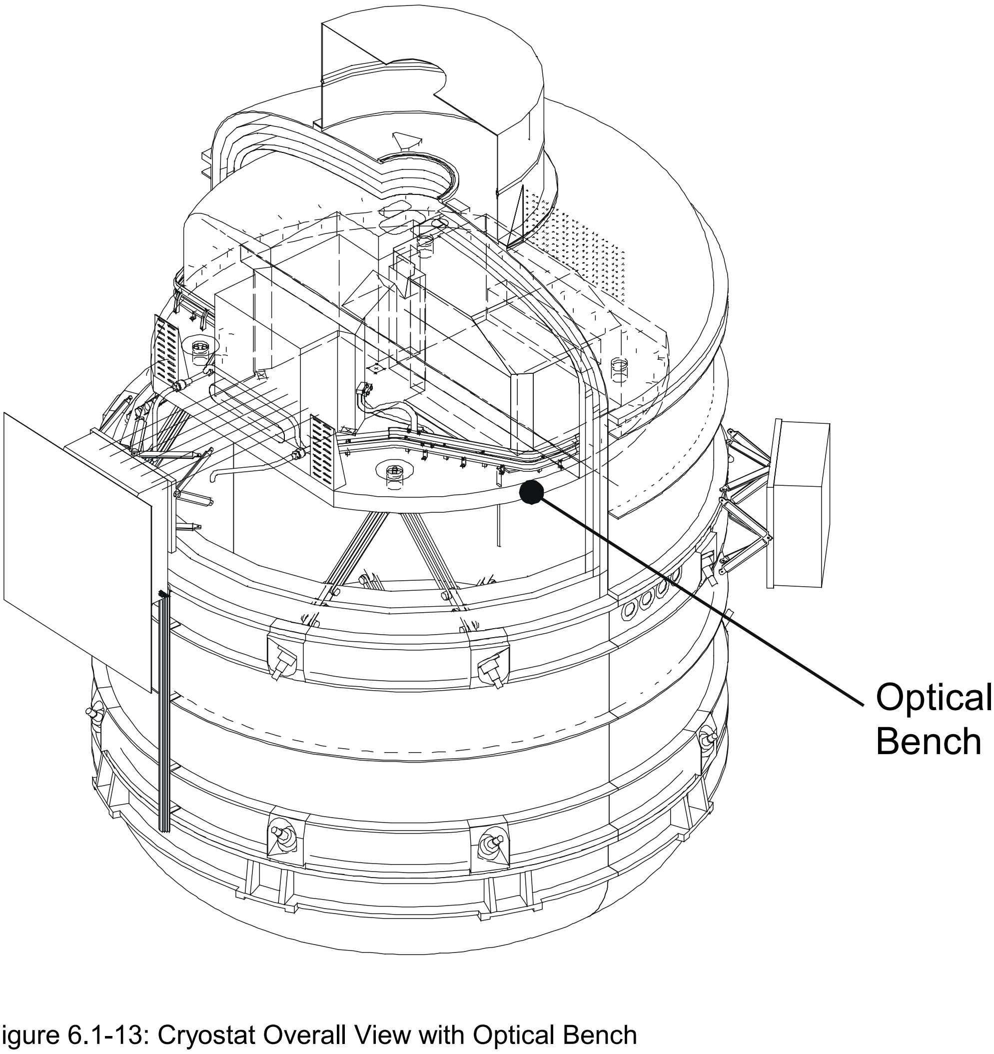


Figure 6.1-11: Upper SFWK (top view) and Lower SFWK (side view) with He I Tank

6.1.2.4 Optical Bench

The OB as part of the FIRST PLM shall provide primarily a mechanical support for the Focal Plane Units (FPUs), the related Harness, the venting tubes and the Instrument Shield. The principal design of the Optical Bench, suspended inside of the Cryostat, is exhibited in the figure below.



f:

Figure 6.1-13: Cryostat Overall View with Optical Bench

The main design drivers for the design/construction of the OB are:

- form stability over temperature range / interface load range
- strength compatibility against launch/interface loads
- eigenfrequency/stiffness requirements

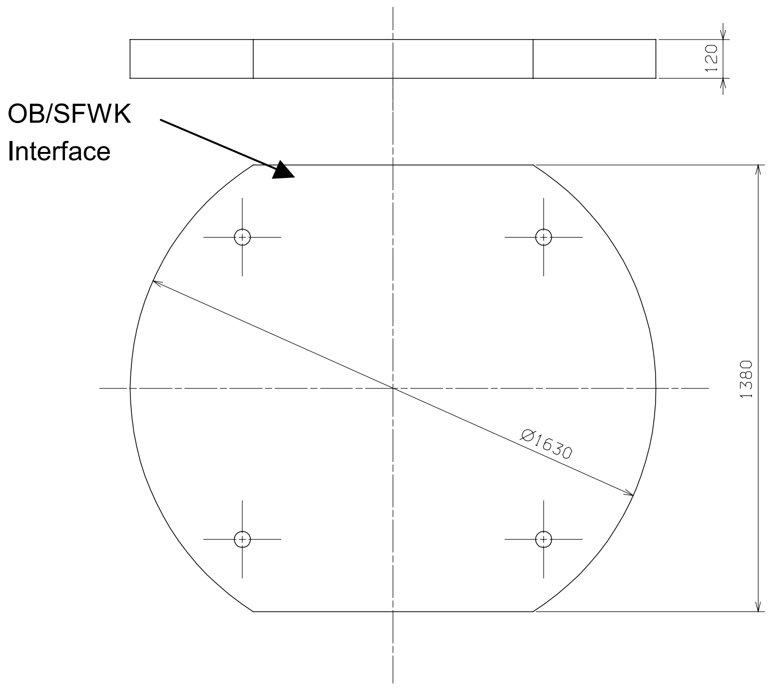


Figure 6.1-15: Optical Bench Dimensions

Components to be carried by the OB

The OB shall provide mechanical support for the following components:

- SPIRE (FPU + JFET Box)
- PACS (FPU)
- HIFI (FPU)

- Connector Brackets
- Harness

- Ventline

- Supports
- Tubing
- L0, L1, L2 Connections

- Instrument Shield
- Shield Structure
- MLI

- Alignment cubes
- Miscellaneous (Screws, Bolts etc.)

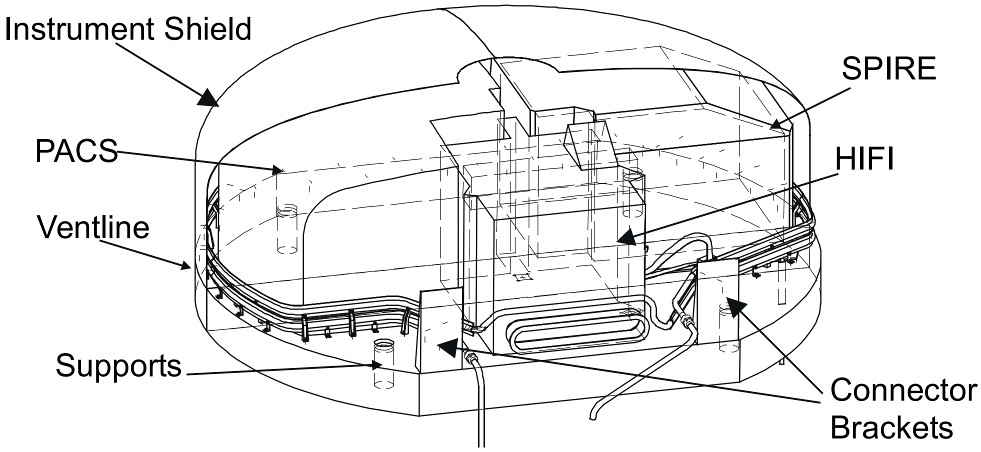


Figure 6.1-17: OB with Instruments and Equipment

Baseline is a milled aluminum plate, as shown in the figure below.

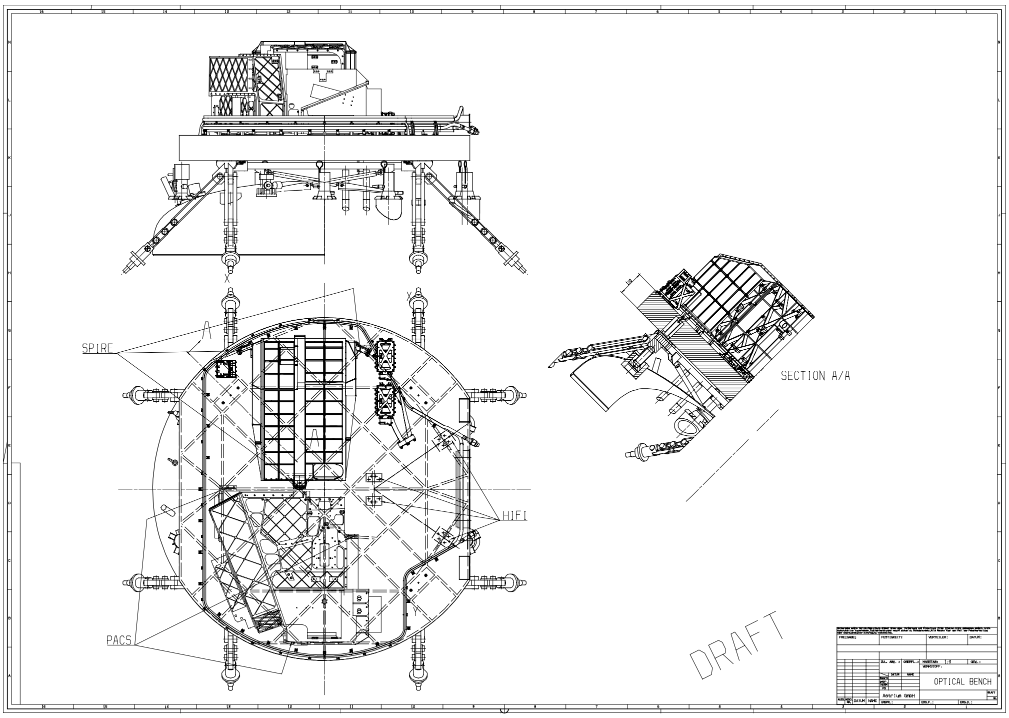


Figure 6.1-19: External Structures

6.1.2.5 External Structures

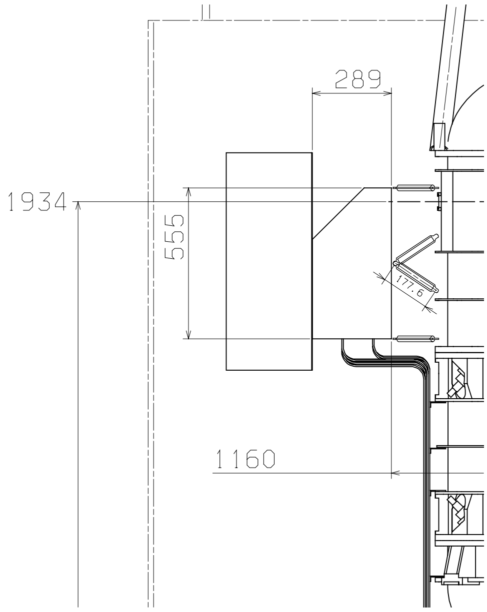
LOU Support

The Local Oscillator Unit provides the HIFI FPU with seven reference signal beams which are linked via vacuum feedthroughs into the CVV. The figure below shows the fixation of the unit, which is similar to the star tracker unit from ISO, but without the mounting baseplate. The LOU is mounted with eight GFRP struts to the CVV. The interface on the LOU side shall be a strut interface. The length of the struts shall be determined during LOU alignment with adjustable dummy struts, which will act as templates for the flight units.

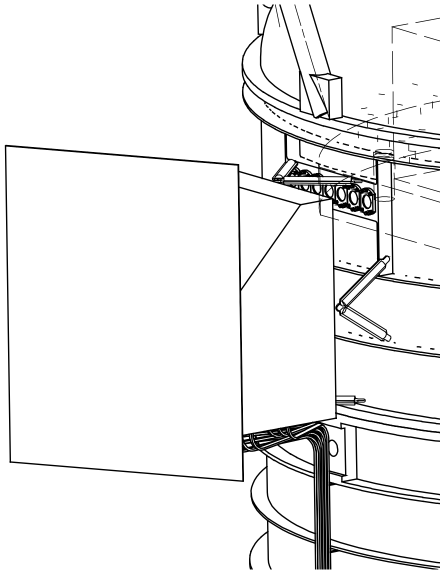
The main functions of the LO Support are:

- Provide a stable mounting basis for the LOU
- Provide a reproducible alignment position of the LOU beams in orbit conditions
- Minimize thermal conduction

View +Z



Isometric View:



Top View:

+X

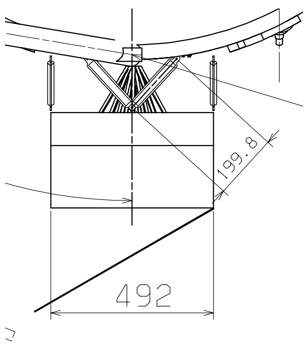


Figure 6.1-21: Local Oscillator Support

BOLA Support

For the Bolometer Amplifier Unit (BOLA) the same fixation principle as for the Local Oscillator is used. The size of the BOLA base-area is 180 x 230 mm, which is mounted on 3 or 4 (tbd.) strut interface points with 6 or 8 (tbd.) GFC struts to the CVV. To achieve the shortest possible length for the FPU to BOLA, the box is fixed at the height of the electrical vacuum feedthroughs, on the +y,-z-side of the cryostat (tbc.).

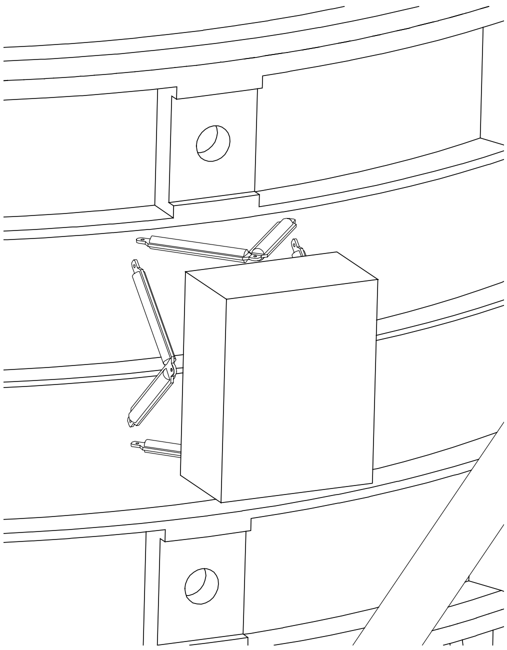


Figure 6.1-23: Bolometer Amplifier Unit fixation

Telescope Support

The FIRST Payload Module Telescope Support Structure is the load transferring element between the cryostat vacuum vessel (CVV) and the Telescope.

The telescope support shall provide the following structural functions:

- a mounting base for the telescope as defined in chapter 3.4.1.
- support the telescope and transfer the loads of the telescope to the CVV
- thermal isolation between the CVV and the telescope

It consists of three triangular strut arrangements with 2 struts and mounting brackets on each end. 6 brackets are equally distributed (60°) at STA x= 2122 on the CVV side and 3 at STA x= 2873 on the Telescope side (see figure below). One Telescope interface will be located on the –Z-axis, at a radial distance of 1.037 mm (tbc.) from the X-axis, the other at 120° respectively.

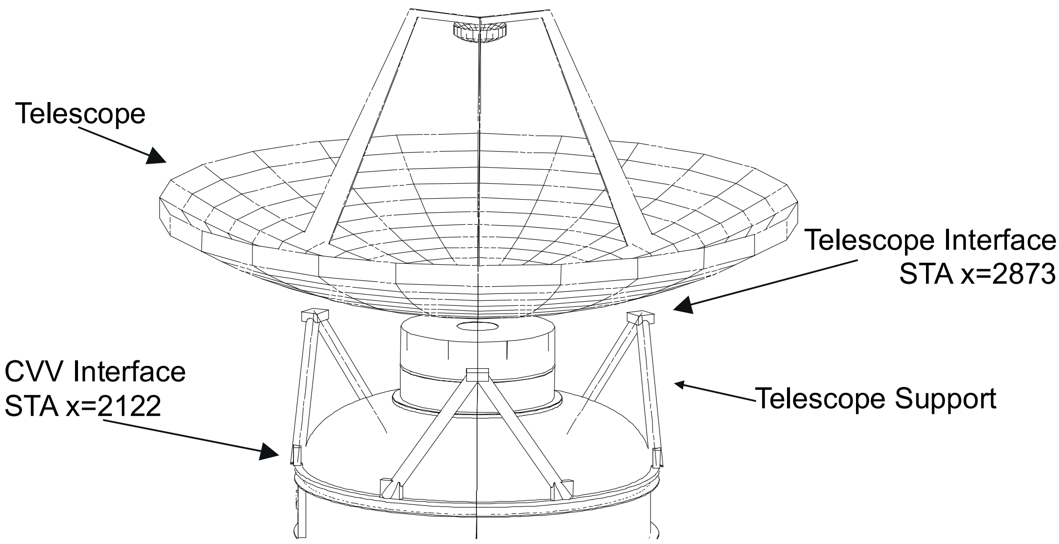


Figure 6.1-25: Telescope Support

Cavity

The CVV Cavity is located on the upper end of the cryostat upper bulkhead. It is made from aluminum material with a flange interface to the CVV. The main function of the Cavity is to protect the CVV entrance from undesired stray radiation.

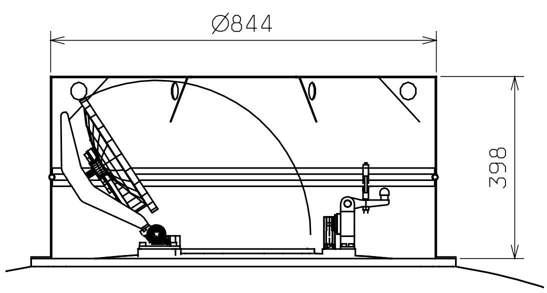


Figure 6.1-27 Cryostat Cavity

Cavity

Radiation Nose

As a result from the FIRST System Optimization Study PLM last year, a so called CVV "nose" shall be implemented. This component shall enlarge the CVV radiation area.

The nose shall be a sandwich panel of tbd. Thickness located on the –Z side of the cryostat. It will be fixed with 4 or 5 (tbc.) mounting brackets and tbd. Lateral ropes to transfer vibration and acoustic loads into the CVV.

The principal configuration is shown in the drawings below.

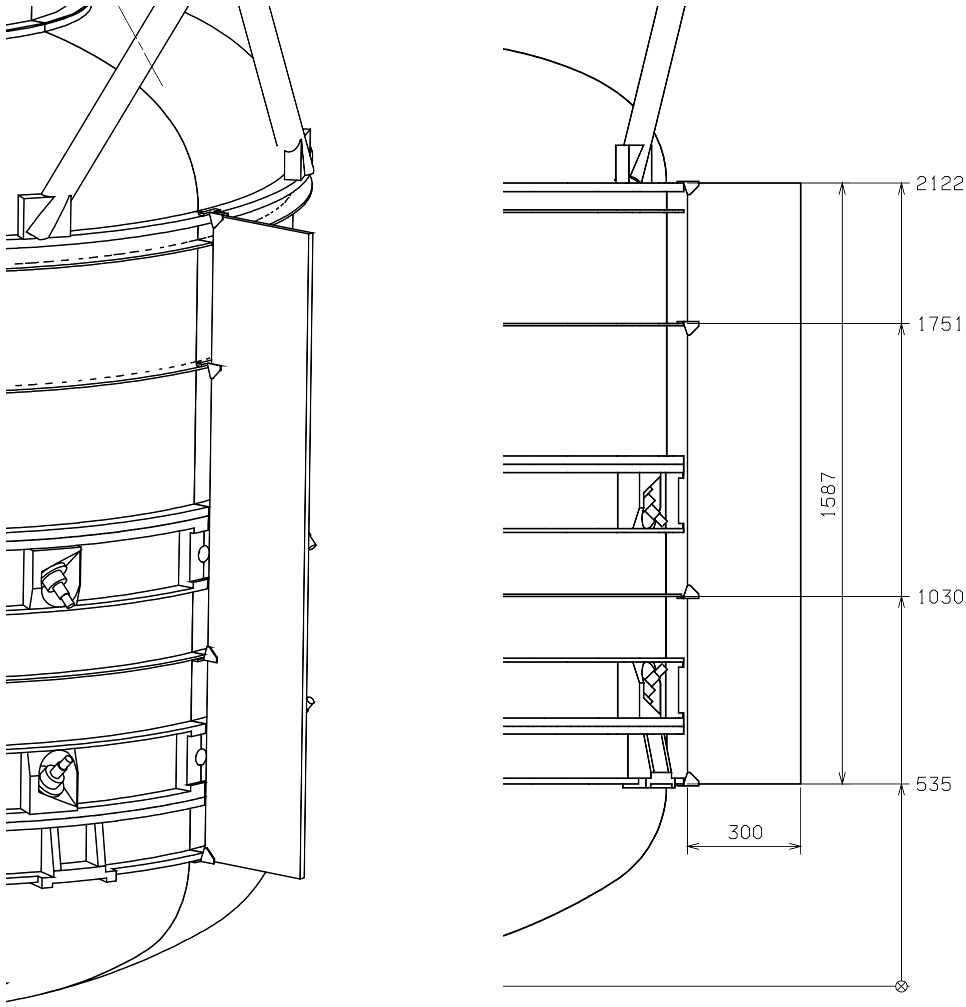


Figure 6.1-29: Additional Radiator Area `Nose´

Optical Feedthroughs

The Local Oscillator provides the HIFI FPU with seven reference signal beams which are linked via vacuum feedthroughs 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. By taking into account alignment considerations the inner diameter is 34 mm to provide the required 30 mm optically free diameter required by the instrument.

In addition 2 lateral windows are used for fine alignment with the same design as the LOU windows and shall be located at the –Y side of the cylindrical part of the upper dome. A further alignment window (on -z-side) is used (tbc).

The figure below shows the principal arrangement of the 7 plus 2 Local oscillator beam windows. These windows must be arranged very closely to each other in one row like the cylinders of a combustion motor. This window-row shall be located very likely on the –Y-side of the upper CVV-bulkhead/skirt cylinder at a tbd height above the CVV-interface flange to the main CVV-cylinder.

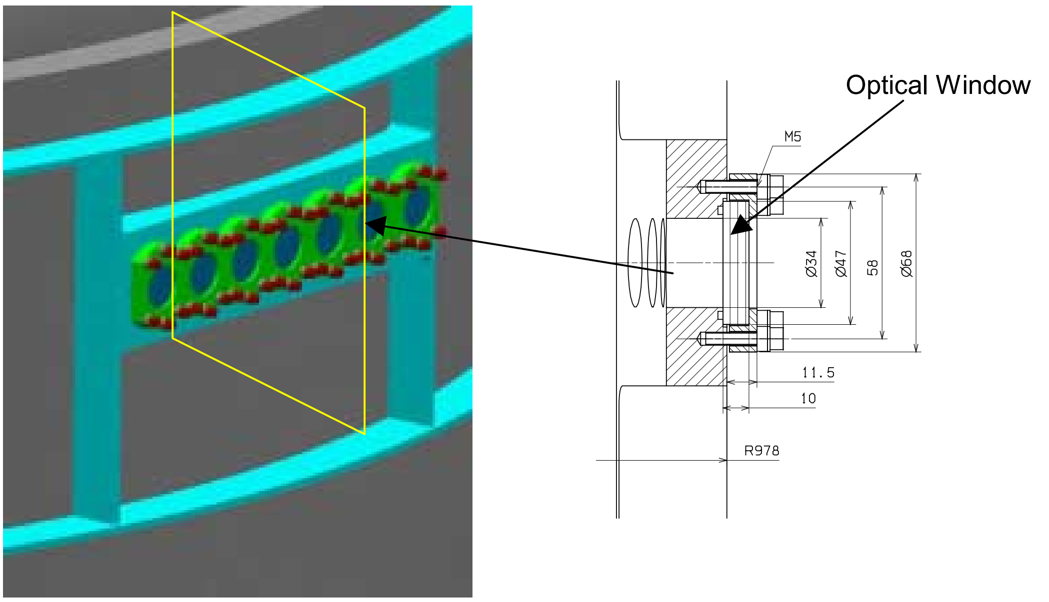


Figure 6.1-31: LO Windows on CVV

6.1.3 Subsystem and Components Interfaces

The Interfaces of the Structure S/S and its components are already mentioned in chapter 5.1.2 for the different components. The most important I/Fs of the Structure S/S are shortly repeated here.

Mechanical and Thermal Interfaces

- CVV and support structures to SVM, Telescope, Sunshield/Sunshade, LOU, BOLA,
- CVV to external ventline
- SFWK to He II tank
- SFWK to He I tank
- Optical Bench to cold instrument units
- Optical Bench to ventline and harness brackets
- CVV to vacuum feedthroughs, harness to suspension system and OB

Electrical Interfaces

N/A

Optical Interfaces

- CVV opening for telescope beam
- Cavity for the telescope beam
- LOU and alignment windows

6.1.4 Engineering Trades/ Analyses Performed

6.1.4.1 Telescope Opening Diameter

The CVV upper bulkhead currently provides an opening diameter of 260mm. The geometrical and mechanical consequences in case of diameter increase have been analyzed. Presently an increase to 270 mm is investigated

6.1.4.2 Spatial Framework

The SFWK design is based in the ISO design. It consists mainly out of a rectangular frame providing the I/F for the optical bench and the tank supports. As the optical bench and as well as the He tanks are made out of aluminum the SFWK is made of aluminum too. The following aspects compensate the disadvantage of the lower stiffness of alu wrt to CFRP, which was used for ISO:

- The risk of alignment shifts between optical bench and SFWK is lower, if the difference in thermal expansion is low.
- The stiffness loss at the I/F is lower for an aluminum design

6.1.4.3 Tank Bone Design

Objective

The 8 tank bones are located between the SFWK upper and lower corner brackets and the HeII tank interface flanges. The main functions are to serve as load transfer elements for longitudinal (x-direction) loads and to reduce the heat flux from the outside via the CVV, the tank suspension straps and the corner brackets into the tank. Furthermore the tank bone elements have to compensate different thermal displacements between the Al-tank and the spatial framework.

Design Approach

The design of the tank bone elements was driven by stiffness requirements and heat flow reduction as far as possible. This led to a cylindrical design made from CFC material and Ti-end caps. The end caps are spherically shaped taking into account the differential thermal displacements on its interfaces. The upper and lower contact surfaces will be coated with MoS_2 .

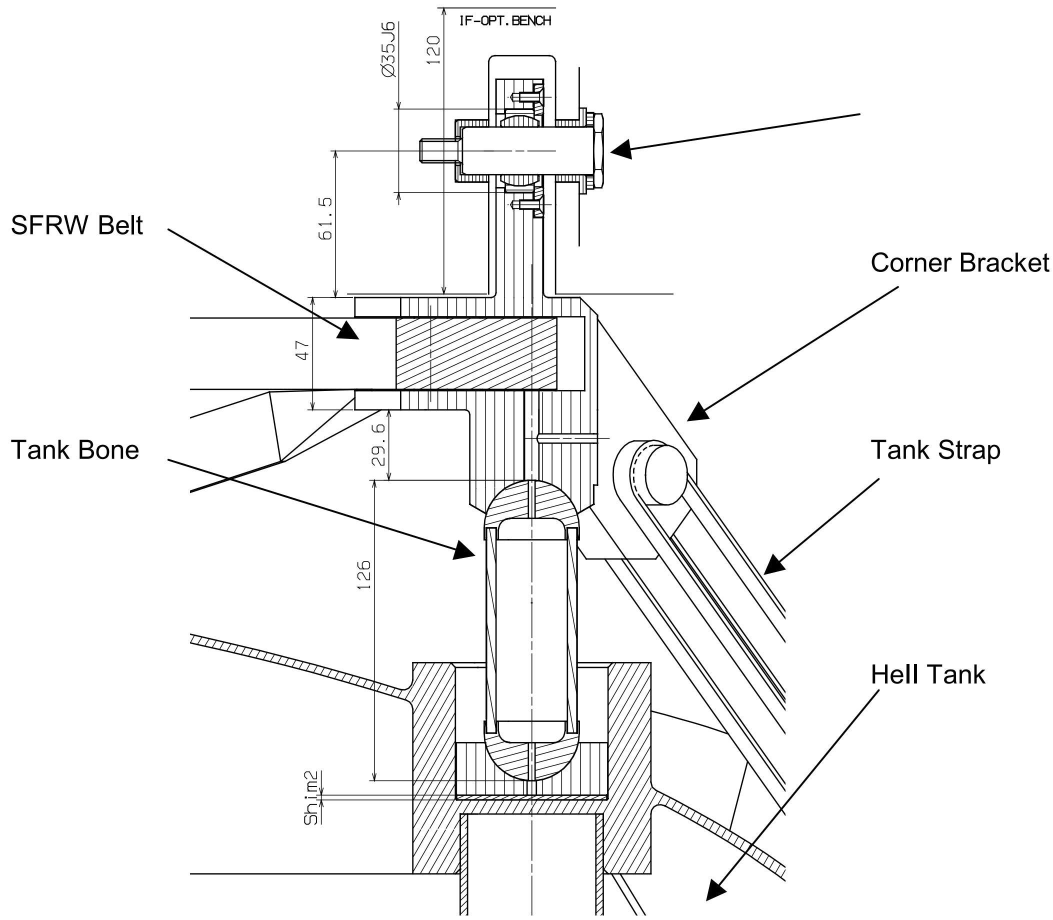


Figure 6.1-33: Tank Bone Design

6.1.4.4 Optical Bench Concepts

Objective

The basic function of the OBP is to serve as a solid mechanical carrier (support) of the "cold" scientific instruments of FIRST. Furthermore it shall provide a mechanical support for the related Harness, the venting tubes and the Instrument-Shield.

The main design drivers for the design/construction of the OB are:

- form stability over temperature range / interface load range
- strength compatibility against launch/interface loads
- eigenfrequency/stiffness requirements

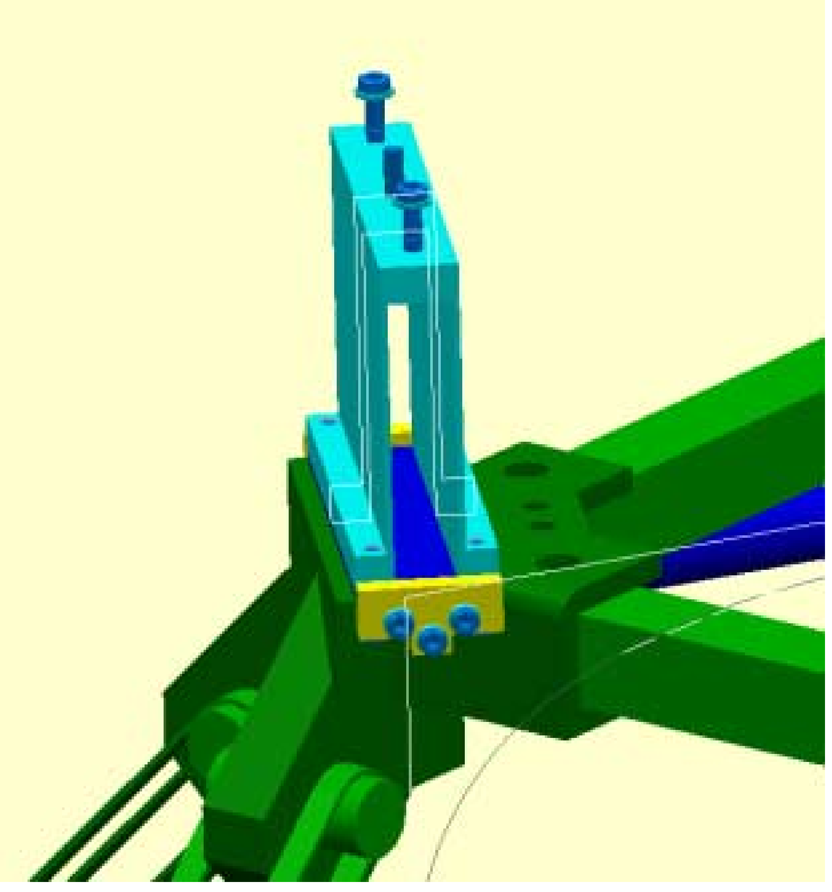
The OB itself will be mechanically supported via 4 interface elements to the SFWK.

6.1.4.5 Optical Bench Support

Objective

The main function of the optical bench support is to serve as load transferring elements between the OB and the SFWK, taking into account system stiffness and strength requirements. In addition these elements shall compensate thermal displacements for avoiding additional forces at the OB and providing position stability of the FPU's.

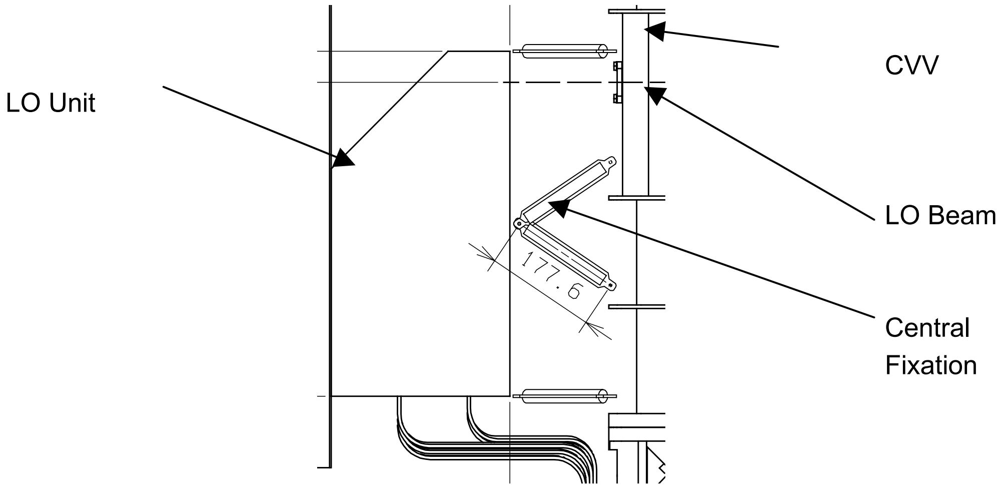
Isostatic mounts, as shown in the figure below are used to fix the optical bench.



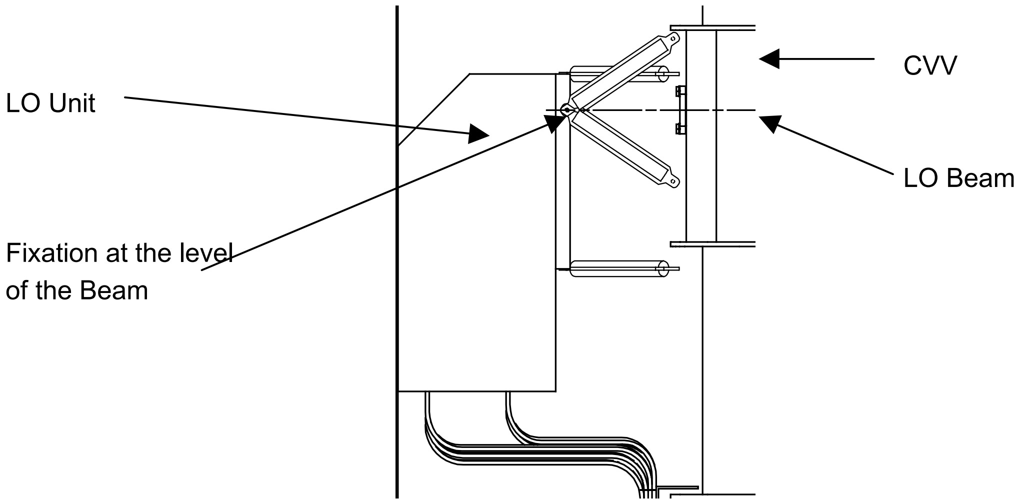
As option an additional support at the center of the optical bench will be investigated.

