TITLE:

FIRST Instrument I/F Study
Final Report

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DOCUMENT CHANGE RECORD

Iss/Rev	Date	Change Notice Number	Modified pages or paragraphs	Observations Nature of change
1/-	02.02.2000	N.A.	N.A.	Initial Issue
1/1	06.04.2000		p.5	≤ sign introduced in table
			p. 6	SPIRE beam shape implemented
			p. 8	PACS beam shape implemented
			p.10	HIFI beam shape implemented
			p.18	Fig. baffle shape in TMM implemented
			p.25	Optical Transmission value corrected
			p. 32	cryostat cover considerations removed
			p.12,13,21,26,27, 28,31,33,57	wording modified
			p. 63, p.67	typing errors corrected

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1. Scope

This final report describes the present design of the instrument interfaces and the update of the PLM design after implementation and accomodation of the instruments to the PLM. The fundamental design of the PLM, developed in former studies, has been kept.
This report includes the thermal analysis report, the structural report and the recommendations for the instrument harness.

2. Documents

1. FIRST-PLANCK System Specification, PL-0000231, issue 1, 25.07.1997
2. IID A, PT-IID-A-04624, Issue 0, rev. 1, 31.08.99 (chapter 4 and 5)
3. IID B SPIRE, PT-SPIRE-02124, Issue 0, rev.2, 01.08.99
4. IID B PACS, PT-PACS-02126, Issue 0, rev.2, 01.09.99
5. IID B HIFI, PT-HIFI-02125, Issue 0, rev.2, 01.08.99
6. F/P Merger Report PLM, FIRST-GR-B0000.008, issue 1, 31.3.98
7. SPIRE thermal transient cases for cryostat study, SPIRE-RAL-NOT-nnnn, 14.12.1999

3. Introduction

The main objectives of the study have been

- the implementation of the present FIRST instruments design
- check of the cryostat performances after implementation
- detail of the instrument interfaces

4. Requirements

4.1 Cryostat overall requirements

The main overall requirements are

- the cryostat shall accommodate three Focal Plane Units (FPUs) with an actual total mass of 130.3 kg + 20% margin (heavily increased w.r.t F/P merger-study from 86.5 kg) and an overall dimension envelope of 1709 mm by 1174 mm and a maximum height of 460 mm
- the cryostat shall provide three operational temperature levels
- the PLM shall meet the structural stiffness requirements: cryostat first axial eigenfrequency ≥ 42 Hz and first lateral eigenfrequency ≥ 20 Hz
- the cryostat shall provide external mounting interfaces for the Local Oscillator, the Buffer Amplifier Unit, the Startracker, the Telescope Assembly, the Sunshield and the SVM/PLM interface struts

4.2 Instrument Requirements

SPIRE

Mechanical Requirements:
The SPIRE FPU has outer dimensions of 538 x 742 x 452 mm and a mass of 31.5 kg. It is mounted by 8 CFC struts or by a tbd number of CFC or Steel blades thermally insulated to the Optical Bench. The whole FPU is covered by a faraday cage.
For the SPIRE JFET/Filter box outer dimensions of 81 x 450 x 92 mm and a mass of 2.5 kg has been given. This box is directly mounted to the OB. There is no temperature requirement for this box. The position and size of this box at the end of this study is tbd. The SPIRE JFET/Filter box is part of the faraday cage.
The outer envelope of the SPIRE FPU and JFET/Filter Box is given in Fig. 4.2-1
The SPIRE BAU is an amplifier unit with outer dimensions 200 x 150 x 120 mm (JPL 360 x 50 x 380 mm) with 3 kg mass, which is mounted on a support structure on the CVV.

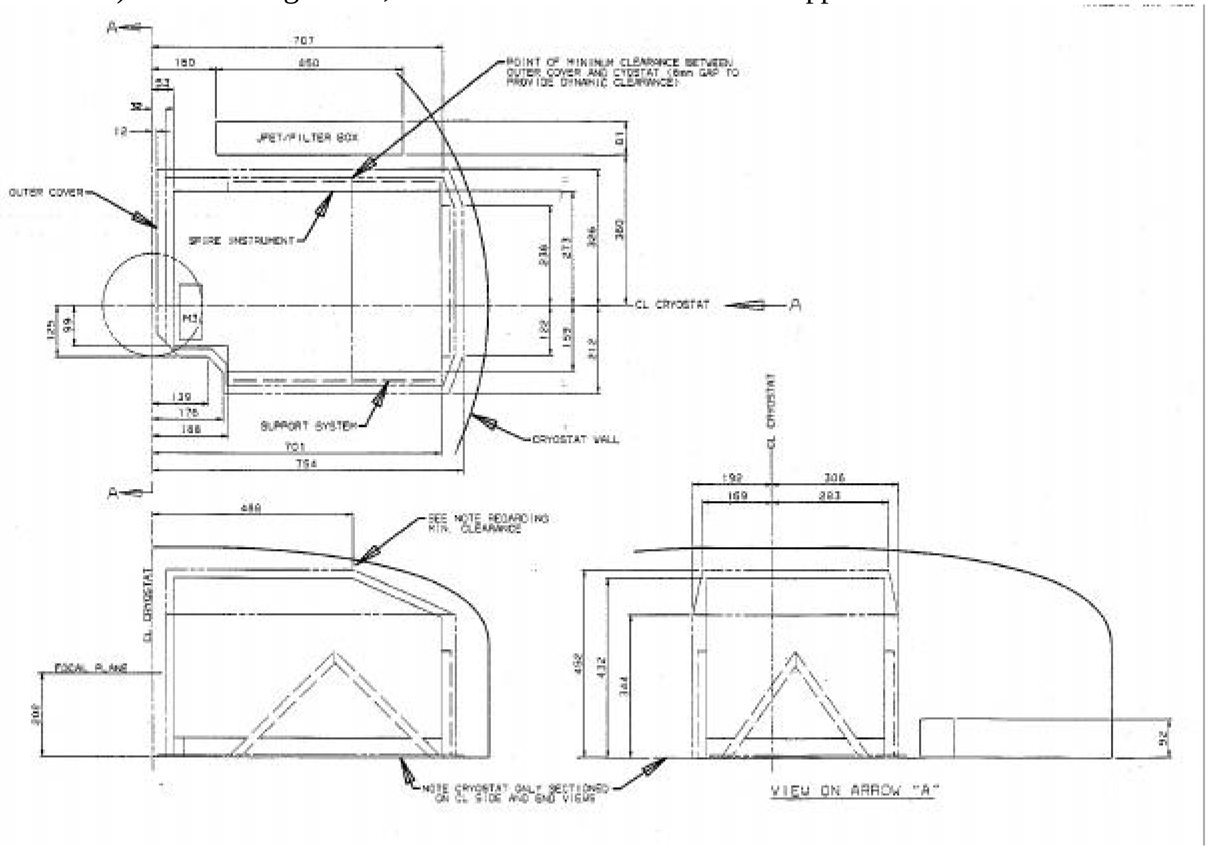


Fig 4.2-1: SPIRE FPU and JFET/Filter Box outer envelope

Thermal requirements:
The SPIRE FPU requires two different temperature levels with level 0 < 2K and level 1 < 6K. The outer envelope of the instrument is at level 1 temperature. Inside the instrument a sorption cooler is operating. There is no temperature requirement for the SPIRE JFET/Filter box.
The SPIRE BAU temperature goal is between 120K and 150K and the dissipation is 2.5 Watt.

At the moment there are three different detector options: The Feedhorn option, the CEA option and the GSFC option. The dissipations at the different levels are given in the following table:

Dissipation	Level 0	Level 1	Level 2
Feedhorn option - Photometer mode - FTS mode	2 mW avg.* 2 mW avg.	4. 1 mW 7.4 mW	33 mW 9.4 mW
CEA option - Photometer mode - FTS mode	5 mW + 2mW avg. 3 mW + 2mW avg.	4.1 mW 7.4 mW	0 0
GSFC option - Photometer mode - FTS mode	0.5 mW + 2mW avg. 0.2 mW + 2mW avg	4.1 mW 7.4 mW	0 0

* 2 mW avg is for all options the average cooler dissipation assuming it is being recycled every 48hrs.

Electrical requirements:
All wires from the FPU to the outside of the cryostat are routed via the JFET/Filter box. The harness is subdivided into a harness for housekeeping and mechanism control which is independent of the options and which is routed from the JFET/Filter box via the CVV connectors directly to the SVM (180 wires/39 shields). The detector signal and control harness which is different for the above options is routed from the JFET/Filter box via the CVV connectors to the BAU. Finally the BAU is connected to the SVM.

SPIRE detector harness to BAU	Number of shields/ wires	Resistance
Feedhorn Option	1116 / 77	≤ 1000 Ohm
CEA Option	594 / 60	≤ 1000 Ohm
GSFC option	633 / 26	≤ 70.2 Ohm (tbc)

For the GSFC option no co-ax cables are required, shielded cables are sufficent.

Optical requirements:
The FPU uses only part of the 260 mm diameter telescope beam area. The beam shape has been given for different distances from the focus. The following figure 4.2-2 shows the SPIRE beam at a distance of 385 mm from the focus in the +x –direction (from SPIRE-RAL-NOT-000301).

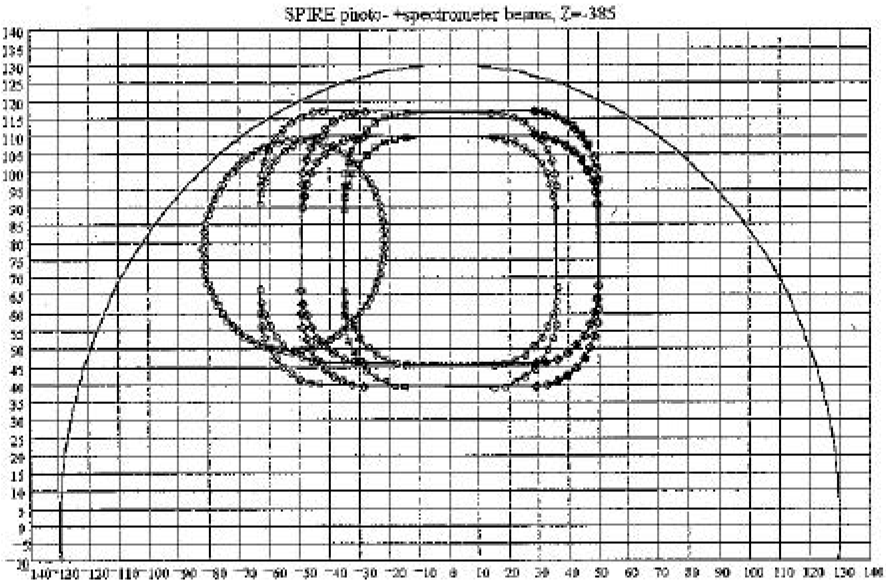


Fig. 4.2-2: SPIRE beam shape at x = 385 mm from focus (from SPIRE-RAL-NOT-000301)

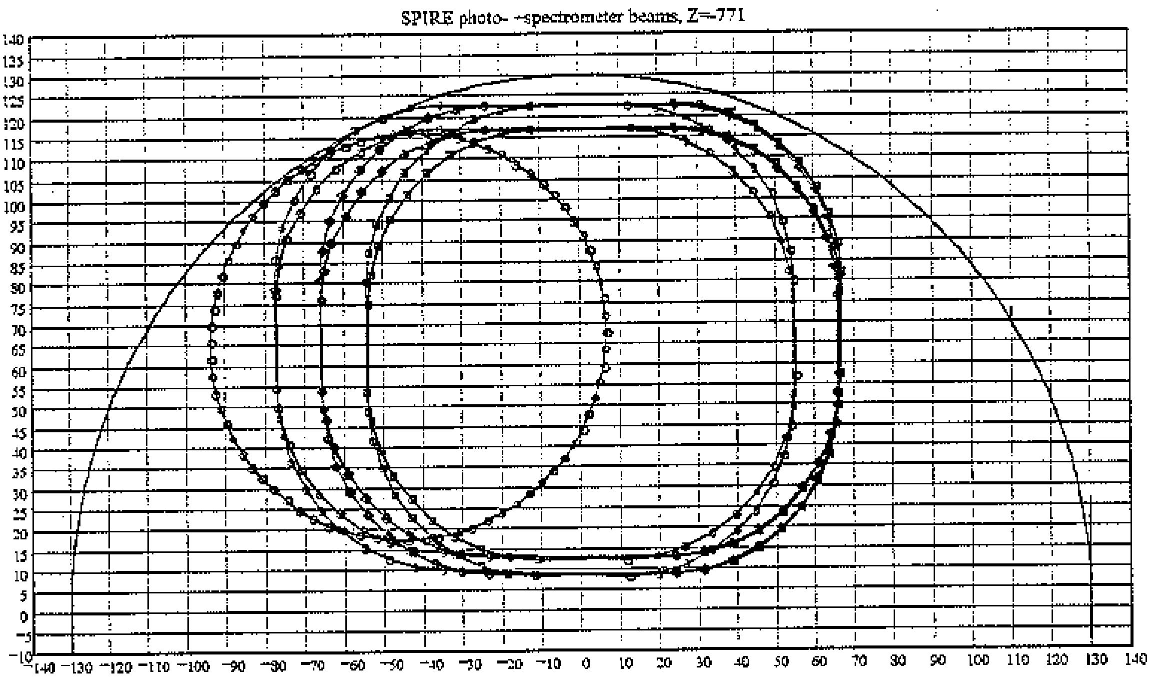


Fig. 4.2-2: SPIRE beam shape at x = 771mm from focus (from SPIRE-RAL-NOT-000301)

Alignment requirements:

FPU: Instrument adjustment in the focal plane w.r.t OB: axis 8 arcmin, lateral 3 mm (from FIRST Alignment Plan PT-PL-02220)

JFET/Filter Box and BAU: No alignment requirement

PACS:

The PACS FPU outer dimensions are 920 x 745 x 460 mm, the mass used in this study is 48 kg (latest information: further increase further to 57 kg). The FPU is mechanically mounted, but thermally insulated from the OB by 6 CFC-struts.

Fig. 4.2-3 shows the food-print of the FPU, Fig. 4.2-4 a 3D-view of the outer envelope.

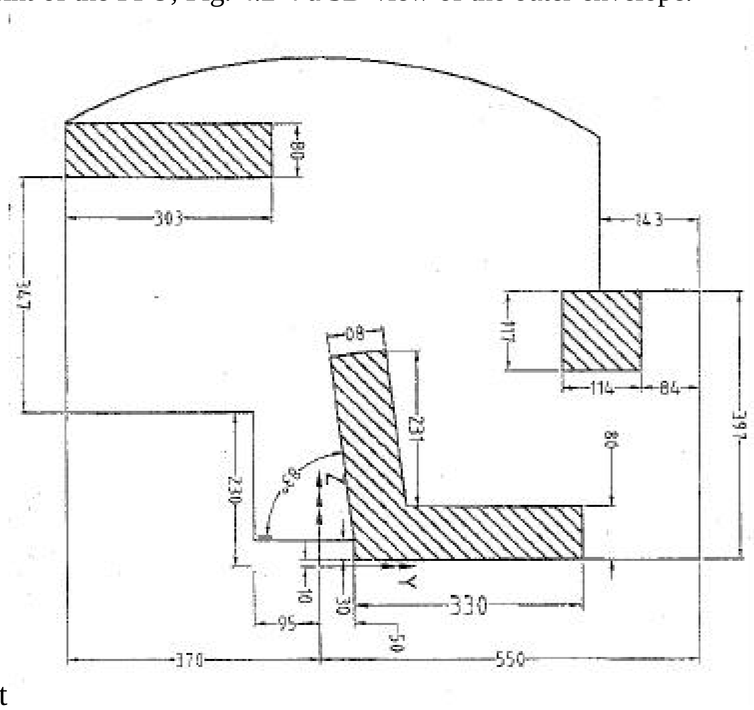


Fig. 4.2-3 PACS Foodprint

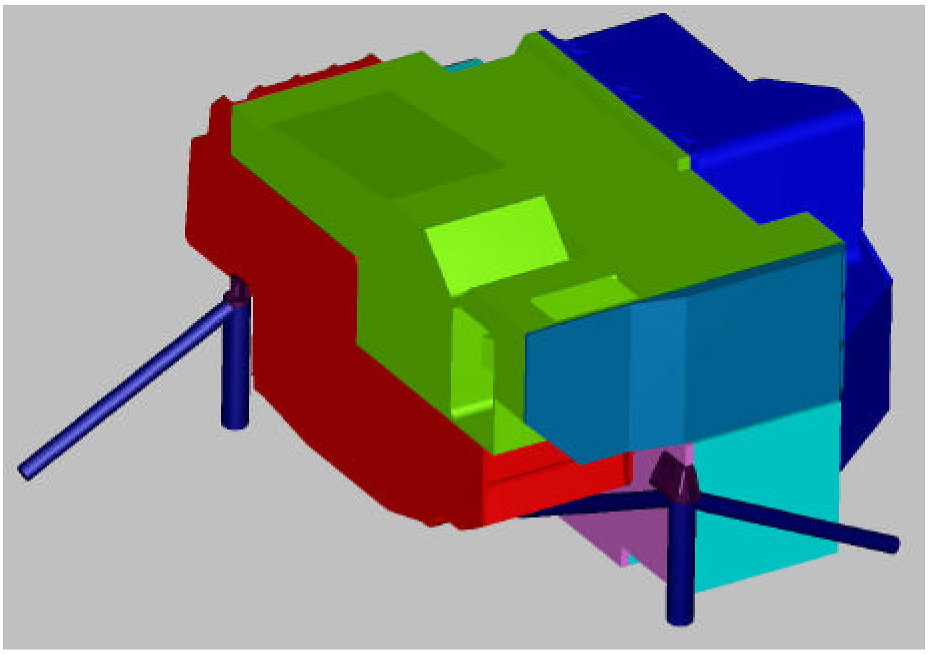


Fig. 4.2-4 PACS 3D-view

Thermal requirements:
Three temperature levels are required for PACS: level 0 at < 1.75K, level 1 at < 4.3K and level 2 < 15K. Inside the FPU there are insulated parts which are at level 0 and at level 2 temperature, the main part of the instrument is at level 1 temperature.

dissipation	Level 0	Level 1	Level 2
	0.5 mW	7.9 mW	7.4 mW

Electrical requirements:
The PACS harness is routed from the instrument connectors (at level 1 temperature) via the connectors at the OB bracket and the CVV connectors to the SVM. In total 686 wires with 175 shields are needed .

Optical requirements:
Also the PACS instrument uses only a part of the 260mm diameter telescope beam. The beam fits into a circle of radius 107 mm at a distance of 385 mm above the focus. Oversizing of the aperture (5 mm estimation) is required to avoid diffraction losses is required and in addition for relative alignment margin between telescope and FPU.

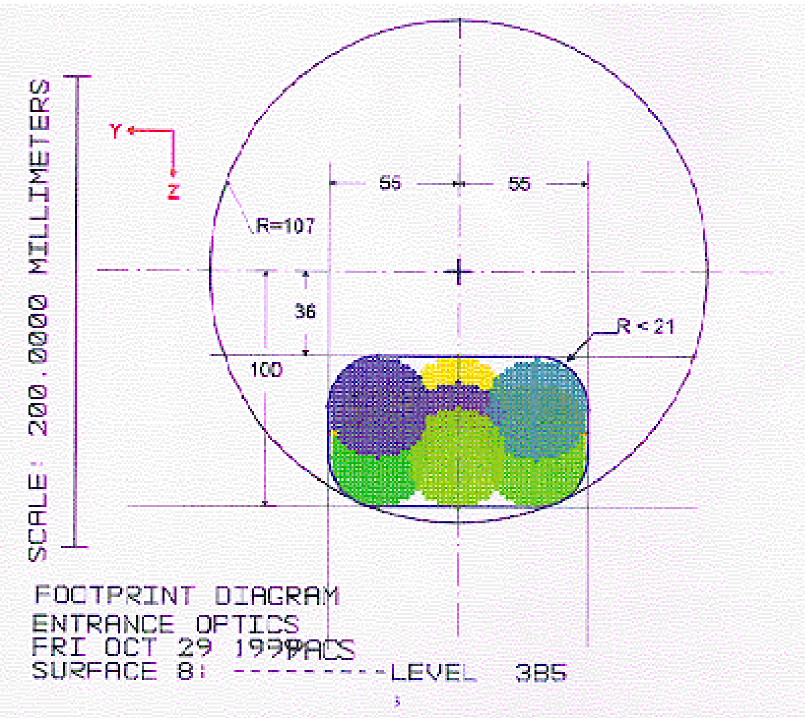


Fig. 4.2-2a: PACS beam shape at x = 385 mm from focus (from PACS-ME-TN-005 draft 01)

Alignment requirements:

Instrument adjustment in the focal plane w.r.t OB: axis 8 arcmin, lateral 3 mm (from FIRST Alignment Plan PT-PL-02220)

HIFI:
The HIFI FPU outer dimensions are 647 x 489 x 460 mm, the mass used in the study is 48.3 kg (latest information further increase to 50 kg). The instrument is mounted directly on 3 feet to the OB. The HIFI LOU has outer dimensions of 440 x 357 x 220 mm and is mounted on a support structure on the CVV. The mass used in this study is 13 kg including a radiator panel.

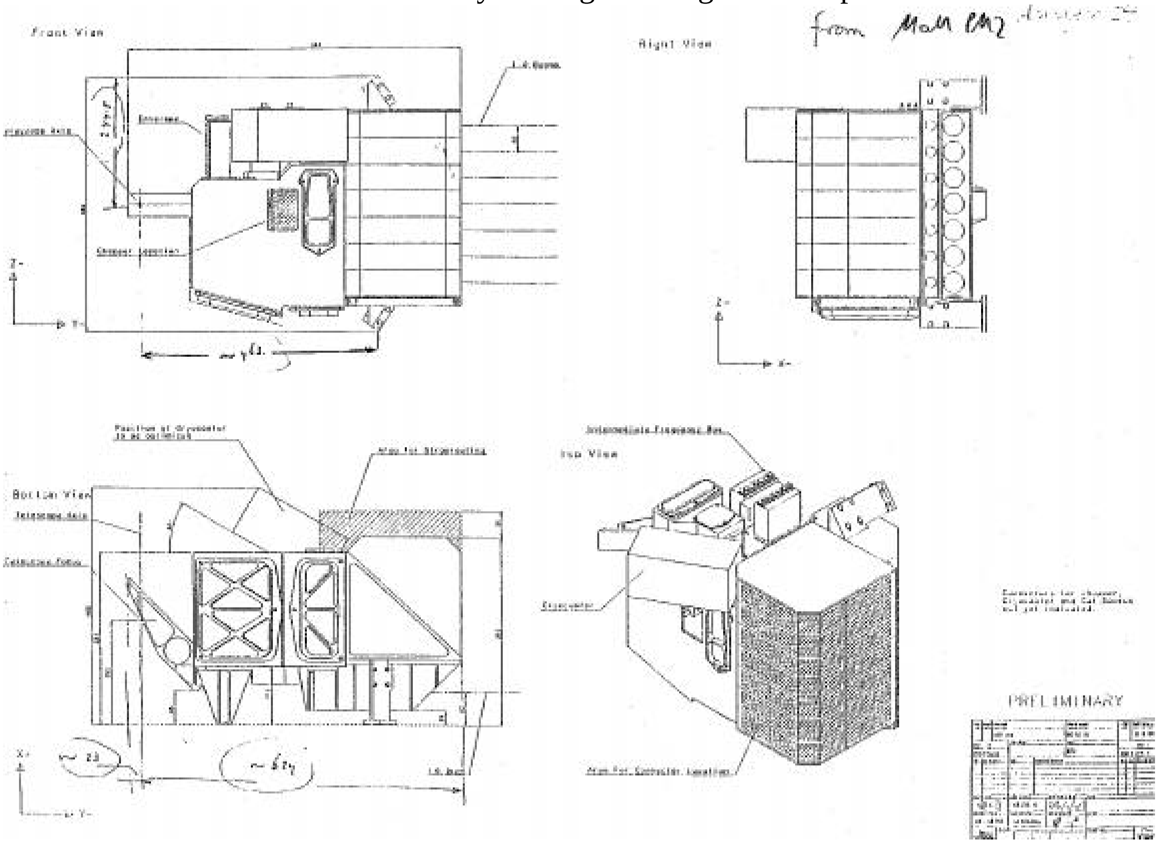


Fig. 4.2-5: HIFI outer envelope

Thermal requirements:
Three temperature levels are required: level 0 at < 2K, level 1 at < 6K and level 2 at < 20K. The outer envelope of HIFI is coupled to level 2 temperature.

dissipation	Level 0	Level 1	Level 2
	2.4 mW avg.	0.8 mW	26 mW

The LO temperature goal assumed in this study was 120K for the Multiplier of the LOU with 1 Watt dissipation and 200K for the Amplifier with 12 W dissipation.

Electrical requirements:
The HIFI harness investigated has 554 wires/ 9 shields including 4 coax wires. It is routed from the FPU connectors (at level 2 temperature) via the CVV connectors to the SVM.
An updated and more detailed harness table has been received close to the end of the study. The number of shields/wires is now 634 wires / 27 shields including the 4 co-ax wires.
The LO is directly connected with the SVM.

Optical requirements:
The part of the telescope beam which HIFI is using is in the center, shifted to the –y-side.

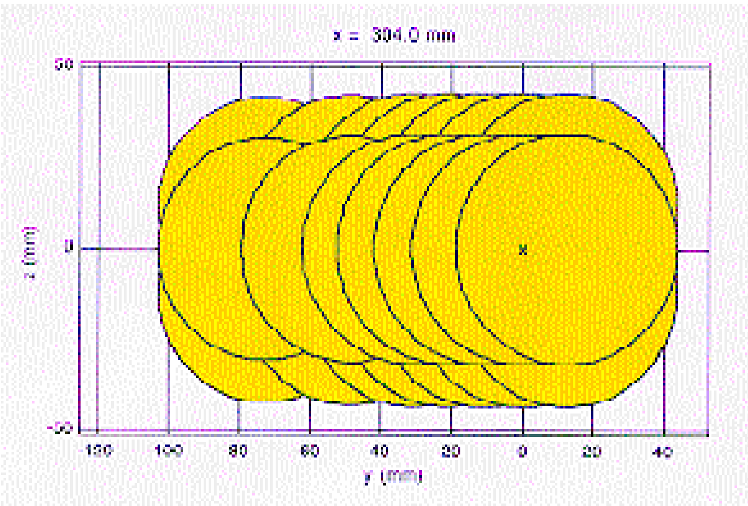


Fig. 4.2-5a: HIFI beam shape at x = 304 mm from focus (from e-mail to ESTEC from N. Whyborn 03. Nov.1999)

Alignment requirements:
Instrument adjustment in the focal plane w.r.t OB: axis 8 arcmin, lateral 3 mm (from FIRST Alignment Plan PT-PL-02220);
Between LOU and FPU: The alignment requirement in x and z-direction has been changed from 0.8 mm to 0.66 mm at the end of the study.

Alignment w.r.t FPU (x, y, z, Θx,Θy,Θz)	±0.66 mm, ± 70 mm, ±0.66mm, ± 0.03°, ± 0.38°, ± 0.03°
Align.stability w.r.t FPU/100s (x, y, z, Θx,Θy,Θz)	±0.066mm, ± 0.002mm, ± 0.066mm, ± 0.003°, ±0.04°, ± 0.003°

The total transmission of window and filter has been changed from 0.9 per item (window, filter) to 0.8 in total.

5. Instrument Accomodation

5.1 FPUs on Optical bench

The three cold instruments, as described in the chapter before, have been arranged on the Optical Bench.