6.1.4.6 LOU Support

The LO support structure is composed of 8 struts, which interface to the cylindrical section of the CVV upper bulkhead. Two struts shall be fixed on each side of the LO housing by forming a triangular arrangement with a common strut fixation at the LO side. The position of the struts shall be basically, as for the ISO star tracker housing, in the geometrical center of the LO base lines, as shown in the figure below.



Another position for the struts parallel to the x-y plane has been identified at the level of the LO reference beams. This position might have advantages in terms of alignment stability, but needs to be analysed more in detail. The principal arrangement is shown below:



A detailed thermal displacement and alignment analysis shall be made at the beginning of phase B to select the final position of the LO struts.

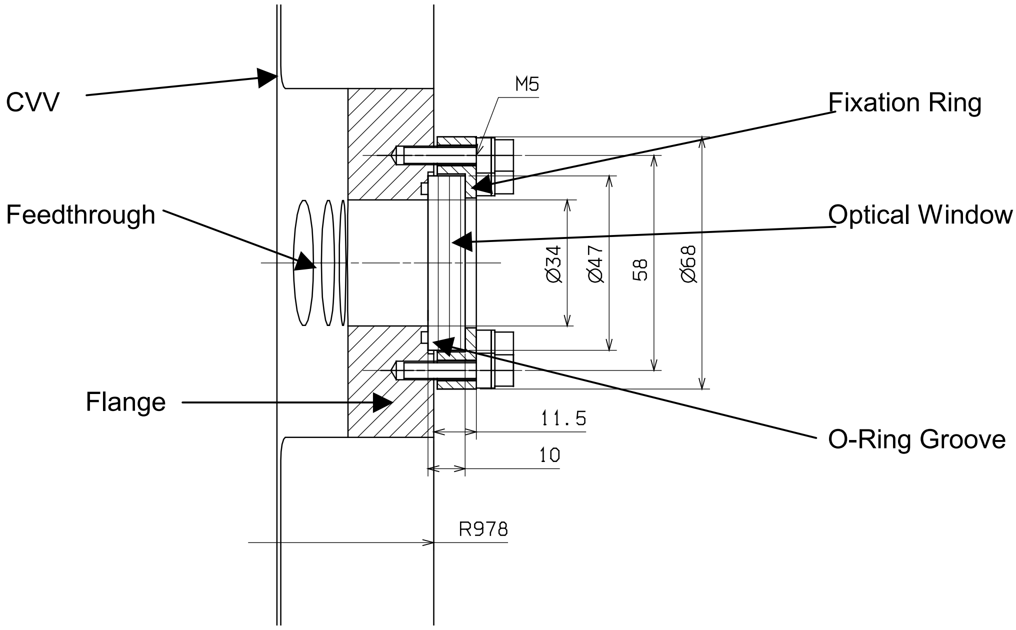
5.1.4.7 LO Optical Windows

Objective

Seven vacuum feedthroughs through the CVV are used to provide the HIFI FPU with reference signal beams from the local oscillator.

For the seven LO beams, seven flanges for mounting of the windows are foreseen. The spacing between the beam centers is 50 mm. By taking into account alignment considerations, the inner diameter is 34 mm to provide the required 30 mm optically free diameter required by the instrument.

Each feedthrough consists of a flange, a vacuum sealing, an optical window and a fixation ring. The sealing is a vacuum tight viton o-ring, embedded in turned o-ring grooves.



The minimum distance between the two optical windows has been found at 50mm.

The windows must be cylindrical, due to the vacuum sealing, that requires turned o-ring grooves

LOU Optical Window Transmissions:

The HIFI Instrument is a heterodyne receiver using a so called Local Oscillator Unit (LOU) as a very stable monochromatic signal reference in order to translate the pass band of the observed astronomical signal by mixing with the monochromatic reference to much lower frequencies. For thermal reasons this local oscillator unit is mounted on the outside of the cryostat vacuum vessel. Therefore an optical coupling through the cryostat vessel and the inside cryostat thermal shields is required. It enables the optical pass form the LOU to the cryo cooled HIFI instrument part. The observation range of HIFI is subdivided into 7 wavelength channels and therefore a set of 7 individual breakthroughs through cryostat vessel and shields has been designed. The requirements on these 7 (so called) LOU

Optical Windows are therefore a combination of optical performance requirements imposed by HIFI and functional requirements derived from cryostat performance:

- window (in the cryostat vacuum vessel) has to withstand atmospheric pressure
- one heat filter per channel at inside cryostat shields
- transmission of > 80% per optical channel (window and filter, if any)
- optically free diameter ≥ 30 mm

Based on the above requirements there are actually three design possibilities to build each individual optical channel. These two designs differ from the definition of the inside thermal filter only, which could be either a second inner quartz window with heat filter or a mesh filter designed to work as a heat filter. Preliminary results of the thermal analysis show that from a thermal point of view no further filtering is necessary. This case is described by the third design possibility. The following list describes the main design features:

Design Possibility 1:

1. one crystal quartz window in outer cryostat vessel (about 80K in orbit) and a second thinner quartz window at one inner shield (about 30K in orbit)
2. use of poly-ethylene anti-reflection coatings on crystal quartz
3. inner quartz window with heat filter
4. usable diameter = 30 mm
5. all window surfaces are parallel within 5 arcsec
6. windows are tilted by 2° (according to FIRST IID, PT-HIFI-02125)

Design Possibility 2 :

1. one crystal quartz window in outer cryostat vessel (about 80K in orbit) plus one mesh filter* on the inner side (30K in orbit)
2. use of poly-ethylene anti-reflection coatings on crystal quartz window
3. mesh filter as a heat filter
4. usable diameter = 30 mm
5. window surfaces are parallel within 5 arcsec
6. quartz window and mesh filter are tilted by 2° (according to FIRST IID, PT-HIFI-02125)

Design Possibility 3 :

one crystal quartz window in outer cryostat vessel (about 80K in orbit) without any thermal filter at the inner shield (about 30K in orbit)
use of poly-ethylene anti-reflection coatings on crystal quartz
usable diameter = 30 mm
window surfaces are parallel within 5 arcsec
windows are tilted by 2° (according to FIRST IID, PT-HIFI-02125)

The selected technique to build up the LOU optical channels has finally to be verified for its performance and its correlated manufacturing process by measurements and/or testing at operational temperatures. No literature data about material/filter properties and optical transmission performances have been found for the applicable wavelength ranges at the applicable operational temperatures (about 80K).

The following table shows the division of the spectral bands as used for the requirement specification of the LOU Optical Windows:

Band No.	Spectral Band [GHz]	Spectral Band [GHz]	Spectral Band [µm]	Spectral Band [µm]	Spectral Band [cm^{-1}]	Spectral Band [cm^{-1}]	Material	Coating
1	488	633	615	474	16	21	crystal quartz	polyethylene
2	647	793	464	378	22	26	crystal quartz	polyethylene
3	807	953	372	315	27	32	crystal quartz	polyethylene
4	967	1113	310	270	32	37	crystal quartz	polyethylene
5	1127	1242	266	242	38	41	crystal quartz	polyethylene
6	1418	tbd	212	tbd	47	tbd	crystal quartz	polyethylene
7	tbd	1908	tbd	157	tbd	64	crystal quartz	polyethylene

Table 6.1-1: FHLOU Optical Windows Spectral Bands

Nevertheless the definition of the above described design possibilities is based on the following rationale:

To withstand the outside air pressure during cryostat on ground operation a necessary thickness of 6 mm for the quartz-window in the cryostat vacuum vessel has been calculated. In literature, the following measurements values for the transmission of 6 mm thick crystal quartz at 2700 GHz have been found. The wavelength of 2700 GHz has been selected, because it is the upper frequency edge of the LOU wavelength bands and therefore covers the worst case condition in this consideration:

Temperature	Transmission (ordinary direction)	Transmission (extra-ordinary)
at 300 K	0.6	0.89
at 10 K	0.985	0.999

Because no transmission measurements for 80 K have been found yet, the transmission values to be applied for the LOU window have been estimated by interpolation.

A z-cut crystal quartz has to be used to achieve maximum transmission values. Each quartz window requires anti-reflection coating to improve its optical transmission. Ideal minimum transmission losses have been calculated at the edges of an λ/4 coating optimised for each LOU channel. Transmission budget of window in outer cryostat vessel based on the design: Crystal quartz window with polypropylene anti-reflection coating. A possible manufacturer of these AR-coated windows is the QMC Instruments Ldt. (UK).

	Channel	1	2	3	4	5	6	7
1	Transmission loss of quartz window	2%	2%	2%	2%	2%	3%	5%
2	Theoretical losses at edges of λ/4 coating	2%	1%	1%	1%	1%	2%	1%
3	- not ideal coating material - change of refractive index over band - change of refractive index - (ambient versus 80 K) - total	2%	2%	2%	2%	2%	2%	2%
4	Manufacturing uncertainty	2%	2%	2%	2%	2%	2%	2%
5	Degradation during life-time	2%	2%	2%	2%	2%	2%	2%
	total loss of transmission	10%	9%	9%	9%	9%	11%	12%

Assuming a worst case consideration, the same transmission losses for the inside thermal filter, the minimum optical transmission for a channel made of a window and a filter on quartz substrate is estimated at 77% (Possibility 1). Following the information from Peter Ade (Queen Mary and Westfield College, London) about mesh filters, the total worst case optical transmission would achieve 83 % (Possibility 2):

	Possibility 1	Possibility 2	Possibility 3
	1 quartz window + 1 quartz filter	1 quartz window +1 mesh filter	1 quartz window
Window in cryostat outer vessel	88%	88%	88%
Heat filter	88%	95%	./.
Total	77%	83%	88%

The required optical transmission for LO optical channel is 80%. Since the thermal analysis showed that the emitted radiation form the outer LOU Optical window at operational temperatures is not significant, possibility 3 (single crystal quartz window) is the design baseline.

6.1.5 Structure S/S Design and Development Approach

The following table gives an overview on the structure S/S design and development approach.

Structure S/S Components	Design Identical / Based on	Models	Analysis/ Test	Comments
CVV	Based on ISO, lower bulkhead and diameter identical to ISO	1PFM + material	Structural Integrity Analysis Buckling Analyses Leak Test Cleaning	Final Qualification performed on PLM level
Cryostat Cover	based on IBSS Release mechanism based on ISO (tbc)	1 PFM (tbc) + parts	Static Analysis Functional Analysis Leak test (warm) Functional test (warm) Vibration Test (warm) Functional Test (warm) Functional Test (cold) Leak test (warm)	
Tank Support System consisting of: - tank straps - tensioning devices - SFWK frame - SFWK struts	Tank straps based on ISO, SFWK frame based on ISO tensioning devices identical ISO	1 DM of tank straps and SFWK struts 1 PFM + spare parts	Static Analysis Static Tests Fatigue + rupture tests of samples Proof tests of tank straps	
Optical Bench		new development 1 DM 1 Model for EQM 1 PFM	Static Analysis Static Tests Vibration with dummies (DM, warm) Thermal test + Alignment (DM)	
External structures consisting of: - LOU support - BOLA support - Telescope struts - Cavity - Radiator Area (Nose)	LO and BOLA support based on ISO STR	LOU + BOLA: DMs, 1model for EQM 1 model for FM + spares Telescope Struts: DM + FM + spares Cavity + Nose: PFM	Static Analysis Static Tests Rupture Tests of samples (for LOU,BOLA, Telescope support)	

Structure S/S Components	Design Identical / Based on	Models	Analysis/ Test	Comments
Optical feedthroughs (LO windows, alignment windows)	Alignment windows based on ISO	Qual Phase, FMs + spares for EQM and PFM	Qual Phase (LO windows): - Selection of substrate and coating - Optical performance Verification - Environmental Testing (cycles) - Radiation resistance verif. (tbc) - Optical Performance Verification Acceptance (LO + Align. windows): - Coating of substrates - reduced Environmental Testing - Optical Performance Verification	

6.2 He S/S

6.2.1 He S/S Components Overview

An overview of the He subsystem, its components and function is given in chapter 5.7 of the current document.

6.2.2 He S/S Components

6.2.2.1 He II Tank Assembly

The He II tank assembly consists of the He II tank and the following components attached to it:

- Passive Phase Separator PPS 111 with T111 and T112
- DLCM 1/2 with T101/102 and H101/102
- Level Probe L101/102
- Fluid Thermometer T104/105
- Surface Thermometer T103 (Pt500) T106/ T107 (CX)
- Rupture Disc RD124
- H103/104
- SV123
- Internal He-valves V102,103,104,105,106,701
- P101
- Adsorber

- Filling port with SV121, OD101, S101
- 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).

He II Tank

The tank shall provide a cold volume of 2160 litres with a tolerance of + tbd, -0. It is foreseen that this tank will be filled to 98% of its volume with superfluid Helium.

The main design drivers for the design, construction and operation of the He II tank are as follows:

- Tightness to He II conditions
- Because of its unique zero viscosity property, He II has the tendency to penetrate any material which is not absolutely tight, especially in very narrow geometrics (e.g. capillaries, fine pores, micro cracks, etc).
- Safety against
  - Straps preloading
  - Launch and structural testing loads
  - Pressure (internal and external)
- Cleanliness during manufacturing and AIT
- Stiffness/eigenfrequency empty and with He II
- Stiffness/form stability of interface points

The basic design of the He II tank is shown by Figure 6.2-1. It is a cylindrical tank with an upper and lower dome (bulkhead) and an internal dome, the function of which is described later.

The axial (± x-axis) loads acting on the tank (by pretension of the straps, dynamic payload forces) shall be transmitted through the tank via 4 pillars, being either tubes (preferred) or wide-flanged double-T-bars. All lateral (± y-, ±z-axes) loads shall be transmitted through the upper and lower domes which are equipped for this (but not only for this) purpose with internal ribs. The introduction of the axial forces on the He II tank is foreseen by short and hollow rods. The lateral forces are transferred by struts or straps from the corner brackets of the SFWK. If the internal pillars are tubes, these tubes shall be open to the He II inside the tank near the upper and lower pillar ends. The inner side of such tubes shall be specifically clean in order to prevent contamination sources.

The upper, lower and intermediate domes shall be equipped with stiffening ribs (not yet shown for the intermediate dome) in order to 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. There shall be a sufficient clearance between the pillars and this dome. There shall also be several open areas in this dome of tbd mm^2 area either near its outer edge (inside the tank near the tank cylinder) or in the centre of the dome. These open areas are necessary to ensure He communication between the two tank compartments.

There shall be penetrations through the intermediate dome for 2 liquid level sensors (requiring the full tank length) and probably 2 fluid thermometers (He II temperature).

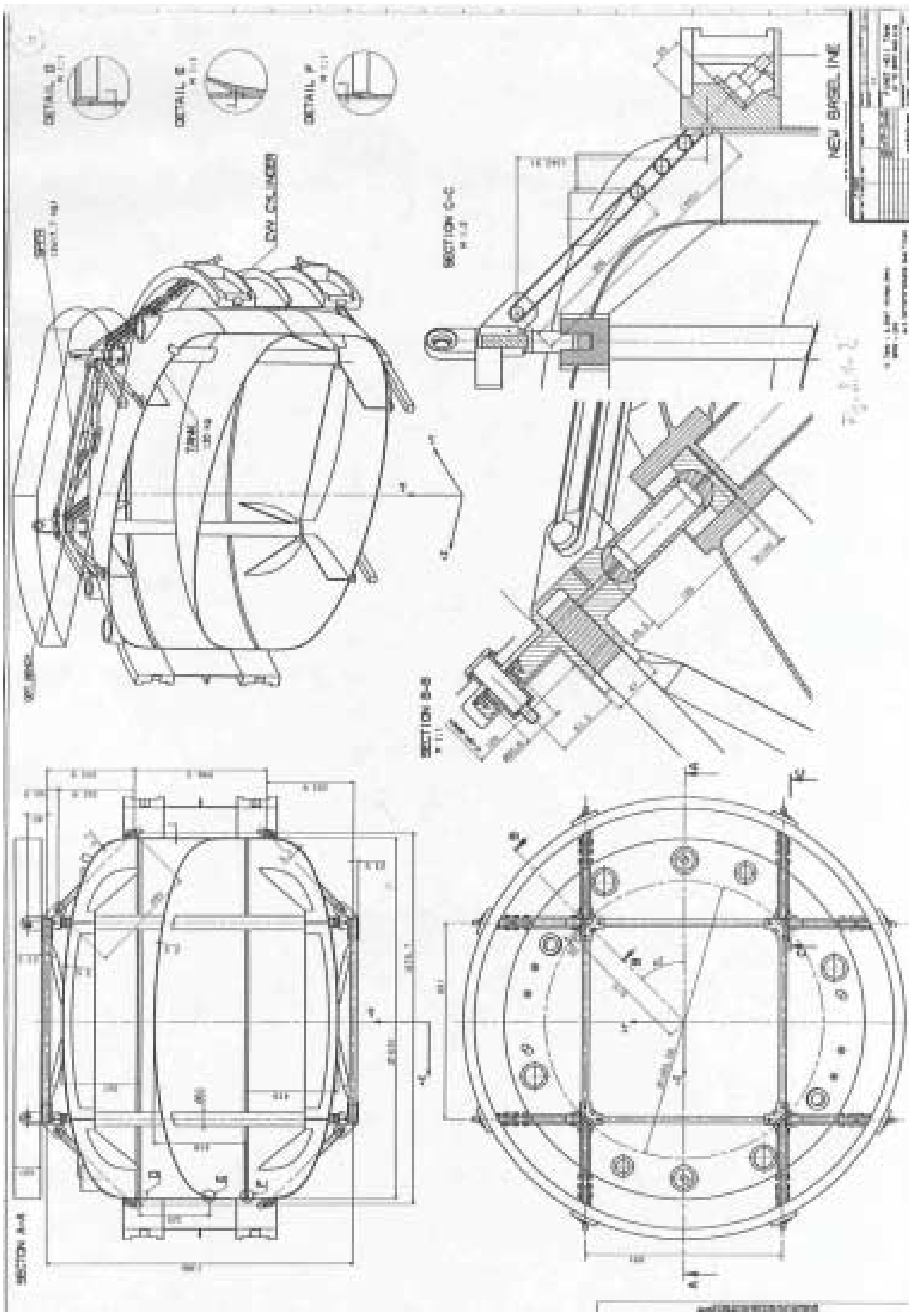


Figure 6.2-1: Herschel He II Tank (Baseline)

Phase Separator PPS 111 with T111,112

For space cryostats such as the Herschel mission, a superfluid helium phase separator which operates without disturbances over the anticipated lifetime is necessary.

During the Infrared Space Observatory (ISO) project a passive phase separator (PPS) of the porous plug type successfully demonstrated reliable operation due to its simple design and the absence of any active control. The bath temperature in the cryostat and hence the working point of the phase separator adjusts automatically to the corresponding heat load by the temperature and pressure dependant flow impedance of the porous plug. Such passive control is well suited for systems with moderate variations of the bath temperature.

The PPS is a device for separation of liquid He II from gaseous He under zero gravity condition. It allows only gaseous He (GHe) to reach the vent gas system whereas the superfluid He II is restrained within the tank. As the porous plug phase separator is of a passive design the pressure drop along the PPS is determined by mass flow rate which in turn is governed by the heat load on the He II tank. The vapour pressure in the tank and thus the He II bath temperature then depends on the accumulated pressure drops over the PPS and all other vent line elements.

The PPS consists of a porous stainless steel plug of specific porosity, permeability and dimensions. The disc-shaped plug is shrunk into a cylindrical holder which is exchangeably mounted to the PPS housing. This housing is flanged onto the He II tank and connected to the vent line. The porous plug is located inside the tank so that its inlet face is in contact with the superfluid helium (He II).

The PPS design allows the implementation of two temperature sensors at the outlet side of the plug for redundancy.

The mass flow rate and pressure drop requirements for the PPS will result from the Herschel vent line model calculations to be carried out for four design cases:

1. Nominal in-orbit steady state case: Mass flow rate is >2.0 mg/s (from TMM); the pressure drop over the PPS shall not be less than 0.8 mbar (necessary for safe PPS operation).
2. Evacuation of He I tank: The vent line and the He I tank need to be evacuated to the environment during launch before starting the PPS, and the PPS has to be started before the beginning of the first zero gravity phase. The nozzle configuration (and thus the vent line flow impedance downstream of the PPS) which is necessary to guarantee timely GHe depletion defines the conditions for the initial in-orbit cool down phase.

3. Initial in-orbit cool down: A high mass flow rate through the PPS and the vent line is required in order to cool the system down to its nominal steady state temperatures from the increased level reached during the launch phase. This design case defines the maximum orbital mass flow rate and pressure drop for the PPS.
4. Ground operations: The PPS and the vent line have to be capable of venting the respective maximum mass flow rates expected during the various ground operations (e.g. cool-down, filling, testing).

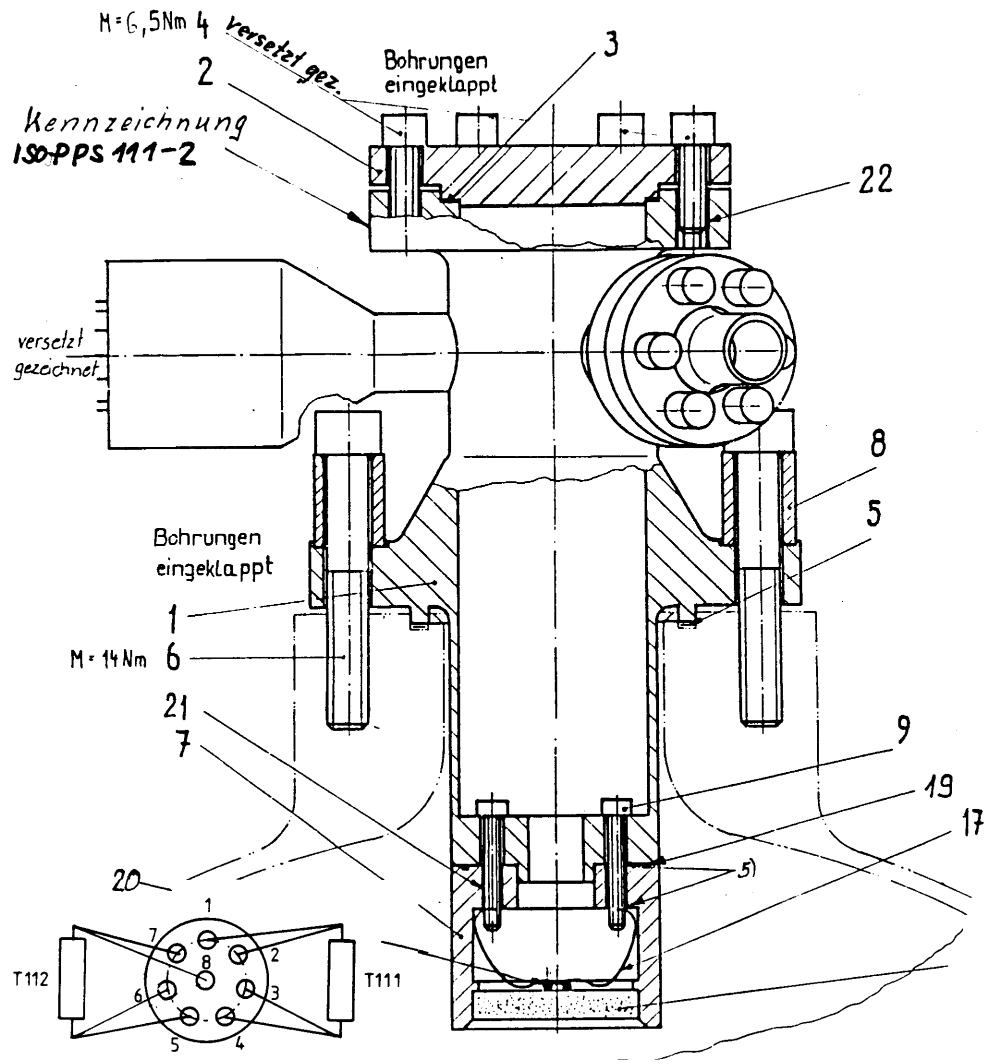


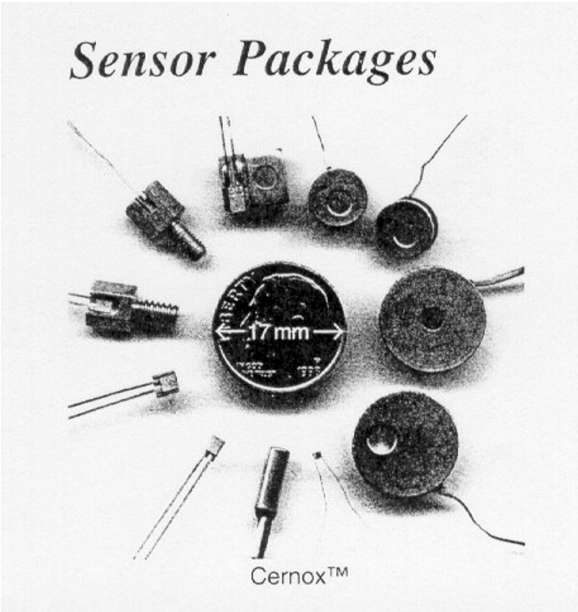
Figure 6.2-3: Detailed Sketch of the Porous Plug Phase Separator

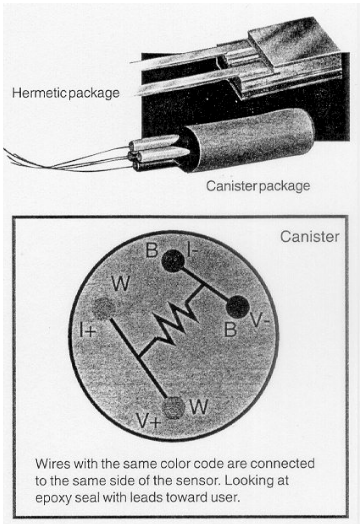
Temperature Sensors

The C10/C100 temperature sensors manufactured by Linde which were used in the ISO programme are no longer available. A replacement will be selected after the benchmarking of alternative sensors which is still going on.

A possible replacement is the CERNOX sensor CX-1030-AA-0,3L in a copper canister mounting package with a temperature range from 0.3 K to 325 K. As an advantage wrt the C10/C100 sensors this CX sensor could be used as the single standard temperature sensor for the complete temperature range covered in the Herschel He subsystem.

The CX sensor is manufactured by „LAKESHORE“ and delivered via „Cryophysics“ in Darmstadt, Germany





Direct Liquid Content Measurement (DLCM 1/2 with T101,102 and H101/102

The DLCM consists of two identical devices (DLCM 1 and DLCM 2) used for measuring the He II content of the He II space cryostat during ground operation as well as in orbit. It may also be used for depletion of the He II tank during ground operation. The DLCM shall be located at the very bottom of the Herschel He II tank.

A heating coil is mounted on the inner tube. The heater itself is situated concentrically within the outer perforated tube. A CX thermistor is fixed below the bottom of the inner tube.

Caused by the surface tension of the He II under zero gravity the cavity within the DLCM is filled with He II in orbit even when the tank is almost empty.

In active state, the heater is driven by a constant electric current over a certain time. The heat pulse is absorbed by the superfluid He content and is determined by measuring the current as well as the voltage via the 4-wire electric contact. Immediately after completion of the heat pulse, the absolute temperature and the temperature increase of the He II bath is measured by the CX thermistor.

With the very well known specific heat of the He II its mass can be deduced (the specific heat of the tank is negligible at the low temperatures). Immediately after the heat pulse a new steady state temperature will be established in the entire liquid volume because of the very high heat conductivity of He II.

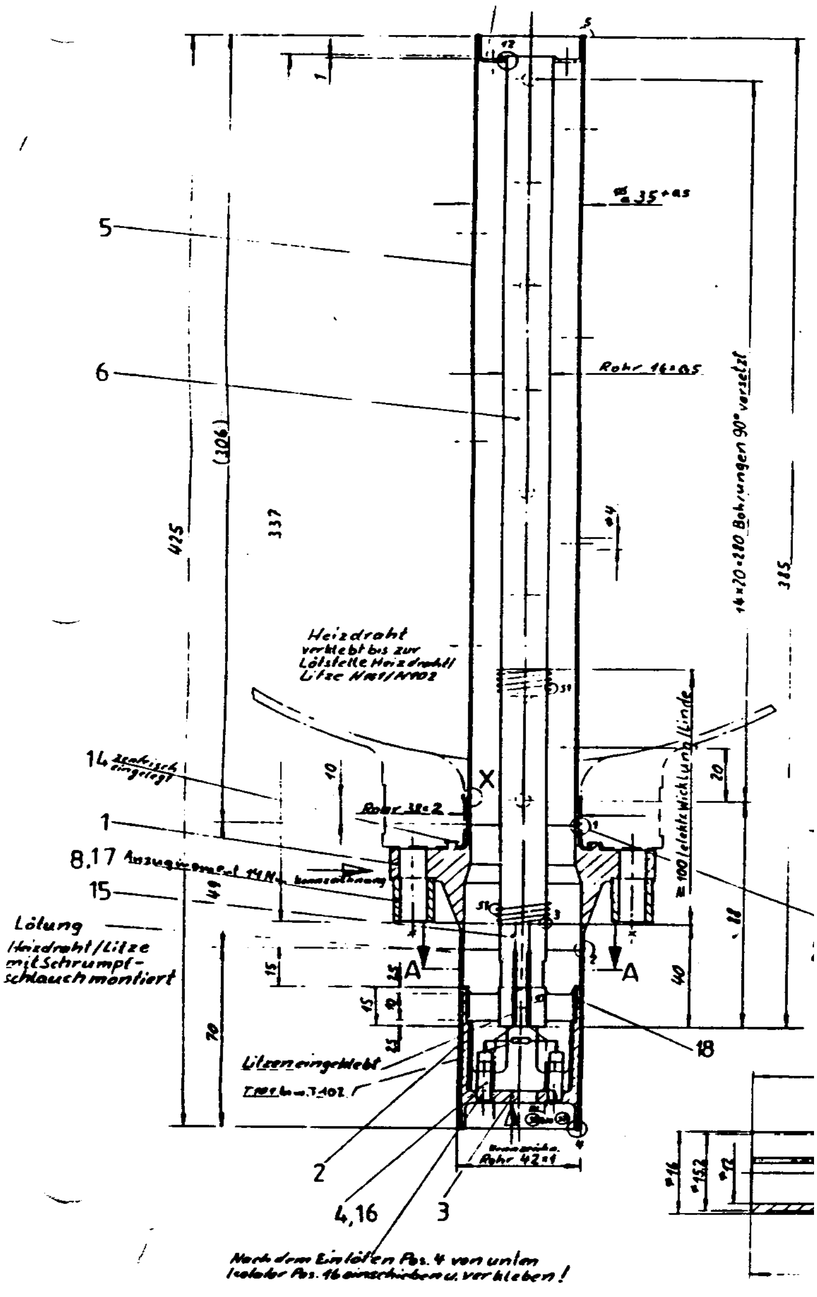


Figure 6.2-5: Detailed Sketch of the Direct Liquid Content Measurement DLCM

Level Probe L101/102

The superconducting level probes measure the level of the liquid helium in the He II tank. This type of level measurement can only be used on ground under normal gravity conditions.

A superconducting wire is strained in a slotted pipe. At the top of the superconducting wire, above the maximum of liquid level, an `ignition´ resistor is soldered. A wound aluminium wire, surrounding the superconducting wire, is installed to avoid connection with the tube.

During operation, the part of the superconducting wire which is located above the liquid level is heated to a temperature above the transition temperature for superconductivity by the ignition resistor. Thus the resistance of the measuring wire is a measure of the length of the level probe in the gaseous helium.

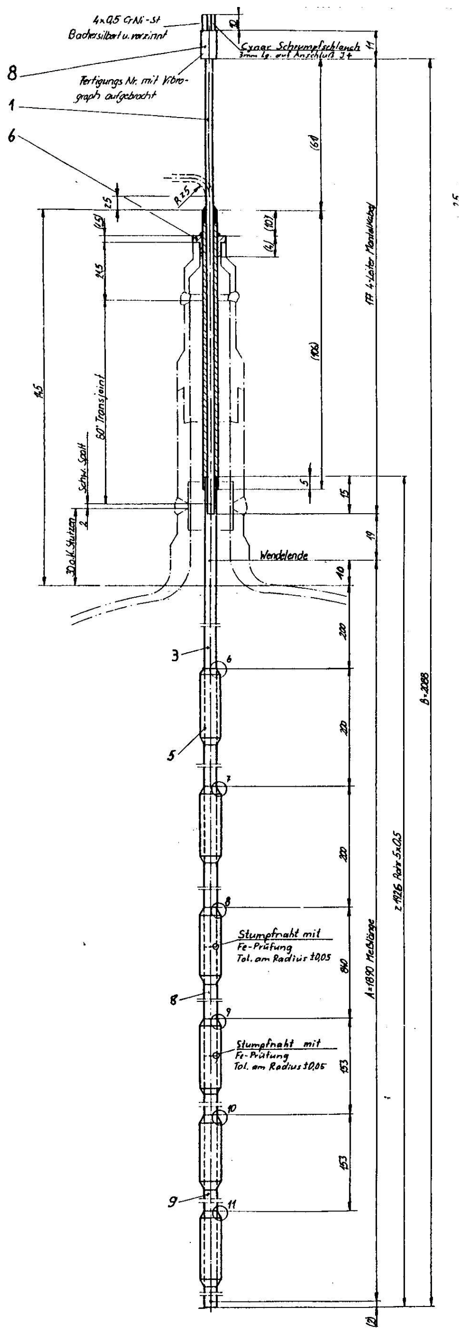


Figure 6.2-7: Detailed sketch of the Level Probe L101/102

Fluid Thermometer T104/105

The fluid thermometers T104/105 are sensors for low temperature measurement and shall measure the temperature of liquid and gaseous helium in the He II tank. They shall be mounted on the upper part of the tank and can be used for temperatures below 20 K. The medium thermometer T104 is also foreseen as a redundant thermometer for the DLCM.

A hot moulded carbon resistor of 100 Ohms at 273 K is fitted in a tube of stainless steel and connected with a stainless steel jacket cable. This configuration is calibrated in the respective temperature range. The thermometer operates in the four-wire-technique. The resistance of the carbon resistor increases with decreasing temperature giving a temperature depending signal. Each thermometer must be calibrated individually.

Measuring range and accuracy of T104/105 :

Temperature [K]	Calibration error [± K]	Typical resolution [Ohms/K]
1.5	0.01	26000
2.2	0.01	8800
4.2	0.03	570
10	0.2	44
20	1.0	3
40	2.5	1.7

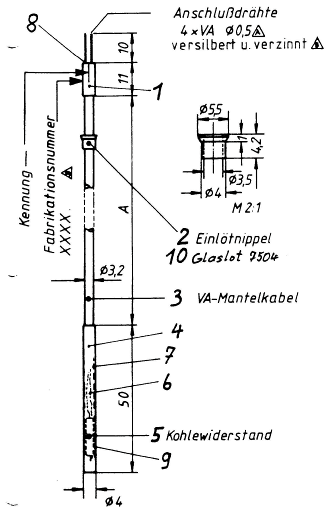


Figure 6.2-9: Detailed sketch of the Medium Thermometer T104/105

Surface Thermometer T103 (Pt500) T106/ T107 (CX)

The T103 is an encapsulated Pt-sensor used during cool-down and warm up operations.

The surface thermometers T106 / 107 are sensors for low temperature measurement. They will be mounted on a surface to measure the present temperature.

The surface thermometer T106 measures the temperature of the He II tank on the lower tank flange on ground during test and in orbit.

A hot moulded carbon resistor of 10 Ohms at 273 K is encapsulated and sealed in a tube of stainless steel. After calibration in the required temperature range, this insert is bonded into a disc shaped mounting plate made from AlMg3.

The thermometer operates in four-wire-technique. The resistance of the carbon resistor increases with decreasing temperature.

Temperature Ranges

- Measuring range : 1.5 40 K
- Acceptance level : 1.5 353 K
- Qualification level : 1.5 363 K

Accuracy

Temperature [K]	Calibration error [± K]	Typical resolution [Ohms/K]
1.5	0.02	370
2.2	0.03	100
4.2	0.05	15
10	0.2	1.4
20	1.0	0.3
40	3.5	0.1

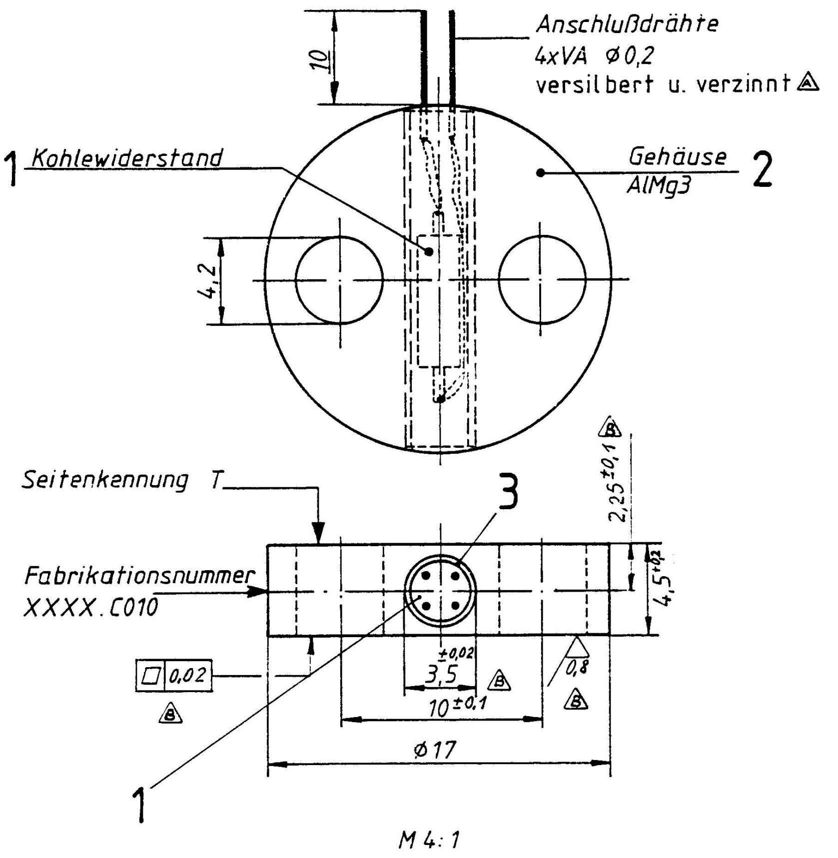


Figure 6.2-11 Surface Thermometer T106/107

Rupture Disc

The cold rupture disk RD124 is a safety device for protection of the Herschel He II tank against pressure increase in case of failure of all other safety devices. It is flanged to the surface of the Herschel He II tank. In case of intolerable pressure increase inside the He II tank e.g. air leak in the insulation vacuum vessel and subsequent condensation of air on the He II tank, He gas will be released by the rupture disk RD124 into the insulation vacuum space and via Safety Valve SV921/922 into the atmosphere.

The rupture disk consists of a thin convex prebulged Ni-membrane, welded into a stainless steel housing. On the low pressure side a cutting device is foreseen for opening the whole cross section area when the set pressure is reached and the membrane buckles. The housing of the burst disk incorporates a flange to be mounted onto the He II tank. The flange connection is Kapton foil sealed.

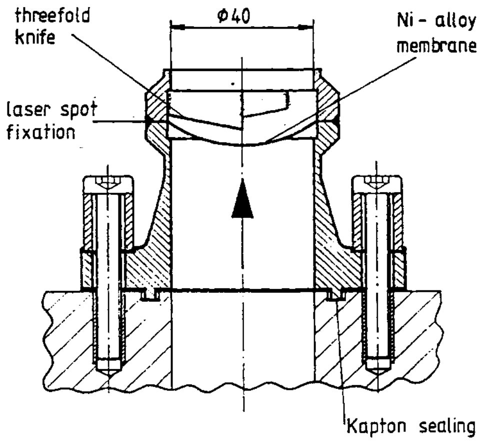


Figure 6.2-13: Sketch of the Rupture Disk RD124

Functional Requirements

- Set pressure (at 4.2 K): Δp = 2.8 bar
- Set pressure tolerance band: ± 10%
- Max. flow rate: > 5030 g/s
- Max operation temperature: 353 K
- Min. operation temperature: 1.6 K
- Leak tightness: < 10^{-8} mbar l/s

Heater H103/104

The electrical heaters H103/104 mounted on the He II tank are foreseen for vaporising liquid helium to increase the mass flow rate if required and to deplete the tank during ground operations and / or after tests. The electrical heaters H701/702 of the same type mounted on the He I tank are foreseen for depleting the tank before launch in a short period of time. The electrical heaters are high load resistors. The dissipated power increases with increasing voltage.

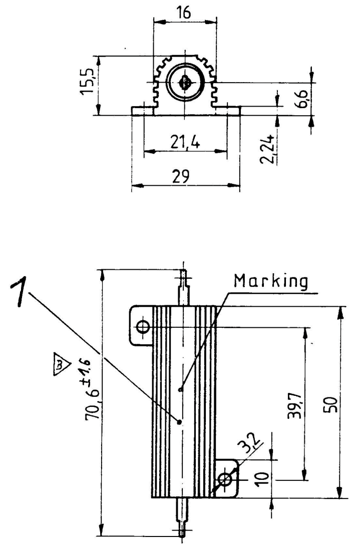


Figure 6.2-15: Sketch of the Electrical Heaters H103/104/701/702

Electrical Requirements H103/104

- Nominal resistance at RT: 332 Ohms ± 1%
- Typical resistance at 4.2 K: appr. 306 Ohms
- Typical resistance at 1.8 K: appr. 306 Ohms
- Nominal power at ambient temperature: 30 W
- Operation power at LHe temperature: 10 W

Safety Valve SV123

The cold safety valve SV123 is a spring loaded safety device for protection of the Herschel He II tank against pressure increase in case of failure e.g. of the shut-off valve. It shall be located at the upper bulkhead of the Herschel He II tank.

In case of intolerable pressure increase inside the He II tank He gas will be released by SV123 via the filling port and SV121 into atmosphere.

The safety valve is an absolute pressure operated bellows relief valve with a soft seat. The valve is permanently closed by a spring. When the response pressure is reached in the inlet tube the pressure acting on a bellow via a conduction line opens the valve against the spring force.

The outer space of this working bellows is in contact with the environmental pressure via housing bores so that the response pressure of the valve is always the differential pressure between inlet and environmental pressure. As the valve shall be located in the insulation vacuum of the Herschel cryostat the reference pressure is always p = 0 bar so that the valve will be operated on absolute pressure.

Temperature Requirements

- Nominal: 1.6 K
- Operational level: 1.6 K to 353 K
- Acceptance level: 1.8 K to 353 K
- Qualification level: 1.5 K to 363 K

Pressure Drop and Flow Requirements

- Operational level :
  Gaseous Helium 86 g/s at T = 4.9 K
  $\Delta p \leq 0.6$ bar; p = 1.76 bar

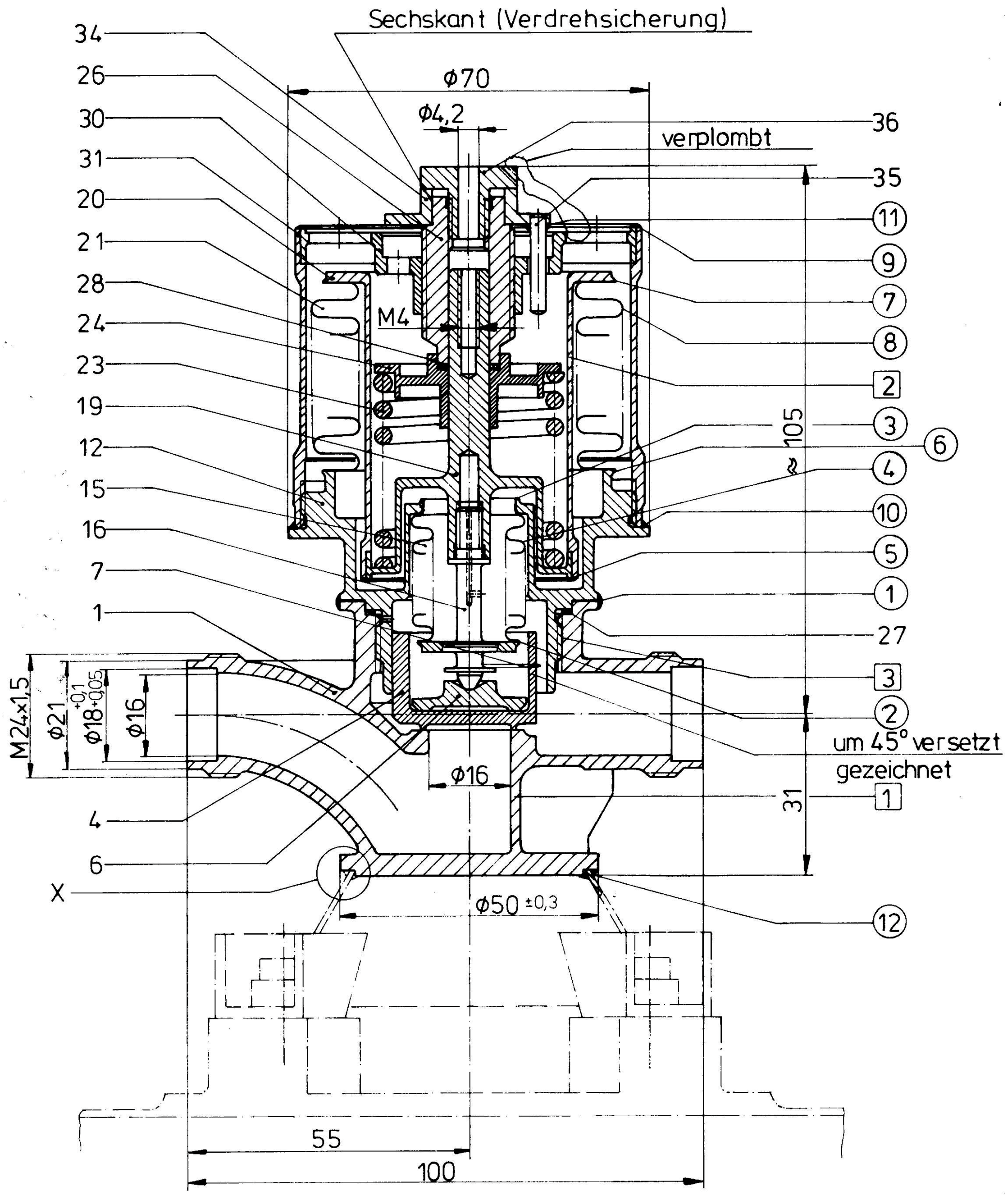


Figure 6.2-17: Detailed Sketch of Safety Valve SV123

Internal He valves V102, 103, 104, 105, 106, 701

The He valves have to enable or stop mass flow from the He II tank and the auxiliary He I tank and therefore to allow the different required operations on ground, during launch and in orbit. Although the ISO valves, which are bi-stable latch valves, would be fully applicable for Herschel's requirements, it is considered reasonable to improve the force margins by some minor modifications without changing the main features of the qualified ISO valves. It must be noted that there was never any electro-mechanical failure observed on the ISO valves during all testing.

The valves V102, V104, V105, V701 are equipped with a heater and temperature sensor.

The main requirements are:

Valve	Temp. on ground	Temp. in orbit	Pressure diff. on ground	Pressure diff. in orbit
V102	1.6K - 363 K	1.6K - 2.1K	< 1.3 bar	N/A
V104	1.6K - 363 K	1.6K - 2.1K	< 1.3 bar	N/A
V103 and V106	1.6K - 363 K	1.6K - 2.1K	< 1.3 bar	~ 0
V105	1.6K - 363 K	1.6K - 2.1K	< 1.3 bar	~ 0
V701	1.6K - 363 K	1.6K - 2.1K	< 1.3 bar	N/A

Leak Tightness Requirements:

The most critical tightness requirements derived from Herschel's system needs for the electrically operated valves are for a: (the test requirements are tbd).

- temperature of 1.7K: 0.15 mbarl/s for valve V102, V104 and V701,Δp 2-3mbar, He II
- temperature of 4.5K: 2.5 mbarl/s for valve V102, V104, V103, V106, Δp 1bar, GHe
- temperature of 293K: 4.9E-3 mbarl/s for air for valves V501, V503, Δp 1bar, air

Mechanical Loads

For the evaluation of the force margins the following levels have been assumed:

- Internal valves: sinusoidal load of 22.5 g
- Switching valves V103/106: Acceleration < 0.5g.

Switching Cycles

The counted maximum number of switching cycles for Herschel/PLANCK AIT are :

- 208 switching cycles at cold temperature (4.2K or below) for V105,
- 5 switching cycles at 80K for V501, V503
- 58 switching cycles at 293K for V501, V503
- 5 switching cycles at 363K for V102, V105

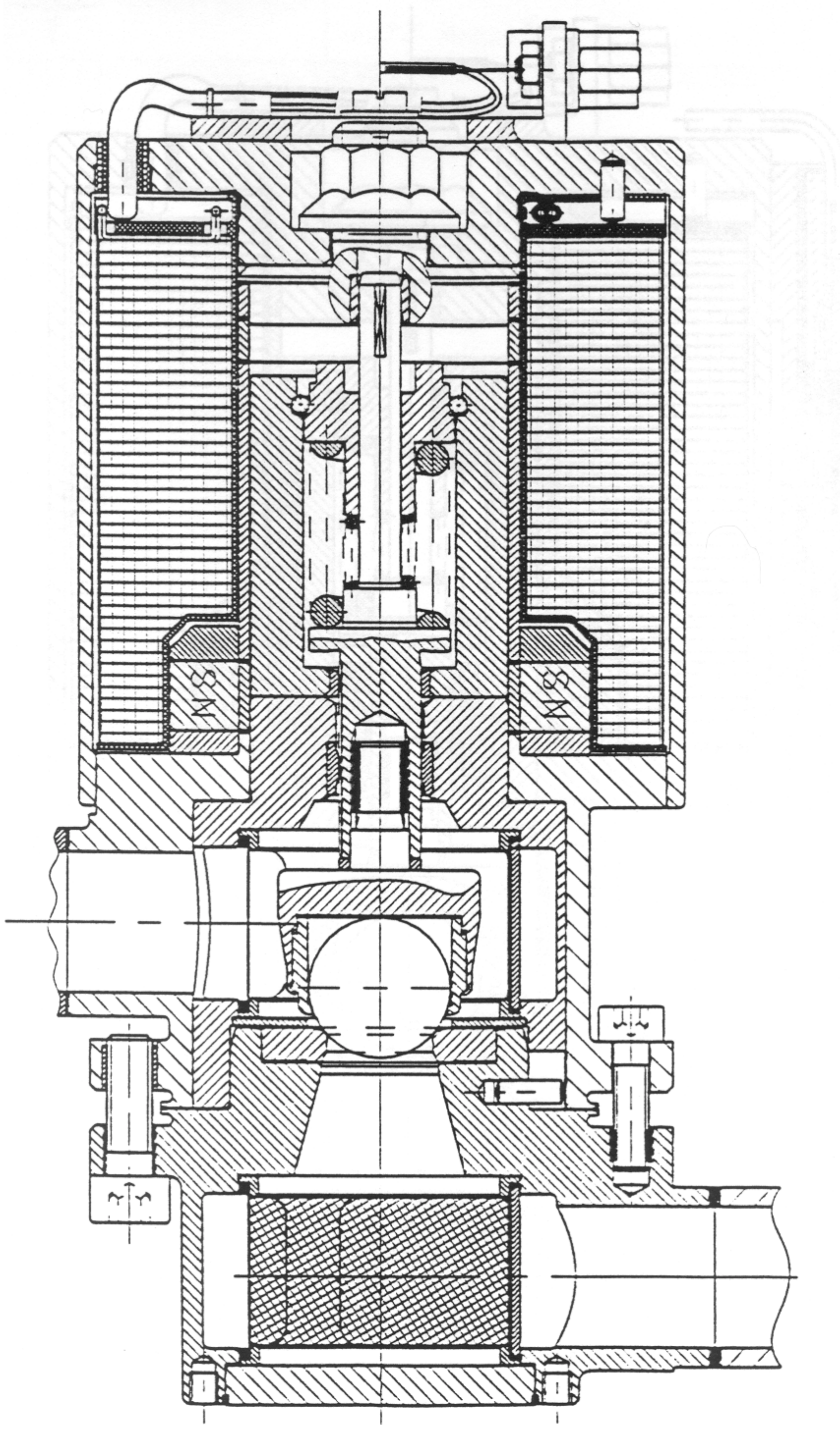


Figure 6.2-20: Overall Design of Improved Valve with Status Indicator

Pressure Sensor P101

The pressure transducer P 101 measures the absolute pressure of the He II tank. It is mounted on the support of the rupture disc RD 124 and connected with a capillary pipe to the vent line near the He II tank. The pressure transducer P 101 monitors the tank pressure during filling and testing operations on ground.

Pressure Ranges :

Measuring range :	0 to 1.6 bar abs.
Operational level :	0 to 1.76 bar abs.

Accuracy:	at 295K	at 4.2 K
absolute calibration error	< ± 3 mbar	< ± 3mbar
non linearity and hysteresis	< ± 8 mbar	< ± 8 mbar

Bridge Resistance :		
Nominal bridge resistance	at RT :	1000Ω ± 5 %
Typical resistance	at 4.2 K :	1600Ω ± 5 %

Adsorber

The adsorbers A101-107 each consist of a housing filled with a package of carbon foil used to adsorb He gas in the insulation vacuum space in case of a small He leak. These adsorbers ensure that a potential leak during ground operations does not lead to an increase of pressure in the insulation vacuum and thus to an increase of heat input to the cryo system. In orbit, when the cryostat cover is ejected, the insulation vacuum is connected to space and hence the adsorbers are no longer required.

The housing will be closed by adhesive on the lower side. On the upper surface the housing is closed by a wire cloth to prevent the escape of particles from the housing but to enable helium to enter the adsorber housing. The adsorbers shall be located at the fixation adapters of the Herschel cold valves on the upper bulkhead of the Herschel He II tank by screw connections.

The adsorbers shall be designed to adsorb a He leak of 1×10^{-4} mbar l/s for a time of at least 1000 h (tbc) at nominal temperature, during ground operations.

Filling Port with Safety Valve SV121, Oscillation Damper OD101, FilterS101

The filling lock SV121 consists of a safety plug with catching device, an air lock for inserting the transfer line and a blind flange.

For filling/refilling operations, the SV121 will be used as an evacuable air lock for inserting the LHe transfer line into the filling port. During all other tests, ground operations and cold transportation, the SV121 will be used as a safety device. During vibration tests and before launch the SV121 will be blind flanged. The SV121 is a part of the He S/S safety system.

The set pressure is defined by the friction of the gasket (quadring) and shall be $\Delta p = 0.45 \pm 0.15$ bar. The SV121 must allow the same flow rate as SV123 (i. e. m = 86 g/s at 5 K)

By using a second gasket (O-ring) a very low leak rate (< 10^{-6} mbar l/s) shall be guaranteed.

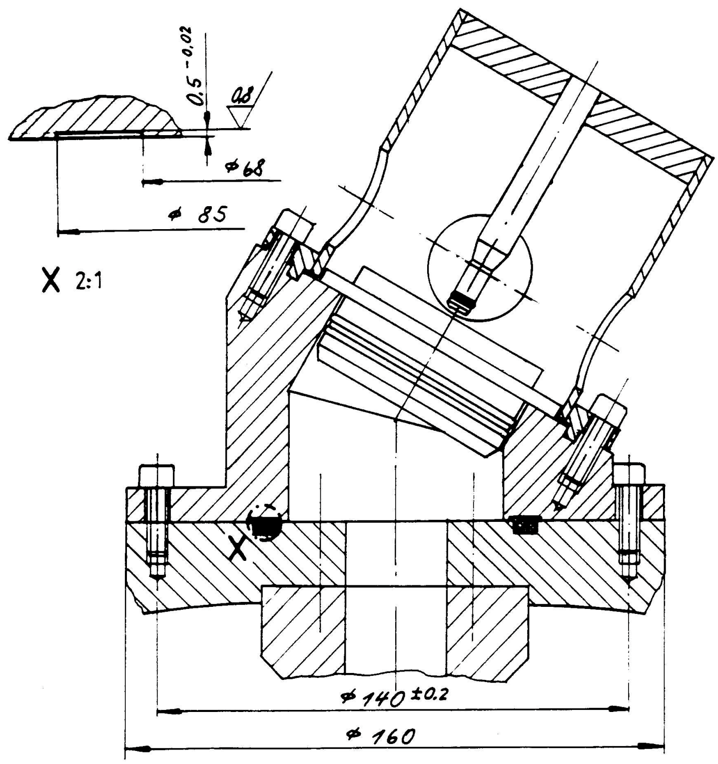


Figure 6.2-21 Safety Valve Configuration SV121

The oscillation damper is a device for protection of the He II tank against heat input which could be caused by either gas oscillations in the internal vent line between filling port and tanks or gas circulation between the He I tank and filling port.

The oscillation damper shall be located inside the filling port. Its tasks are to block the bypass line via the filling port to prevent gas circulation between He I tank and filling port and to dampen the formation of gas oscillations in the filling port and internal piping.

Since the oscillation damper closes the filling line inside the filling port, it can only be inserted after He II top-up and final top-up of the He I tank. Should an additional filling be required (caused for example by a launch delay) it has to be dismounted to enable insertion of the filling line.

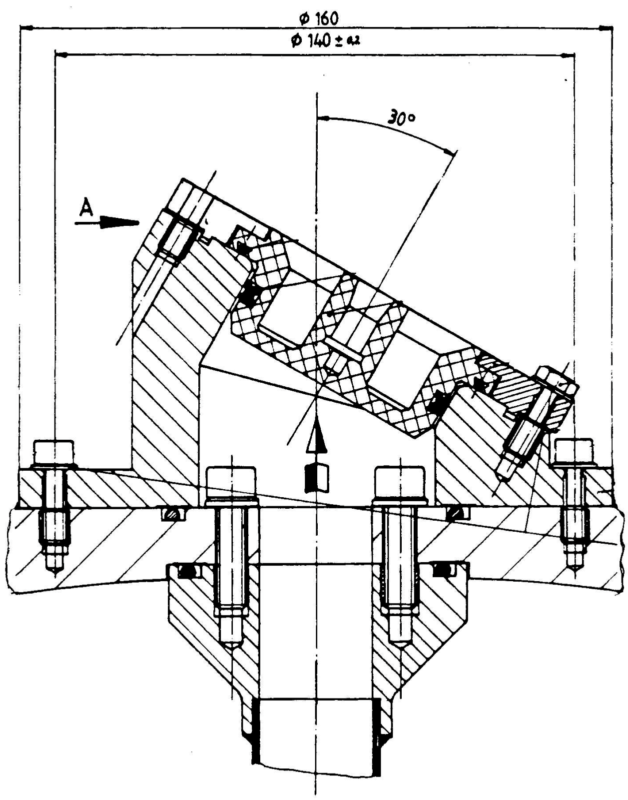


Figure 6.2-23: Flight Configuration SV121

For Herschel, the filling port shall be fixed in the cylindrical part of the CVV (He filling operations also with the Telescope on top of the PLM).

He II Tank Tubing

The tubing on the He II tank interconnects the He II tank with the valves, the filling port/ SV 121, the Helium I tank, the safety valve SV 123 and the inlet of the OB tubing

Requirements:

- Independent cool-down and filling of the He II tank and the He I tank
- Venting of the He I tank through V701 and V105
- Venting of the He II tank through the phase separator and the valves V103/106
- Bypassing of the phase separator during cool-down and ground tests
- Venting of GHe flow from the safety valve SV 123 into the filling line and from SV121 to atmosphere

The design of the vent pipes shall fulfil the following requirements:

Nominal ground mass flow	30 mg/s
orbit mass flow	2.5 mg/s
max. flow during cool down	2 g/s
pressure drop on orbit	tbd
pressure drop during cool-down	< 0.1 bar (tbc)

The design of the exhaust line from SV 123 through the filling line and SV 121 shall allow a mass flow of ≥ 86 g/s.

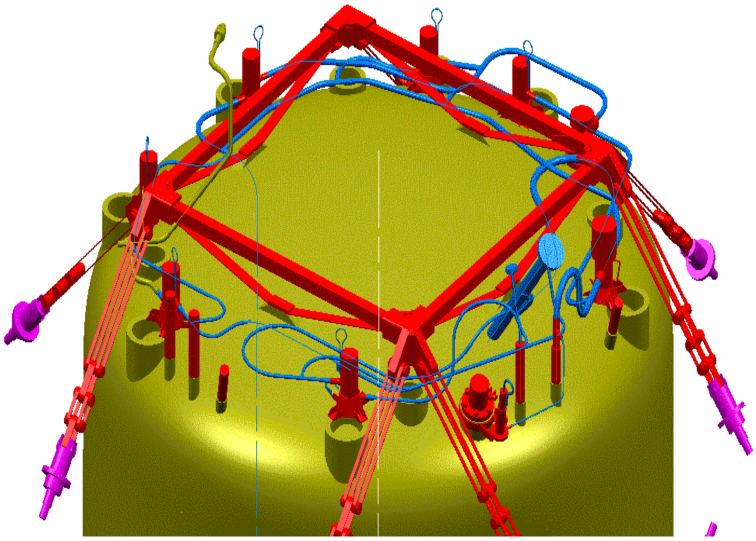


Figure 6.2-25: He II Tank Tubing (preliminary)

6.2.2.2 He I Tank Assembly

The He I tank assembly consists of the He I tank and the components level probe L701/702, the heaters H701/702 and the surface thermometers T701, T702/703 attached to it.

He I Tank

The He I tank shall serve as the reservoir for normal liquid helium (LHe) to provide the cooling power for the actively cooled cryostat during some ground tests and pre-launch operations (launch autonomy). Especially during the pre-launch operations the He I tank shall provide sufficient cold gaseous He (GHe) to cool the cryostat heat shields in order to prevent the He II in its tank, which is shut off from the outside of the cryostat, being heated to a temperature of > 2.1K during the so-called „launch autonomy" period of the Herschel PLM which is defined to be 6 days after the last filling (tbc) and thermal conditioning of the He II tank.

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

- The He I tank shall provide a cold volume of 80 l minimum. This volume shall be increased as much as possible by a suitable final definition of the tank geometry.
- The tank shall be fillable to ≈ 100 % by optimum location of the GHe outlet port
- Tightness to LHe condition at ≈ 4.2K
- Safety against
- Launch and structural testing loads
- Pressure (internal and external)
- Cleanliness during manufacturing and AIT
- Stiffness/Eigenfrequency empty

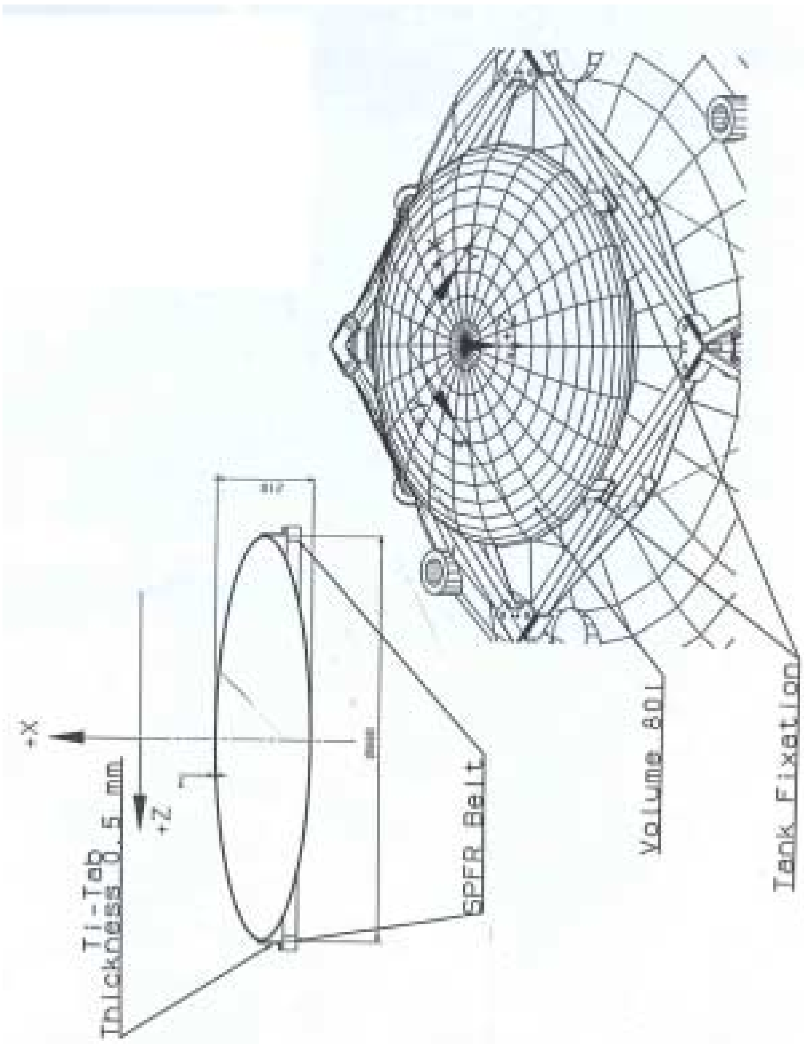


Figure 6.2-28 He I Tank (preliminary)

Level Probe L701/702

The principle of function of the Level Probe L701/702 is the same as for the L101/102 of the He II tank; it is shortened due to smaller tank dimensions. Due to the limited space between the He II and He I tanks and to arrange it as high as possible in the tank (to control the level as far as possible up to 100%), the electrical connection shall be bent and the Level Probe flanged to the tank (tbc).

H701/702

The electrical heaters H701/702 are mounted on the He I tank and are foreseen to deplete the tank before launch in a short period of time.

Electrical Requirements H701/702

- Nominal resistance at RT : 49.9 Ohms ± 1%
- Typical resistance at 4.2 K : appr. 46 Ohms
- Typical resistance at 1.8 K : appr. 46 Ohms
- Nominal power at ambient temperature: 30 W
- Operation power at LHe temperature : 10 W

Surface Thermometer T701 (Pt 500) T702/ T703 (CX)

The surface thermometers T702/703 measure the temperature of the He I tank during ground operation. The T 701 sensor is used for cool-down operations. The sensors are identical to the sensors described before for the He II tank.

6.2.2.3 Optical Bench Tubing and Fixation/Thermal Hardware

The vent line comes from the He II tank tubing, twice surrounds the instruments and provides the temperature levels 1 and 2 to the instruments. The level 0 is provided by direct strapping to the He II tank. For connection of the instruments to levels 0, 1 and 2 the use of copper straps with 20 mm x 1mm cross section, as used for ISO, is proposed. For the connection between instrument and Cu-strap the standard ISO mounting concept is proposed. The straps to the He II tank (level 0) are routed through holes in the Optical Bench.

To keep the temperature difference between the instrument and the He gas in the vent line small, the use of the ISO copper quality for level 1 and 2 seems sufficient, but for the connection to the He II tank the use of copper with higher conductivity and an increase of the contact area is necessary. The number of straps per instrument and temperature level is tbd, but should be limited to one as far as possible.

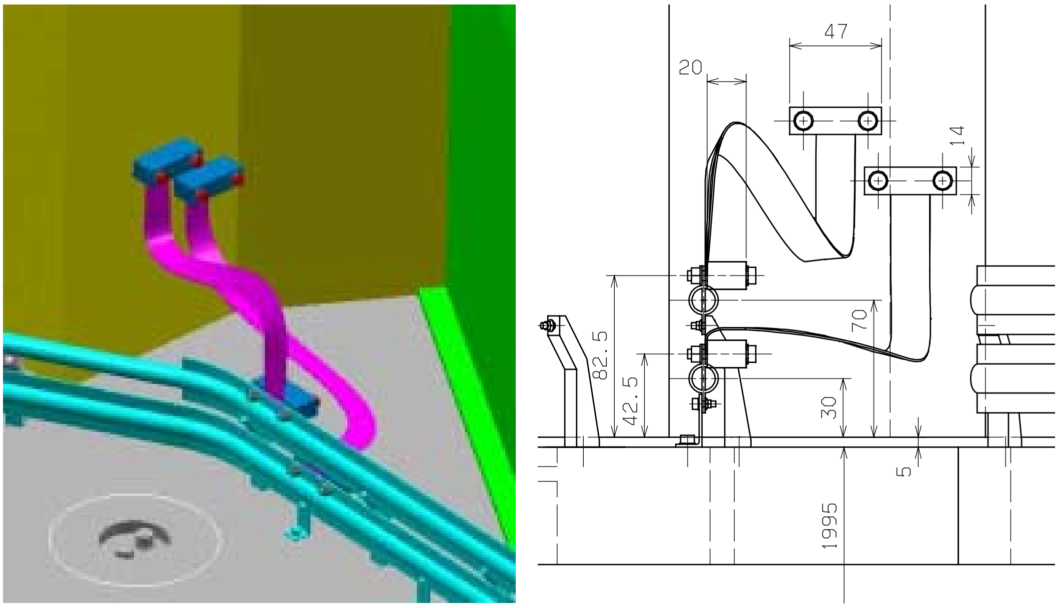


Figure 6.2-29 Connection of Instruments to vent line (level 1 and 2)

The level 1 vent line is thermally insulated from the OB by CFC fixations, the level 2 vent line is thermally connected by Al fixations.

6.2.2.4 Internal Vent line on Shields

After leaving the OB tubing, the GHe cools the three thermal shields. The fixation and routing of the vent line on the shields is similar to ISO. Between the shields SST-AL-transition joints are used. Compared to ISO the vent line routing has to be modified due to the reduced cylinder height and cooling length considerations The following figure shows a possibility for the routing of the vent line on the shields. Detailed analysis for heat transfer from the heat shields to the vent line and pressure drop calculations have to be performed in Phase B.