The following figure 5.1-1 gives an overview on the design activities performed on the Optical Bench:

- Adaptation of instrument volumes (SPIRE FPU and JFET/Filter Box, PACS FPU, HIFI FPU)
- Implementation of a baffle for the entrance beams of LO
- Update of electrical I/F
- Update of thermal interfaces
- Update of OB size and required area for OB mounting to SFWK

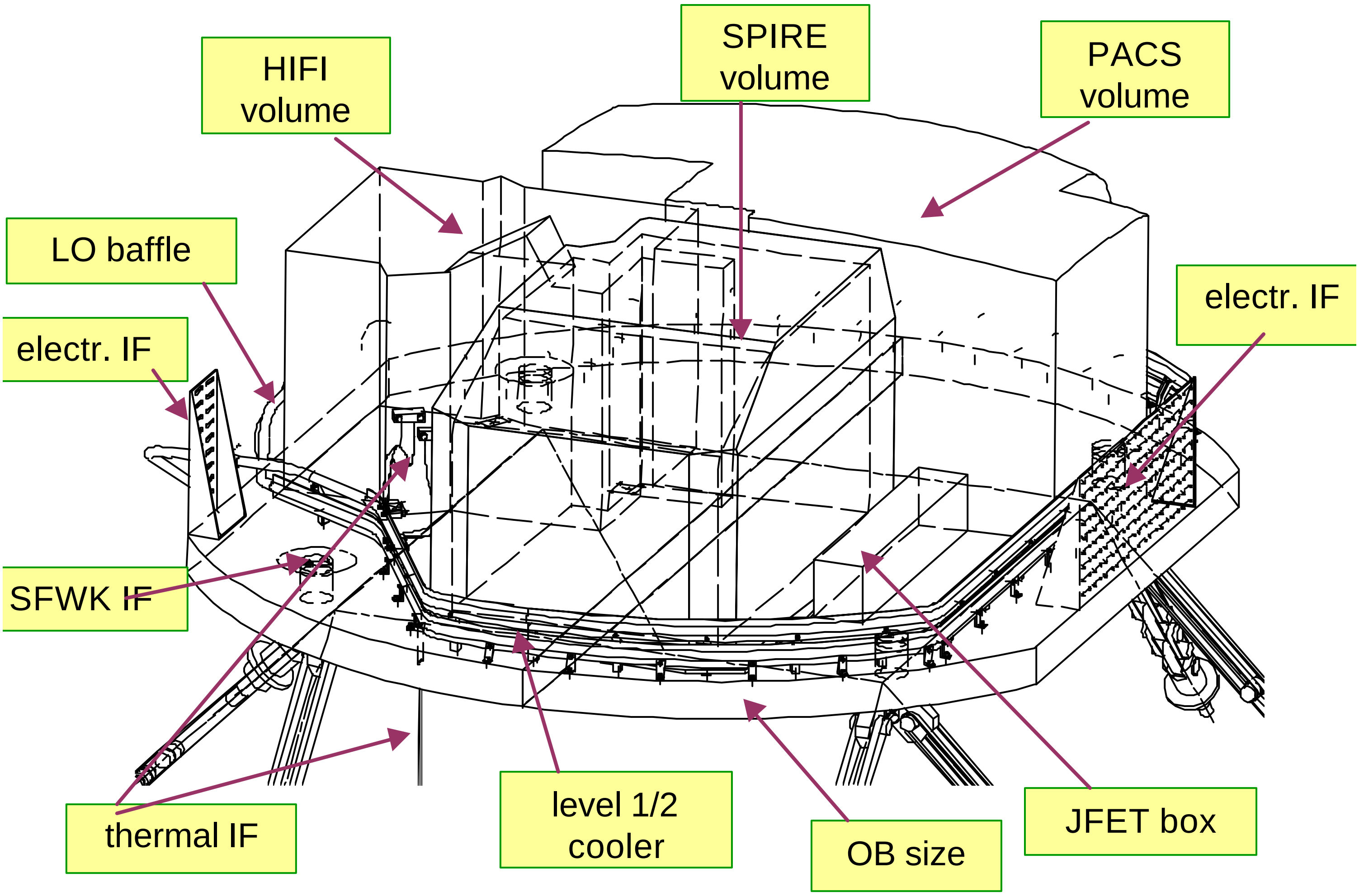


Fig. 5.1-1: Arrangement of FPU´s – overall view

Mechanical Interfaces:

The following figures 5.1-2, 5.1-3 and 5.1-4 shows the arrangement of the FPUs on the Optical Bench. Due to the increased instrument volume the area of the OB has been increased.
The volume shown for PACS is a maximum outer envelope, the area for mounting of this instrument to the OB is indicated. The HIFI FPU has a irregular shape. Since no design model of this instrument has been made available, the envelope has been determined/estimated from the external drawings (see chapter 4.2, which does not include all necessary dimensions) and is given below. There is a collision especially between HIFI and SPIRE using the HIFI envelope, but following mutual agreement between the instrument teams a minimum distance of 10 mm will be kept (see also MoM PM2 23.11.1999). Also the distance between HIFI and PACS is critical and has to be verified. The SPIRE JFET/Filter box position is tbd. It is agreed with SPIRE to leave the area for the mounting interface of the OB to the SFWK free (120 mm dia. and accessibility from top).

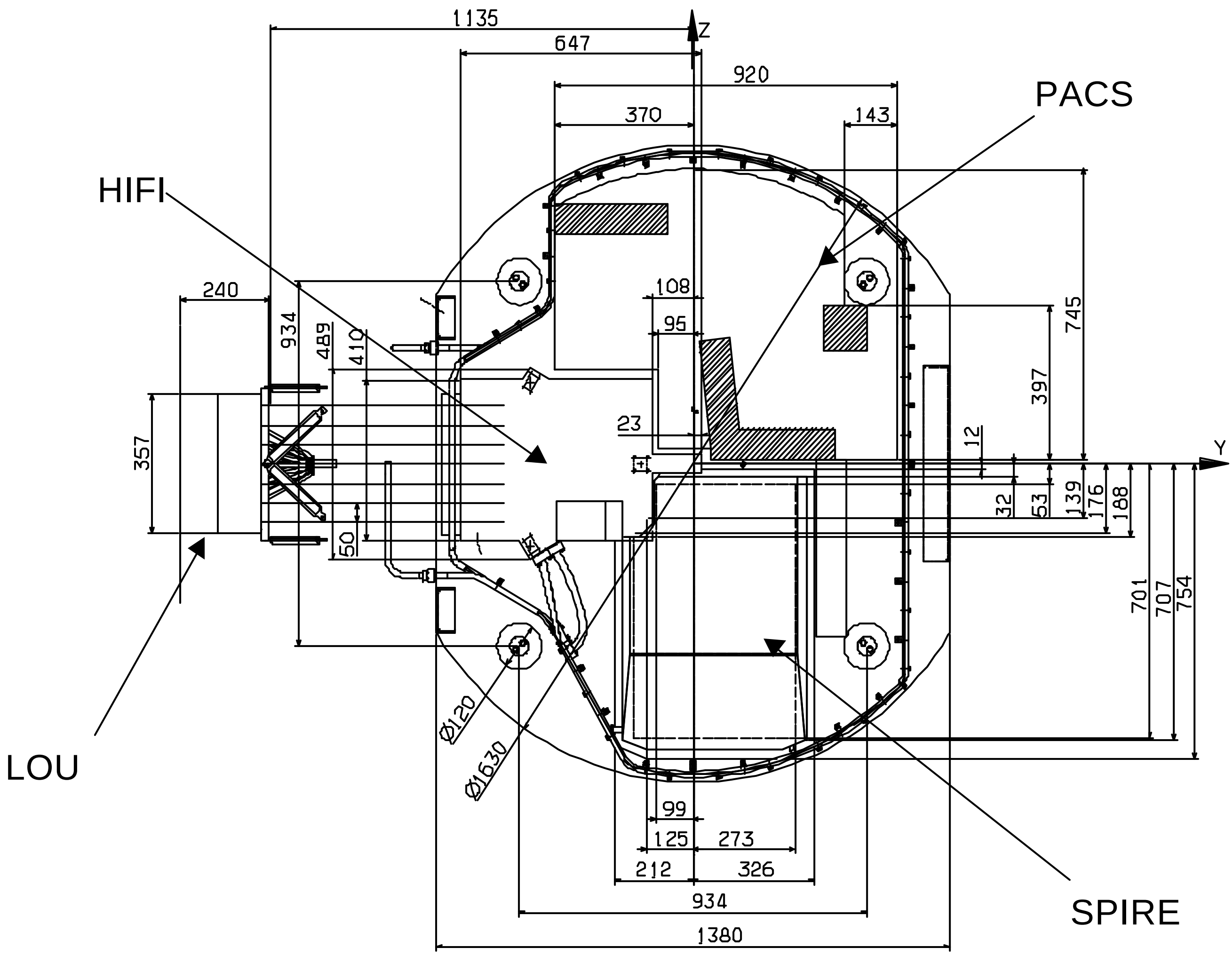


Fig. 5.1-2: Arrangement of FPU´s – top view

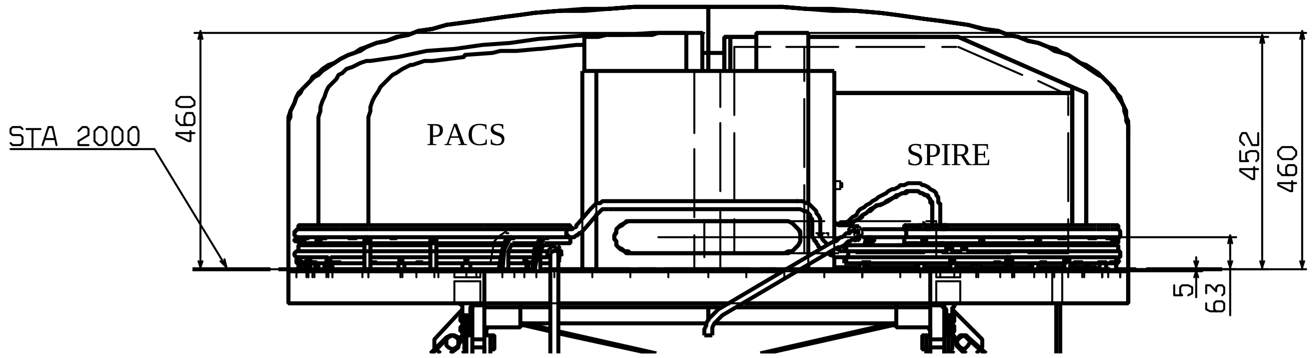


Fig. 5.1-2: Arrangement of FPU´s – side view (from–y-side)

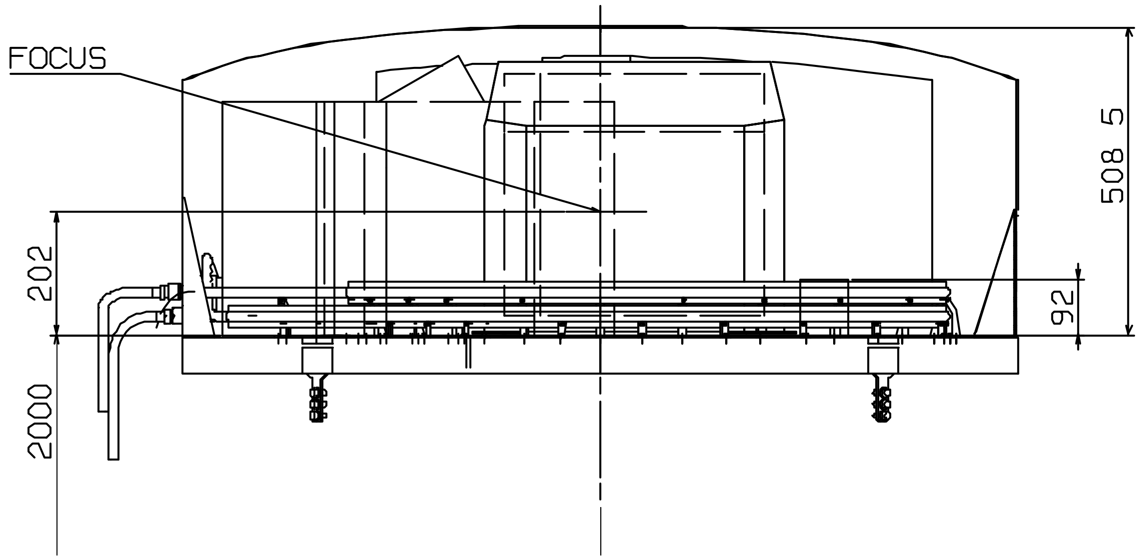


Fig. 5.1-3: Arrangement of FPU´s – side view (from –z-side)

Instrument Fixation on the OB:

- The number of fixation points is different for each instrument: PACS 6, HIFI 3, SPIRE 3, 4 or 8
- Fixation interface is at STA x = 2000 mm
- For each instrument one mounting reference hole has to be defined from y =0 and z =0,
- It is recommended to have the reference hole as close as possible to the center 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 fixation principle shall be similar for all three instruments. It is proposed to provide for all fixation points a central hole ∅ 12 H7 (tbc) and a screw pattern of 4 screws M6 size
- All holes on OB are fixed - no provisions for compensation of thermal displacements. Provisions for alignment adjustment and thermal displacements shall be done on instrument side

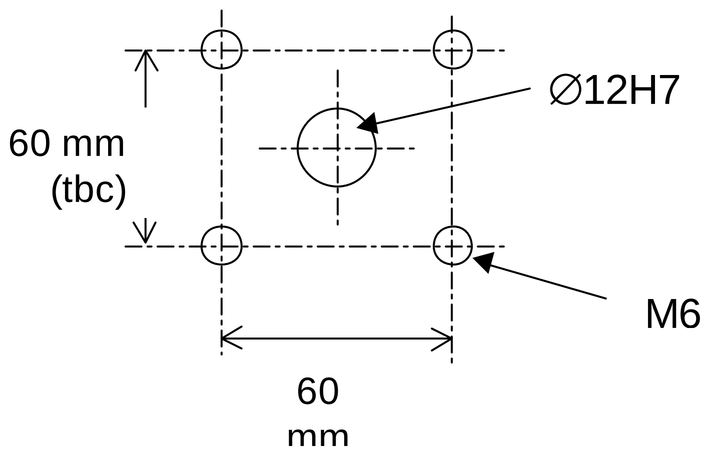


Fig. 5.1-4: Sketch of instrument fixation

- The instruments fixation shall be accessible/ mountable from +X-side
- Each instrument shall be mountable/dismountable without removing another instrument
- No additional forces due to thermal expansions shall be applied to the optical bench, since the preliminary coplanarity requirements of the OB (0.1 mm (tbc) between any two mounting interfaces of all three FPU´s, see IID A) are very stringent. There are different possibilities to avoid any additional forces (e.g. by using struts or sliding bolts).

Thermal interfaces:
During the study it has been decided to replace the wheel-shaped heat-exchanger mounted below the OB by a ventline part running around on the OB. So the ventline is now two times surrounding the instruments and provides the temperature level 1 and 2 to the instruments. The level 0 is provided by direct strapping to the HeII-tank.
For connection of the instruments to the 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 (see figure 5.1-6) is proposed. The strap to the HeII-tank (level 0) is routed through holes in the Optical Bench.
To keep a small temperature difference between the instrument and the He-gas in the ventline, 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.
One strap per instrument and temperature level is foreseen.