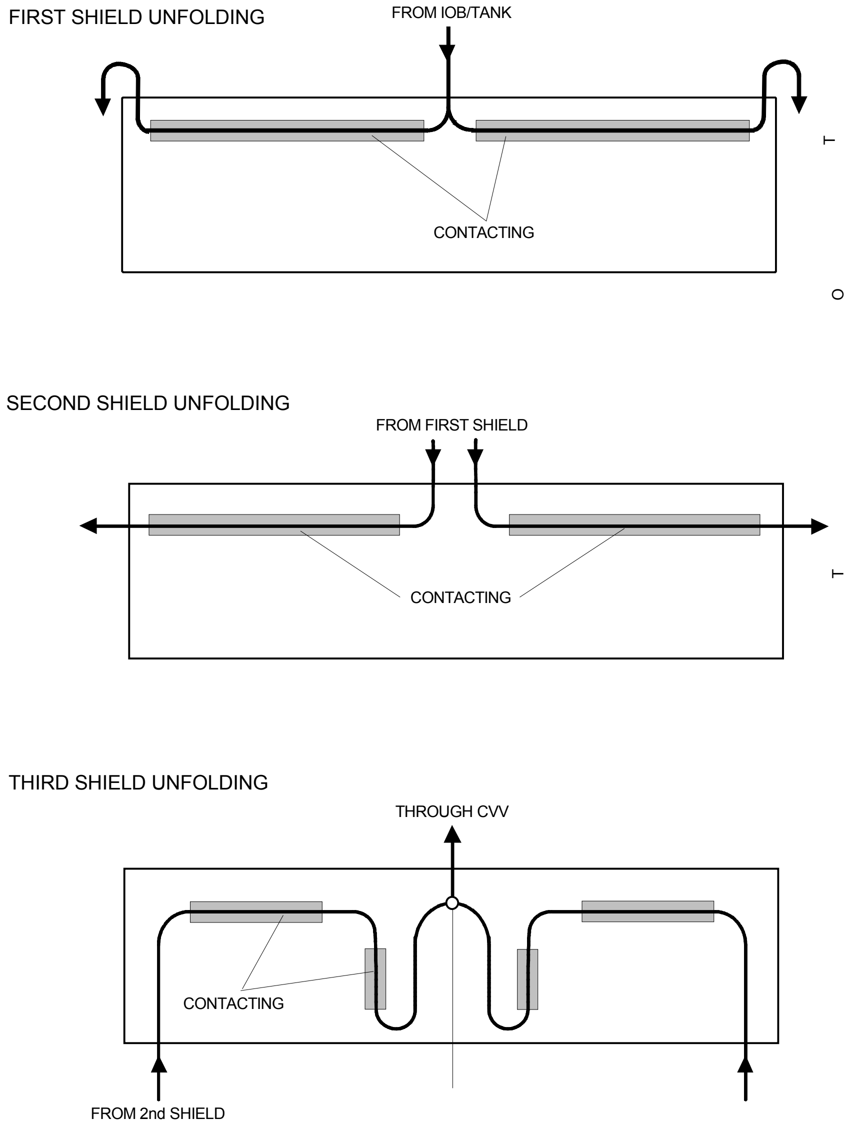


Figure 6.2-31 He Flow on Heat Shields (Schematic)

6.2.2.5 External Vent line Assembly

The external vent line assembly consists of the following components:

- H501 with S501, T502 and V502
- H502
- T501/503
- SV 521
- V506
- P501/502
- External valves V501/503/504/505
- Nozzles 511/512 and 513/514
- Tubing

The external vent line assembly has to vent the GHe flow on the CVV outer side during all PLM operations. Venting of the GHe during cool-down, warm-up, filling, top up and normal ground operation shall be performed through the manually operated valve V502. The external vent line assembly together with the internal vent line parts shall be designed to fulfil the requirements described in chapter 5.7.2.

Heater H 501 with Filter S501, Thermometer T502 and Valve V502

The heater H501 is used to warm up the cold helium vent gas from 30 K to ambient temperature during the depletion of the He I tank. It prevents subcooling of the vent gas line and the external valves and therefore condensation of water from air on these hardware items.

The temperature sensor T502 (thermocouple) protects the heater from superheating in case of no mass flow.

The filter S501 is installed to protect the external valves and the safety valve SV521 from dust and particles coming from the shields.

Valve V502 enables a high helium flow rate during filling the cryostat with LHe / He II and during pumping down to superfluid helium conditions.

The heater H501 consists of 3 single heater elements. They are wound to a heat exchanger and integrated in a vacuum isolated housing. The heater elements are pipes (stainless steel) in which the heat wire is embedded in high compressed magnesium Oxy. The ends are closed by ceramic parts. The electrical connections of the heater elements are connected in parallel.

The temperature sensor T501, a coated thermocouple, is thermally well coupled to the heater elements.

Downstream of the heater H501 the filter S501 is installed. This multilayer stainless steel mesh filter has a filtration rate of 2 µm (nominal).

Opposite to the H501 housing inlet the valve V502 is arranged. It is a spring loaded and hand operated valve and will be operated by an actuator mounted in the coupling of the vent line. During vibration tests and launch the valve is additionally closed by a blind plug. The valve housing of V502 is made of titanium alloy because of the high strength of the material combined with a low thermal conductivity.

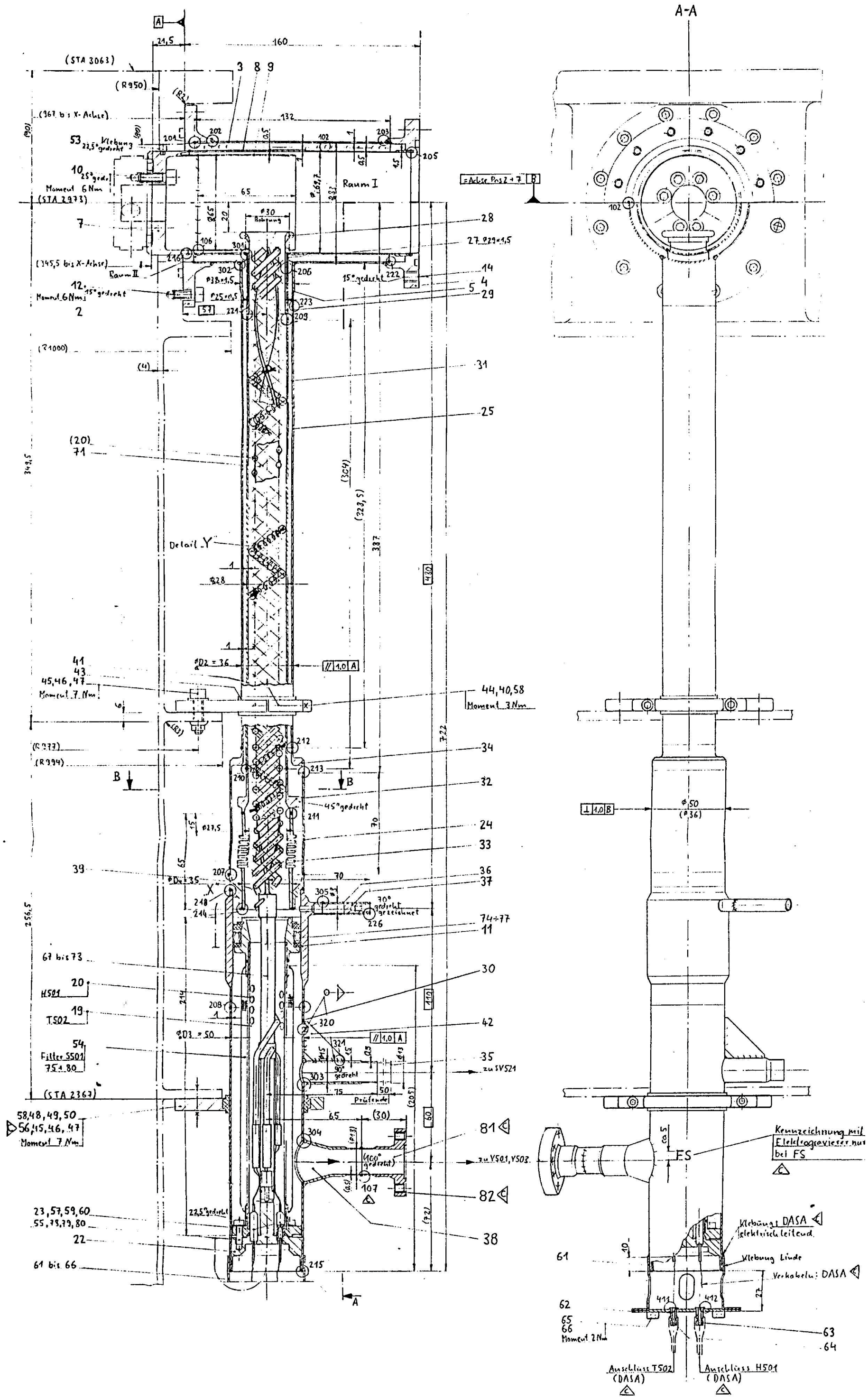


Figure 6.2-34 Heater H501, S501, T502 and V502

Heater H502 (Heater Foil)

H 502 is used on ground for heating the gas flow during normal operation of the cryostat to avoid condensation or freezing. It is situated near the outlet of the GHe from the heater H501, the available power is > 6W.

Temperature Sensors T501/T503

These sensors are Pt-500 sensors which are glued on the external vent line.

Safety Valve SV521

The safety valve SV521 is a spring loaded check valve with a fixed set pressure of 0.35 bar. It is located at the external tubing in parallel to valve V501 and V503.
The purpose of SV521 is primarily to release small amounts of gas entrapped in the vent line in case of a closure of V103/106 and/or V501/503.

Manual Shut-off Valve V506

The shut-off valve V506 is a manually operated bellow valve with a metal seat.
It is located at the external tubing in parallel to P501. The purpose of V506 is to have the possibility of installing temporarily (during ground operations and tests) an additional manometer or pressure transducer in parallel to the existing P501. In this configuration the properly closed status of the external valves (V501 to V505) could be approved. During launch and vibration tests of the PLM the valve will be closed and capped; the handle will be dismounted.

Pressure Sensor P501/502

The purpose of the pressure transducer P501 is to monitor the pressure between the third radiation shield and the valves V501/V503. Together with the vapour pressure in the He II tank this pressure allows an analysis of the vent line impedance during ground tests and in orbit. Since on the other hand the pressure drop across the valves V501/ V503 and the low thrust nozzles 511/512 is directly related to the vent gas mass flow rate, the pressure P501 could also be used to estimate the mass flow rate during the mission. The pressure transducer shall be located outside the vacuum vessel as part of the external piping.

Pressure range P501: 0 to 35 mbar
Pressure range P502: 0 to 1.6 bar

External Valves V501/503/504/505

The external valves are of the same design as the internal valves. In contrary to the ISO design, the baseline for the Herschel external valves is to be equipped with inlet and outlet filters. The impact of their increased flow impedance will have to be assessed by analysis and testing.

Nozzles N511/N512 and N513/N514

The nozzles are the point where the GHe leaves the vent line and enters the surrounding vacuum. The same type of nozzles as used for ISO shall be used. The nozzle diameter will be adapted to Herschel Δp needs.

Tubing

The external tubing interconnects the H501 with the external valves V501/503/504/505, the vent nozzles, the V506 and the SV 521.

6.2.2.6 CVV Mounted Safety Equipment

SV 921/922 are two identical spring loaded safety valves for protection of the insulation vacuum vessel of the Herschel cryostat against overpressure. They are also used for pumping the insulation vacuum for the He II tank of Herschel. They form a part of the He S/S safety system. SV921/922 are to be located at the vacuum vessel of the Herschel cryostat.

The spring loaded valves open at overpressure within the vacuum space. During launch the springs provide proper tightness of these valves. The safety valves SV921/922 consist of a guided valve seat, a spring pressing the seat against the interface flange of the vacuum vessel and the valve housing that holds the spring in its place.

For evacuation of the cryostat vacuum vessel the safety valves are dismounted. After evacuation the valve seats are placed onto the vessel interface flange using an evacuation sluice. Then the body is installed onto the vacuum vessel. During all normal operation modes (ground operation, test, launch) the valves have to keep the vacuum vessel tight against air leakage. When the burst disk ruptures in the event of a catastrophic air leak of the vacuum vessel the safety valves protect the vacuum vessel against rupture.

Operational set pressure :	0.4 ± 0.05 bar
Proof pressure of valve seat:	3.0 bar at 295 K ± 5 K external to internal differential pressure

6.2.3 Subsystem Interfaces

The main mechanical and thermal interfaces of the He S/S are :

- He II tank to SFWK
- He I tank to SFWK
- Instrument Copper straps to He II tank and He vent line on OB
- He vent line fixation to OB and thermal shields
- Filling port and H501/V502 to CVV
- External vent line to CVV

The electrical interfaces of the He S/S are the I/Fs to all internal and external electrical He S/S components

- T-sensors
- Heaters
- Liquid levels
- Valves

6.3 Cryostat Insulation Subsystem (CIS)

6.3.1 CIS overall Configuration

The HERSCHEL Cryostat Insulation Subsystem (CIS) shall reduce the heat input into the cryogenic system of the HERSCHEL PLM to a minimum and thus forms an important item for the performance and lifetime. It consists of three radiation shields (also named heat shields), the instruments shield, the cover shield and the Multilayer Insulation (MLI) fixed to these shields, to the HeII-tank, to the Cryostat Vacuum Vessel (CVV) and to the Cryostat Cavity.

Figure 6.3-1 shows the principle of the CIS configuration and components. The major components of the insulation subsystem are arranged around the He II-tank almost like the skins of an onion:
Tank MLI – Heat Shield 1 - MLI - Heat Shield 2 - MLI - Heat Shield 3 - MLI - CVV – MLI partly. Only the CVV part facing the warmer Sunshield/Sunshade is covered with MLI, the remaining CVV area serve as radiative heat sink to deep space.

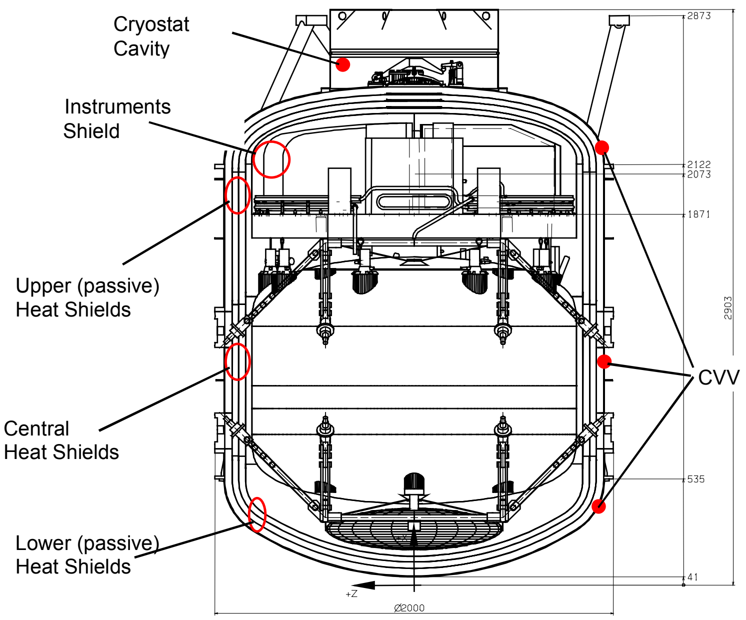


Figure 6.3-1: HERSCHEL CIS with Tanks, CVV and other Structural Parts

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

The MLI serves as passive insulation for the He II-tank, for the radiation shields, as well as for struts and brackets (where necessary) to minimize heat input during the mission and on ground. Depending on the specific purpose, there will be a cryostat internal MLI and a different external MLI. The internal MLI is the most critical because it is used within the active cooling loop of the PLM and therefore shall have the highest requirements for performance and cleanliness. The external MLI reduces the heat load to the Cryostat Vacuum Vessel from the hot Sunshield/Sunshade. There will be many penetrations in the MLI for system relevant components.

6.3.2 Radiation Shields

The CIS consist of following radiation shields:

- 1st (inner) heat shield
- 2nd (middle) heat shield
- 3rd (outer) heat shield
- instrument shield (also called OB shield)
- Cryo-cover shield

Each heat shield consists of a lower and upper part and of a central cylindrical part. The Optical Bench forms the lower part of the instrument shield. The radiation shields 1, 2 and 3 in principle only differ in size and they reach different temperatures in orbit and on ground during testing. The radiation shields will be cooled actively and passively. The active cooling with GHe from the tanks will be performed on the cylindrical central radiation shields starting with shield 1 through shield 3. The cryostat upper and lower radiation shields are passively cooled via the interface to the actively cooled central shields by multiple screw connections to these shields. The shield diameters are the same as in ISO. All shields will be covered with internal MLI.

The shields will be made of aluminum alloy AlMgSi1. The wall thickness of the shields shall be 0.8 mm (tbc) with an increase in the interface areas to about 1.5 mm locally. These changing wall thickness shall be obtained by chemical etching of the outer shield surface after forming the shield shape with a basic thickness of about 2 mm. The dimensional accuracy has to be of high priority.

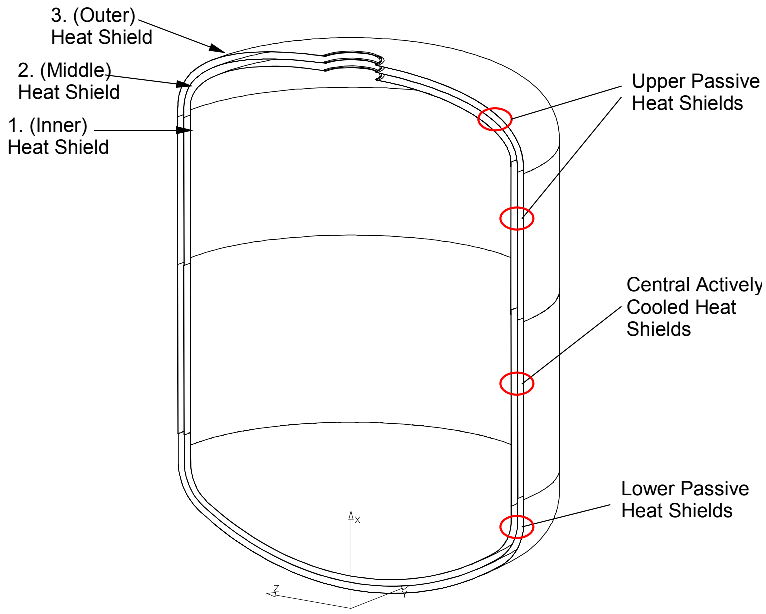


Figure 6.3-3: Arrangement of HERSCHEL Radiation Shields

There are many attachment points on and penetrations in the shields for optical purposes, such as telescope beam and LOU beams, feedthroughs and fixations.

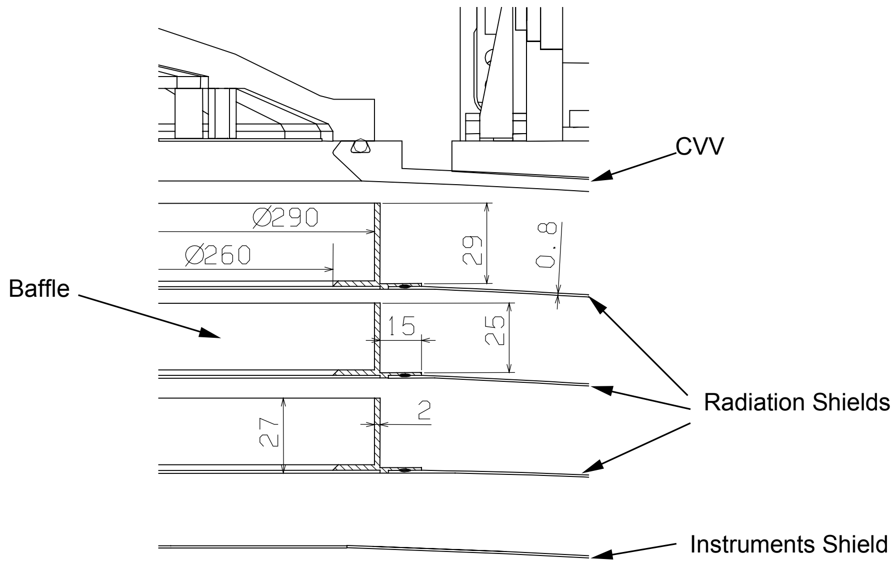


Figure 6.3-5: Attachment of Baffles to HERSCHEL Upper Radiation Shields (diameters tbc)

The Central Radiation Shields provide feedthroughs for the attachment structures between the Spatial Framework Structure and the CVV (8 each) (Figure 6.3-7:REF). The shields will be attached to the straps of the tank suspension system, see Figure 6.3-9:REF. They are equipped with He cooling/venting tubes spot welded to the shields.

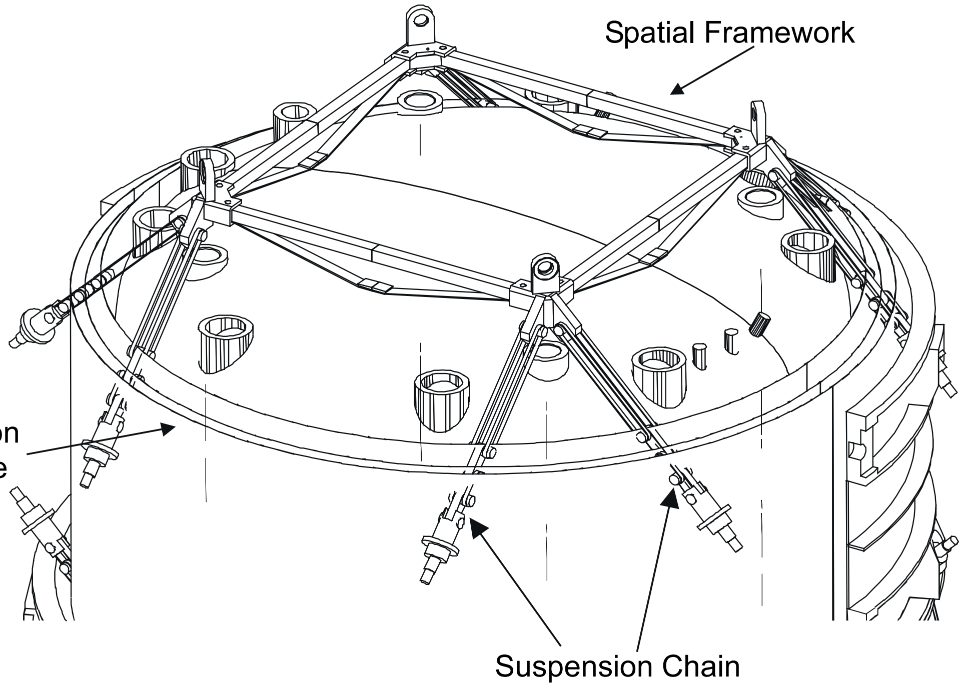


Figure 6.3-7: Attachment of HERSCHEL Radiation Shields and Feedthroughs

The Upper Radiation Shields consist of a cylindrical and a bulkhead part. They are welded together, at least by minimum distance spot welding for good thermal conductivity. They provide cutouts for the telescope beam on central top with a baffle (one each) and for the Local Oscillator Unit beams of the cylindrical part of the shield. In addition, openings and feedthroughs are foreseen for the LHe filling line, the He II tank burst disk exhaust and the GHe-ventline. The Lower Radiation Shields are of undisturbed dome shape and corresponds basically to those used with ISO.

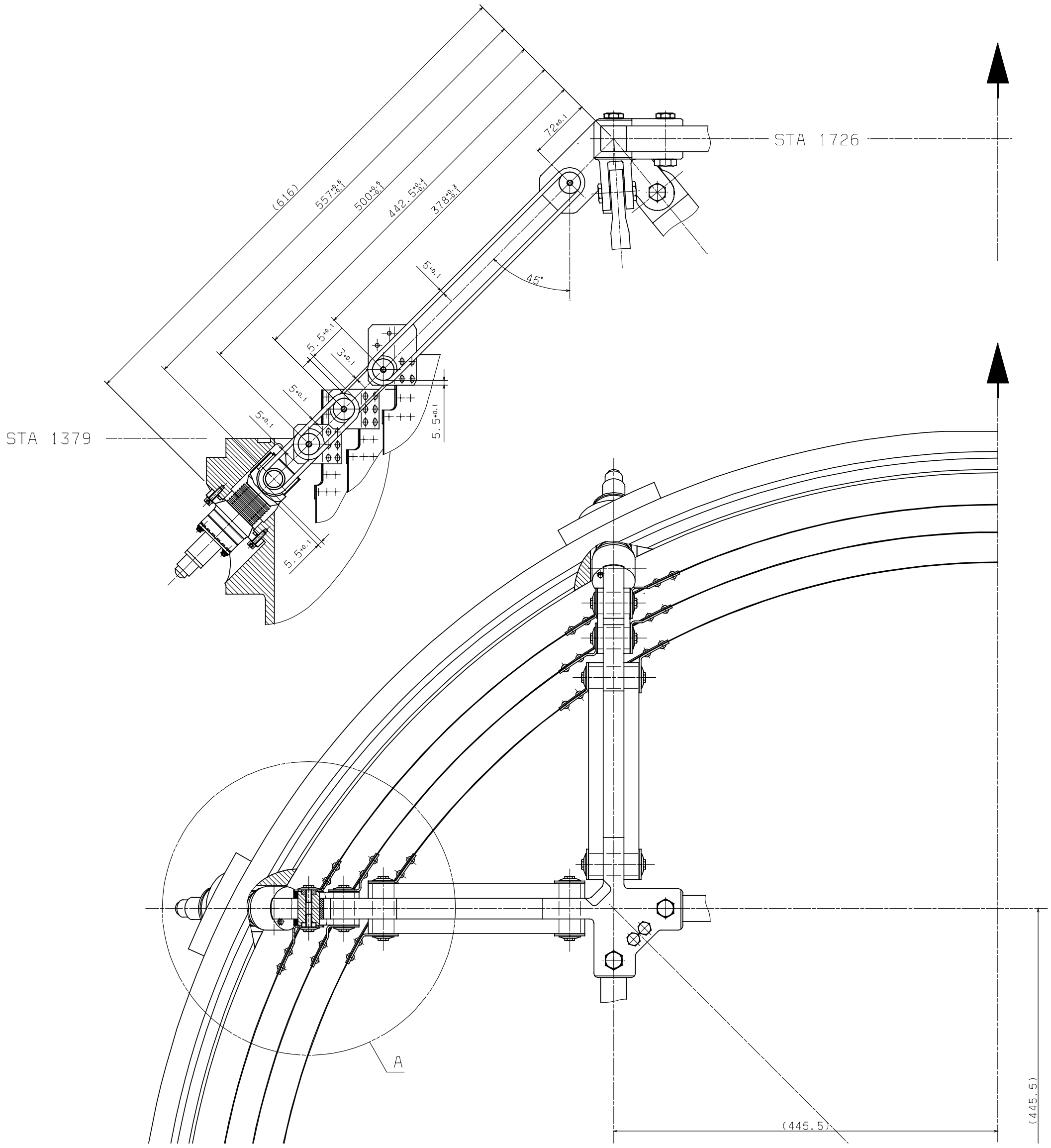


Figure 6.3-9: Shield Attachment to Tank Suspension Straps

Instrument Shield (OB shield)

The Optical Bench with the Focal Plane Units will be equipped with a dome shaped GHe-cooled instrument shield (Figure 6.3-11). This shield will have an unbaffled opening at its central apex for the telescope beam. The instrument shield will provide openings for the GHe-ventline and the LOU beams on -Y (7 or one slot) plus 2 holes for alignment purposes.

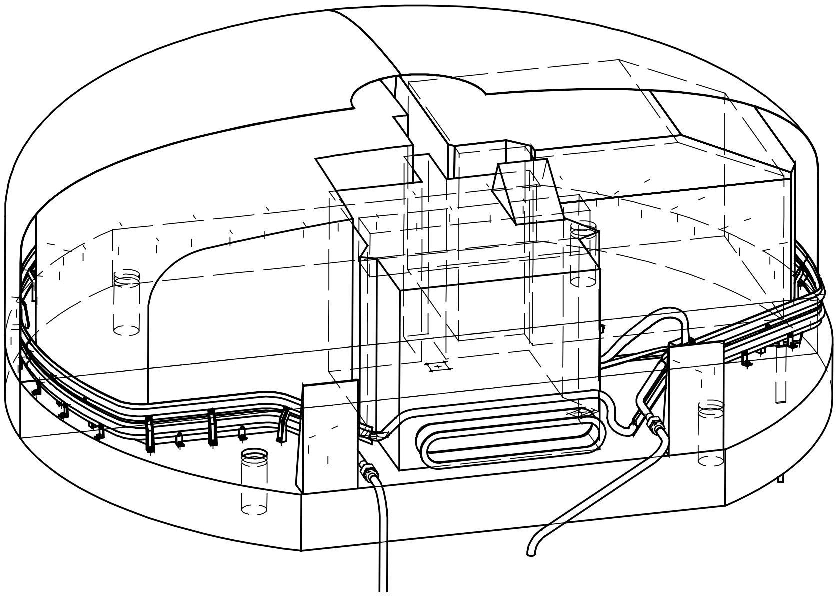


Figure 6.3-11: HERSCHEL Instrument Shield with OB and FPUs

Cryo-Cover Shield

The Cryo-Cover will be equipped with a disk shaped passive radiation shield.

6.3.3 Multilayer Insulation (MLI)

Internal MLI (inside Cryostat)

The internal MLI is attached to the

- He II tank and its components

- 1st (inner) heat shield
- 2nd (middle) heat shield
- 3rd (outer) heat shield
- instrument shield (also called OB shield)

Each heat shield MLI consists of a skirt for the lower and upper bulkhead and for the cylinder part. Depending on the thermal requirements the number of blankets and layers are different. The tank MLI shall not be fixed to the tank structure but shall lie on it "freely" floating. All other MLI shall be attached to the corresponding components via snap studs and buttons.

In general the inner MLI consists of different alternating layers of

- Embossed double side aluminized Mylar (polyester) foil, 6.35 µm thick, and
- monofilament polyester spacer, 48 µm thick.

External MLI (outside Cryostat)

The external MLI is attached to the

- CVV part facing the sunshield
- Cryostat Cavity
- external box LOU
- PLM/SVM support structure (tbc)

The MLI on the external box BOLA is rejected (tbc), since the BOLA box shall serve as radiator to space. The Sunshield/Sunshade rear side MLI is described in chapter 6.5 and the Telescope MLI is part of the Telescope.

The performance characteristic and the requirements of the external MLI blankets are slightly lower than for the internal MLI. Therefore these blankets shall be different from and simpler than the internal ones. The external MLI shall consist of 2 blankets and one thick (for handling/protection purposes) external foil.

Each blanket shall consist of :

- one layer of Kapton-Nomex foil, 12.5 µm thick,
- 700 Å totally aluminized on inner side of the blanket (not visible)
- 6 layers of Kapton foil, 7.5 µm thick,
- 700 Å totally aluminized both sides of the blanket
- 7 layers of monofilament Trevira spacer
- one layer of Kapton-Nomex foil, 12.5 µm thick,
- 700 Å totally aluminized on inner side of the blanket (not visible)

- external thick Kapton foil, 50 µm thick, 700 Å totally aluminized both sides

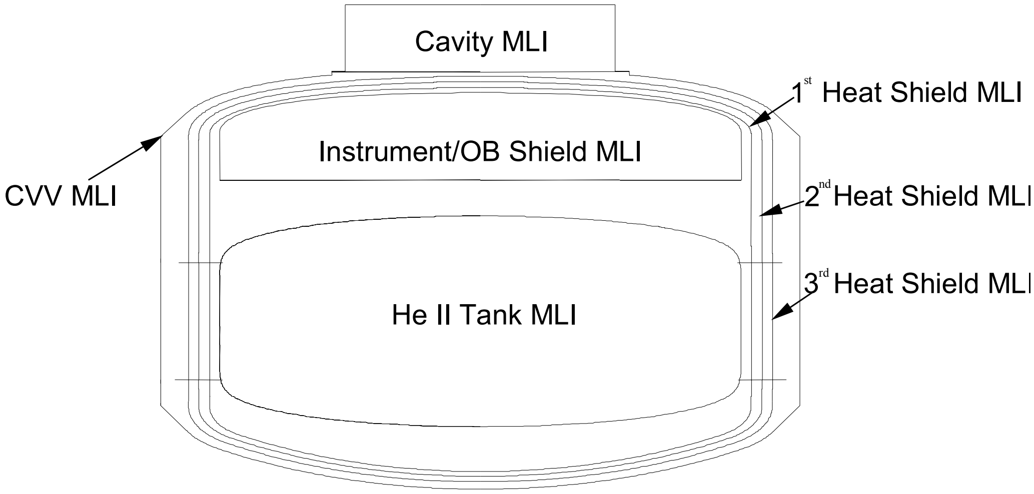


Figure 6.3-13: Principle of MLI Definition

6.3.4 Component Interfaces and Feedthroughs

Mechanical Interface

Internal interfaces exist with

- the radiation shields with bolts and rivet nuts between each set of shield components
- connections between the 3 central shields via the GHe-cooling loops (ventline)
- provisions for MLI fixation studs and MLI grounding
- thermal sensor fixations
- electrical connector and cable fixations (mainly on heat shield 1)
- the instruments shield have interfaces to the Optical Bench and the He-cooling loops

Electrical Interface

There will be thermal sensors and electrical connectors attached to the radiation shield surfaces (tbd. Feedthroughs/openings for routing will be provided. All shields and MLI blankets will be equipped with ground straps (each sheet of MLI-layer shall be contacted) and grounding points. A thermal sensor will be placed on the cryo-cover shield

Optical and Alignment Interfaces

There will be openings for optical and alignment purposes in all three upper radiation shields. The alignment openings in the CVV adjacent to both sides (one each) of the 7 LO windows will be closed after alignment measurement/verification.

	Heat Shields	Instrum. Shield	Internal MLI	External MLI
Telescope beam to Scientific Instruments	X	X	X	X
LHe-filling line	X		X	X
He II - tank burst disk exhaust (safety provision)	X		X	X
GHe ventline	X	X	X	X
Tank support straps	X		X	X
7 LO beams	X	X	X	X
Alignment windows	X	X	X	X

Table 6.3-1: Component Feedthroughs and Cutouts

6.3.5 Design and Development Approach

For the CIS the conceptual design and, in many aspects, identical design of components as for ISO shall be applied for HERSCHEL. MLI tests for an improved tank MLI with increased number of spacers are planned in Phase B.

		Model						
	Qual-Status	EQM	PFM	Spare	GSE	Design	Manuf. + AI [3])	Tests
Radiation Shields	ISO	-	x	-	x [2])	Phase B	Phase C/D	PLM-Environm.
Instruments Shield	simil. ISO	-	x	-	x [2])	Phase B	Phase C/D	PLM-Environm.
Internal MLI	ISO	-	x	-	[1])	Phase C/D [4,5])	Phase C/D	PLM-Environm.
External MLI	ISO/Standard	-	x	-	[1])	Phase C/D [5])	Phase C/D	PLM-Environm.

[1]) no finished blankets, only layer level (e.g. 2m²)
[2]) ISO similar tools
[3]) AI in cleanclass 100
[4]) pre-designed in phase B
[5]) pre-test of HeII-tank MLI in phase B

Table 6.3-4: Subsystem Design and Development Approach

6.4 Electrical Subsystem

The electrical subsystem provides :

- the necessary instrumentation for monitoring and control of the Cryostat
- the electronic for cryostat monitoring and operations

- the interfaces to the electrical ground support equipment (EGSE)
- the interface to Ariane 5 via Umbilical
- the interface to NCA Box

The electrical subsystem consists of:

- the Cryostat Control Electronic (CCE)
- the Cryostat Control Instrumentation (CCI)

6.4.1 Cryostat Control Unit

6.4.1.1 Subsystem Configuration and Components Overview

The Cryostat Control Unit (CCU) is the housekeeping system of the cryostat. It is also essential for the overall system lifetime, to minimize sensor dissipation inside the cryostat. Most measurements require levels of accuracy not ordinarily found on spacecraft. Therefore standardized temperature measurements (or other analog) interfaces provided by some data handling systems cannot be used.

The CCU shall provide 3 primary functions:

- Monitoring of the cryostat status in flight by processing of temperature, valve and pressure signals for telemetry to ground
- Switching of valves initiated by ground command or the launch vehicle sequencer
- Execution of the Direct Liquid Content Measurement (DLCM) which shall allow the determination of the He-tank content by injecting a well defined heat impulse and by the precise measurement of the associated temperature increase of the He.

The CCU is designed for the system in flight only, cool-down and heating operations of the cryostat as well as operations on the launch pad will require additional EGSE equipment.

6.4.1.2 Component Description

A block diagram of the CCU is shown in Fig. 6.4.1-1.The above mentioned functions shall be implemented by a number of functional blocks which are identified below:

- Command and Telemetry Interface

which shall provide the necessary circuitry for distribution and decoding of tbd Memory Load CMD channels, tbd Switch Closure Signals from the launcher and processing of tbd serial digital TM channels for DLCM and for Cryostat Monitoring. The interface to the SVM is a Mil-Std1553 B bus interface.

- Monitoring System for the Cryo Instrumentation

This block shall process all cryo instrumentation sensors (temperature and pressure), and the CCU housekeeping data (TC verification and CCU internal secondary voltages). No cross-strapping between sensors is foreseen.

- DLCM - Heater System

Allows for the injection of a well defined electrical power over a pre-selected time duration into the He-bath. The duration shall be commandable via a related Memory Load CMD. Two redundant heaters are foreseen, which will be powered directly by the satellite electrical bus.

- DLCM - Measurement System

Allows for a precise measurement of the He-bath absolute temperature and the temperature increase. Three temperature sensors are installed. The DLCM operation will be performed about once per month initiated by related tele-CMD's .

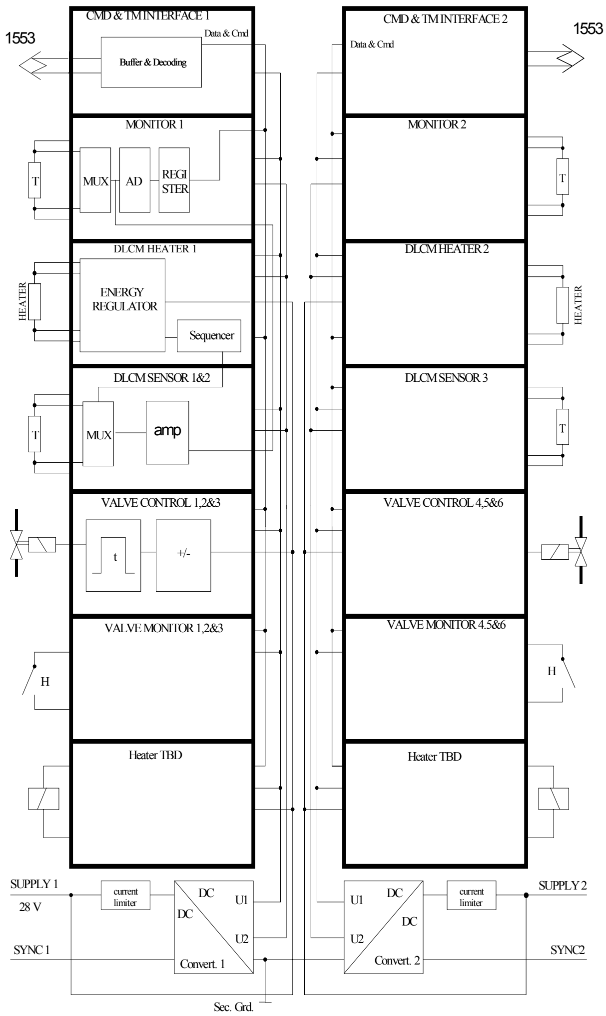


Figure 6.4-1: CCU Block Diagram

- Valve Control

Provides the circuitry for switching two (plus one spare) redundant pairs of valves. Switching power will come directly from the Satellite electrical bus.

- Valve Monitor

Each valve is equipped with a reed contact, sensing the magnetic field configuration and thereby monitoring the valve position. A corresponding data bit has to be generated, for insertion into the HK data-stream.

System Heater

Activation of system heaters shall be provided. There are currently no heaters, the whole block is tbd.

- The Power Supply

Provides all secondary voltages for the functional blocks mentioned above. The converter shall be able to work in synchronized as well as in free running mode.

For reliability reasons the total CCU shall be grouped into two hot redundant branches of functional blocks as outlined in the block diagram, i.e. each of the functional blocks mentioned above shall exist twice at the minimum. The temperature sensors will utilise system symmetries to mount redundant sensors in different locations but with the same expected temperature, for symmetry reasons. In case of all sensors transmitting to ground simultaneously, additional spatial resolution of the temperature distribution within the cryostat can be gained. In case of loss of one branch of the CCU, the remaining sensors provide sufficient information for predictable operation of the cryostat. For the DLCM Measurement System double redundancy in one branch is foreseen.

With the functional blocks mentioned, the CCU shall be allowed to run the sequence of events outlined in Table 6.4.1-1

6.4.1.3 Subsystem/Component Interfaces

Mechanical

The CCU shall not exceed the total mass of 10.0 kg.

The CCU shall not exceed the following dimensions:

height :	250 mm
width :	250 mm (incl. attachment holes)
length :	370 mm

Other sizes may be considered, if an already qualified or proven box design leads to cost effective solutions.

Thermal

The following temperatures are considered:

Operating :	-15°C - 45°C
Start-Up :	-30°C
Switch-Off :	50°C
Non-Operating :	-35°C - 80°C

Electrical

Power Bus: 26 - 29V operating

Power required: 12.5 W during nominal operating conditions.
During valve switching and during DLCM operation peak powers of up to 65 W are required for tbd minutes.

6.4.1.4 Engineering Trades/Analyses Performed

S/S Engineering Trades/Analyses Performed

The whole design is based on the ISO Cryo Electronics. This flight proven design started from a 'no software, no processors' philosophy. Whether the same philosophy should be followed for HERSCHEL will be investigated during phase B.

Components Engineering Trades/Analyses Performed

It is suggested, to go to a 14 bit resolution of the ADC, to facilitate the design of the DC input amplifier.

6.4.1.5 S/S and Component Design & Development Approach

Design Heritage

A similar design was flown successfully on ISO.

Equipment Qualification Status

Most components have to be considered standard EEE parts. Possible exceptions are :

input amplifier high gain
ADC
processor (if used)
FPGA (if used)

Design and modifications are expected and possibly a new subco will require qualification of the CCU. This is presently reflected in a PFM.

Derived D& D Activities

The overall electrical error budget for the thermal measurement channels is the major design goal which has to be fulfilled for all temperature ranges. For valve switching, high reliability is essential.

Model Philosophy

One Proto-Flight Model is foreseen for qualification of the modified design. Two 'Design Models' in 19" crate and with commercial parts will also be delivered, to be incorporated into the EGSE.

Spares

Spares according to applicable documents will be procured.

GSE

A simple 'cryostat simulator' for the CCU can be built essentially by connecting a set of fixed resistors to all inputs. Such an item is useful for a health check and trouble shooting.

The transportation container of the CCU will be suitable to standard electronics boxes, i.e. a hard outer casing of metal filled with vibration damping material. The FM will be welded into a plastic bag filled with desiccant and dry air.

6.4.1.6 Options

No Options are foreseen for the CCU.

6.4.2 Instrumentation and Components Overview

6.4.2.1 Instrumentation Subsystem Configuration and Components Overview

The instrumentation as part of the electrical S/S consists of different components to perform operation, monitoring and control of the HERSCHEL Payload Module during integration, test, pre-launch, launch and the orbital mission phases. Only instrumentation with an electrical interface and which is fixed installed in and on the EPLM is considered in this chapter.

In general the HERSCHEL Cryo Instrumentation consists of the components :

- sensors (for temperature, pressure, liquid levels, accelerometers)

and

- control elements (valves, heaters, NCA's)

The components are located at/in the following different EPLM areas:

- internal cryostat
- external cryostat
- cover & cavity
- sunshield
- sunshade
- telescope

Table 6.4.2.1-1 gives an overview of the assignment to the EPLM subsystems, type of component and quantity of installed components. The number of components is preliminary.

Those instrumentation components shall be connected to the HERSCHEL Cryostat Control Harness to route the sensor signals and control commands between the individual components and the Cryostat Control Electronic, the EGSE and the Umbilical Interface. An overview of the electrical interfaces is given in chapt. 5.8.2.

To limit the heat input to the LHe tanks, the instrumentation shall only be intermittently powered and the carbon and platinum sensors shall be excited sequentially. In general the same type of instrumentation components which are used and approved in the ISO cryostat will also be installed in the HERSCHEL cryostat.

Location	Component/Quantity
HeII Tank (HTT)	9 Temperature sensors 4 Heaters 2 Liquid Level Sensors 1 Pressure Sensor 5 Accelerometer 2 Valves, each equipped with Valve status 102, 103, 104, 105, 106 3 Valves, each equipped with Valve status, Valve heater and Valve temperature sensor
HeI Tank (HOT) (Auxiliary Tank)	3 Temperature sensors 2 Heaters 2 Liquid Level Sensors 1 Valve, equipped with Valve status, Valve heater and Valve temperature sensor
Insulation S/S (CIS)	18 Temperature sensors 2 Accelerometer
Sunshield (FSS)	6 Temperature sensors
Sunshade (FSS)	4 Temperature sensors
Optical Bench (IOB)	22 Temperature sensors 9 Accelerometer
Ghe S/S (External Ventline)	3 Temperature sensors 2 Heaters 2 Pressure Sensor 4 Valves, each equipped with Valve status
Cryostat Cover (CCC)	3 Temperature sensors TBD NCA's TBD further equipment
Cryostat Cavity (CCC)	3 Temperature sensors
Support Straps (TSF)	16 Temperature sensors
Cryostat Vacuum Vessel (CVV)	16 Temperature sensors 2 Pressure Sensors (Vacuum)
Telescope (FTL)	TBD heater TBD Temperature sensor

Table 6.4-1: Overview of HERSCHEL EPLM Instrumentation

6.4.2.2 Component Description

Below is an overview of the different type of instrumentation components:

- Temperature Sensors

The following types of temperature sensor will be used :

  - carbon sensors for the temperature ranges corresponding to those of the liquid helium, component description is given in chapter 6.2.
  - platinum sensors for the temperature ranges above 13K, component description TBD
  - 1 NiCrNi thermo-element at the depletion heater on the external ventline, component description is given in chapter 6.2

- Pressure Sensors

3 pressure sensors, 1 for the HeII tank and 2 in the GHe S/S, shall be used in the HERSCHEL payload module, component description is given in the para. 6.2.

- Pressure Transducer

2 vacuum vessel transducers shall be used to monitor the vacuum in the Cryostat Vacuum Vessel. The vacuum vessel transducers have no electrical interface to the HERSCHEL EPLM Harness. For operation and control, the transducer will be connected via special cable to their own electronic. For readout and storage of data an electrical Interface to EGSE is foreseen. The component description is TBD.

- Liquid Level Sensors

4 liquid level sensors, 2 each in the HeI and HeII tanks, shall be used to measure the liquid content during ground operations, component description is given in the para. 6.2.

- Electrical Latch Valves

Two different types of electrical latch valves will be used, one with status monitoring only and the other with status monitoring, heater and temperature sensor. A detailed description of the Electrical Latch Valves is given in the para. 6.2.

- Heaters
  - The different types of heaters that will be used are:
  - DLCM Heater on the HeII tank

- Depletion Heater on the HeI tank , the HeII tank and the External Ventline
- Heater on the Ghe S/S to prevent ice formation
- Telescope Heater TBD
- Valve heater

The components are detailed in para. 6.2.

- DLCM

The DLCM is subdivided in two parts (DLCM1 / DLCM2) and will be used to measure the liquid content of the HeII tank in orbit. Each DLCM consists of 1 heater and 1 temperature sensor, the component description is given in the para. 6.2.

- Accelerometers

Accelerometers are implemented in the cryostat to monitor the acceleration level of structural parts during vibration (ground test) and will stay in the cryostat during mission. External accelerometers are not considered, they will be removed after use. The component description is TBD.

- NCA
  TBD

- SI (Cover Status indicator)
  TBD

Mass Budget
Instrumentation components are included in the EPLM mass budget.

Table 6.4.2.2-1 gives an overview of the preliminary status of HERSCHEL's EPLM instrumentation.

Table 6.4-3: Preliminary Status of HERSCHEL EPLM Instrumentation

Location			Sensor				Classification				Sensor		CE		Conditioning		Remark
No.	Ref.	Name	Resp.	Type	Name	installed	C I IO	CIGO	CIOG	Exter.	Type	Excitation	Measurement	Accuracy	CE	EGSE	
1	100	Main LHe Tank	TBD	Accelerometer	A101	Upper Tank flange, exact location TBD				1	TBD	TBD					external EGSE
2	100	Main LHe Tank	TBD	Accelerometer	A102	Upper Tank flange, exact location TBD				1	TBD	TBD					external EGSE
3	100	Main LHe Tank	TBD	Accelerometer	A103	Upper Tank flange, exact location TBD				1	TBD	TBD					external EGSE
4	100	Main LHe Tank	TBD	Accelerometer	A104	Upper Tank flange, exact location TBD				1	TBD	TBD					external EGSE
5	100	Main LHe Tank	TBD	Accelerometer	A105	Upper Tank flange, exact location TBD				1	TBD	TBD					external EGSE
6	100	Main LHe Tank	TBD	Heater	H101	1st DLCM Heater (+y-axis, inside He tank)	1				R=90Ω ± 5Ω (ambient) R=50Ω (at 1.8K)	10W			1		4 wire technique:
7	100	Main LHe Tank	TBD	Heater	H102	2nd DLCM Heater (-y-axis, inside He tank)	1		`		R=90Ω ± 5Ω (ambient) R=50Ω (at 1.8K)	10W			1		4 wire technique:
8	100	Main LHe Tank	TBD	Heater	H103	Depletion Heater (between +z-axis & +y-axis outer part of tank), 147° w.r.t. y-axis			1		R=330Ω	10W				1	EGSE
9	100	Main LHe Tank	TBD	Heater	H104	Depletion Heater (between -z-axis & -y-axis outer part of tank), 212° w.r.t. y-axis			1		R=330Ω	10W				1	EGSE
10	100	Main LHe Tank	TBD	Liquid Level Sensor	L101	Inside Main Tank			1		superconducting probe	75mA				1	EGSE
11	100	Main LHe Tank	TBD	Liquid Level Sensor	L102	Inside Main Tank			1		superconducting probe	75mA				1	EGSE
12	100	Main LHe Tank	TBD	Pressure Sensor	P101	Near Main Tank, on ventline between tank and valve V104			1		TBD	TBD				1	
13	100	Main LHe Tank	TBD	Temperature	T101	inside of tank (tank bottom)	1	1			C100	10µA	1.5K - 2.2K	± 0.010K	1	1	DLCM, CE (both 1st & 2nd heaters installled on same tank diameter) SMU, 4.2K-tests Coo
14	100	Main LHe Tank	TBD	Temperature	T102	inside of tank (tank bottom)	1				C100	10µA	1.5K - 2.2K	± 0.010K	1		DLCM, CE
15	100	Main LHe Tank	TBD	Temperature	T103	on lower tank Flange exact location TBD			1		Pt500	1mA				1	Surface Thermometer
16	100	Main LHe Tank	TBD	Temperature	T104	Inside of tank (tank upper part)	1	1			C100	10µA	1.5K - 2.2K		1	1	DLCM, CE (Fluid Thermometer), displayed and printed on launch PAD SMU, 4.2K-tests Cool d
17	100	Main LHe Tank	TBD	Temperature	T105	inside of tank (upper part) exact location TBD			1		TBD	TBD				1	new
18	100	Main LHe Tank	TBD	Temperature	T106	on lower tank Flange exact location TBD	1				C10	100µA	1.5K - 2.2K	± 0.050K	1		Surface Thermometer
19	100	Main LHe Tank	TBD	Temperature	T107	Tank upper part TBD	1	1			C100	10µA	1.5K - 2.2K	± 0.050K	1	1	
20	100	Main LHe Tank	TBD	Temperature	T111	Integrated with PPS	1	1			C100	10µA	1.5K - 2.2K	± 0.010K	1	1	SMU, 4.2K-tests Cool down + Launch PAD
21	100	Main LHe Tank	TBD	Temperature	T112	Integrated with PPS	1				C100	10µA	1.5K - 2.2K	± 0.010K	1		SMU, 4.2K-tests Cool down + Launch PAD
22	100	Main LHe Tank	TBD	Electrical Latch Valve	V102	Near Main Tank (filling valve)			1			constant current 0.5A nominal				1	EGSE
23	100	Main LHe Tank	TBD	Electrical Latch Valve	V103	Behind PPS (PPS shut off valve)	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
24	100	Main LHe Tank	TBD	Electrical Latch Valve	V104	Near Main Tank (vent valve: purging and cooldown)			1			constant current 0.5A nominal				1	EGSE (umbilical) Resistance
25	100	Main LHe Tank	TBD	Electrical Latch Valve	V105	Near Main Tank (bypass valve ensures cooling of shields prior cooling of tank)			1			constant current 0.5A nominal				1	EGSE (umbilical) Resistance
26	100	Main LHe Tank	TBD	Electrical Latch Valve	V106	Behind PPS (PPS shut off valve) :redundant to V103	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
27	100	Main LHe Tank	TBD	Heater	VH102	V102 Valve Body outside near V. filter			1		Heater foil	Pmin. = 6W				1	EGSE
28	100	Main LHe Tank	TBD	Heater	VH104	V104 Valve Body outside near V. filter			1		Heater foil	Pmin. = 6W				1	EGSE
29	100	Main LHe Tank	TBD	Heater	VH105	V105 Valve Body outside near V. filter			1		Heater foil	Pmin. = 6W				1	EGSE
30	100	Main LHe Tank	TBD	Status indicator	VS102	V102 Valve Body outside			1		TBD	TBD				1	EGSE
31	100	Main LHe Tank	TBD	Status indicator	VS103	V103 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
32	100	Main LHe Tank	TBD	Status indicator	VS104	V104 Valve Body outside			1		TBD	TBD				1	EGSE
33	100	Main LHe Tank	TBD	Status indicator	VS105	V105 Valve Body outside			1		TBD	TBD				1	EGSE
34	100	Main LHe Tank	TBD	Status indicator	VS106	V106 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
35	100	Main LHe Tank	TBD	Temperature	VT102	V102 Valve Body outside			1		Pt500	1mA				1	EGSE
36	100	Main LHe Tank	TBD	Temperature	VT104	V104 Valve Body outside			1		Pt500	1mA				1	EGSE
37	100	Main LHe Tank	TBD	Temperature	VT105	V105 Valve Body outside			1		Pt500	1mA				1	EGSE

Location			Sensor				Classification				Sensor		CE		Conditioning		Remark
No.	Ref.	Name	Resp.	Type	Name	installed	CI IO	CIGO	CIOG	Exter.	Type	Excitation	Measurement	Accuracy	CE	EGSE	
38	200	Optical Bench	TBD	Accelerometer	A221	Bench				1	TBD	TBD					new, external EGSE
39	200	Optical Bench	TBD	Accelerometer	A222	Bench				1	TBD	TBD					new, external EGSE
40	200	Optical Bench	TBD	Accelerometer	A223	Bench				1	TBD	TBD					new, external EGSE
41	200	Optical Bench	TBD	Accelerometer	A261	SPIRE				1	TBD	TBD					new, external EGSE
42	200	Optical Bench	TBD	Accelerometer	A262	SPIRE				1	TBD	TBD					new, external EGSE
43	200	Optical Bench	TBD	Accelerometer	A263	SPIRE				1	TBD	TBD					new, external EGSE
44	200	Optical Bench	TBD	Accelerometer	A271	PACS				1	TBD	TBD					new, external EGSE
45	200	Optical Bench	TBD	Accelerometer	A272	PACS				1	TBD	TBD					new, external EGSE
46	200	Optical Bench	TBD	Accelerometer	A273	PACS				1	TBD	TBD					new, external EGSE
47	200	Optical Bench	TBD	Temperature	T211	Spatial Framwork			1		TBD	TBD				1	new
48	200	Optical Bench	TBD	Temperature	T212	Spatial Framwork	1				TBD	TBD	2K - 20K	TBD	1		new
49	200	Optical Bench	TBD	Temperature	T213	Spatial Framwork	1				TBD	TBD	2K - 20K	TBD	1		new
50	200	Optical Bench	TBD	Temperature	T221	Bench			1		TBD	TBD				1	new
51	200	Optical Bench	TBD	Temperature	T222	Bench	1				TBD	TBD	2K - 20K	TBD	1		new
52	200	Optical Bench	TBD	Temperature	T223	Bench	1				TBD	TBD	2K - 20K	TBD	1		new
53	200	Optical Bench	TBD	Temperature	T224	Bench	1				TBD	TBD	2K - 20K	TBD	1		new
54	200	Optical Bench	TBD	Temperature	T225	Bench	1				TBD	TBD	2K - 20K	TBD	1		new
55	200	Optical Bench	TBD	Temperature	T231	Instrument Shield			1		TBD	TBD				1	new
56	200	Optical Bench	TBD	Temperature	T232	Instrument Shield	1				TBD	TBD			1		new
57	200	Optical Bench	TBD	Temperature	T233	Instrument Shield	1				TBD	TBD			1		new
58	200	Optical Bench	TBD	Temperature	T241	Tank Shield Cooling Level L0			1		TBD	TBD				1	new, EQM only ???
59	200	Optical Bench	TBD	Temperature	T242	Tank Shield Cooling Level L0			1		TBD	TBD				1	new, EQM only ???
60	200	Optical Bench	TBD	Temperature	T243	Tank Shield Cooling Level L0			1		TBD	TBD				1	new, EQM only ???
61	200	Optical Bench	TBD	Temperature	T251	Ventline Cooling Level L1			1		TBD	TBD				1	new
62	200	Optical Bench	TBD	Temperature	T252	Ventline Cooling Level L1	1				TBD	TBD	2K - 20K	TBD	1		new
63	200	Optical Bench	TBD	Temperature	T253	Ventline Cooling Level L1	1				TBD	TBD	2K - 20K	TBD	1		new
64	200	Optical Bench	TBD	Temperature	T254	Ventline Cooling Level L1	1				TBD	TBD	2K - 20K	TBD	1		new
65	200	Optical Bench	TBD	Temperature	T255	Ventline Cooling Level L2			1		TBD	TBD				1	new
66	200	Optical Bench	TBD	Temperature	T256	Ventline Cooling Level L2	1				TBD	TBD	2K - 20K	TBD	1		new
67	200	Optical Bench	TBD	Temperature	T257	Ventline Cooling Level L2	1				TBD	TBD	2K - 20K	TBD	1		new
68	200	Optical Bench	TBD	Temperature	T258	Ventline Cooling Level L2	1				TBD	TBD	2K - 20K	TBD	1		new
69	300	Sunshield	TBD	Temperature	T301	TBD				1	Pt500	1mA	100K - 320K	± 1.5K			supplied from SVM
70	300	Sunshield	TBD	Temperature	T302	TBD				1	Pt500	1mA	100K - 320K	± 1.5K			supplied from SVM
71	300	Sunshield	TBD	Temperature	T303	TBD				1	Pt501	1mA	100K - 320K	± 1.5K			supplied from SVM
72	300	Sunshield	TBD	Temperature	T304	TBD				1	Pt502	1mA	100K - 320K	± 1.5K			supplied from SVM
73	300	Sunshield	TBD	Temperature	T305	TBD				1	Pt503	1mA	100K - 320K	± 1.5K			supplied from SVM
74	300	Sunshield	TBD	Temperature	T306	TBD				1	Pt504	1mA	100K - 320K	± 1.5K			supplied from SVM
75	310	Sunshade	TBD	Temperature	T311	TBD				1	Pt505	1mA	100K - 320K	± 1.5K			supplied from SVM
76	310	Sunshade	TBD	Temperature	T312	TBD				1	Pt506	1mA	100K - 320K	± 1.5K			supplied from SVM
77	310	Sunshade	TBD	Temperature	T313	TBD				1	Pt507	1mA	100K - 320K	± 1.5K			supplied from SVM
78	310	Sunshade	TBD	Temperature	T314	TBD				1	Pt508	1mA	100K - 320K	± 1.5K			supplied from SVM
79	420	1st Shield (innermost)	TBD	Accelerometer	A421	at cover shield I/F, -y-axis				1							external EGSE
80	420	1st Shield (innermost)	TBD	Accelerometer	A422	at cover shield I/F, -y-axis				1							external EGSE
81	420	1st Shield (innermost)	TBD	Temperature	T421	1st shield upper part, exact location TBD	1	1			Pt500	1mA	20K - 100K	± 1.0K	1	1	CE, T-orbit = 45K, EGSE, T-Ground >45K
82	420	1st Shield (innermost)	TBD	Temperature	T422	1st shield lower part, exact location TBD	1				Pt500	1mA	20K - 100K	± 1.0K	1		CE
83	420	1st Shield (innermost)	TBD	Temperature	T423	1st shield cyl. part, exact location TBD	1				Pt500	1mA	20K - 100K	± 1.0K	1		CE
84	420	1st Shield (innermost)	TBD	Temperature	T424	1st shield cyl. part, exact location TBD	1				Pt500	1mA	20K - 100K	± 1.0K	1		CE
85	420	1st Shield (innermost)	TBD	Temperature	T425	1st shield upper cone, exact location TBD			1		Pt500	1mA				1	new

Location			Sensor				Classification				Sensor		CE		Conditioning		Remark
No.	Ref.	Name	Resp.	Type	Name	installed	CI IO	CIGO	CIOG	Exter.	Type	Excitation	Measurement	Accuracy	CE	EGSE	
86	420	1st Shield (innermost)	TBD	Temperature	T426	1st shield upper cone, exact location TBD			1		Pt500	1mA				1	new
87	440	2nd Shield	TBD	Temperature	T441	2nd shield upper part, exact location TBD	1	1			Pt500	1mA	40K - 250K	± 1.0K	1	1	CE, T-orbit = 68K, EGSE, T-Ground >68K
88	440	2nd Shield	TBD	Temperature	T442	2nd shield lower part, exact location TBD	1				Pt500	1mA	40K - 250K	± 1.0K	1		CE
89	440	2nd Shield	TBD	Temperature	T443	2nd shield cyl. part, exact location TBD	1				Pt500	1mA	40K - 250K	± 1.0K	1		CE
90	440	2nd Shield	TBD	Temperature	T444	2nd shield cyl. part, exact location TBD	1				Pt500	1mA	40K - 250K	± 1.0K	1		CE
91	440	2nd Shield	TBD	Temperature	T445	2nd shield upper cone, exact location TBD			1		Pt500	1mA				1	new
92	440	2nd Shield	TBD	Temperature	T446	2nd shield upper cone, exact location TBD			1		Pt500	1mA				1	new
93	460	3rd Shield	TBD	Temperature	T461	3rd shield upper part, exact location TBD	1				Pt500	1mA	50K - 300K	± 1.5K	1		CE, T-orbit = 92K, T-Ground HIGHER
94	460	3rd Shield	TBD	Temperature	T462	3rd shield lower part, exact location TBD	1				Pt500	1mA	50K - 300K	± 1.5K	1		CE, T-orbit = 92K, T-Ground HIGHER
95	460	3rd Shield	TBD	Temperature	T463	3rd shield cyl. part, exact location TBD	1	1			Pt500	1mA	13K - 370K	± 1.0K	1	1	CE, T-orbit = 92K, T-Ground higher
96	460	3rd Shield	TBD	Temperature	T464	3rd shield cyl. part, exact location TBD	1				Pt500	1mA	40K - 250K	± 1.0K	1		CE, T-orbit = 92K, T-Ground HIGHER
97	460	3rd Shield	TBD	Temperature	T465	3rd shield upper cone, exact location TBD			1		Pt500	1mA				1	new
98	460	3rd Shield	TBD	Temperature	T466	3rd shield upper cone, exact location TBD			1		Pt500	1mA				1	new
99	500	GHe S/S, outside CVV	TBD	Heater	H501	Near outlet of venting line			1		Heater R=3.8Ω	650W				1	EGSE (umbilical)
100	500	GHe S/S, outside CVV	TBD	Heater	H502	near outlet of GHe venting line			1		Heater foil	Pmin. = 6W				1	EGSE, type: Nicolitch 200
101	500	GHe S/S, outside CVV	TBD	Pressure Sensor	P501	Inside of GHe venting line, upstream positioned w.r.t. Valve V501	1				BHL 4105-00	10mA on 1180Ω bridge	0 - 35mbar	0.5% fs	1		CE, (4 wire technique); (not damaged while submitted to atmospheric pressure)
102	500	GHe S/S, outside CVV	TBD	Pressure Transducer	P502	external tubing near P501	1				BHL 4105-00	10mA on 1180Ω bridge	0 - 35mbar	0.5% fs	1		CE, (4 wire technique); (not damaged while submitted to atmospheric pressure)
103	500	GHe S/S, outside CVV	TBD	Temperature	T501	on GHe venting line, upstream positioned w.r.t. V501, V502 - 225° w.r.t. y-axis	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE, Fluid Thermometer
104	500	GHe S/S, outside CVV	TBD	Temperature	T502	Near outlet of venting line			1		Thermoeleme nt NiCrNi					1	EGSE (umbilical)
105	500	GHe S/S, outside CVV	TBD	Temperature	T503	GHe venting line			1		Pt500	1mA				1	EGSE, (umbilical)
106	500	GHe S/S, outside CVV	TBD	Electrical Latch Valve	V501	Isolation valve near exhaust nozzle	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
107	500	GHe S/S, outside CVV	TBD	Status indicator	VS501	V501 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
108	500	GHe S/S, outside CVV	TBD	Electrical Latch Valve	V503	Isolation valve near exhaust nozzle (redundant to V501)	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
109	500	GHe S/S, outside CVV	TBD	Status indicator	VS503	V503 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
110	500	GHe S/S, outside CVV	TBD	Electrical Latch Valve	V504	Isolation valve near exhaust nozzle (redundant to V501)	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
111	500	GHe S/S, outside CVV	TBD	Status indicator	VS504	V503 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
112	500	GHe S/S, outside CVV	TBD	Electrical Latch Valve	V505	Isolation valve near exhaust nozzle (redundant to V501)	1					constant current 0.5A nominal	Pull in current		1		CE via TC-3rd stage AR4 Res
113	500	GHe S/S, outside CVV	TBD	Status indicator	VS505	V503 Valve Body outside	1				TBD	TBD	TBD	TBD	1		CE
114	600	Cryostat Cover	TBD	NCA	N601	attached to clamb band				1	TBD	TBD					Supplied from Satellite
115	600	Cryostat Cover	TBD	NCA	N602	attached to clamb band				1	TBD	TBD					Supplied from Satellite
116	600	Cryostat Cover	TBD	Status indicator	SI601	Cover mechanism				1	TBD	TBD					Monitored from Satellite
117	600	Cryostat Cover	TBD	Status indicator	SI602	Cover mechanism				1	TBD	TBD					Monitored from Satellite
118	600	Cryostat Cover	TBD	Temperature	T601	Cover, exact location TBD			1		TBD	TBD				1	EGSE, ????Transport Monitoring????
119	600	Cryostat Cover	TBD	Temperature	T602	Cover inner shield, exact location TBD			1		TBD	TBD				1	
120	600	Cryostat Cover	TBD	Temperature	T603	Cover inner shield, exact location TBD			1		TBD	TBD				1	
121	650	Cryostat Cavity	TBD	Temperature	T651	Cover, exact location TBD			1		TBD	TBD				1	EGSE, ????Transport Monitoring????

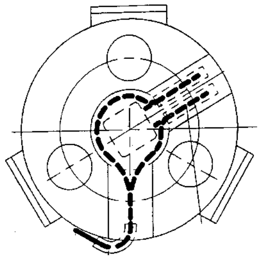
Location			Sensor				Classification				Sensor		CE		Conditioning		Remark
No.	Ref.	Name	Resp.	Type	Name	installed	C I IO	CIGO	CIOG	Exter.	Type	Excitation	Measurement	Accuracy	CE	EGSE	
122	650	Cryostat Cavity	TBD	Temperature	T652	Cover inner shield, exact location TBD			1		TBD	TBD				1	
123	650	Cryostat Cavity	TBD	Temperature	T653	Cover inner shield, exact location TBD			1		TBD	TBD				1	
124	700	Auxiliary He-Tank	TBD	Heater	H701	Tank bottom (applied on tank outer surface)			1		high load resistor	0.5W - 1.5W controlled 10W max.				1	EGSE (umbilical), ????Transport? ???
125	700	Auxiliary He-Tank	TBD	Heater	H702	Tank bottom (applied on tank outer surface)			1		high load resistor	0.5W - 1.5W controlled 10W max.				1	EGSE (umbilical)
126	700	Auxiliary He-Tank	TBD	Liquid Level Sensor	L701	Inside of Tank			1		superconducting probe	75mA				1	EGSE (umbilical)
127	700	Auxiliary He-Tank	TBD	Liquid Level Sensor	L702	Inside of Tank, 180° rotated w.r.t. L701			1		superconducting probe	75mA				1	EGSE (umbilical)
128	700	Auxiliary He-Tank	TBD	Temperature	T701	on tank outer surface, exact location TBD			1		Pt500	1mA				1	EGSE
129	700	Auxiliary He-Tank	TBD	Temperature	T702	on tank, STA 3410, exact location TBD	1				C10	100µA	3.0K - 30K	3K ± 0.1K	1		CE, Surface Thermometer
130	700	Auxiliary He-Tank	TBD	Temperature	T703	on tank, STA 3410, exact location TBD	1				C10	100µA	3.0K - 30K	3K ± 0.1K	1		CE
131	700	Auxiliary He-Tank	TBD	Electrical Latch Valve	V701	Vent Valve (auxiliary tank)			1			constant current 0.5A nominal				1	EGSE (umbilical) Resistance
132	700	Auxiliary He-Tank	TBD	Heater	VH701	V701 Valve body outside near V. filter			1		Heater foil	Pmin. = 6W				1	EGSE
133	700	Auxiliary He-Tank	TBD	Status indicator	VS701	V701 Valve Body outside			1		TBD	TBD				1	EGSE (umbilica)
134	700	Auxiliary He-Tank	TBD	Temperature	VT701	V701 Valve body outside			1		Pt500	1mA				1	EGSE
135	800	Support-Straps	TBD	Temperature	T801	Corner part of spatial framework +z/+y-axis			1		Pt500	1mA				1	EGSE
136	800	Support-Straps	TBD	Temperature	T802	Strap 1 coldest position			1		Pt500	1mA				1	EGSE
137	800	Support-Straps	TBD	Temperature	T803	Strap 1, near shield 1			1		Pt500	1mA				1	EGSE
138	800	Support-Straps	TBD	Temperature	T804	Strap 2, near shield 1			1		Pt500	1mA				1	EGSE
139	800	Support-Straps	TBD	Temperature	T805	Strap 2, near shield 2			1		Pt500	1mA				1	EGSE
140	800	Support-Straps	TBD	Temperature	T806	Strap 3, near shield 2			1		Pt500	1mA				1	EGSE
141	800	Support-Straps	TBD	Temperature	T807	Strap 3, near shield 3			1		Pt500	1mA				1	EGSE
142	800	Support-Straps	TBD	Temperature	T808	Strap 4, near shield 3			1		Pt500	1mA				1	EGSE
143	850	Support-Straps	TBD	Temperature	T851	Corner part of spatial framework +z/-y-axis			1		Pt500	1mA				1	EGSE
144	850	Support-Straps	TBD	Temperature	T852	Strap 1 coldest position			1		Pt500	1mA				1	EGSE
145	850	Support-Straps	TBD	Temperature	T853	Strap 1, near shield 1			1		Pt500	1mA				1	EGSE
146	850	Support-Straps	TBD	Temperature	T854	Strap 2, near shield 1			1		Pt500	1mA				1	EGSE
147	850	Support-Straps	TBD	Temperature	T855	Strap 2, near shield 2			1		Pt500	1mA				1	EGSE
148	850	Support-Straps	TBD	Temperature	T856	Strap 3, near shield 2			1		Pt500	1mA				1	EGSE
149	850	Support-Straps	TBD	Temperature	T857	Strap 3, near shield 3			1		Pt500	1mA				1	EGSE
150	850	Support-Straps	TBD	Temperature	T858	on warmest strap segment TBD			1		Pt500	1mA				1	EGSE
151	900	Cryostat Vacuum Vessel	TBD	Pressure Sensor	P901	Pressure in vacuum (transducer on CVV)			1		Penning Gauge	3kV	$5x10^{-8}$ - $5x10^{-3}$	± 1.5% FS		1	EGSE
152	900	Cryostat Vacuum Vessel	TBD	Pressure Sensor	P902	Pressure in vacuum (transducer on CVV)			1		Penning Gauge	3kV	$5x10^{-8}$ - $5x10^{-3}$	± 1.5% FS		1	EGSE
153	900	Cryostat Vacuum Vessel	TBD	Temperature	T901	Upper part of CVV-Cylinder +z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
154	900	Cryostat Vacuum Vessel	TBD	Temperature	T902	Upper part of CVV-Cylinder -z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
155	900	Cryostat Vacuum Vessel	TBD	Temperature	T903	Lower part of CVV-Cylinder +z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
156	900	Cryostat Vacuum Vessel	TBD	Temperature	T904	Lower part of CVV-Cylinder -z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
157	900	Cryostat Vacuum Vessel	TBD	Temperature	T905	Middle part of CVV-Cylinder +y Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
158	900	Cryostat Vacuum Vessel	TBD	Temperature	T906	Middle part of CVV-Cylinder -y Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
159	900	Cryostat Vacuum Vessel	TBD	Temperature	T907	Upper Cone, upper part +z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
160	900	Cryostat Vacuum Vessel	TBD	Temperature	T908	Upper Cone, upper part -z Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
161	900	Cryostat Vacuum Vessel	TBD	Temperature	T909	Upper Cone, upper part +y Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
162	900	Cryostat Vacuum Vessel	TBD	Temperature	T910	Upper Cone, upper part -y Direction	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
163	900	Cryostat Vacuum Vessel	TBD	Temperature	T911	on the lower bulkhead of the CVV (-x-axis), i.e. lowest point of lower bulkhead	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
164	900	Cryostat Vacuum Vessel	TBD	Temperature	T912	on the lower bulkhead of the CVV (+z-axis), near fixation plane with lower ring	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE
165	900	Cryostat Vacuum Vessel	TBD	Temperature	T913	on Wave Guides near LOU	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE, new

Location			Sensor				Classification				Sensor		CE		Conditioning		Remark
No.	Ref.	Name	Resp.	Type	Name	installed	C I IO	CIGO	CIOG	Exter.	Type	Excitation	Measurement	Accuracy	CE	EGSE	
166	900	Cryostat Vacuum Vessel	TBD	Temperature	T914	on Wave Guides near SVM	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE, new
167	900	Cryostat Vacuum Vessel	TBD	Temperature	T915	on LOU Baseplate	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE, new
168	900	Cryostat Vacuum Vessel	TBD	Temperature	T916	on BOLA Baseplate	1				Pt500	1mA	100K - 320K	± 1.5K	1		CE, new
169	1000	Telescope	TBD	Temperature	T1001	TBD				1	Pt500	1mA	100K - 320K	± 1.5K			supplied from SVM
170	1000	Telescope	TBD	Heater	H1001	TBD				1	TBD	TBD	TBD	TBD			supplied from SVM
171		CVV	TBD	strain gauge	F001	CVV, tank straps				1	Tension Device						external EGSE
172		CVV	TBD	strain gauge	F002	CVV, tank straps				1	Tension Device						external EGSE
173		CVV	TBD	strain gauge	F003	CVV, tank straps				1	Tension Device						external EGSE
174		CVV	TBD	strain gauge	F004	CVV, tank straps				1	Tension Device						external EGSE
175		CVV	TBD	strain gauge	F005	CVV, tank straps				1	Tension Device						external EGSE
176		CVV	TBD	strain gauge	F006	CVV, tank straps				1	Tension Device						external EGSE
177		CVV	TBD	strain gauge	F007	CVV, tank straps				1	Tension Device						external EGSE
178		CVV	TBD	strain gauge	F008	CVV, tank straps				1	Tension Device						external EGSE
179		CVV	TBD	strain gauge	F009	CVV, tank straps				1	Tension Device						external EGSE
180		CVV	TBD	strain gauge	F010	CVV, tank straps				1	Tension Device						external EGSE
181		CVV	TBD	strain gauge	F011	CVV, tank straps				1	Tension Device						external EGSE
182		CVV	TBD	strain gauge	F012	CVV, tank straps				1	Tension Device						external EGSE
183		CVV	TBD	strain gauge	F013	CVV, tank straps				1	Tension Device						external EGSE
184		CVV	TBD	strain gauge	F014	CVV, tank straps				1	Tension Device						external EGSE
185		CVV	TBD	strain gauge	F015	CVV, tank straps				1	Tension Device						external EGSE
186		CVV	TBD	strain gauge	F016	CVV, tank straps				1	Tension Device						external EGSE
187		CVV	TBD	strain gauge	G001	Cryostat bottom				1	Weight						external EGSE
188		CVV	TBD	strain gauge	G002	Cryostat bottom				1	Weight						external EGSE
189		CVV	TBD	strain gauge	G003	Cryostat bottom				1	Weight						external EGSE

6.4.3 Subsystem / Component Interfaces

Mechanical

Mechanical Interfaces of the He S/S components are described in chapter 6.2. Additional ESD protection shall be considered where necessary. Fixation of components to structures shall be performed by proper methods (e.g. screwed , glued, taped). Removable devices (e.g. strap pretension devices) shall be mounted only if used. The sketch below shows a mechanical application of a PT500 temperature sensor



Thermal

- Temperature sensors shall be fixed in such a manner, that a reliable contact to the relevant surface is performed
- Selection and calibration of temperature sensors shall correspond to the relevant temperature range.