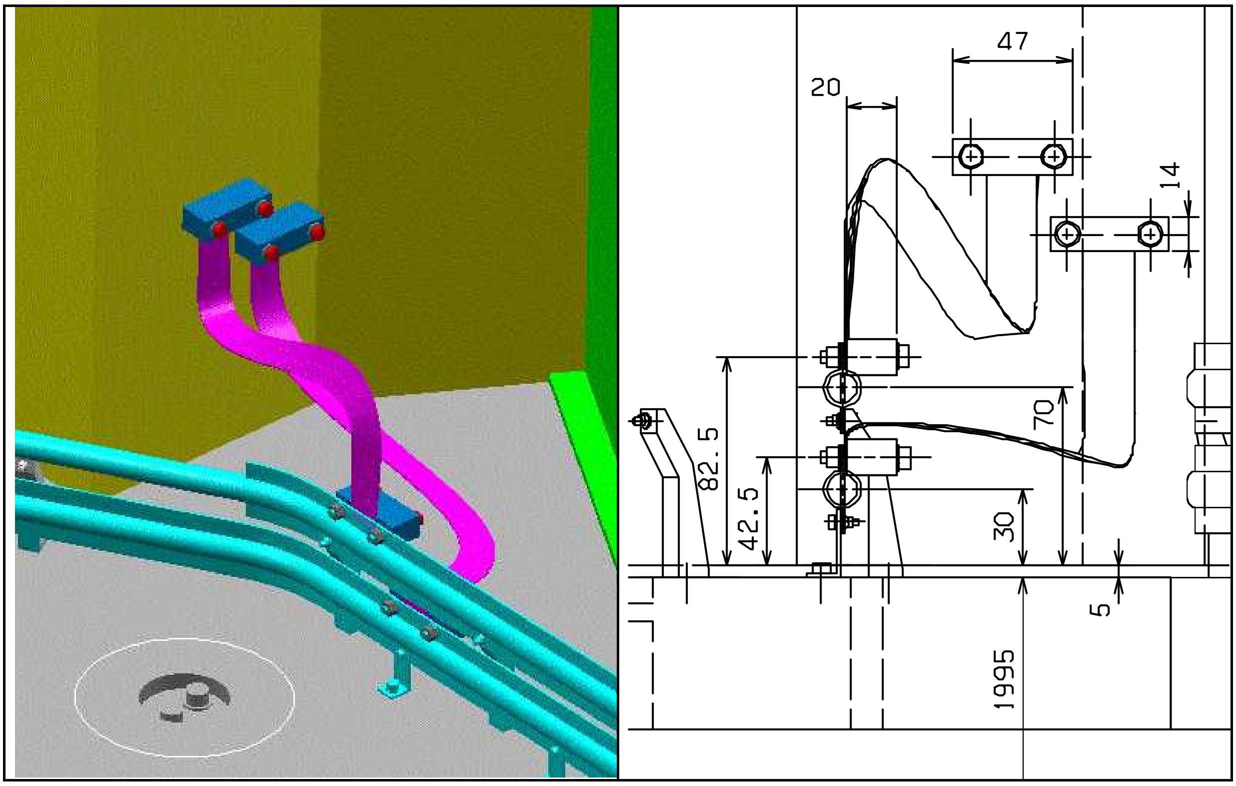


Fig. 5.1-5: Connection of instruments to He-ventline (level 1 and level 2)

ITEM	DESIGNATION	MATERIAL
01	STM TELESCOPE + FPA ASSEMBLY	
02	TANK STRAP FIXAT. INSULATING BRACK.	VESPEL SPL
03	OBS COOLING STRAP FIXAT. BRACKET	EZ6 NCT 25
05	EXPERIMENT THERMAL STRAP (20 X L)	
06	EXPERIMENT TANK THERMAL STRAP	
07	INSULATING WASHER (DIAM 8X4.1XEP1)	FIBER GLASS
08	SCREW TYPE A-SAT SILVERED	EZ6NCT25
09	SCREW TYPE A-SAT SILVERED	EZ6NCT25
10	WASHER (EP 0.8)	Z2CN18-10
11	GROUPLEX WASHER	Z6CN18-09

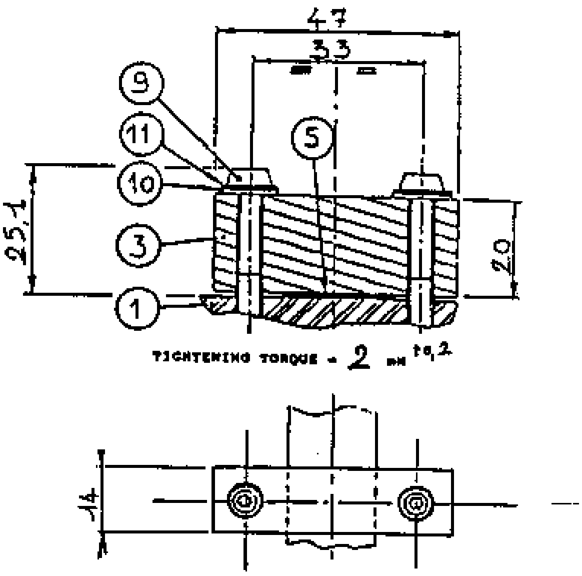


Fig. 5.1 - 6: Standard ISO mounting concept

Electrical Interfaces (Harness on OB between instruments and connector brackets)

Each instrument has its connector bracket on the Optical Bench. For the HIFI instrument two small brackets might be situated on both sides of the instrument (together 40 connectors, 37 pins), for PACS and SPIRE a common bracket might be possible (90 connectors, 37 pins). The harnesses of the three instruments are very different.
The electrical I/F of the HIFI and the SPIRE JFET/Filter box are at a similar temperature as the connector brackets and so a conventional technology can be used (tbc). Most of the HIFI connectors are situated on the –y-side and on top of the instrument.
All SPIRE wires are routed via the JFET/Filter box. The harness from SPIRE FPU to JFET/Filter box is instrument internal. The SPIRE connectors are on the +y –side of this JFET/Filter box, the position of the box is tbd.
The electrical I/F of the PACS harness is at the cold instrument box and a harness technology to minimize the heatload from the connector bracket to the instrument box has to be used. The position of the PACS instrument connectors is tbd.

The harness length to be considered between instrument and connector bracket is between 0.3 m and about 1 m depending on the location of the connectors. The position of the connectors at the instrument box and at the connector bracket has to be defined carefully with respect to distances to the common instrument shield (e.g. on HIFI –y-side), between instrument and connector bracket and between instrument and He-ventline (PACS and SPIRE on + y-side). The minimum space required on the instrument connector frontside for the mounted harness connector is 50 mm (clearance between FPU envelope and instrument shield), the same is valid on the connector bracket side. Additional space has to be provided for mounting/ dismounting of the connectors. The distance between PACS instrument maximum envelope (if it is used and connectors are situated there) and connector bracket as shown in fig. 5.1-2 is not sufficient. The connector bracket area directly above the OB (about 80 mm) has to be kept free due to the ventline arrangement.

Details of the harness connector bracket – CVV are described in the chapter cryostat design.

Optical interfaces:

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 5.1-7. Taking into account additionally some 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 heatshield 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 diameter opening (approximately 4 mm), the other two beams have more distance. Fig 5.1-7 a shows the implementation of this baffle in the TMM.

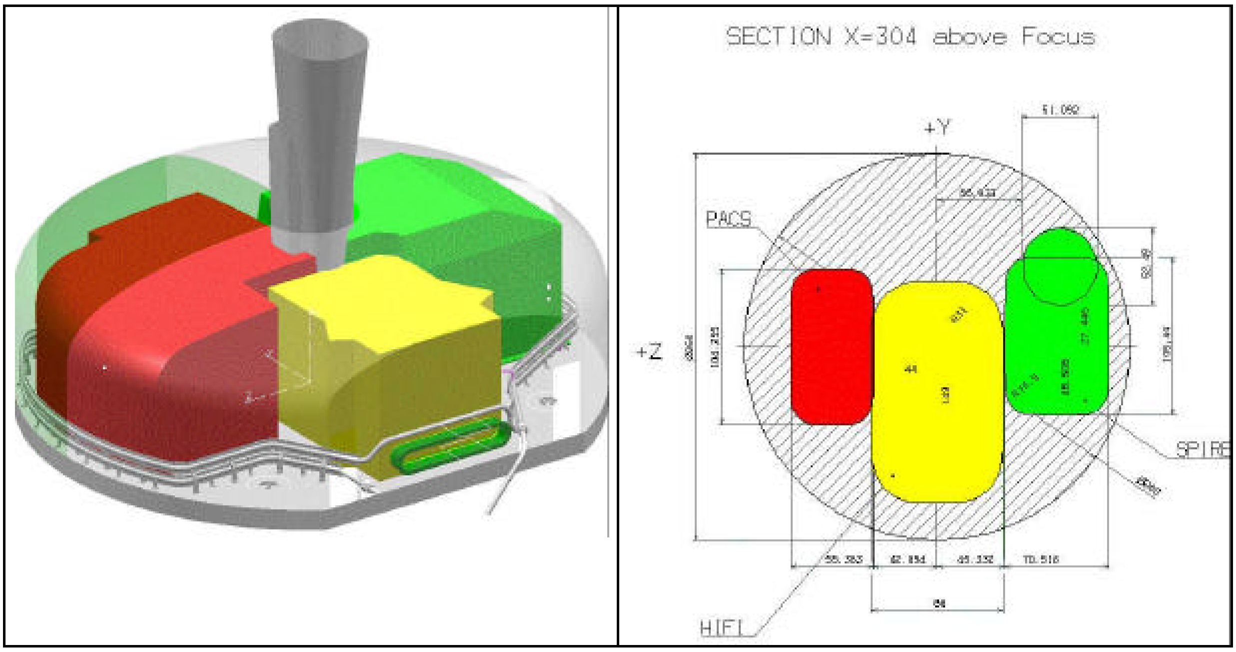


Fig. 5.1-7 : Beam Pattern for the three instruments

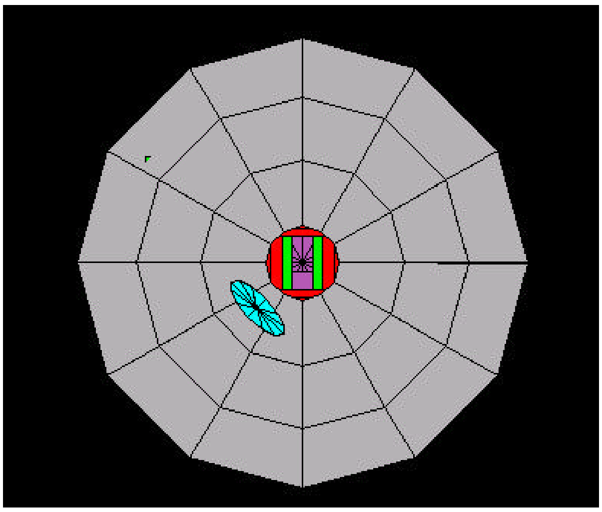
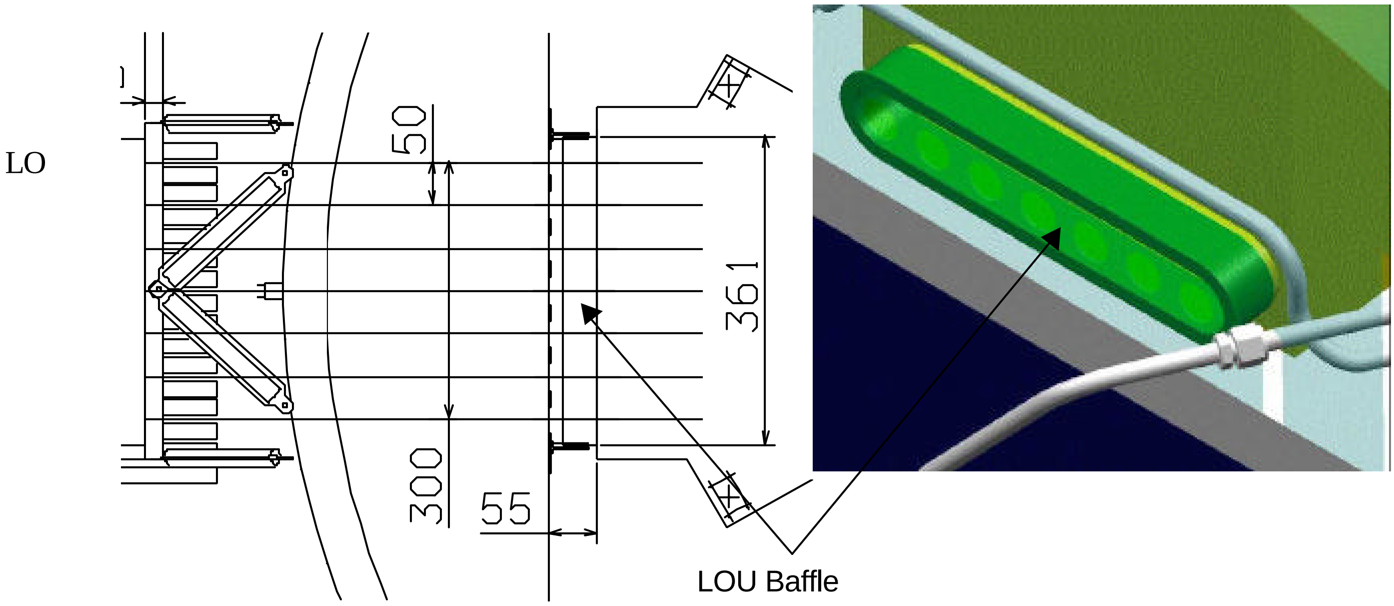


Fig. 5.1-7a Top view in the TMM on the CVV opening and the rectangular baffle on the instrument shield

The straylight analysis has to be updated using the actual optical design of the instruments.

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 be consisting of two parts, one mounted to the HIFI instrument and one mounted to the instrument shield, overlapping each other to generate a labyrinth.



5.2 Local Oscillator

The Local Osciallator provides the HIFI FPU with seven reference signal beams which are coupled via vacuum feedthroughs into the CVV. The fig. 5.2-1 shows the fixation of the unit. The LO is mounted on a baseplate which is fixed with eight GFC struts to the CVV. The LO consists internal of two parts which are operating at different temperatures. Each part is equipped with a radiator which allows to radiate most of the internal dissipation to space. The LO box is wrapped into MLI.
For a structural model of the LO mounting plate and fixation see chapter 7-1. For results of the thermal analyses see chapter 7-2. For alignment of LO see chapter 6- 2.