Electrical

- The four wire technique will be employed for the carbon and platinum sensors.
- electrical connection to the Cryostat Control Harness shall be performed using the interconnection technology described in para. 5.8.2.
- instrumentation components used for ground test phases only, but not removed before flight, shall be grounded to the structure by termination connectors
- to instrumentation components, which are used for ground and in orbit monitoring, EGSE access shall be performed via a T-adapter described below.

Optical / Alignment

Not applicable

6.4.3.1 Engineering Trades/Analysis Performed

S/S Engineering Trades/Analysis

- are not performed for the proposal phase, the ISO instrumentation technique is used as baseline.

Component Engineering Trades/Analysis

- for components of the He S/S see chapter 6.2.
- for components of the other parts, no engineering trades/analysis is performed, ISO instrumentation technique is used as baseline

6.4.3.2 S/S and Component Design and Development Approach.

- Applications of instrumentation components will be modified where necessary

PT sensors application will be replaced by mechanical clamping or an approved gluing technique

- Model Philosophy will be based on:
  - 1 set of complete instrumentation for PFM, see table 6.4.2.1 and
  - 1 set of instrumentation for HERSCHEL parts used in EQM (e.g. optical bench). Adaptation of ISO EQM instrumentation which can be used for HERSCHEL EQM
- Spares Policy will be based on
  - having the relevant mechanical parts (e.g. sensors) stored locally.

  The spare policy for He S/S components is described in chapter 6.2.
- Equipment Qualification Status here describes the status of PT500 sensors and accelerometers, instrumentation components belonging to the He S/S are described in para. 6.2.
  - Components identical to ISO components will be used without additional qualification, environmental and/or acceptance test before integration will be performed as required.
  - Components based on ISO and adapted to HERSCHEL application will be delta qualified
- S/S – GSE and Component GSE will use standard equipment

6.4.3.3 Options

There are none applicable.

6.5 Sunshield / Sunshade (HSS)

The basic function of the HERSCHEL Sunshield/Sunshade (HSS) is to shadow the Cryostat Vacuum Vessel (CVV) and the Telescope from solar radiation and to provide the electrical power for the HERSCHEL spacecraft. The HERSCHEL orbit at the Lagrangian point L2 at a distance of 1500 000 km in anti-sun direction from the earth allows simultaneous shielding of the payload from sun and earth leading to an effective passive cooling stage.

The main requirements for the HSS are:

- To provide shade for the payload module considering a solar aspect angle of ± 30° around the y-axis and ± 5° around the x-axis
- To minimize the heat transfer from the HSS to the payload module to ensure a lifetime of 3.5 years
- To provide 1350 W EOL for worst case solar aspect angles EOL
- To fit under the ARIANE 5 fairing.

6.5.1 HSS Baseline Configuration

The HSS design is based on former FIRST optimization studies, trade-offs performed for the Phase B, C/D, E1 proposal and further optimizations at begin phase B. Engineering trade-offs on HSS are treated in Chapter 7.They cover

- an increased solar aspect angle around the X-axis of +/-23° to account for ARIANE 5 uncertainties during launch
- a panel support truss with 24 instead of 32 struts mounting the HSS on the SVM/CVV, decreasing the mechanical stiffness, but increasing life-time through less heat transfer from HSS to CVV
- alternative lateral SSH fixation on the SVM

The HSS is split in two parts, the upper part is the Sunshade (SSD), providing the shade mainly for the Telescope and the lower part is the Sunshield (SSH), which provides shading and the electrical power. The HSS is characterized by the following:
The baseline configuration provides sufficient margins with respect to the shading function as shown in Figure 6.5-1. The margin w.r.t. solar aspect angle around y-axis amounts to 2.7°. Around the x-axis the margin is 6.6° at the Telescope and even more at the LOU radiator, which is the most salient component located on the CVV.

- The two individual parts SSH and SSD are linked via an axial joint to form the HSS. Each of the two parts is supported separately via a set of lateral and vertical struts to the SVM respectively the CVV, allowing separate production and verification.
- The SSH consists of 3 separate panels of (2.5 x 1.6 m²) each carrying the photovoltaic assembly. The SSH assembly is supported by means of 10 struts made of CFRP which are connected to the SVM plus 6 struts made of GFRP which are

connected to the cryostat. The whole rear of the unit is covered with 20 layers of highly efficient MLI.

- The SSD part consists of 3 different subpanels. The individual panel shape is generated by the Ariane 5 Fairing dimensions, its task to provide full telescope shadowing and to match the SSH shape. The panels are bonded together by the use of additional doublers and are attached to the SSH via an axial connection, designed as a profile carrying axial loads, providing axial stiffness and at the same time low heat transfer. The SSD assembly is supported by means of 16 struts made of GFRP. 6 of these struts are connected directly to the cryostat. In addition each of the two SSD ears is linked to an external hardpoint via two struts, which again is linked to the CVV via three struts. There is no connection to the SVM. The front of the SSD is covered with OSRs. The SSD and the SSH are thermally de-coupled. The entire rear of the SSD is covered with highly efficient MLI.
- The sandwich design is identical for SSH and SSD to reduce manufacturing effort (except local doublers). The face sheet material is M55J with orthotropic lay-up of ±45°. The core is a lightweight aluminum core of about 16 kg/m3 as typically used for solar generator substrates.
- GFRP and CFRP struts have mainly longitudinal layers with +/- 5°. The end fittings are made out of titanium.

The HSS baseline configuration can be summarized as follows:

Number of SSH Panels:	**3**
Number of SSD Panels:	**3**
Total Number of Struts:	**32**
Number of Struts of SSH to SVM:	**10**
Number of Struts of SSH to CVV:	**6**
Number of Struts of SSD to SVM:	**0**
Number of Struts of SSD to CVV:	**16**
Number of Joints between SSH and SSD:	**4**

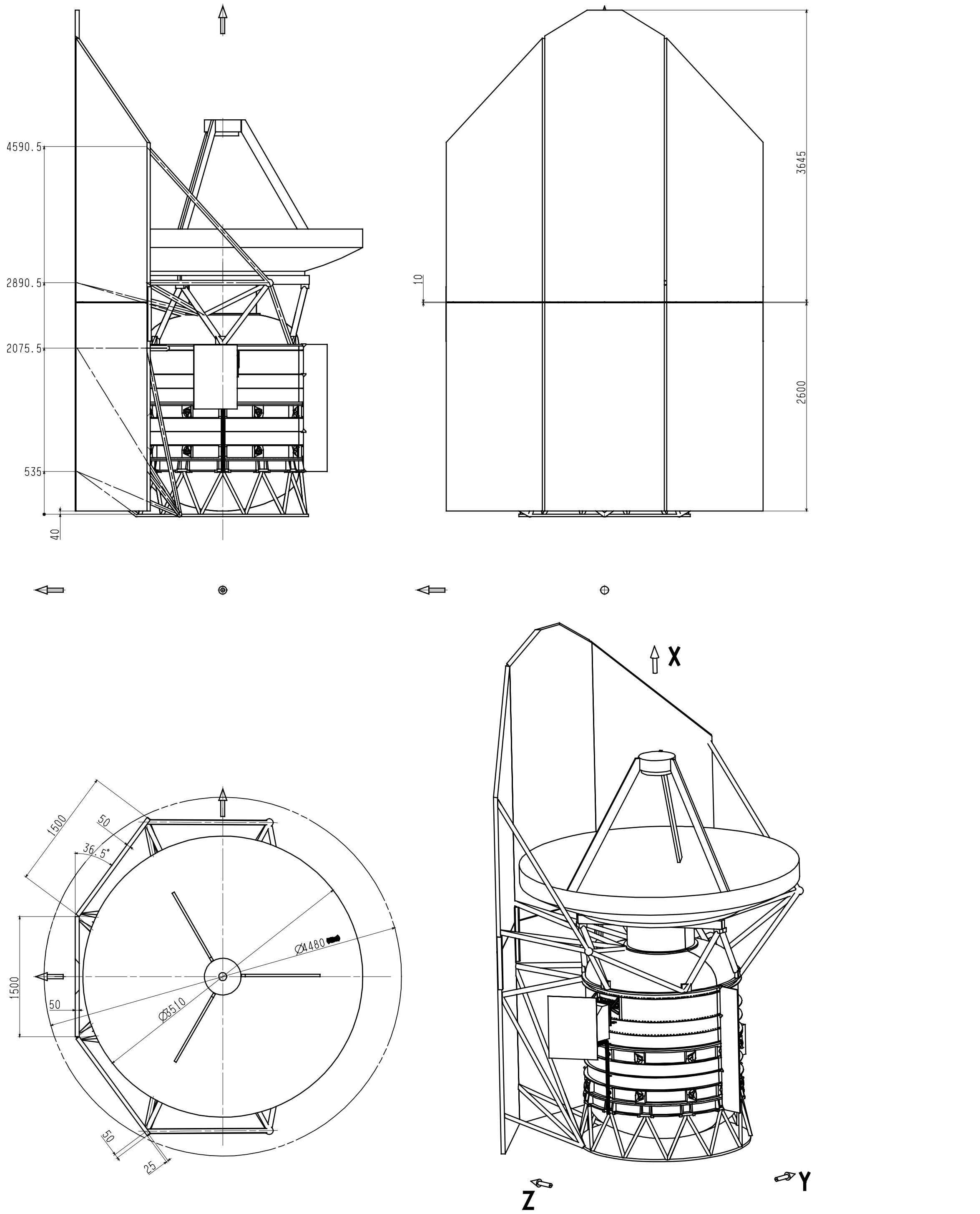


Figure 6.5-1: HSS Baseline Configuration

6.5.2 HSS Thermal Design

The main thermal requirements are:

- optimization of HSS and strut thermal/mechanical design to minimize radiated and conducted heat onto the Telescope and CVV. The HSS design shall allow the achievement of the temperature and temperature gradient requirements of the Telescope. The minimization of the heat transfer between SSH/SSD and CVV requires a strut material of low thermal conductivity as e.g. GFRP.
- provision of a Telescope temperature of less than 90 K under consideration of the thermo-optical properties of CVV, Telescope +x face and HSS -z face
- design for a nominal lifetime of 3.5 years

The thermal design can be characterized by the following:

The Sunshade is completely covered with OSRs because of their low α/є ratio and low degradation during lifetime. In the present thermal analysis a degraded solar absorption of 0.20 after 4 years has been assumed as conservative value.
For the ITO coated ORSs of XMM, a solar absorption of 0.18 after 10 years has been taken into account based on ERS-1 and SOHO flight data and further contamination considerations. For HERSCHEL, the conditions are even more favourable compared to XMM since standard OSRs without ITO coating could be used which reveal an even lower degradation. During phase B this aspect will be further investigated. Alternatively the suitability of SSM tape (with a worse α/є ratio and a stronger degradation but less expensive and easier to apply) will be investigated in Phase B.

10 out of the 16 SSH struts shall be linked to the SVM, in order to minimize heat transfer from the hot SSH to the cold CVV.

The cross-section to length ratio of the GFRP struts from the SSH to the CVV is in total about 1.4 mm. The sensitivity of GFRP cross-section to length ratio on lifetime is roughly 7 days per 1 mm (this rule of thumb is valid in a close range around the design point only).

For temperature monitoring of the PFM HSS a total of about 10 thermistors (6 at SSH and 4 at SSD) will be implemented at the sandwich -z faces.

The grounding concept for the OSRs and blankets to the HSS structure is addressed in the 'EMC baseline design description'.

Thermal Analysis

To investigate the feasibility of the baseline design, a thermal mathematical model (TMM) has been established. All relevant material properties, as listed in Table 6.5-1, are implemented as a temperature dependent function.

The solar constant at L2 is 1300 W/m² at the summer solstice (for solar generator sizing) and 1400 W/m² at the winter solstice (for hot case analyses). The SVM temperature is assumed to 293 K. The thermal analysis for nominal attitude at EOL provides the heat flows as shown in Figure 4.1-1.

Item	Material / Component	Mass / kg/m^2	Thermal Data	α EOL	$\varepsilon_{external}$
Sunshield (Solar Generator)	CFRP skins, Al-Honeycomb solar cells & wiring Ti I/F brackets	5.34	0.25mm x 50mm	0.72	0.82
HSS Support Struts	GFRP struts to CVV CFRP struts to SVM Ti end fittings (Ti 6 Al V4)			n.a.	
Sunshade (for Telescope shadowing)	CFRP skins, Al-HC OSR Ti I/F brackets	3.3	0.25mm x 50mm	0.20	0.84
Sunshield -Z MLI	2 mil Kapton x VDA + Dacron Spacer + 3 x (VDA x 0.3 mil Kapton x VDA + Dacron Spacer) + 15 x (VDA x 0.25 mil Mylar x VDA + Dacron Spacer) + VDA x 1 mil Kapton x VDA	0.6	$\varepsilon_{eff} < 0.015$	n.a.	0.05
Sunshade -Z MLI	2 mil Kapton x VDA + Dacron Spacer + 18 x (VDA x 0.25 mil Mylar x VDA + Dacron Spacer) + VDA x 1 mil Kapton x VDA	0.6	$\varepsilon_{eff} < 0.015$	n.a.	0.05

Table 6.5-1: Item List for HERSCHEL Sunshield/Sunshade

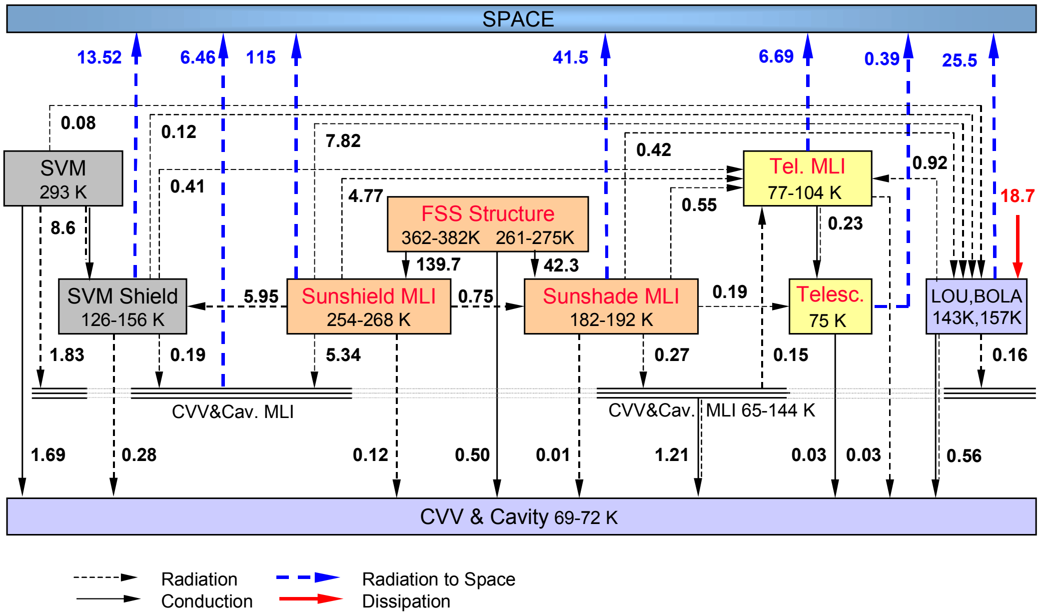


Figure 6.5-4: HSS Heat Flow Chart (Main Paths) in W and Temperature Distribution for EOL

6.5.3 Electrical Design

The following assumptions are made for the electrical design:

- worst case solar constant at L2: 1350 W/m² (summer solstice at L2) EOL
- worst case solar aspect angle: 30° around Y and 5° around X.
- solar cell area: 3 x 3.74 m² (3 identical panels)

The electrical power generation is calculated for different seasons and orientations of the HERSCHEL S/C, see following table. The worst case is, when the S/C is tilted by 30° around y-axis and by 5° around x-axis during summer solstice. In this case an EOL power of about 1250 W is expected for a dual-junction GaAs cell type and 1655 W for a multi-junction GaAs cell type. The growth potential of the solar panel area is limited to 15 %, which corresponds to a panel height of 3 m. This would yield about 1435 W. An increase of panel height would have to be introduced at the bottom end of the SSH. Increasing the solar cell area into the SSD would expose the Telescope to a higher thermal radiation from the Sunshade.

Dual junction type GaAs cells:

Case	Panel (+z) Power [W]	Panel (+z) Temp. [°C]	Panel (-y) Power [W]	Panel (-y) Temp. [°C]	Panel (+y) Power [W]	Panel (+y) Temp. [°C]	Total Power [W]
BOL, WS	647	122	517	101	517	101	1681
BOL, SS	600	115	479	95	479	95	1558
EOL, WS	588	128	484	106	484	106	1556
EOL, SS 30°y +5°x	482	106	413	92	361	80	1256

Multi-junction cascade type GaAs cells:

Case	Panel (+z) Power [W]	Panel (+z) Temp. [°C]	Panel (-y) Power [W]	Panel (-y) Temp. [°C]	Panel (+y) Power [W]	Panel (+y) Temp. [°C]	Total Power [W]
BOL, SS 30°y; 5°x	708	101	640	87	572	87	1920
EOL, SS 30°y ; 5°x	616	104	552	90	487	90	1655

Multi-junction cascade type GaAs cells are selected as baseline, because of the high power efficiency which minimizes the Sunshield height leading to a long Sunshade and hence low Telescope temperatures. The maximum predicted non-operating temperature of the solar cells is about 140°C. Measures to reduce this temperature or to cope with this temperature by proper design need to be investigated in detail in close co-operation with the solar generator supplier during phase B.

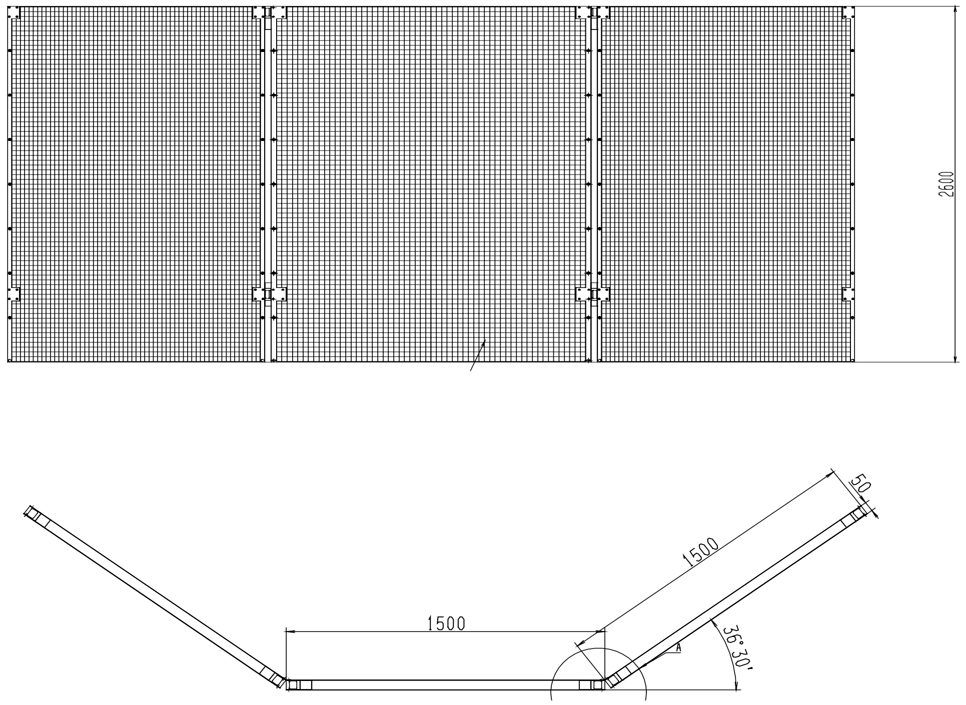


Figure 6.5-7: Solar Array Dimensions

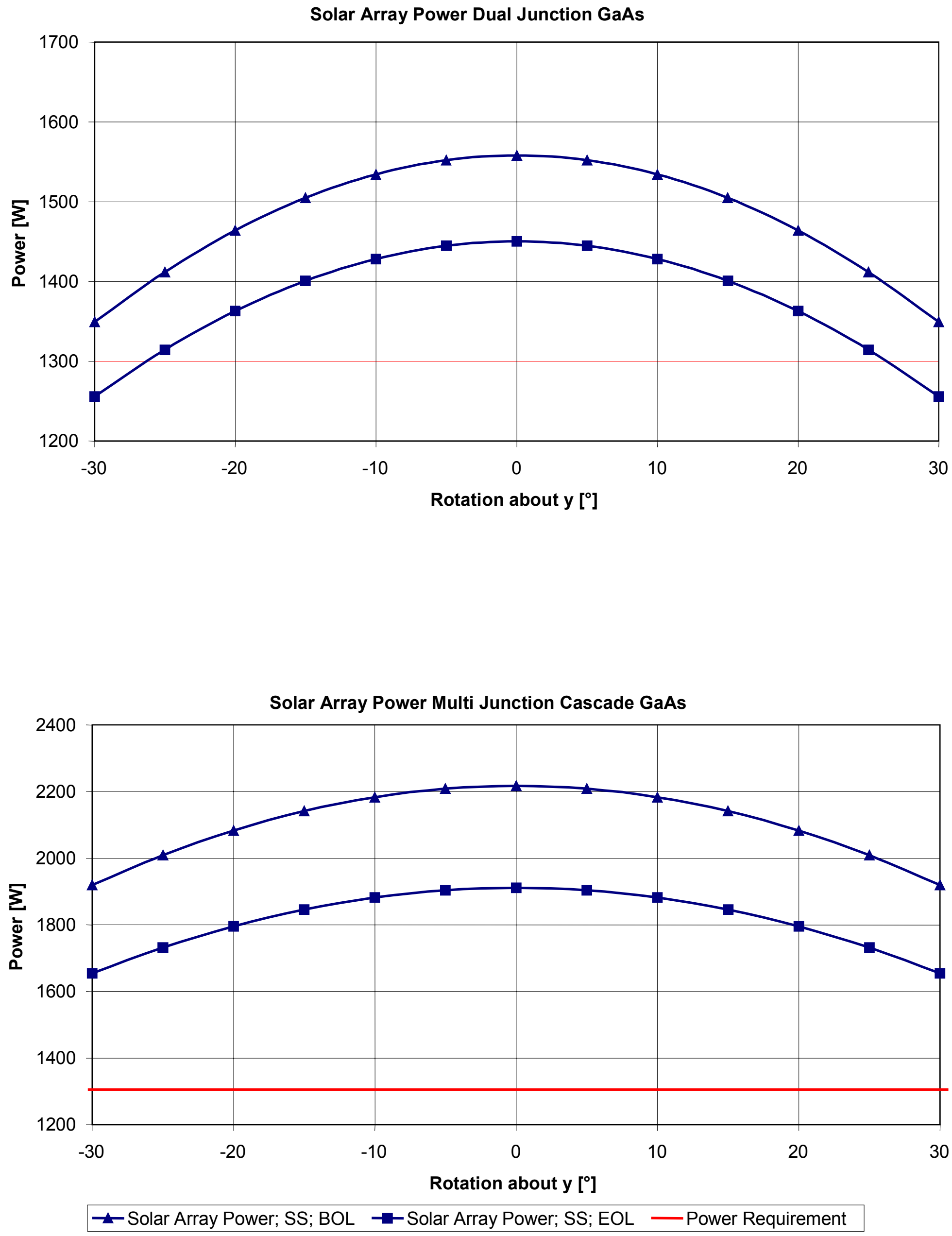


Figure 6.5-10: Solar Array Power

6.5.4 Mechanical Design

The mechanical design of the SSH/SSD is driven by

- the requirement of a minimized total mass including significant non-structural masses. This requires minimum sandwich face sheet thickness and light weight cores, which is in contradiction to solar cell and OSR bonding requirements and generally to strength requirements.
- the dimensions of about 6.3 m in height and about 4 m in width with large non-supported dimensions which lead to low frequency eigenmodes. A stiffness requirement in the range above 50 Hz, which would be necessary to place the lateral frequency well above the second Herschel/Planck S/C eigenmode, can only be achieved with a total HSS mass of 190kg. With a 170kg design (also increasing life time) the first HSS lateral resonance frequencies of the HSS are between the first and second lateral resonance frequencies of HERSCHEL/Planck S/C. Tuning of the HSS lateral resonance frequencies will be performed by applying local doublers in areas of high dynamic strain energy.
- the exposure of the Sunshade to high dynamic accelerations during the launch and the tests phase. Adequate design loads will cover this effect. Special care will be taken of the acoustic noise environment, which acts on the huge unsupported panels.
- minimizing heat transfer between SSH/SSD and CVV which requires a strut material of low thermal conductivity as e.g. GFRP.
- the OSR and Solar Cells bonding requirements. The sandwich plates supporting OSRs and solar cells should be as far as possible homogeneous to avoid disturbances generated by local mechanical and thermal loads.
- the limited space available under the ARIANE 5 Long Fairing and the Telescope field of view. This requirement limits effective stiffening by additional circumferential or longitudinal frames. The tilt of the lateral panels is further limited by the reflector diameter of 3510 mm. Accounting for an additional gap margin of about 50 mm to reflector and fairing, the minimum possible angle is 36.5°.

Design Description

The HSS is supported by 32 GFRP/CFRP struts, which are connected to the CVV/SVM. There are 10 CFRP struts between SSH and SVM, 6 GFRP struts between SSH and CVV and 16 GFRP struts between SSD and CVV.

The baseline design of the HSS panels uses a very low-density sandwich core (16 kg/m³), which is standard for extreme lightweight solar substrate panels. This keeps the HSS mass low and increases the resonance frequencies.

The expected high accelerations in the resonance frequencies of the HSS will be carefully controlled to avoid glass and solar cell cracks during vibration and acoustic testing. The surface treatment, flatness and CTE of the CFRP-sandwich will be according to the needs of the OSRs and Solar Generator parts. The manufacturing specification, which is the basis for the manufacturing proposal for Phase B, already accounts for these needs.

Astrium GmbH has recently developed struts for application at cryo-temperatures and high load and/or strong stiffness requirements. The lessons learnt in these developments have already influenced the HSS strut design especially at the I/F between GFRP tube and the Titanium end fittings.

The following analyses of the HSS have been performed using an FEM

- normal mode analyses with parametric variations
- sine response analysis (accelerations and interface forces)
- quasi-static load analysis.

The main outcome of the investigations is as follows:

- Sufficient frequency decoupling from the S/C main modes can be achieved
    - the first minimum lateral resonance frequency lies at 49.5 Hz
    - The first axial mode lies at 87 Hz.
- The total mass is 192 kg.

Mode No.	Frequency [Hz]	m_{eff} in x [%]	m_{eff} in y [%]	m_{eff} in z [%]	I_{eff} about x [%]	I_{eff} about y [%]	I_{eff} about z [%]
1	33.9			3.8		2.2	
2	39.6		8.2		4.0		8.2
3	40.8						3.0
4	41.7			7.1		13.4	
5	49.5			15.9		14.1	
6	51.8						
7	52.7	1.1		34.7		31.5	
8	53.5	1.0		1.3		7.2	
9	54.2		20.9		33.0		14.5
10	57.1		25.0		42.6		15.5
11	61.9	2.2		8.8		6.8	
12	64.8				2.6		
13	73.0	4.4		5.7		8.7	
14	77.4	3.3					
15	79.3		6.1		11.7		19.9
16	80.2		16.7		3.7		21.2
17	84.2	2.5				1.6	
18	87.0	14.5				2.9	
19	91.9	1.8					
20	101.5	2.9		2.2		1.4	

Table 6.5-4: Main Eigenfrequencies and Effective Mass

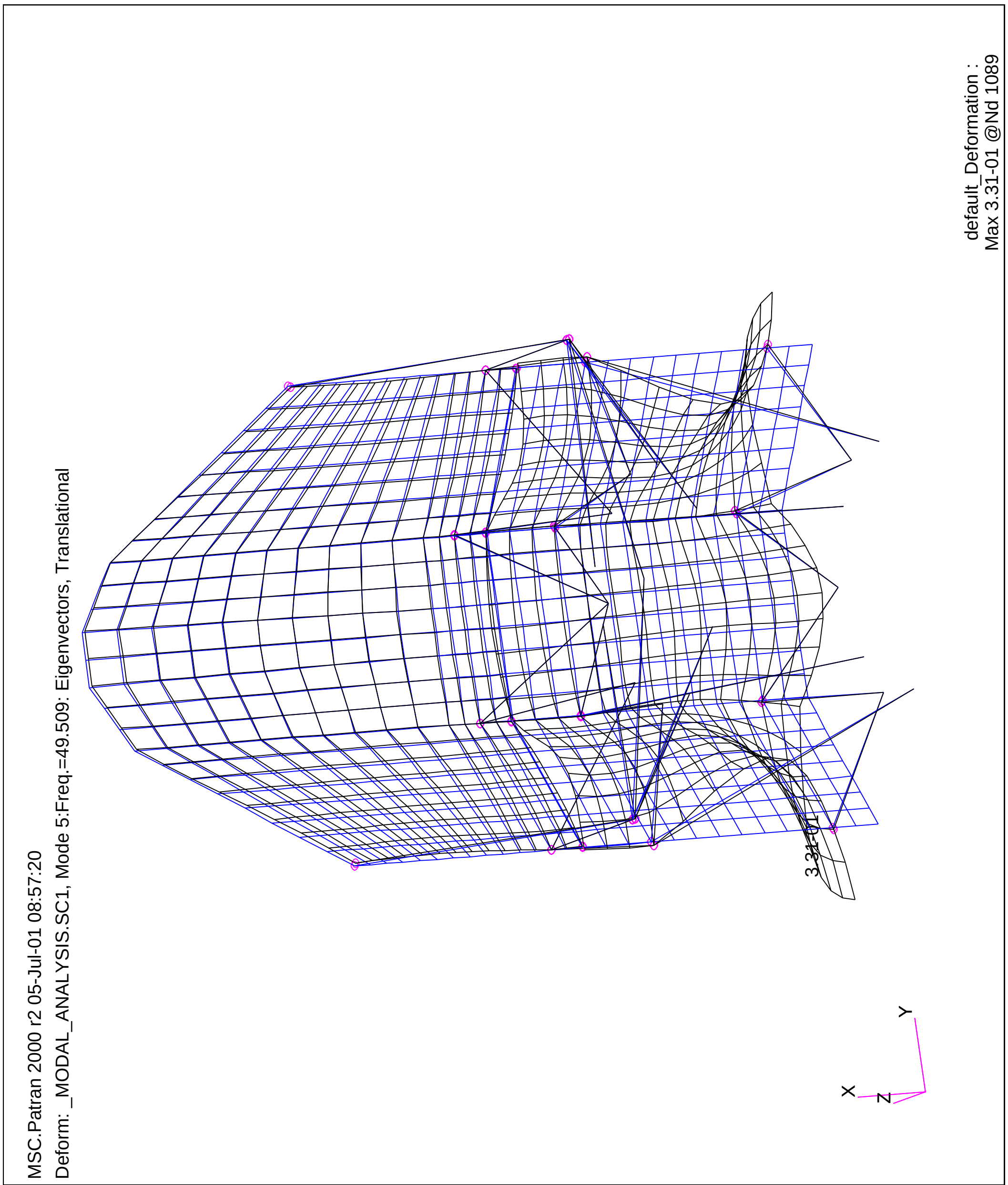


Figure 6.5-13: Mode 5 at f = 49.5 Hz, meff in z = 16%

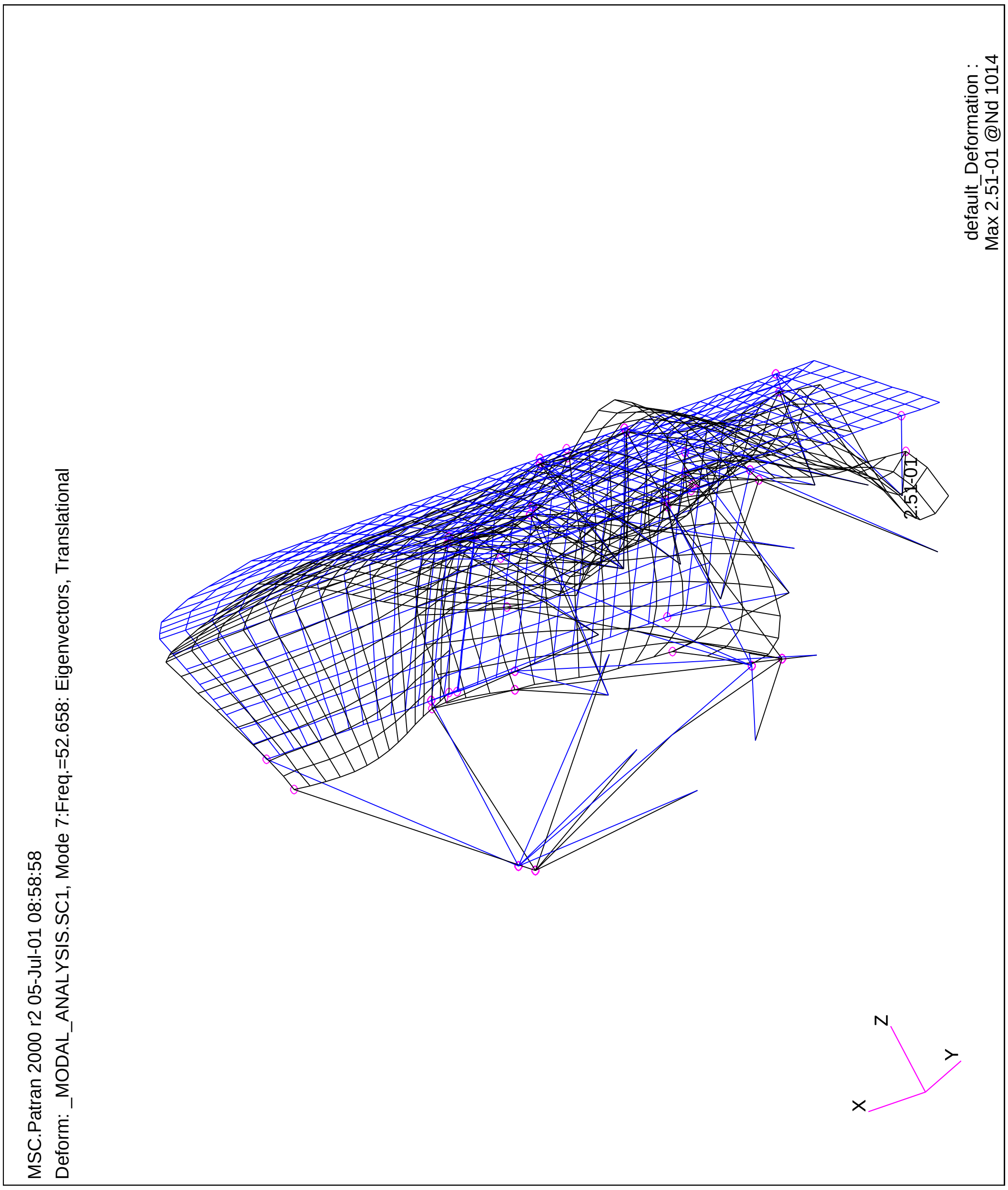


Figure 6.5-16: Mode 7 at f = 52.7 Hz, meff in z = 35%

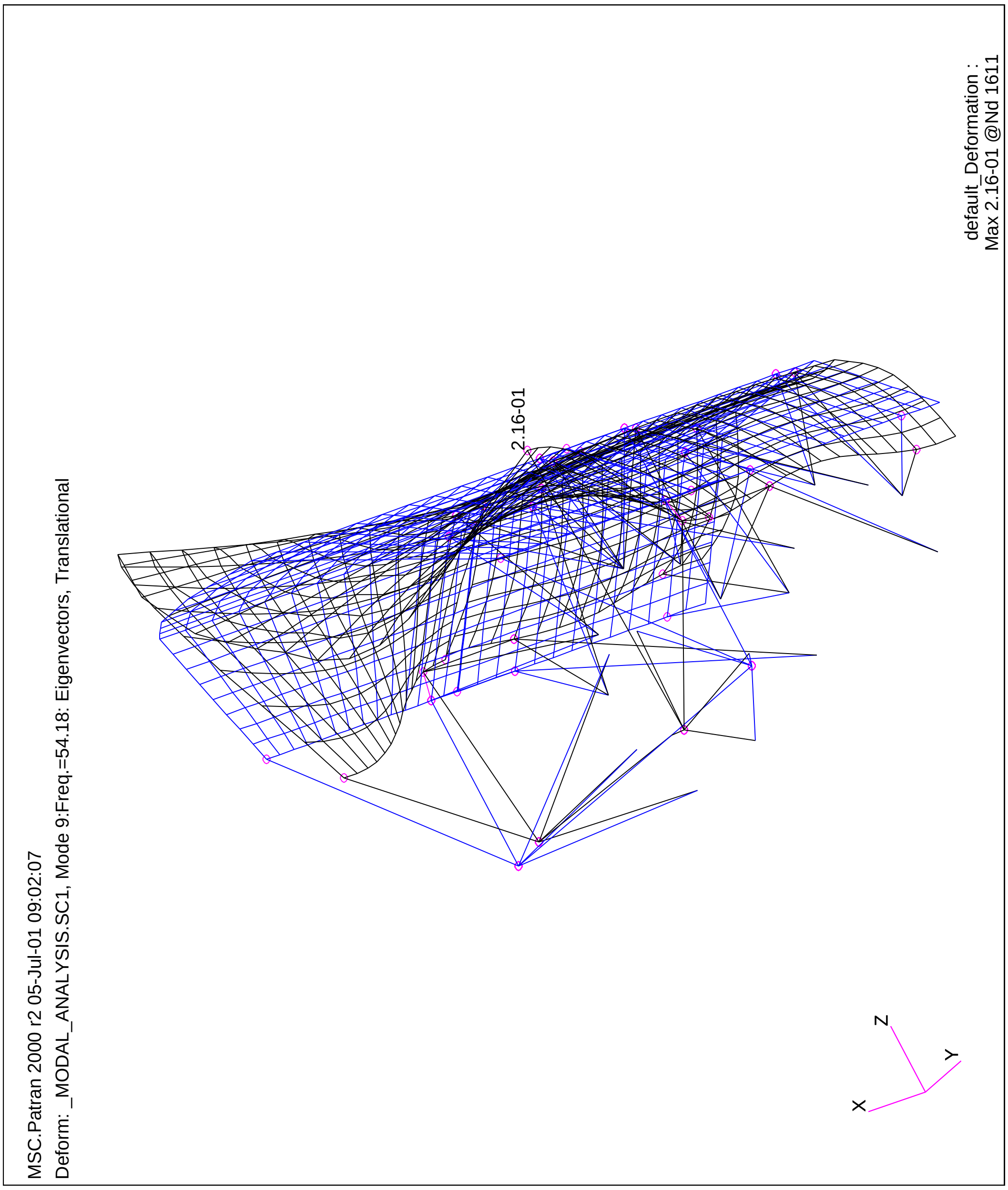


Figure 6.5-19: Mode 9 at f = 54.2 Hz, meff in y = 21%

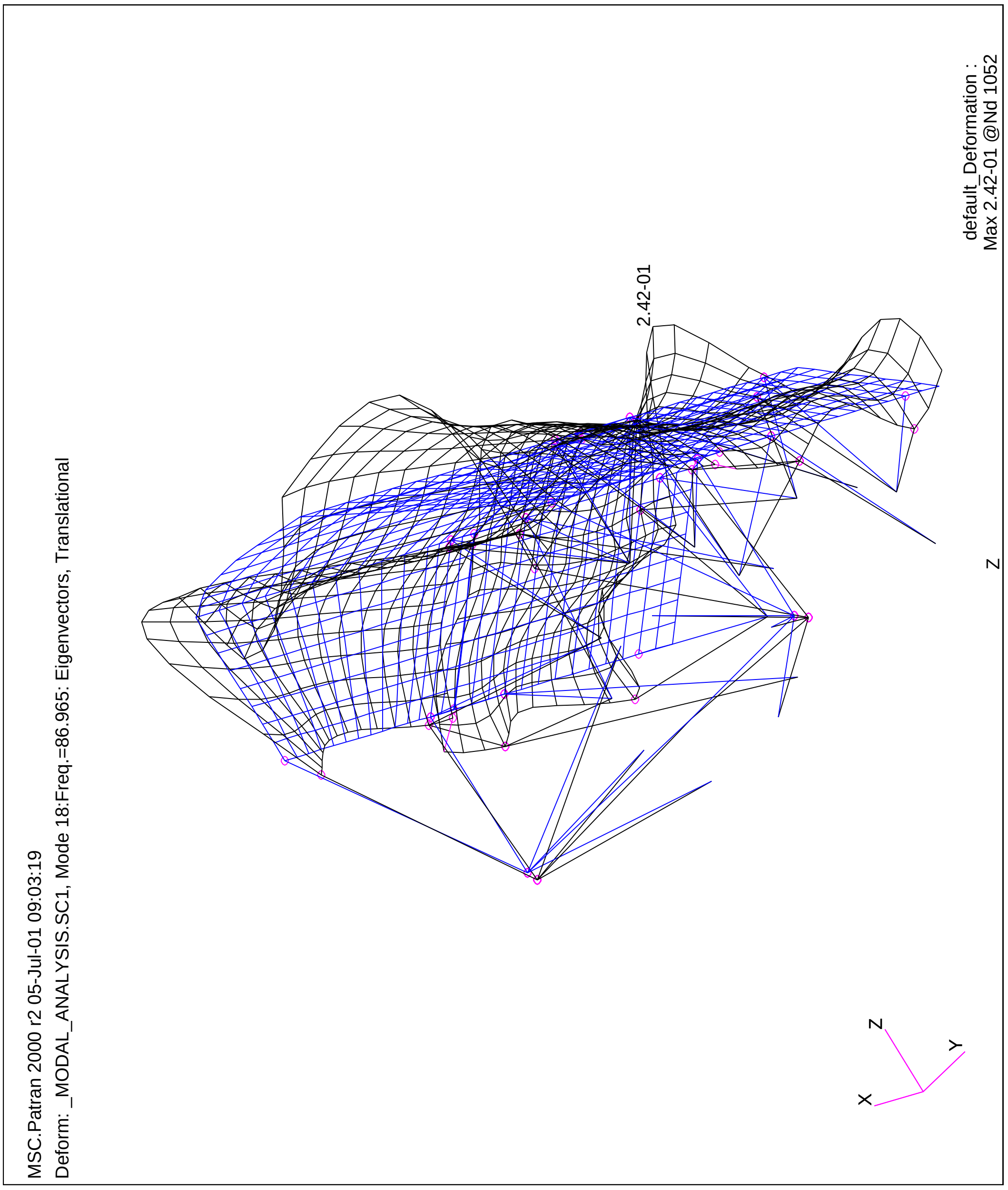


Figure 6.5-22: Mode 18 at f = 87 Hz, meff in x = 15%

6.5.5 Design and Development Approach

Thermal insulation/heat transfer and electrical power demands as well as strength and frequency requirements drive the HSS-structure design. To find an optimum solution, various concepts have been investigated for the proposal. A fine-tuning of the design will be performed in phase B. Engineering trade-offs are described in Chapter 7 The optimization of the design requires a very close co-operation of all engineering activities in the fields engaged. Investigations will be performed in the following areas:

- optimisation of the HSS shape
- size of the Sunshield to provide the required electrical energy
- type of solar cells: dual junction GaAs cells versus multi-junction cascade GaAs cells
- support strut geometry
- OSRs versus SSM tape
- tuning of fundamental frequencies of HSS by strut geometry and additional panel doublers

Sample and Coupon Tests

Sample tests will demonstrate in an early phase the validity of the selected mechanical design. The application and resistance against mechanical and thermal environment of the solar cells and the OSR will be verified with coupon tests.

Qualification Panel

One entire qualification panel of the Sunshield, fully equipped with solar cells, will be exposed to acoustic noise. The panel will be refurbished after the test and used as a flight spare.

STM HSS

The STM HSS will be mechanically identical with the flight HSS with the exceptions that only 10 % of the surface are covered with solar cells and OSRs in critical locations, the other areas are covered with dummy cells. The STM will participate together with the CVV in the vibration, acoustic noise and the thermal tests. The FM HSS will participate in all environmental test of the extended payload module.

A leak in the CVV can be initiated by:

- rupture of an optical window

- burst/leakage of an electrical feedthrough
- crack in the AL-alloy of the CVV
- inadvertent opening of CVV cover

The largest leak size, most likely the rupture of an optical window, will lead to very high GHe mass flow rates and consequently to a burst of the rupture disc. Depending on the leak size, the safety system of the EPLM cryostat will recognise the rising overpressure and through opening of the safety valves the GHe will be released via the filling/vent lines to the atmosphere.

- Operational Handling Errors

An often experienced handling error in cryogenics is the entrapment of air during cool-down, filling/refilling, final top up and warm up operations. In these cases cold pipes may be blocked by frozen air which will be observed immediately during the operation. However, even in the case when either the inlet line or the vent line is blocked, the system remains safe and any overpressure can be released by manual operation of the shut-off valves, by the safety valves or the rupture disk.

The above described failure modes and the corresponding effects of the cryostat safety system shows that danger to personnel will be prevented by the introduced safety concept. A safety concept, which is mainly concentrated on the needs during the test activities on ground and during the launch preparation activities, will be established by the responsible safety team.

7 Trade-Offs and Analyses

7.1 Cryo System Trade Offs

Although strongly based on ISO heritage, the Herschel He subsystem has several aspects which are different and need to be considered.

- The mass flow rate through the phase separator covers a wide dynamic range from 2 mg/s (minimum in-orbit operation) to 32 mg/s (on-ground steady-state value as worst case estimation).
- In the current baseline launch sequence only a comparatively short time (343 s compared to 876 s for ISO) is available for the evacuation of the He I tank between payload fairing jettison and lower stage engine shutdown. Together with the increased He I tank volume and the smaller nominal mass flow rate, this makes the layout of the vent line wrt pressure drop more difficult.
- The baseline Herschel He subsystem with its long filling lines connecting warm (filling port) and cold (tanks) parts seems to be even more susceptible to thermo-acoustic oscillations than the ISO set-up.

Six options, which address parts or all of the problems inferred by the ISO / Herschel differences are described below:

Option 1: Heating of He I tank to higher temperature
The time needed for evacuation of the He I tank in orbit depends on the flow impedance of the external vent line and on the mass to be evacuated. By increasing the tank temperature during rapid depletion, a smaller amount of gas has to be evacuated. However, the advantage of the decreased amount of gas is not considered significant, especially taking into account the increased cooling effort which becomes necessary in the initial orbit phase.
Quantitative assessments can only be evaluated when a detailed vent line pressure drop model is available.

Option 2: Second phase separator for orbital cool-down
With the implementation of a second phase separator in parallel to PS111 with larger cross section allowing an increased mass flow rate during the initial in orbit cool-down the use of very low-impedance nozzles 513/514 for the He I tank evacuation would be possible without exaggerating the risc introduced by a very wide dynamic mass flow rate range of a single phase separator. This option would require two redundant valves with the respective tubing and an additional phase separator at the top of the He II tank.

Option 3: PPS start-up during upper stage burn

When the time between payload fairing jettison and lower stage engine shut-down is not sufficient for PPS start-up, starting the PPS during the upper stage burn (i.e. after waiting for 90 min in µg) could be considered. The geometrical setup of the PPS and the vent line up to the internal valves V103/V106 would then have to be arranged in such a way that the g forces during the upper stage burn force the LHe contained in the vent line between PPS and valves back through the PPS into the He II tank.

This approach seems risky and would have to be qualified by early testing.

Option 4: Additional set of nozzles for He I tank evacuation

If the low flow impedance of the external vent line as required for timely He I tank evacuation proves to impose an excessively wide dynamic mass flow rate range on the PPS, a third set of nozzles can be applied to the external vent line which would only be opened for He I tank evacuation and closed before opening the internal valves. An additional redundant set of external valves would be required.

Option 5: Separate He I circuit

In the “ISO Lessons Learned”, the introduction of separate fill and drain valves for the main and auxiliary tanks is recommended to decrease the susceptibility to thermo-acoustic oscillations. By introducing the means to disconnect the He I tank vent line from the normal He II tank vent line at the end of the launch autonomy phase as shown in Figure 6.5-1, several advantages could be gained which include

- operational flexibility: possibility to launch with LHe in the He I tank. Even in the case of a last-minute launch delay the GHe evaporating from the He I tank can be used for further cooling of the system. The He I tank can be depleted by opening the redundant valves V801/V803 during the coast phase before ignition of the Ariane V upper stage. However, the impact of LHe being released to the environment has to be considered.
- simplified PPS startup: only the vent line volume downstream of the internal valves V103/V106 needs to be evacuated before opening the internal valves. Thus the PPS can be started shortly after opening the external valves without having to wait for the He I tank volume to be evacuated. The flow impedance of the He II vent line nozzles 513/514 can be larger, thus reducing the pressure drop over the porous plug and the maximum mass flow rate immediately after the PPS startup.
- additional flexibility with the possible ability to interrupt thermo-acoustic oscillations by closing valve V702.
- functionality of baseline system is fully conserved when V801/V803 are closed. V702 has to be operated to toggle between He I and He II tank filling.

- He I tank can be operated independently from He II tank.
  - ➢ the He I tank can be used as a cryo trap to prevent contamination of the He II system and OB/FPU during ground testing.
  - ➢ the high impedance flow path from the He I tank via the oscillation damper OD101 to the optical bench can be explicitly cut off.

The separation of the He I and He II vent lines would require

- an additional cold valve V702 (same design as V102)
- an additional safety valve V821 (same design as V521)
- additional external redundant valves V801/V803 (same design as V501/V503)
- additional nozzles 811 and 812
- additional tubing (also leading through the CVV)
- the oscillation damper OD101 would possibly be dispensable (tbc)

Drawbacks of the separate He I vent line are

- additional heat leak via the He I tank vent line: When no heat exchangers are foreseen on the additional vent line, a thin-wall stainless steel tube with small diameter can be used in order to minimize heat leakage.
- the possibility of LHe being released to environment during (in orbit) depletion of the He I tank
- increased total mass (additional components and LHe contents of the He I tank at launch)
- increased size and thus complexity of the system (although no newly designed components are necessary)

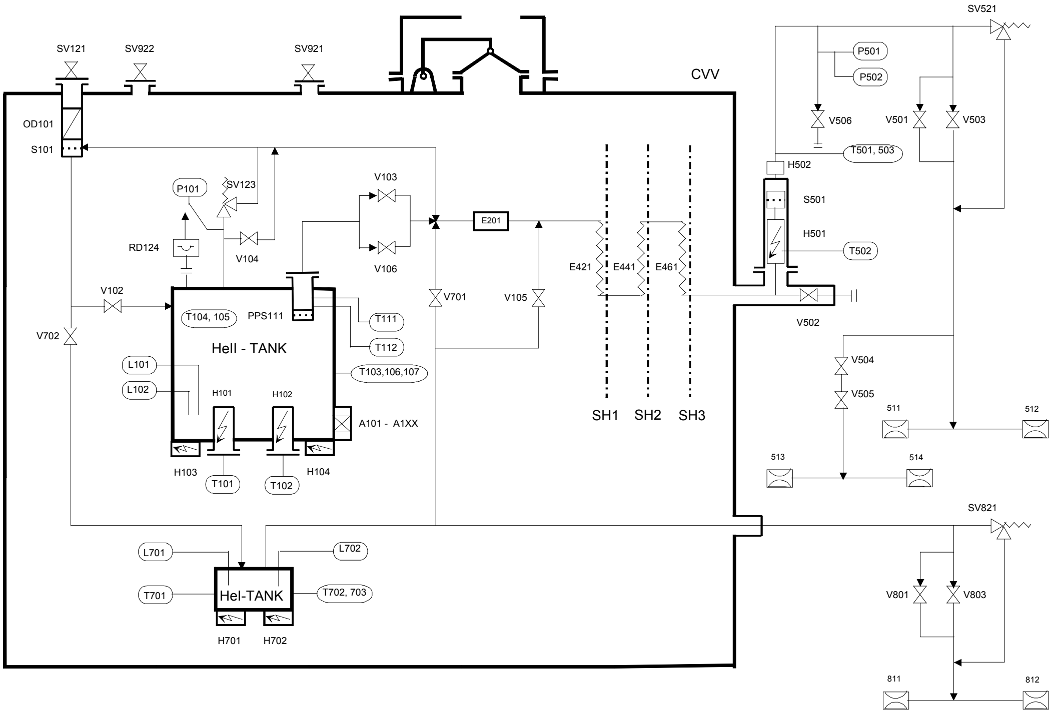


Figure 7.1-1: Optional He subsystem configuration with separate He I tank vent line

The above figure shows a first draft of the separate He I circuit. Details regarding e.g. the safety system and the redundancy philosophy still have to be considered.

Other possible configurations with separate He I and He II vent lines (e.g. separate filling port and/or separate vent line with heat exchangers on OB, shields and/or CVV instead of the connection to the He II vent line via V701/V105) further increase the system complexity and mass without leading to significant advantages.

Option 6: Launch sequence with uninterrupted thrust phase

When a direct L2 transfer scenario is chosen with no significant coast phase between the lower stage engine cut-off and the upper stage engine ignition, the time which is available for the evacuation of the external vent line and the He I tank and for PPS start-up is increased by approx. 9 min, the duration of the upper stage engine thrust phase. Such a scenario would significantly ease the safe PPS start-up before the onset of zero gravity. The impact of the solar illumination of the telescope caused by SAA restriction violations identified in the Arianespace feasibility study will have to be thoroughly assessed.

7.2 Tank Design and Tank Support

The He II tank design has been review and analyzed ert. the following aspects

1. Fluid Dynamics
2. Tank Fixation Options

7.2.1 Fluid Dynamics

The helium II is a compressible fluid, which has natural frequencies, if contained by a tank of the size if the Herschel tank. Without any measures the first natural axial frequency of the helium would be below the frequency requirement of the PLM. Therefore an additional internal bulkhead has to be introduced in the tank. The following figure shows the principle tank design and the possible shape of the first axial and lateral mode.

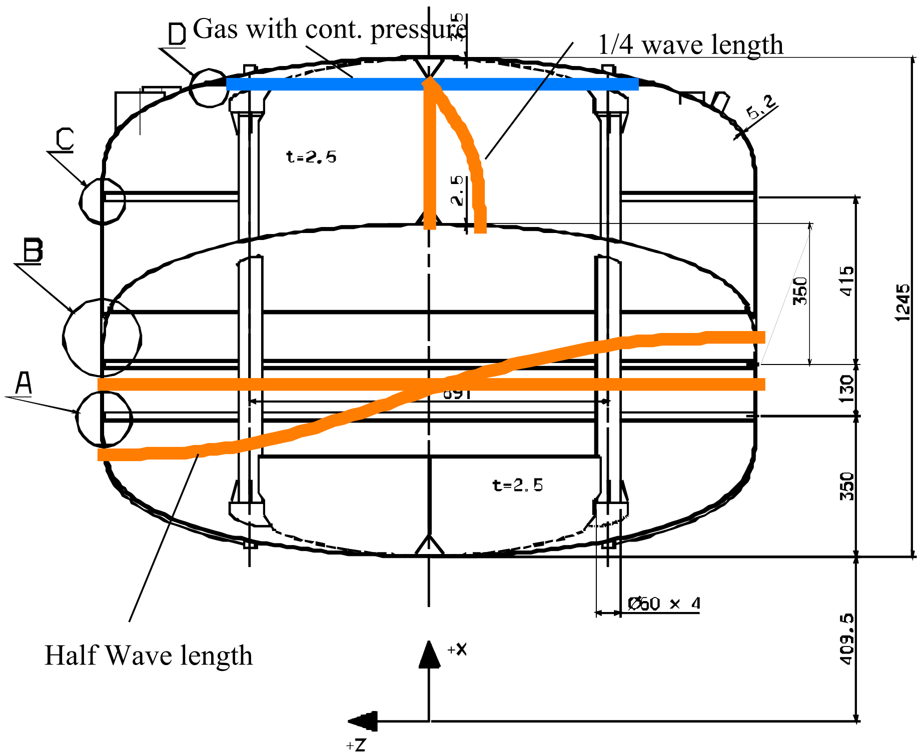


Figure 7.2-1: Mode Shapes in the tank.

In first rough approximation natural frequencies can be analyzed as follows:

Sound Speed:
Launch: c = 238 m/s
Vibration Test: c = 170 m/s

Basic formulas
Longitudinal: f = 0.5 c/l or f = 0.25 c/l
lateral: f = 0.58 c/d

These considerations yield to following approximation for the natural frequencies of the tank with internal bulkhead.

Compartment		Launch	Vibration Test	
	c =	238	170	
Lower	lateral	87	62	
	axial	149	106	Hz
Upper	lateral	-	-	
	axial	170	121	Hz

One sees, that the behaviour during launch and vibration test will be somewhat different, because of the helium different material under these conditions.
At one hand to be able to calculate the lateral frequency in upper compartment of the tank , at the other hand to check if the internal bulkhead provied enough stiffness, an FEM analysis with ABAQUS has been performed.

The analysis uses fluid elements with pressure as variable, fluid /structure contact area and structural shell elements, to simulate the behaviour of the tank walls. The sloshing at the fluid surface is up to now not included in the analysis.

The FE analysis results, which are listed in the table below, shows especially for the upper compartment some significant differences to the hand calculations, which are resulting at one hand form the stiffness of the tank walls, at the other hand by the by the more complex mode shakes in the upper compartment.

	c =	238	
Lower	lateral	88	
	axial	163	Hz
Upper	lateral	48	
	axial	82	Hz

The following shows the mode shapes for the 98% filled tank.

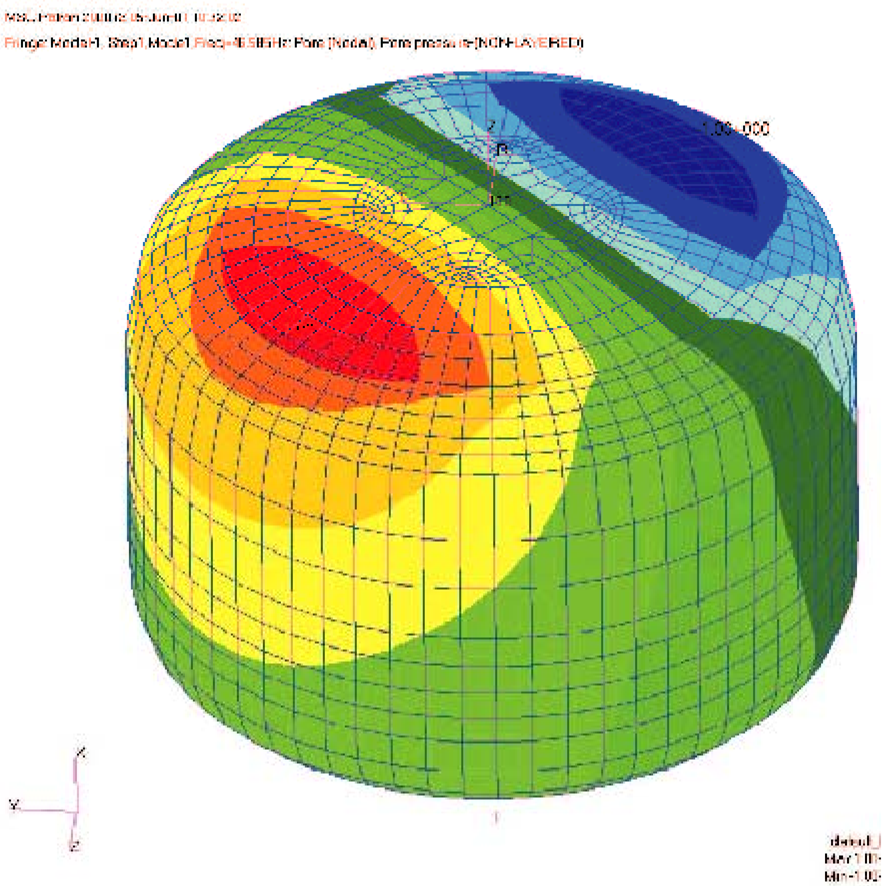


Figure 7.2-3: Mode 1, f = 42 Hz, Lateral mode in upper compartment

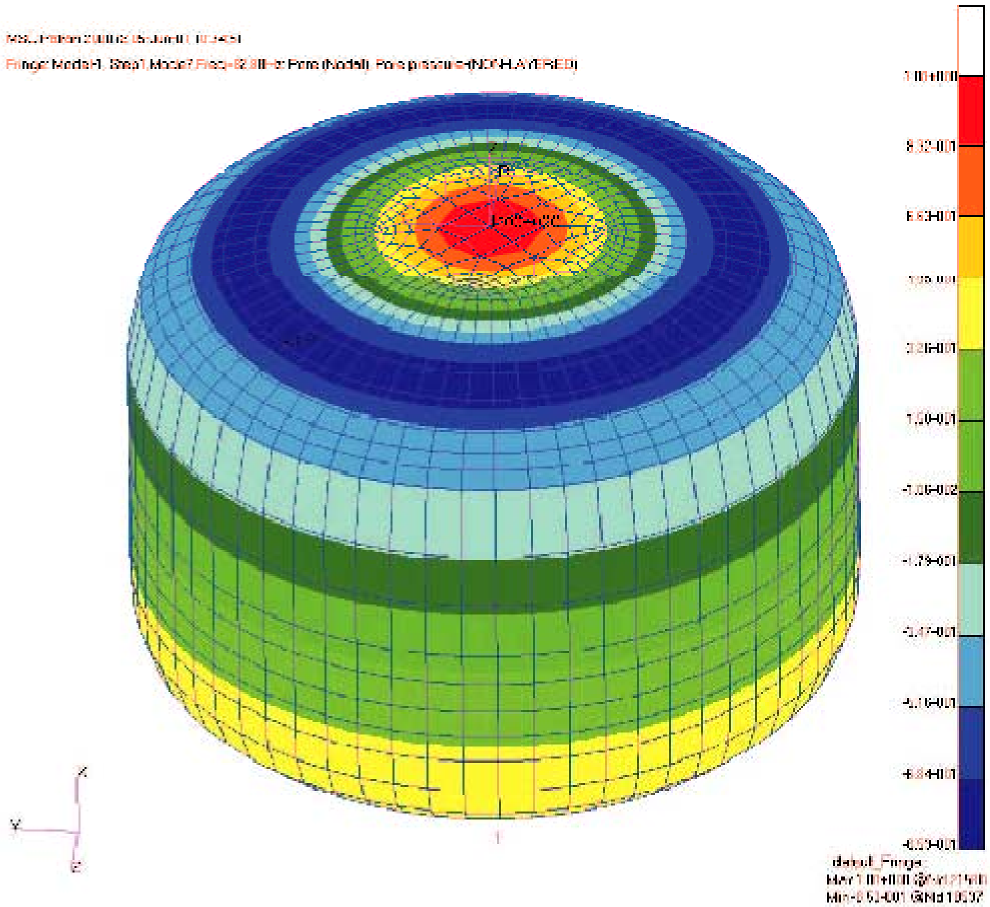


Figure 7.2-5: f = 82 Hz, Axial mode in the upper compartment

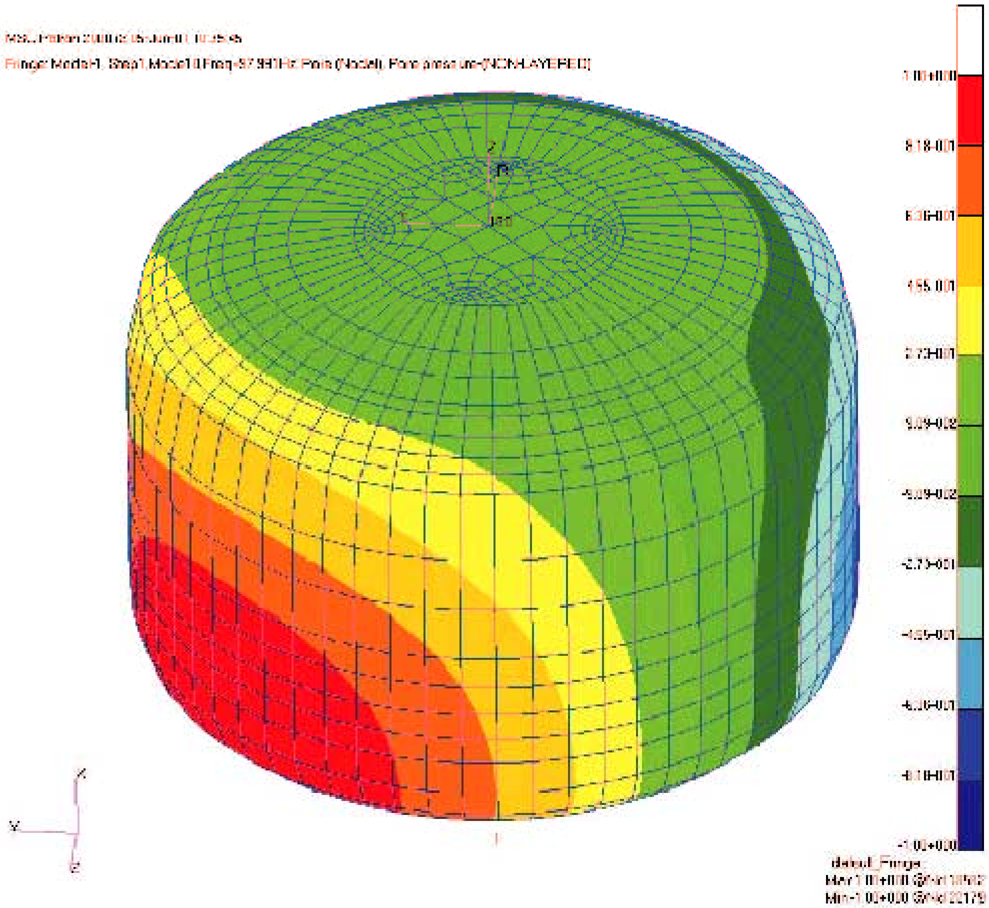


Figure 7.2-7: Lateral mode in the lower compartment

The analysis has been performed for 90%, 98% and 100% filled tank. The lateral mode in the upper compartment is strongly dependent on the amount of gas in the tank. This dependence is shown in the figure below.