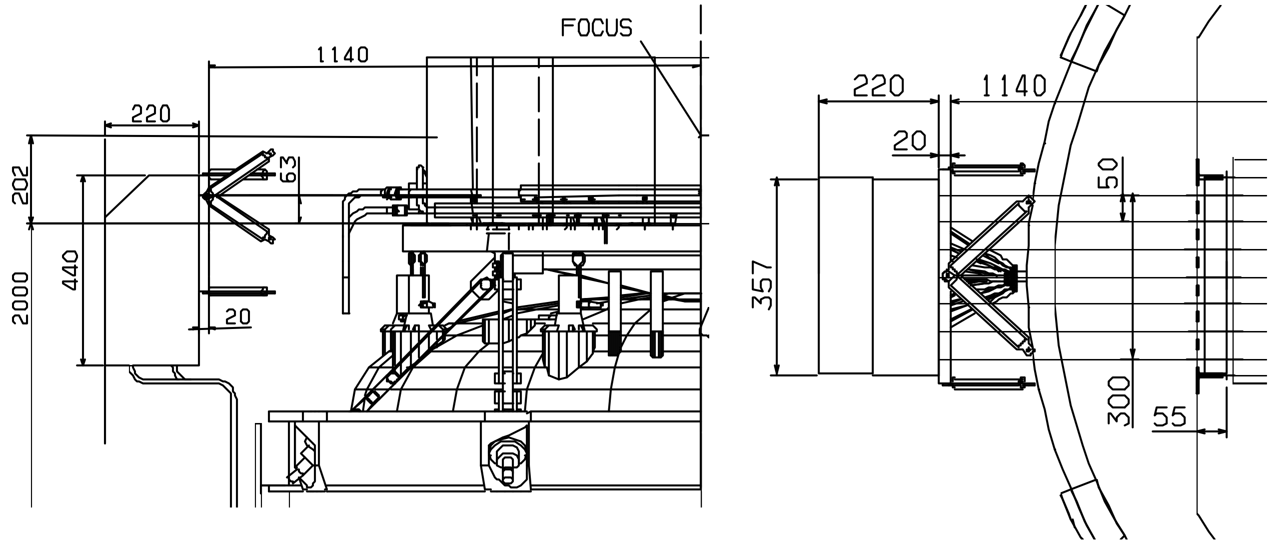


Fig. 5.2-1: LO Installation Layout

The LO is connected with the warm electronics in the SVM via 14 waveguides and the LO-SVM harness. The waveguides (WR-26) are bundled together below the level of the OB. They are mechanically fixed, but thermally insulated, to the CVV and routed down along the CVV and then via the PLM/SVM struts to the warm electronic in the SVM. To reduce shadowing of the CVV radiator they might be fixed in a position slightly shifted in +z-direction on the CVV.
To compensate the differential thermal expansion and the movements during the vibration the waveguides shall be equipped with flexible elements. The material and size/thickness of the waveguides are important for the heatinput on the CVV. The thermal impact of Al and SST waveguides have been investigated (see chapter also 7-2). Thin SST waveguides show lowest impact on cryostat.

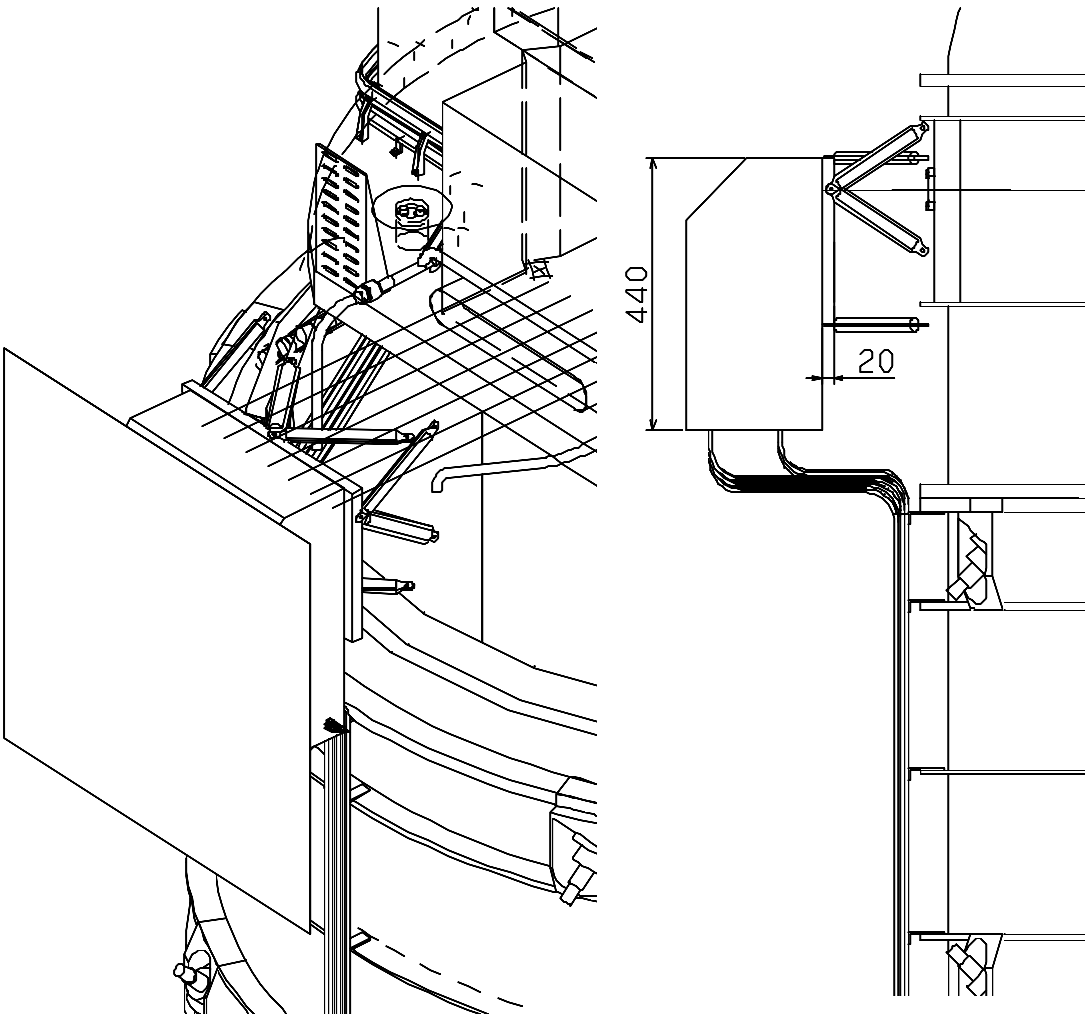


Fig. 5.2-2: LO waveguide routing and fixation

For the seven LO beams seven flanges for mounting of the windows are foreseen (see figure 5.2-3). 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.

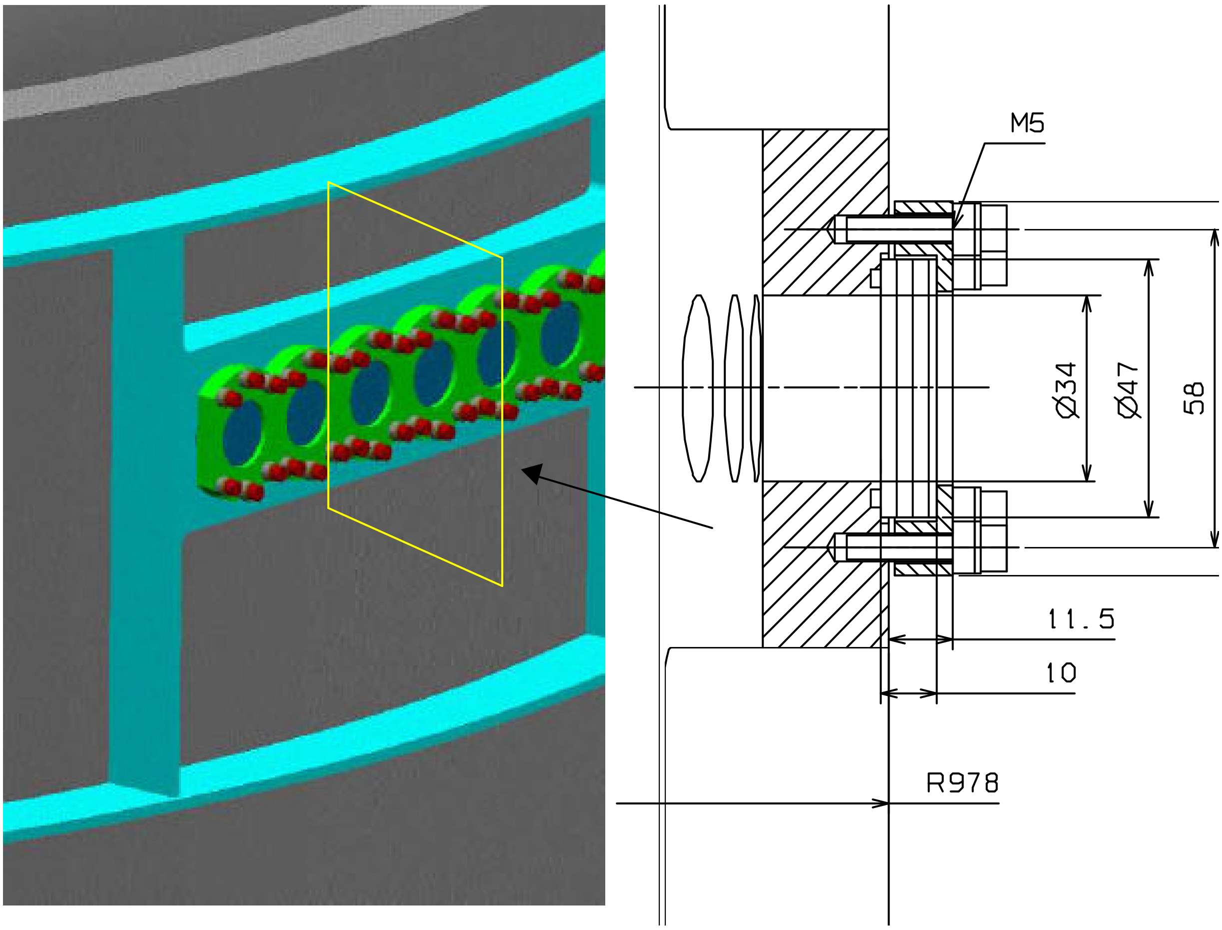


Fig. 5.2-3: LO vaccum feedthroughs

LO feedtroughs- transmission:

The HIFI Instrument is a heterodyne receiver using a so called Local Oscillator as a very stable monochromatic signal reference in order to translate the passband 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 and therefore requires optical coupling through the cryostat vessel and the inside cryostat thermal shields 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 Channels 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 window and per heat filter
- Optically free diameter ≥ 30 mm

Based on the above requirements actually there are two design possibilities to build up 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. The following list describes the main design features:

Design Possibility 1:

- **one quartz window** in outer cryostat vessel (about 80K in orbit) and **a second quartz window** at one inner shield (about 30K in orbit)
- use of poly-ethylene anti-reflection coatings on quartz
- inner quartz window with heat filter
- usable diameter = 30 mm
- windows are wedged and tilted by 2° (according to FIRST IID, PT-HIFI-02125)

Design Possibility 2:

- **one quartz window** in outer cryostat vessel (about 80K in orbit) plus **one mesh filter*** on the inner side (30K in orbit)
- use of poly-ethylene anti-reflection coatings on quartz window
- mesh filter as a heat filter
- usable diameter = 30 mm
- quartz window and mesh filter are tilted by 2° , quartz window is wedged (according to FIRST IID, PT-HIFI-02125)

Both above described techniques to build up the LOU optical channels have finally to be verified for their performance and their 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.

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 wavelenth of 2700 GHz has been selected, because it is the upper frequency edge of the LOU wavelenth bands and therefore covers the worst case condition in this consideration:

Temperature	T (ordinary direction)	T (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.

Each quartz window requires anti-reflection coating to improve for its optical transmission. Ideal minimum transmission losses have been calculated at the edges of an $\lambda/4$ coating optimized for each LOU channel. Based on optical experience further transmission losses have been roughly estimated and presented summed up in the following table:

Transmission budget of window in outer cryostat vessel
quartz window with polyproplene anti-reflection coating

	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 ?/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%**

For window temperature at 80K

Assuming in 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**
	1 quartz window + 1 quartz filter	1 quartz window +1 mesh filter
Window in cryostat outer vessel	88%	88%
Heat filter	88%	95%
Total	**77%**	**83%**

The required optical transmission performance for the LOU was changed during the study from 0.9 per element (window, filter) to 0.8 for the LOU channel (e.g. one quartz window combined with one inside heat filter).

Because of the uncertainties in the estimation described above both the design possibilities 1 and 2 seem to work and therefore shall be considered as a promising candidates.

5.3 Buffer Amplifier Unit

For the Buffer Amplifier Unit (BAU) the same fixation as for the Local Oscillator is used. The size of the baseplate is 400 x 400 mm, which is mounted with 8 GFC struts to the CVV. The box is fixed at the height of the electrical vacuum feedthroughs, on the +y,-z-side of the cryostat, to achieve the shortest possible length for the FPU to BAU wires (see fig. 5.3-1).
The BAU is wrapped in MLI, its side towards space is equipped with a radiator of 0.2 m² size or used itself as a radiator to space.
For thermal calculations see chapter 7.2, for harness from vacuum connectors to BAU and from BAU to SVM see chapter 6.

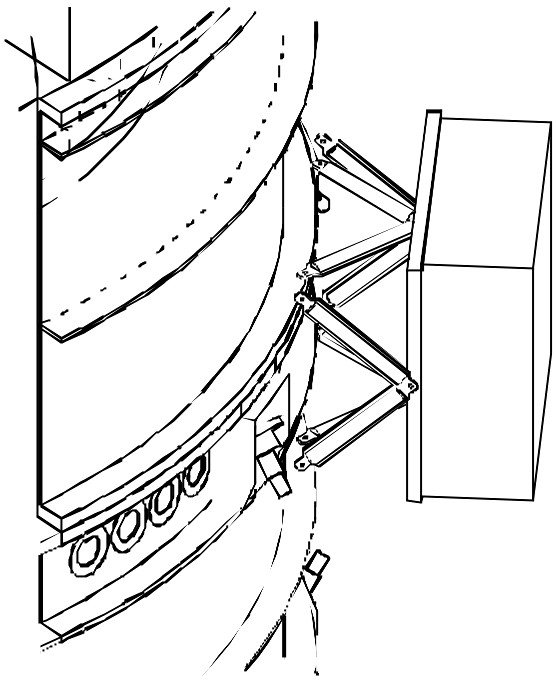
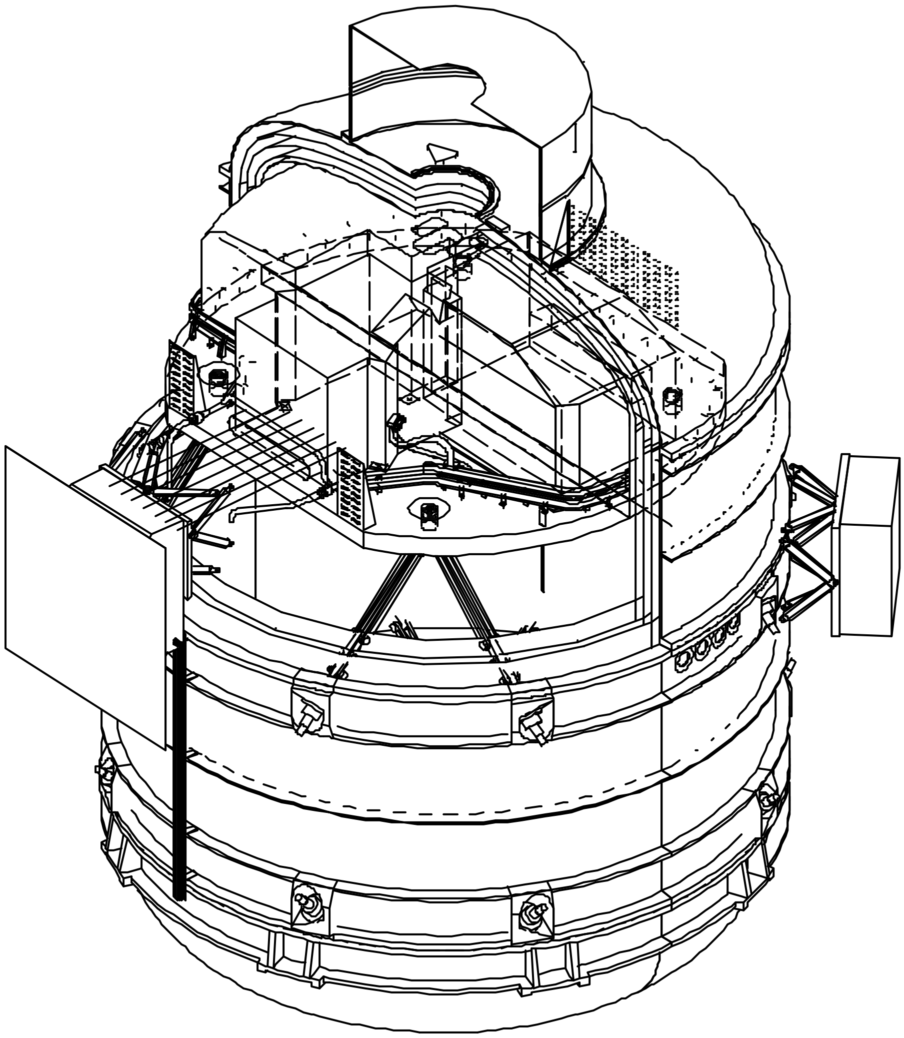


Fig. 5.3-1: Buffer Amplifier Unit Fixation

6. Cryostat Design Update

The principal overall cryostat design from previous studies has been kept. The present configuration is shown in fig. 6-1.



Due to the increased volume of the FPUs, the size of the Optical Bench has been adapted. Based on the structural analysis of the Optical Bench for the highly increased instrument mass different configurations have been considered. As described in more detail in chapter 7-1 the necessary support for the instruments can be provided by a 100 mm thick Al-honeycomb baseplate or a 70 mm thick CFC - honeycomb structure. The increase of OB height has not been included in the PLM overall design.

To reach the PLM eigenfrequency requirements for the increased instrument mass, the tank strap cross-sections have been adapted and also used in the thermal analysis.

6.1 Harness

The harness tables and requirements given in the IID B´s have been analysed.

SPIRE:
The cryo harness from 4.3K to 15K is the instrument internal harness (from FPU to JFET/Filter Box) and not considered further.
The SPIRE cryo harness 15K to 300K housekeeping and mechanism control has some connections with a 10 Ohm requirement. For these cables AWG 30 brass wires have been foreseen.
There are three different options for the detector signals and control harness from 15K instrumet level to BAU at CVV outside.
In terms of thermal impact the GSFC option is considered most critical, since the resistance for each of the 633 wires shall be less than 70.2 Ohm (tbc) and the currents are in the mA range. It has been clarified by SPIRE that there are no coax cables required as mentioned in the IID B, shielded bundles of wires are sufficient. For these cables brass wires (AWG 38) with SST shields have been taken into account. The required capacity of the cables can be fulfilled by the ISO type wires, but the inductivity requirement (2.4E-6 H, tbc) is critical and should be checked by SPIRE.
In terms of number of wires the Horn option is most critical. The 1116 wires/ shields shall be routed with minimum cable length to the BAU. They can be divided and fixed on two tank straps. The principal routing of the harness from the connector brackets on the OB to the vacuum connectors is shown in fig. 6-2. About 14 vacuum connectors are required in a quarter of the CVV circumference. The length from the bracket to the vacuum connectors is between 870 mm and 1400 mm, the length from the CVV connectors to the BAU is about 500 to 1200 mm. The resistance requirement for this option can be fulfilled by SST wires, but the inductivity requirement can not be fulfilled and should be checked by SPIRE.
The SPIRE cryo-harness detector signals and control 100K BAU to 300K is very similar to the `15K to 100K harness´, the number of connections is increased.

For all connections ISO-type cables can be used, the harness is thermally coupled to the heatshield 1.
In the thermal model the following values have been used (according to GSFC option as worst case):
Cross-sections: brass 8.78 mm², SST 18.5 mm², PTFE 222 mm² (incl. 20% margin), for the ohmic dissipation a value of 0.21 mW/m has been used.
This value has been updated at the end of the study to 5.6 mW/m (incl. 20% margin).

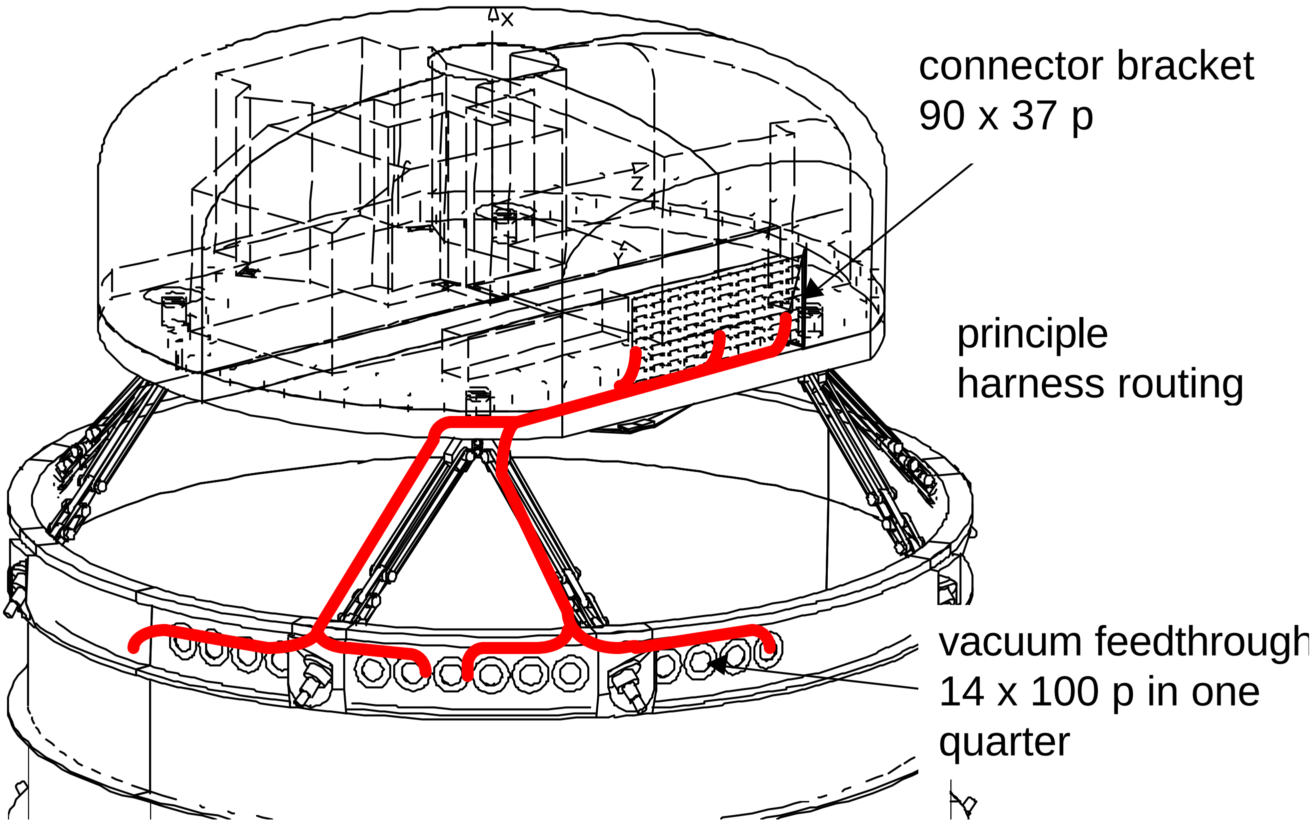


Fig. 6-2: Principle harness routing

PACS:

From the OB connector bracket the PACS harness with 686 wires and 175 shields is routed via the CVV connectors to the warm electronics in the SVM. For the low current signals AWG 38 SST wires shall be used. For a harness length of at least 5m between OB connector bracket and SVM a resistance of 600 Ohm will occur which is slightly above the given values. For the high current wires AWG 30 brass wires have to be taken. For all wires ISO type cables can be used, the cable configuration (number of wires per shields) shall be optimized to reduce not used connections within cables.

In the thermal model the following values have been used:

Cross-sections: brass 4.08 mm², SST 28.8 mm², PTFE 272 mm² (incl. 20% margin), for the ohmic dissipation a value of 7.3 mW/m (incl. 20% margin) has been used.

HIFI:
Close to the end of the study an updated, more detailed harness table with 634 conductors with 27 shields incl. 4 coax-wires (before 554 wires, 9 shields) has been provided by HIFI and has been roughly analysed:
There are 61 connectors on the FPU and 46 connectors on OB bracket. The harness configuration between Instrument and OB bracket is complicate, since the wires of the instrument connectors are each connected with many connectors of the OB bracket (looks like a spider). Wires with identical function from all bands are routed via one connector, this has to be considered w.r.t redundancy concepts.
The defined twisted groups are not compatible with ISO-type wires. For the AWG 38 SST wires a 400 Ω resistance is not compatible (see design rules). Since there are a lot of connections with high currents (e.g. 10mA, 50 mA) and high duty cycles (e.g. 1/7) the total required brass cross-section has been estimated to be increased to 15 mm². The ohmic dissipation is then at about 25 mW/m. It has been understood that the given maximum currents are not final and have to be reconsidered.

In the thermal model the following values have been used:
Cross-sections: brass 0.54 mm², SST 15.2 mm², PTFE 58.7 mm² (incl. 20% margin), for the ohmic dissipation a value of 9.5 mW/m (incl. 20% margin) has been used.
The effect of the increased brass cross-section and ohmic dissipation has been investigated in a sensitivity analysis (see chapter thermal analyses).

The harness between the LO and the SVM consists of 436 + tbd wires with 15 shields. There is a tbd number of wires for the power amplifiers and amplifier returns with currents in the Ampere – range and low resistance requirements of 0.05 Ohm. The duty cycle is small (1/14). These wires are considered critical for thermal impact to the CVV and it might be necessary to route them thermally insulated from the SVM to the LO.

ISO harness technology application for FIRST:

- Increased number of connections for FIRST compared to ISO
- ISO harness technology fully applicable for connectors and wires except vacuum feedthroughs
- The connection technology used for ISO vacuum feedthroughs should not be reused
- The ISO MDM connector technology is not applicable for vacuum feedthroughs with high number of used pins due to spacing
- A technology of soldering the SST wires to the pins is proposed to be used.
  This process has been studied DSS internal and shows good results. To get the technology available a delta qualification is necessary.

General design rules:

- Estimated harness length: Instr. to OB connector bracket between 0.3 m and 1m depending on location of instrument connectors, OB bracket to SVM 5 m
- Harness resistance: AWG 38 SST at ambient 120Ω/m, at cold conditions 85Ω/m
  AWG 38 brass 10Ω/m, AWG 30 brass 1.2 Ω/m
- Estimated resistance from OB bracket via CVV to SVM for SST AWG38:600 Ω
- Instruments shall identify harness bundles to be separated (signal, power)
- Instruments shall identify harness bundles to be separated w.r.t. redundancy for harness routing, OB connectors and low number of CVV connectors; critical connections shall be clearly identified
- Instr. shall provide free areas for fixation and routing of harness on instruments
- Number of diff. cable types shall be limited, ISO cables shall be used as baseline
- The distance between MDM connectors and space for mounting/ dismounting has to be taken into account (e.g. distance Instr./ OB bracket); perfect mounting of harness connector to unit connector has to be ensured (wall thickness);

6.2 Alignment

For the alignment of the FIRST instruments within the FIRST Payload Module (PLM) the following integration and alignment sequence is planned:

1.1 Integration of the **3 FPUs on Optical Bench (OB)** and Alignment to OB reference cube.

1.2 Integration of OB into CVV (w/o upper dome) and **coarse alignment of OB to CVV**.

1.3 Mounting of CVV upper dome and **fine alignment of OB/HIFI to:**
- the 7 LOU-windows - using the two additional LOU/HIFI alignment channels - and
- the CVV reference cube

1.4 **Integration of LOU** on lateral CVV framework and alignment to HIFI **-** using LOU/HIFI alignment channels -

1.5 **Alignment check in cold conditions** using the a.m. LOU/HIFI alignment channels

The present alignment concept is based on using autocollimating theodolite measurements.. The proposed method assumes the following aligment references on Cryostat Vacuum Vessel (CVV), Optical Bench (OB) and Scientific Instruments. The arrangement for the most critical LOU to HIFI alignment task is presented in figure 6-3.