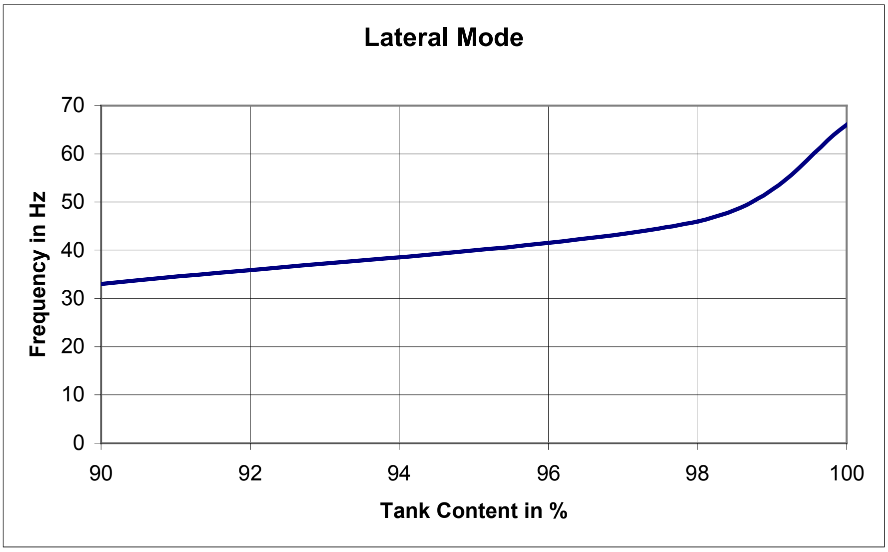


Figure 7.2-9: Lateral Mode dependency on tank content

The summary of the analysis is, that the internal bulkhead shift the axial natural frequency above the PLM frequency requirement. The design, as baseline design of the proposal is verified to be meaningful.

7.2.2 Axial Load Introduction in the Helium II Tank

Extensive analysis has been performed comparing different design options for the axial load introduction in the tank. The following options have been looked into:

Tank Design as described in the Proposal

The key features of the design is, that the pretension forces of the tank suspension are taken by 4 rods, which are located in the tank. To carry the inertia loads of the tank and the gas to the 8 "tank bones" the upper and lower bulkheads are reinforced.

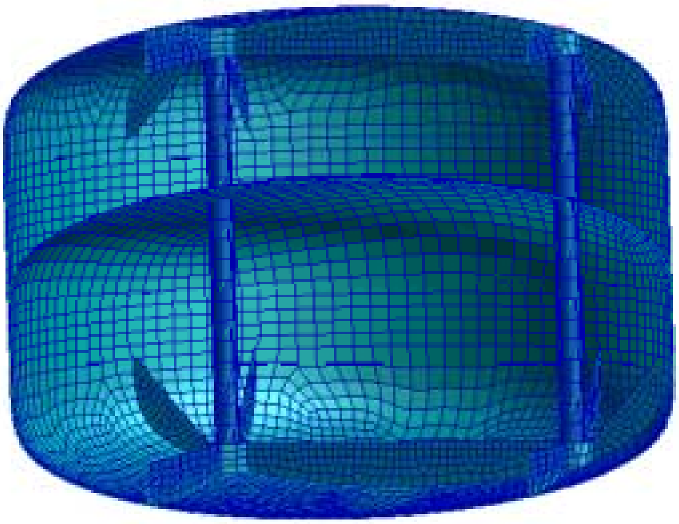


Figure 7.2-10: Helium II tank baseline design.

Tank without Rods

The baseline design has two separate load path, which connect the upper and lower bulkhead. This increases the complicity of the manufacturing process, because the tolerances of the rods and the cylindrical part of the tank has to be adjusted. The idea is, to simplify the design, by removal of the rods.

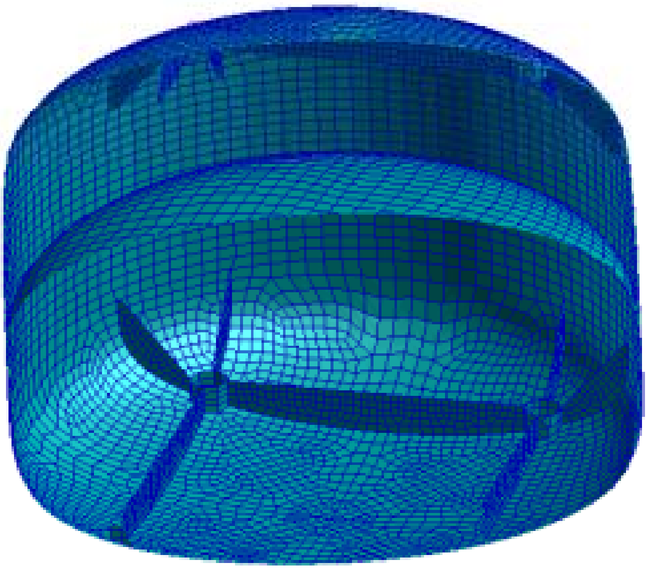


Figure 7.2-12: Tank without rods

Load introduction at the Center Bulkhead

An other possibility to reduce the manufacturing risk, is to fix the rods at the center bulkhead. This would result in a separate load path for pressure load cases and inertia load cases.

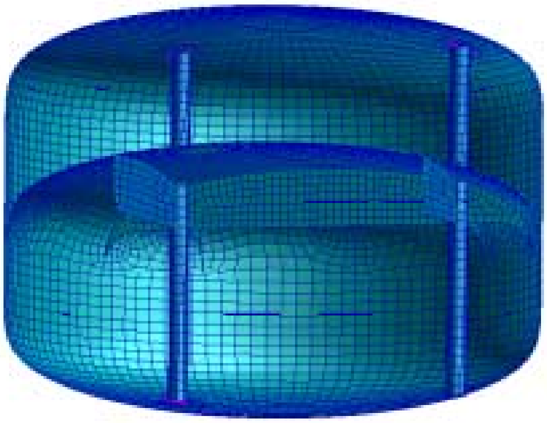


Figure 7.2-14: Tank with load introduction at the center bulkhead

The three design options has to be compared wrt. to the following design cases:

Load Case	Internal pressure of 30 mbar	Internal pressure of 1.76 bar	Internal pressure of 3.36 bar	External Pressure	Pretension of straps	Flight load axial	Flight load lateral	Remark
1	x				x	x		nominally flight
2	x				x		x	
3		x			x	x		
4		x			x		x	
5			x					
6				x	(x)			

Table 7.2-1: Load cases for the Helium II Tank

The most critical design case is the superposition of the mechanical vibration loads with a internal pressure of 1.76 bar. This case is resulting from safety considerations. The possible scenario of this case is, that the pressure in the tank increases during vibration up to opening of the safety valves.

The following figure shows an overview, which load case is critical for which part of the tank.

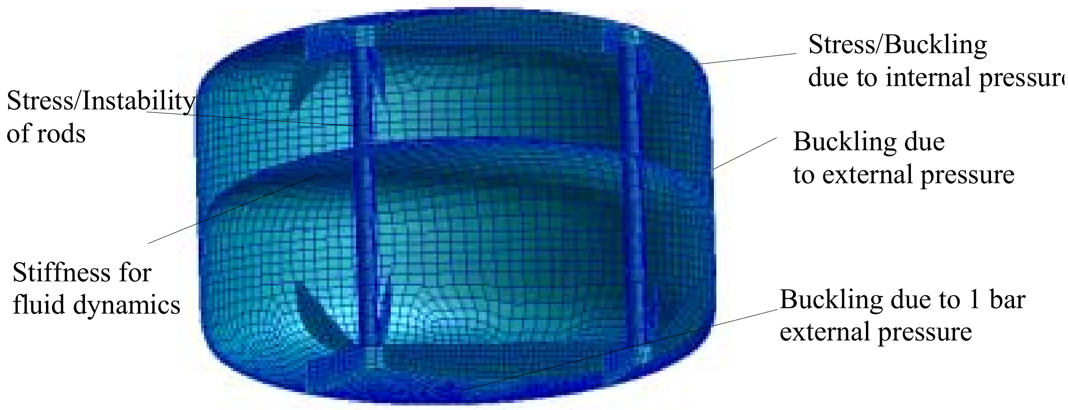


Figure 7.2-17: Overview of load cases critical to the tank

7.2.2.1 Analysis of the Baseline Design

Some key results of the stress analysis are baseline design are show below.

The load situation in the rods show, that the rods are under compression, if if the internal pressure of the tank is 1.76 bar. This means, that the suspensions are not loaded by the internal pressure load cases.

Pretension Load	34 KN
Additional load in rod due to 1 bar external load	9.2 KN
Reduction of load due to 1.76 bar internal load	16.2 KN

The stresses in the tank provide positive margins of safety.

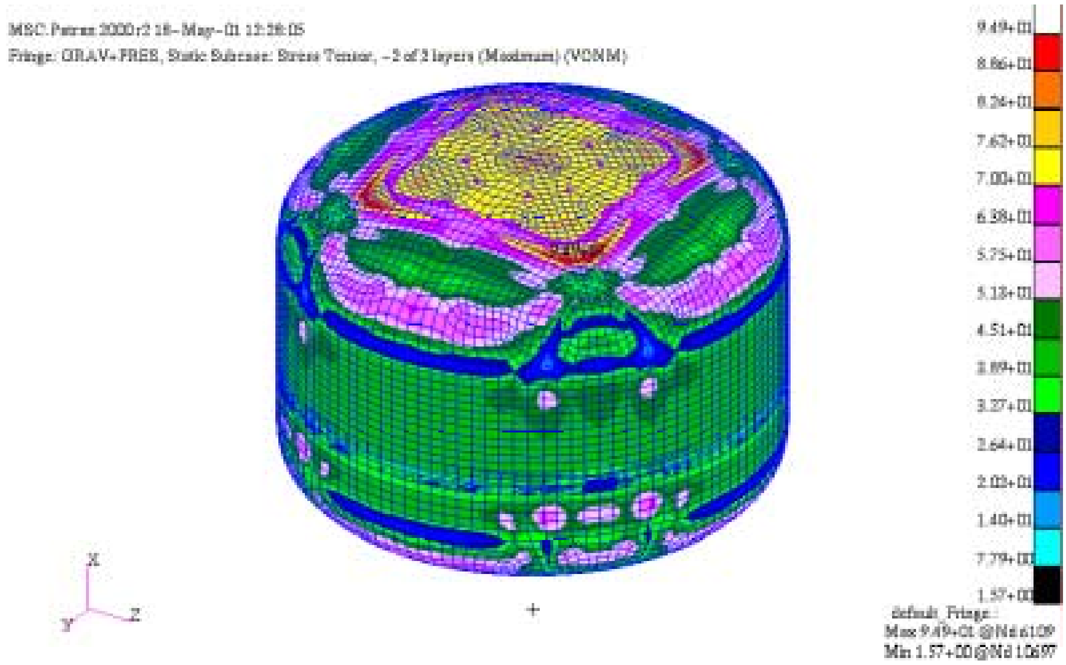


Figure 7.2-18: Stress in tank due to 15 g load in axial direction combined with an internal pressure o f 1.76 bar.

Based on the material data of 5083 the resulting margins of safety are shown in the figure below.

	N/mm^2	yield	ultimate
Stress (Global)	76	0.10	0.81
Local stress	98	0.28	0.40

Stability (Draft based on hand calculations)	Margin	Remark
upper bulkhead (external pressure)	negative	reinforcement needed
upper bulkhead (internal pressure)	o.k.	(based on pressure vessel design rules)
cylindical part external pressure	o.k.	(based on pressure vessel design rules)

7.2.2.2 Tank without Rods

The main disadvantage of this design is, that due to the flexibility of the tank the optical bench will change the axial alignment, if the pretension of the straps changes. For the actual tank wall thickness loading of the straps will move the optical bench 2.67/2 = 1.3 mm. For ground operations this is not critical, because this can be readjusted. But we have a change of the suspension preload from earth to orbit, because the CVV is cooling down. I our opinion, it is too critical to rely on analytical prediction for the alignment, for such a complex load case.

For that reason the tank without rods is no real option.

In addition this tank configuration would need thicker tank walls and therefore a higher mass.

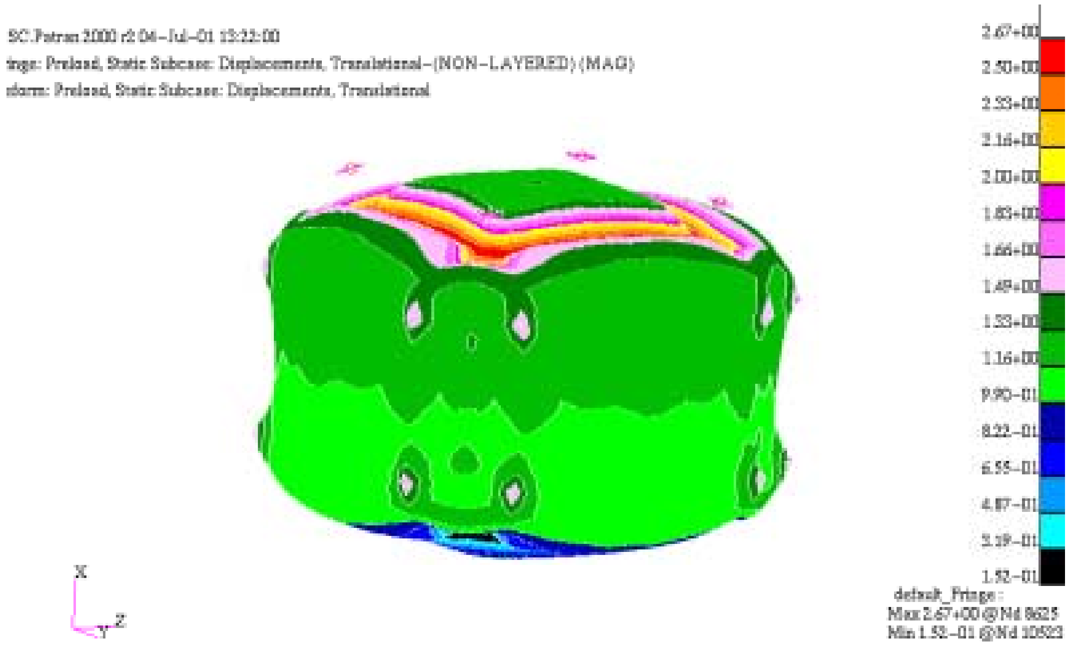


Figure 7.2-20: Deformation under preload

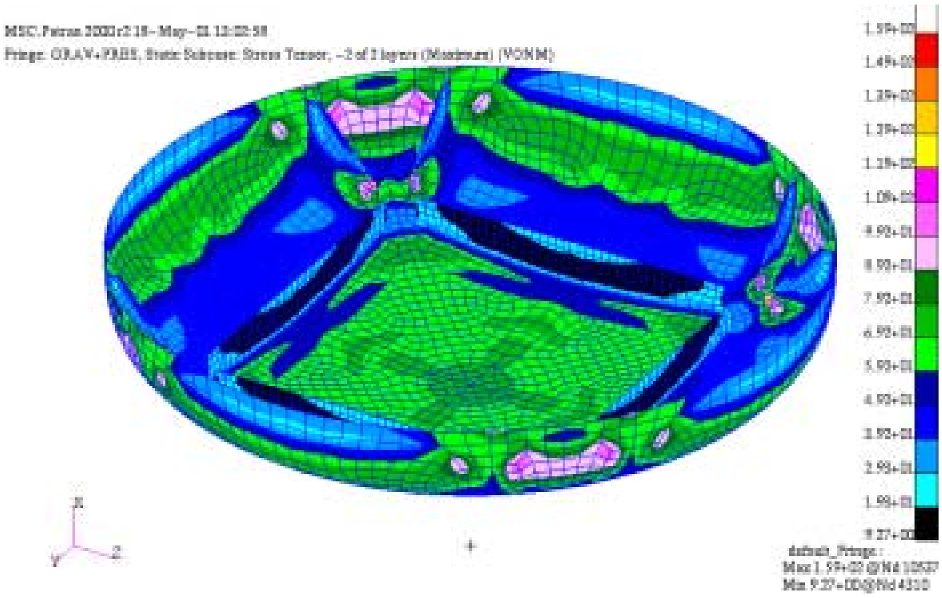


Figure 7.2-22: Stress in tank under a pressure of 1.76 bar and launch loads

7.2.2.3 Tank with Load Introduction at the Center Bulkhead

To reinforce the center bulkhead would reduce the loads in teh struts due tp pressure:

Pre load in rods due to 1 bar: 4000 N
Rod load (1.76 + flight): 20000 N

Wrt. to the stress in the tank wall, this is a feasible design.

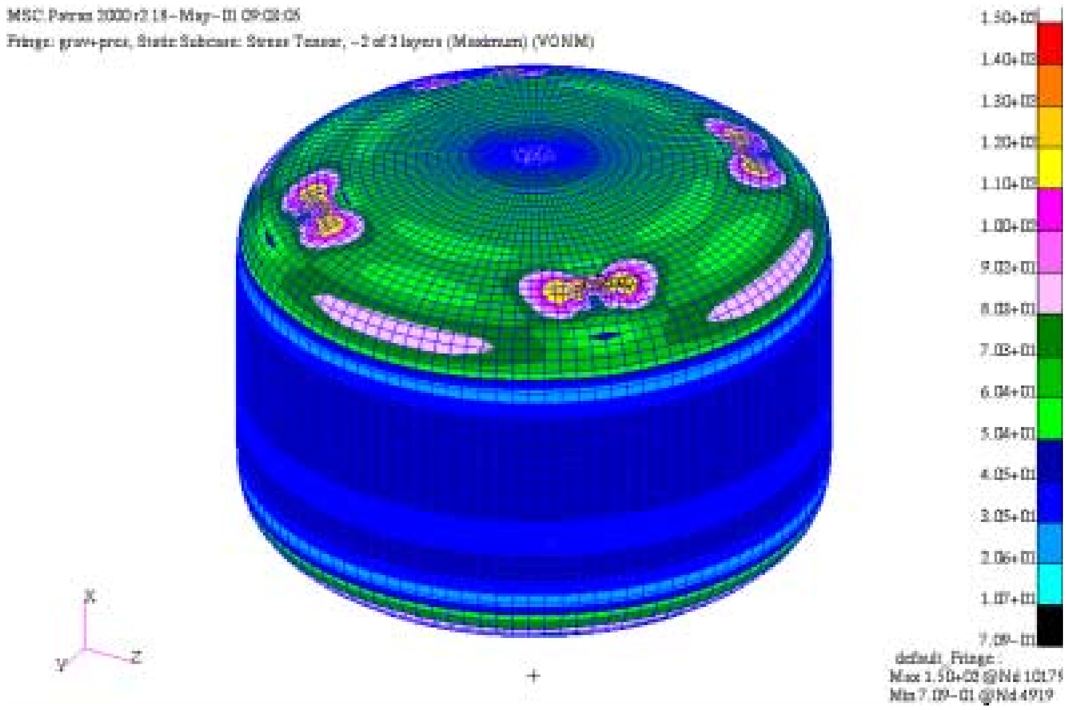
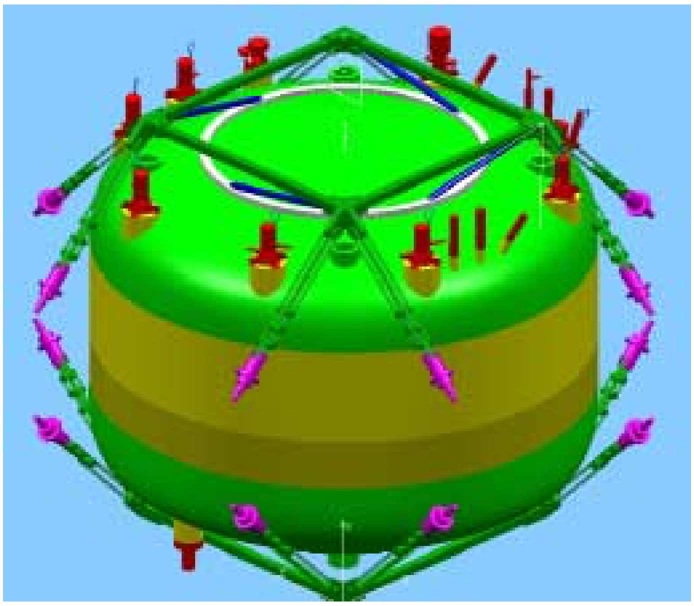


Figure 7.2-24: Stresses in the Tank due to 1.76 internal pressure and launch loads

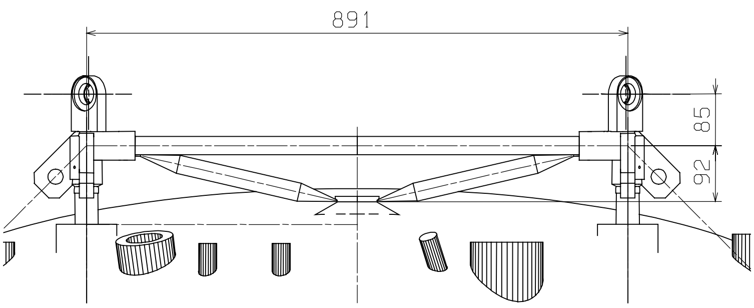
As the upper and lower bulkhead has to be reinforced anyhow, for the external pressure load case, this option is less attractive as the baseline design.

7.2.3 Lateral Load Introduction

The baseline for the lateral load introduction is the configuration of the struts, shown in e figure below. On each I/F to the SFWK 4 struts are carrying the loads. The orientation allows the tank to rotate during cooling down and pressurising. This avoids residual strut loads. The rotation of the tank seems to be no problem.



The load introduction is lateral to the bulkhead walls.



The proposal design is a feasible design, but the pretension change during cooling down and pressure changed can not controlled from outside the cryostat and seem to be risky.

7.3 Optical Bench

The baseline design for the optical bench is a milled aluminum plate. The locations of the rips is optimized wrt. the optical bench support points and wrt. the instrument I/F points.

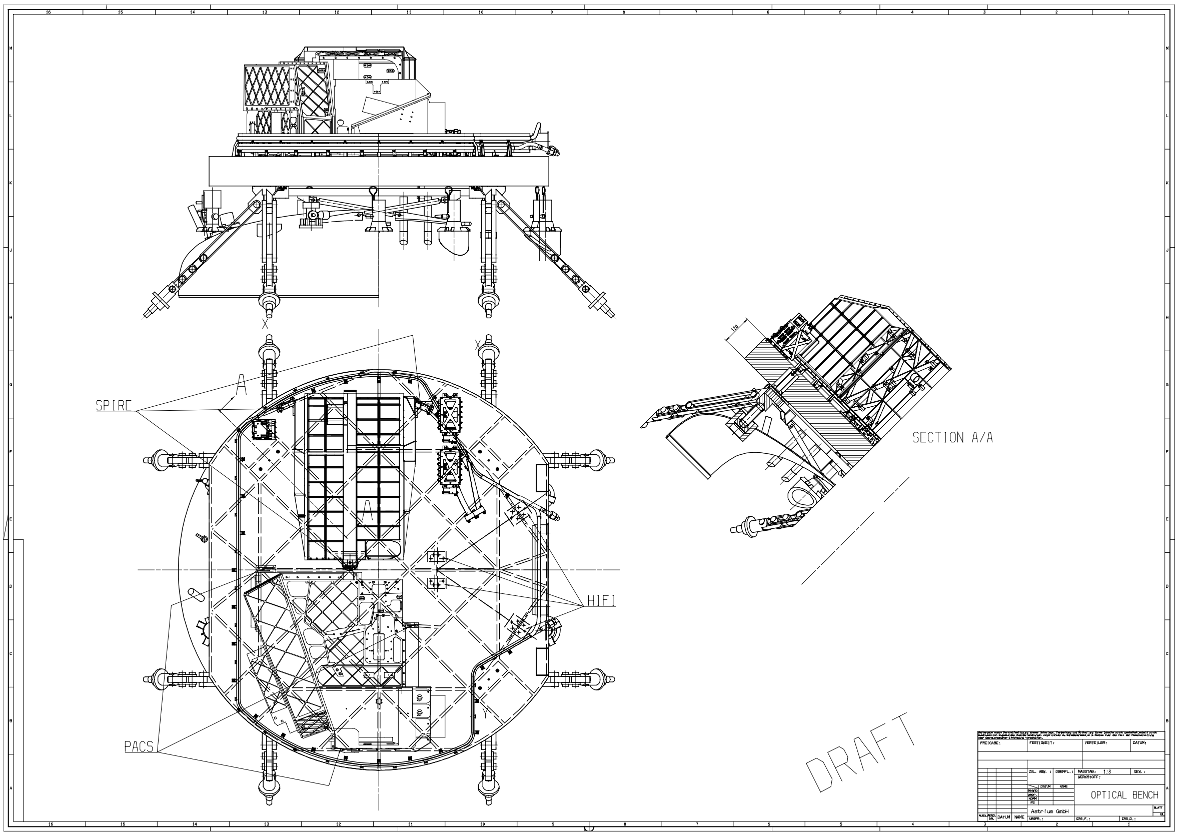
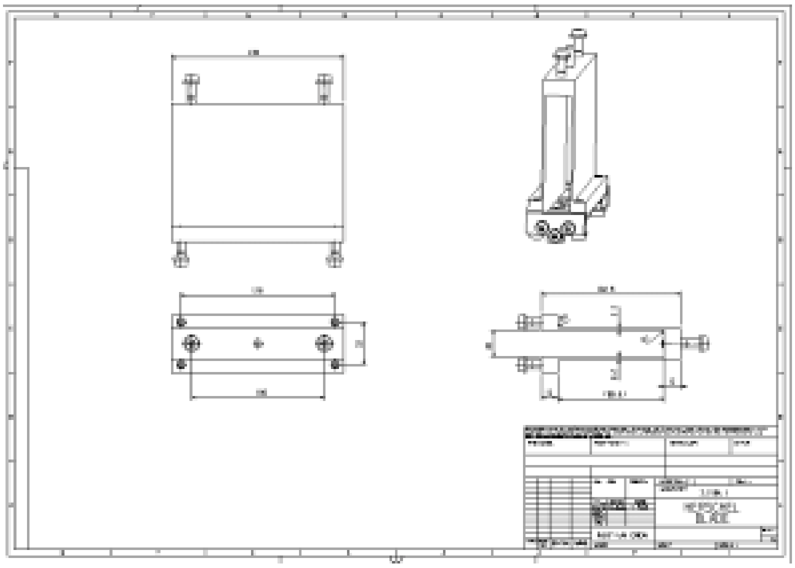
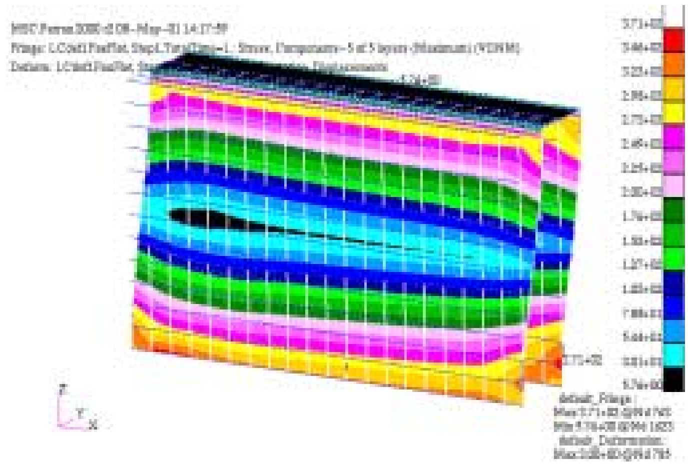


Figure 7.3-1: Optical Bench Design

The support of the optical bench will be supported by isostatic mount - as shown in the figure below.





The analysis of these mounts provides a positive margin of safety and a factor of 8 reserve for buckling.

7.4 Sunshield / Sunshade

Three different trade-offs have been performed on the sunshield/sunshade configuration:

1. the influence of an increased solar aspect angle around the X-axis to +/-23° accounting for ARIANE 5 uncertainties during launch

2. a panel support truss with 24 instead of 32 struts mounting the HSS on the SVM/CVV, decreasing the mechanical stiffness, but significantly simplifying the structure, saving mass and increasing life-time through less heat transfer from HSS to CVV
3. alternative lateral SSH fixation on the SVM

7.4.1 Solar Aspect Angle of +/-23° around the X-axis

The HSS baseline design considers a solar aspect angle of currently +/-5° around the X-axis, providing an additional margin of 6.6°. According to ARIANESPACE there is an uncertainty on this solar aspect angle during launch, which could lead to an increase to +/-23°.
Figure 7.4-1 shows the E-PLM configuration for solar aspect angles of –30°/0°/+30°/+60°/+90° around Y-axis super-positioned by 23° around X. As can be seen in all cases (Y-axis variation from –30° to +90°) the telescope is exposed to direct solar irradiation.
The most critical case is when Y=30° and X=23°, because then the reflector side of the telescope has a view factor towards the sun. Also the local oscillator unit gets into the view field of the sun. Detailed thermal transient analysis will have to be performed in order to check the impact of such irradiation.
In all cases the CVV is protected against solar irradiation by the HSS.
For rotation around Y-axis less 0° the SVM (not shown in the figure) will protect the PLM from solar radiation.

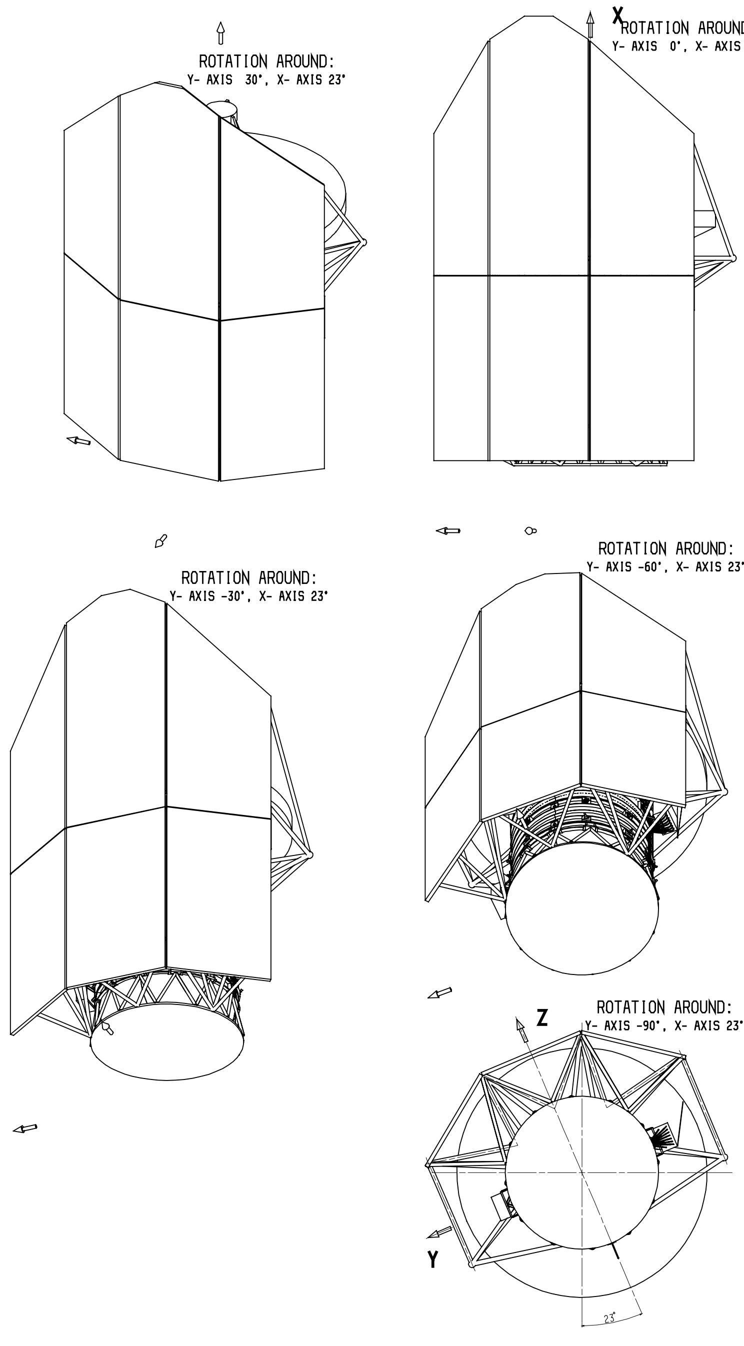


Figure 7.4-1: Solar aspect angles of –30°/0°/+30°/+60°/ +90° around Y-axis and 23° around X-axis

7.4.2 Panel Support with 24 instead of 32 Struts

The baseline design described in Chapter 6.5 includes a sunshield/sunshade panels support structure of 32 struts in total. With this rather high number of struts the HSS can be supported rather efficiently in terms of stiffness and loads. On the other hand it is obvious that having a lower number of struts has some advantages

- Integration of the sun shield unit, integration of the sun shade unit, integration of SSH/SSD into the E-PLM becomes easier
- Mass can be saved, 20kg at current state of design
- Heat conduction from HSS to CVV decreases and thus lifetime is increased.

For this reason an alternative design of a panel support truss with 24 instead of 32 struts mounting the HSS on the SVM/CVV as shown in Figure 7.4-4 has been investigated.

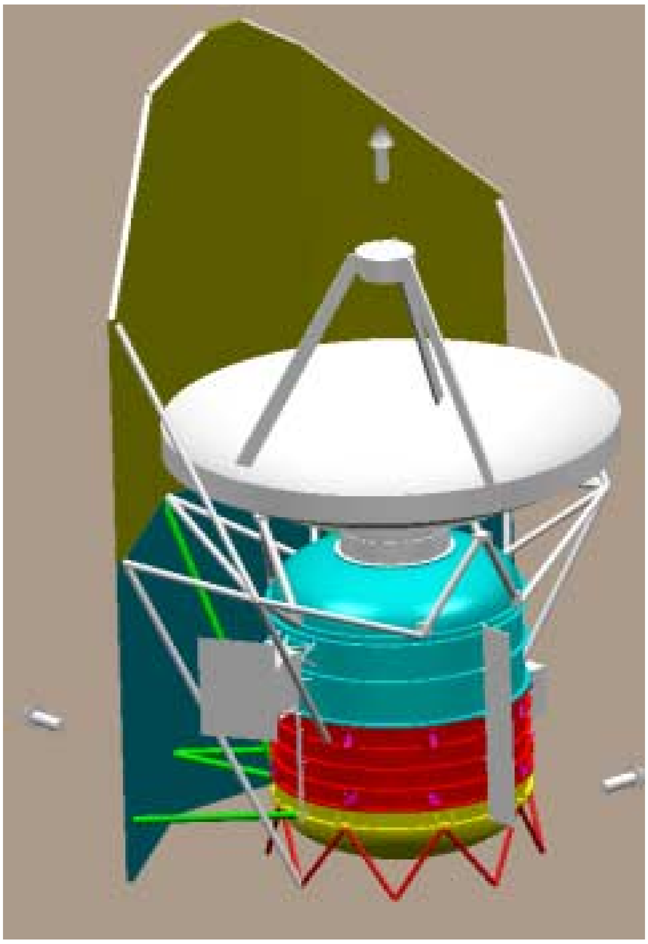


Figure 7.4-4: HSS Support Truss with 24 Struts

This design can be summarized as follows

Number of SSH Panels:	**3**
Number of SSD Panels:	**3**
Total Number of Struts:	**24**
Number of Struts of SSH/SSD I/F to SVM:	**4**
Number of Struts of SSH to SVM:	**6**
Number of Struts of SSH/SSD I/F to CVV:	**6**
Number of Struts of SSD to SVM:	**0**
Number of Struts of SSD to CVV:	**8**
Number of Joints between SSH and SSD:	**4**

The panels are connected via bolts, providing flexibility during integration and transport. Compared to the baseline design with 32 struts the mechanical stiffness is decreased to a first mode at 22Hz. Nevertheless this figure may not be compared to the 49Hz of the baseline design directly. Introduction of 8 additional struts in the baseline design raises the fundamental frequency by only 6Hz in the first significant Z-mode and 10Hz in Y. The 49Hz are only reached after further stiffening measures such as adding four vertical 'beams' between the SSD and SSH support nodes (+5Hz in Y, +11Hz in Z), stiffening of the SSD outer panel edges (+2Hz in Z), increasing strut cross sections (+4Hz in Z).

This means that there is potential to also increase the fundamental frequency of the 24 struts design by optimizing the strut cross sections, locally reinforcing the panels, etc.

A decision on the design to be used as a baseline for further optimizations strongly depends on the design requirements to be established for the E-PLM and the HSS as an integral part of it. A stiffness investigation on just a hard-mounted HSS might mislead to a design that is not the most efficient solution once incorporated in the complete E-PLM (with simulated SVM stiffness).