1.) **Optical Bench (OB)**

The OB, forming a common baseplate for the three instruments, incorporates an alignment cube with reticles indicating the OB coordinate axes for instrument to OB alignment and OB to CVV alignment. The cube can even be sighted through the cover window respectively through lateral CVV windows. For OB / HIFI alignment to the LOU-windows the HIFI cubes or flats will be used.

2.) **Instruments (= Focal Plane Units or FPUs)**

Each instrument has to be equipped with an external reference mirror cube (or flats) with reticles representing its optical axis (position and direction). HIFI has to be equipped with two additional alignment mirrors for LOU alignment. For direct focus axial, lateral and axis measurements in warm and cold conditions the FPUs have to incorporate special auxiliary reference mirrors with reference marks. These references can e.g. be inserted into the instrument ray path by wheels or flaps.

3.) **CVV**

The CVV is equipped with two alignment cubes mounted at opposite positions on the circumference of the CVV cylinders upper part. Also they serve as the reference for the later telescope accomodation. The cubes mirror faces indicate the nominal **direction** of the telescopes optical axis. The reticles on the cube faces are located at known positions in CVV coordinates. They serve as references for the wanted **position** of the telescope axis. For fine alignment of OB/HIFI to CVV the LOU alignment windows on the -Y side of the CVV upper dome have to be equipped with reticles in their centers and their autocolli-mation figures should be usable as references.

4.) **CVV Cover**

The **cover window** is arranged such, that the window itself or its flange (equipped with a mirror) can serve as a reference for the CVV coordinate system.

The alignment considerations in this study have been concentrated on the PLM-level alignment tasks by investigating the following subjects:

a.) establish the achievable instrument alignment budget (driver: LOU to HIFI alignment accuracy)

b.) derive the requirement on the optically free LOU-windows size based on the requirement to guarantee an optically free 30mm diameter for the LOU beams in operating conditions

The specified tolerances of LOU to HIFI alignment are:

Xrot	Yrot	Zrot	Xpos	Ypos:	Zpos
± 0.03deg	± 0.38deg	± 0.03deg	± 0.66mm	± 70mm (uncritical)	± 0.66mm

The alignment budget basically consist of:

1. Alignment accuracy of HIFI to LOU-windows (through LOU-alignment windows)
2. Alignment accuracy of LOU to HIFI (through the LOU-alignment windows)
3. Structural deviations (ISO experience)

The details of the corresponding alignment budgets are established in the following tables.

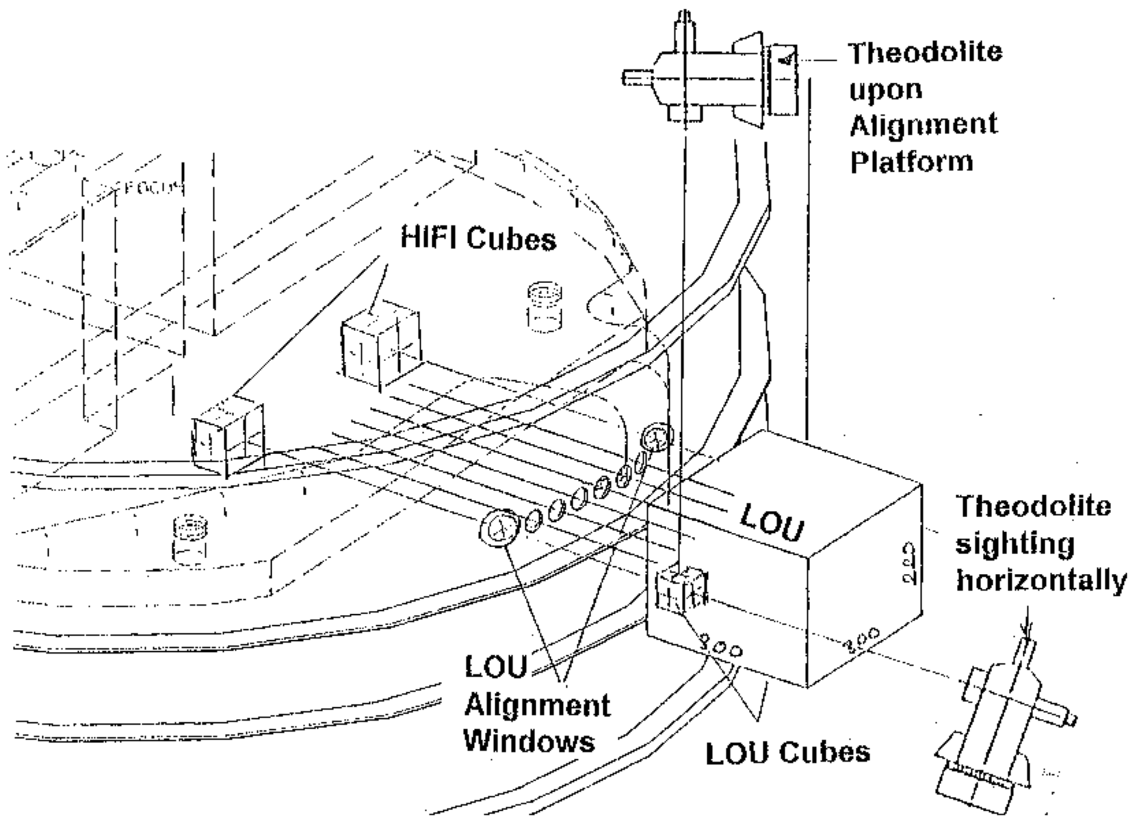


Fig. 6-3: Arrangement for LOU to HIFI Alignment

Alignment accuracy of HIFI to LOU- windows:

(Rotations are measured by autocollimating theodolite to the normals on the 2 LOU-alignment windows, located left and right of the 7 LOU-IR windows. Positions are measured relative to reticles on these alignment windows).

Xrot and Zrot uncertainties:

1	unknown deviation of HIFI cube normal from nominal position (TBC by HIFI)	± 0.001deg)*	
2	unknown deviation of LOU-alignment window normal from nom. pos.	± 0.001deg	
3	measurement uncertainty on HIFI cube	± 0.001deg	
4	measurement uncertainty onLOU-alignment window normal	± 0.001deg	
5	HIFI adjustment resolution	± 0.001deg	
	Total rot uncertainty 2 to 5 (worst case)	± 0.004deg	
	Xrot, Zrot: ± 0.004deg correspond to a linear error at LOU-window position of		± 0.02mm
	Yrot calculated from position uncertainty beneath (± 0.5mm on 300mm)	± 0.1deg	

)* value has not to be considered in PLM alignment budget. This item belongs to the instrument internal alignment budget.

Xpos and Zpos uncertainties:

1	unknown deviation of HIFI marks from nominal position (TBC by HIFI)	± 0.1mm)*
2	unknown deviation of LOU-alignment window marks from nom.pos.	± 0.1mm
3	measurement uncertainty on HIFI marks	± 0.1mm
4	measurement uncertainty on LOU-alignment window marks	± 0.1mm
5	manufacturing tolerances of window positions to each other	± 0.1mm
6	HIFI adjustment resolution	± 0.1mm
	Total pos uncertainty 2 to 6 (worst case)	± 0.5mm

)* value has not to be considered in PLM alignment budget. This item belongs to the instrument internal alignment budget.

Ypos is uncritical.

Alignment accuracy of LOU to HIFI:

(Sequence: LOU is adjusted to HIFI through the LOU-alignment windows. Afterwards LOU alignment to LOU- alignment windows is checked).

Xrot and Zrot uncertainties:

1	unknown deviation of LOU cube normal from nominal position (TBC by HIFI)	± 0.001deg)**	
2	unknown deviation of HIFI cube normal from nominal position (TBC by HIFI)	± 0.001deg)*)**	
3	measurement uncertainty on LOU cube	± 0.001deg	
4	measurement uncertainty on HIFI cube	± 0.001deg	
5	LOU adjustment resolution	± 0.001deg	
	Total rot uncertainty (LOU to LOU-windows) 1, 3, 4, 5 (worst case):	± 0.004deg	
	Total rot uncertainty (LOU to HIFI) 3, 4, 5 (worst case):	± 0.003deg	
	Xrot, Zrot: ± 0.003deg correspond to a linear error at LOU window position of		± 0.02mm
	Yrot calculated from position uncertainty beneath (± 0.4mm on 300mm) ~	± 0.1deg	

Xpos and Zpos uncertainties:

1	unknown deviation of LOU marks from nominal position (TBC by HIFI)	± 0.1mm)**
2	unknown deviation of HIFI marks from nominal position (TBC by HIFI)	± 0.1mm)*)**
3	measurement uncertainty on LOU marks:	± 0.1mm
4	measurement uncertainty on HIFI marks:	± 0.1mm
5	LOU adjustment resolution:	± 0.1mm
	Total pos uncertainty (LOU to LOU-windows) 1, 3, 4, 5 (worst case):	± 0.4mm
	Total pos uncertainty (LOU to HIFI) 3, 4, 5 (worst case):	± 0.3mm

)* not to be considered in LOU to LOU- window Alignment Budget (part of internal instrument alignment budget)

)** not considered on LOU to HIFI Alignment Budget (part of internal instrument alignment budget)

Ypos is uncritical

Structural experience from ISO

	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	
	Sum: 1 + 2 (worst case) (Zrot only) Sum: 1 + 2 (worst case) (Xrot, Yrot)	± 0.035deg)** ± 0.02 deg	^ 0.2 mm ^ 0.12mm
3	Expected position ground to orbit transition effect on LOU (assessment)		0.2 mm)*
4	Uncertainty of shrinking effect of vacuum vessel		± 0.2 mm)***
	Total position uncertainty (worst case) (Zrot) Total position uncertainty (worst case) (Xrot, Yrot)		± 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 precompensation)

)** 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 crucial figure!]

)*** shrinking effect of Al for the expected ?T: 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

The summation of the inaccuracies defined above leads to the following total PLM-level aligment error budget. As worst case consideration the individual errors have summed up linearly.

Total Alignment Budget for LOU to HIFI:

1. Allowed tolerances of LOU to HIFI alignment					
Xrot	Yrot	Zrot	Xpos	Ypos:	Zpos
±0.03deg	±0.38deg	±0.03deg)*	± 0.66mm	±70mm (uncritical)	± 0.66mm

2. Calculated accuracy of LOU to HIFI alignment					
±0.003deg	±0.1deg	±0.003deg	±0.32mm		±0.32mm
3. Structural uncertainty					
±0.02deg	±0.02deg	±0.02deg)*	±0.52mm	±0.52mm	±0.4mm)**
Sum of 2. and 3.					
+/- 0.023 deg	+/- 0.12 deg	+/- 0.023 deg	+/- 0.84 mm		+/- 0.72mm)**

)* precompensation of 0.015 deg applied
)** precompensation of 0.2 mm applied

Size of LOU windows:

The corresponding requirement on the size of the LOU window can be derived from the following budget:
Worst case position uncertainties of LOU beams to LOU windows (Xpos, Zpos) are derived to obtain the really needed free LOU-window diameter on the basis of a free 30mm diameter for the LOU beams inspite of possible alignment errors and structural uncertainties.

1	HIFI alignment to LOU-alignment windows on CVV	
	* worst case position error of HIFI to LOU-windows is:	± 0.5 mm
	* contribution of HIFI rotation error to LOU-windows is:	± 0.02mm
2	LOU to HIFI alignment	
	* worst case position error of LOU to HIFI is:	± 0.4 mm
	* contribution of LOU rotation error of LOU to HIFI is:	± 0.02mm
3	Uncertainty derived from ISO structural experience	± 0.6 mm
4	Shift of LOU beams due to LOU-window tilt (3°))*	± 0.16 mm
	Total uncertainty (worst case)	± 1.7 mm
	Total uncertainty (worst case) inclusive margin of 0.3mm	± 2 mm
	To guarantee an always free LOU-window diameter of 30mm, the really needed free LOU-windows diameters have to be: 30mm ± 2 mm =	34 mm

)* Quartz window 6mm thick, 3deg tilt, n = 2.1 for far IR (v=e*d*(n-1)/n)
(can be precompensated!)

6.3 Instrument Testing – Cryo GSE

To allow low temperature background testing the cryostat shall provide the FPUs within the PFM cryostat with an environment which is as close as possible to the orbit conditions
The following ground conditions are achievable (derived from former calc.) by increase of the massflow.

Massflow	20 mg/s	30 mg/s	40mg/s
OB	32.3 K	13.3 K	10.6 K
OB shield	32.6 K	13.4 K	10.7 K
HS1 upper bulk	93.1 K	33.0 K	21.5 K
HS 1 Baffle	96.7 K	36.6 K	25.0 K
HS 2 upper bulk	156 K	92.7 K	54.4 K
HS 2 Baffle	156 K	93.6 K	55.4 K
HS 3 upper bulk	216 K	188.6 K	164.5 K
HS 3 Baffle	213 K	186.5 K	163.3 K
CVV, Cover Dome, Cavity	293 K	293 K	293 K
Cover HS	212 K	204 K	200.5 K

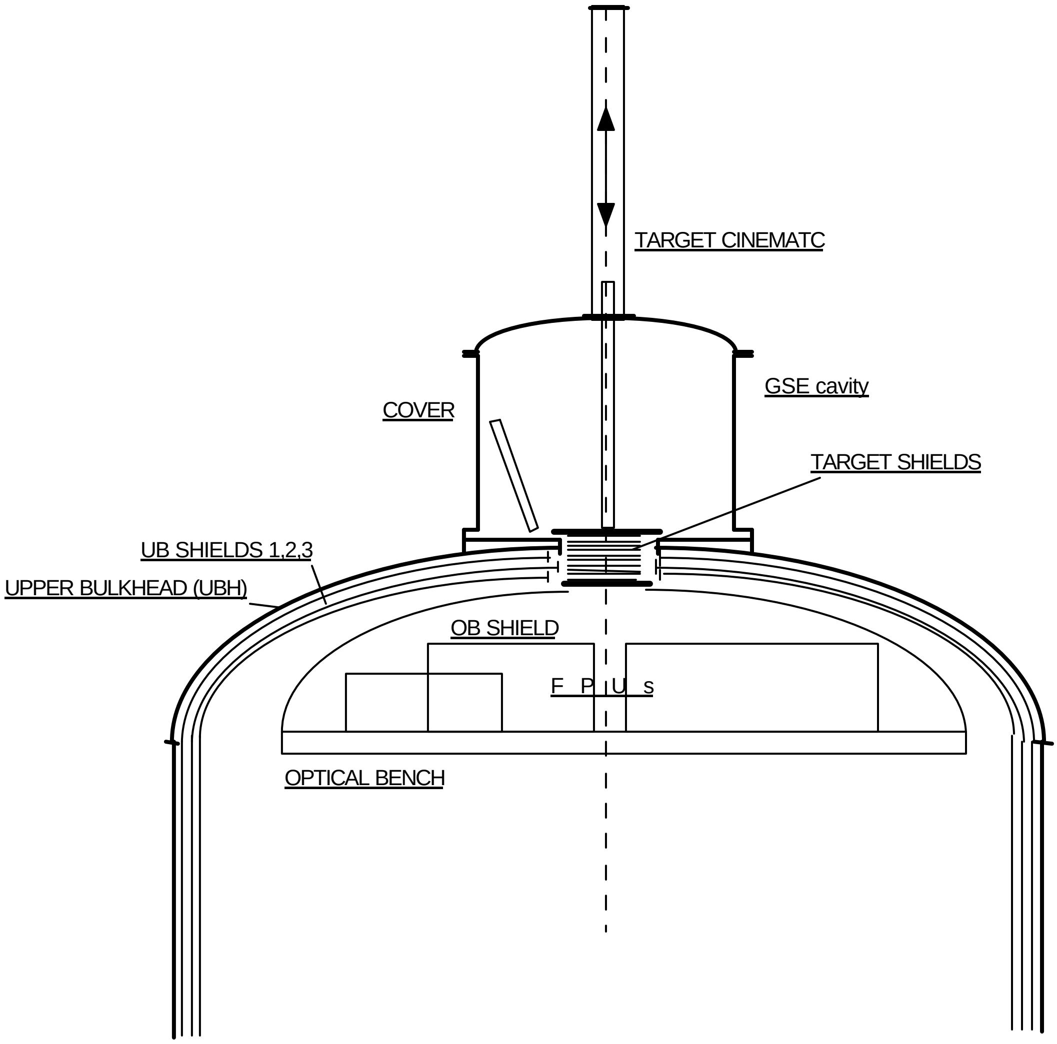
As can be seen the temperature of the OB and the OB shield can be reduced significantly but the temperature of the baffles and the cover heatshield remains high. Different concepts have been considered to reduce these items further to achieve a colder environment. They can be divided in:

a) remaining within PLM
- Cover flushing
- Shutter on OB shield level

b) removed after test

- GSE cavity and actively cooled plate above CVV opening
- GSE cavity and actively cooled plate let down within opening
- GSE cavity and passively cooled plate let down on Instrument Shield

The proposed concept is a GSE cavity with a passively cooled plate let down on the Instrument Shield.
The GSE cavity allows to open and close the cryostat cover. With a GSE mechanism a plate (target) can be moved downwards into the CVV and put on (thermally coupled to) the Instrument Shield. On top of this plate there is a lot of insulation (MLI) to reduce the heatload from the GSE-cavity and the baffles on this plate and thus to reach a low temperature by passively cooling to the instrument shield.
The plate is removed after the test , the cyostat cover is closed and the GSE cavity is replaced by the PLM flight cavity.



6. 4 FIRST Telescope Interface

The distance Reference Plane to Telescope I/F-plane has changed from 1052 mm to 1002 mm (see IID A page 4-8). The distance between CVV and primary mirror rear-side (height of cavity) remains unchanged.

7. Analysis
7.1 Structural Analysis

- Structural models of the OB with the instruments and the LO fixation have been established, structural analysis performed
- Impact of the higher instrument masses on the PLM has been investigated by eigenfrequency analysis

7.1.1 Optical Bench

The following requirements have been taken for the OB:

- Stiffness: OB shall be designed to be decoupled from any major frequency of the spacecraft; minimum ratio of 1.4; axial mode of PLM at 42Hz -> min. 60 Hz for OB;
  => aim: 80 Hz at hardmounted boundary conditions
- Preliminary design loads: 15 g longitudinal and 5g lateral
  4 g lateral
- Instrument mass: 156 kg (including 20% mass margin) and 25 kg for additional items
- Eigenfrequencies of instrument boxes at hardmounted conditions > 100Hz (assumption, no instrument structural models available)

FINITE ELEMENT MODEL

The finite element model is established for stress analyses and for eigenfrequency analyses. In order to get realistic stresses the mesh is rather fine.

The design of the instrument boxes was not available at the beginning of this study. Therefore the maximum allowable volume of each instrument has been idealized by volume elements with homogeneous mass and low stiffness. This volume is supported by an artificial framework with a dimensioning of the cross-sections in such a way, that each instrument has a first eigenfrequency above100 Hz. This led to eigenfrequencies of 133 Hz for PACS, 167 Hz for HIFI and 137 Hz for SPIRE. This kind of idealization is more realistic for the behaviour of the optical bench than a simple 1-mass point with RBEs idealization for each instrument.

Each instrument is connected by 3 to 6 RBAR Elements with the mounting plate.

The sandwich plate is idealized by QUAD4 plate elements with appropriate stiffness values for membrane, bending and shear.

Around each mounting point of the instruments and around each connection area of the interface blades a rather big area of solid material is idealized (insert region). A more precise design later will have to idealize these regions in more detail.

The interface blades from the mounting plate to the spatial framework are idealized by plate elements.

For the finite element analysis the lower ends of the blades (at the spatial framework) are totally fixed.
The finite element model of the OB is shown in fig. 7.1-1 and 7.1-2.

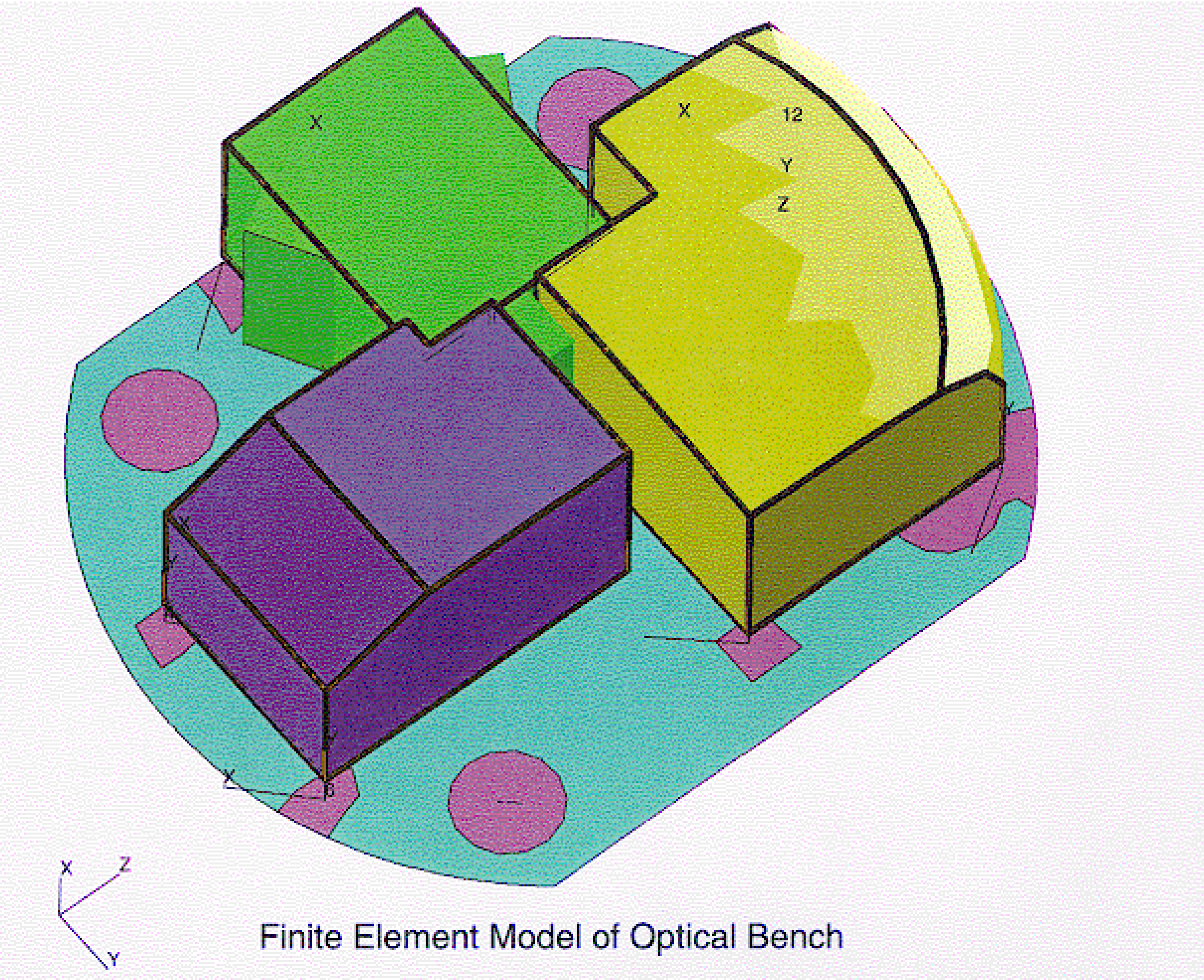


Fig. 7.1-1: Finite Element Model of Optical Bench (from top)

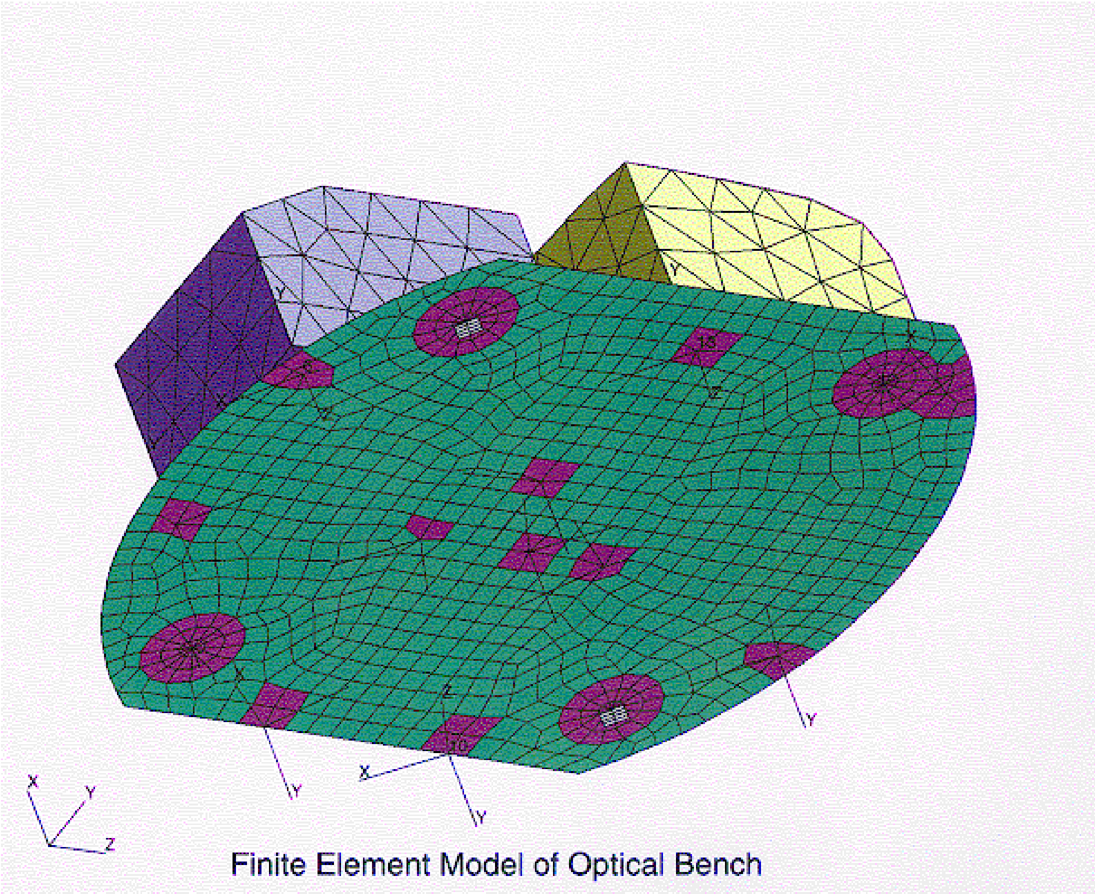


Fig. 7.1-2: Finite Element Model of Optical Bench (from lower side)

RESULTS OF CONSIDERED DESIGNS

In order to reach the required stiffness and strength under the dimensioning loads, the following parameters have been varied:

- core thickness,
- thickness of face sheets,
- material of face sheets,
- material of core,
- blade thickness,
- material of blades.

The necessary strength and stiffness is achievable by two different OB designs

- 100 mm alu sandwich with 2 mm alu face sheets, mass 65kg
- 70 mm cfc-sandwich with 2.5 mm cfc face sheets, mass 36 kg

1 mm thick SST blades for fixation of the OB to the SFWK show positive margins, for cfc blades a more detailed design of the interface has to be established.

7.1.2 Local Oscillator

The local oscillator is located on the outer wall of the cryostat vessel. The connection is done by 6 S-Glass rods.

A stiffness requirement of 100 Hz and limit loads of 30g spherically superimposed must be considered.

FINITE ELEMENT MODEL

As for the optical instruments no detailed design exists at the moment. Therefore the mass of 14 kg is distributed homogeneously with low stiffness in the foreseen volume. The support of this mass is done in the finite element model by an artificial massless framework with stiffness to reach a 1. hardmounted eigenfrequency of 250 Hz.

This frame is mounted on a cfc-plate, which is connected by 6 182 mm long S-glass rods with the cryostat wall. The ends of the rods are totally fixed in this analysis. The outer diameter of the rods is 22.0 mm. To find the wall thickness of the rods is task of the analysis.

The finite element model is shown in figure7.1-3.

RESULTS OF EIGENFREQUENCY AND STRESS/STRENGTH ANALYSIS

The stiffness requirement is the design driver for the wall thickness of the rods. The minimum thickness is 0.7 mm to reach a first eigenfrequency of f_1= 110 Hz.

For this design 30g limit loads are analyzed in each direction and the resulting rod forces and stresses are spherically superimposed.

The superposition gives maximum rod stresses of 74 N/mm^2. With allowable stresses of 503 N/mm^2 a margin of safety of **MOS_{ult}=4.91** is calculated.

The buckling load is 45159 N. The maximum rod force after spherically superpostion is 3466 N. Considering a safety factor of 1.3 the margin against buckling is **MOS_{buckl}=9.0**.

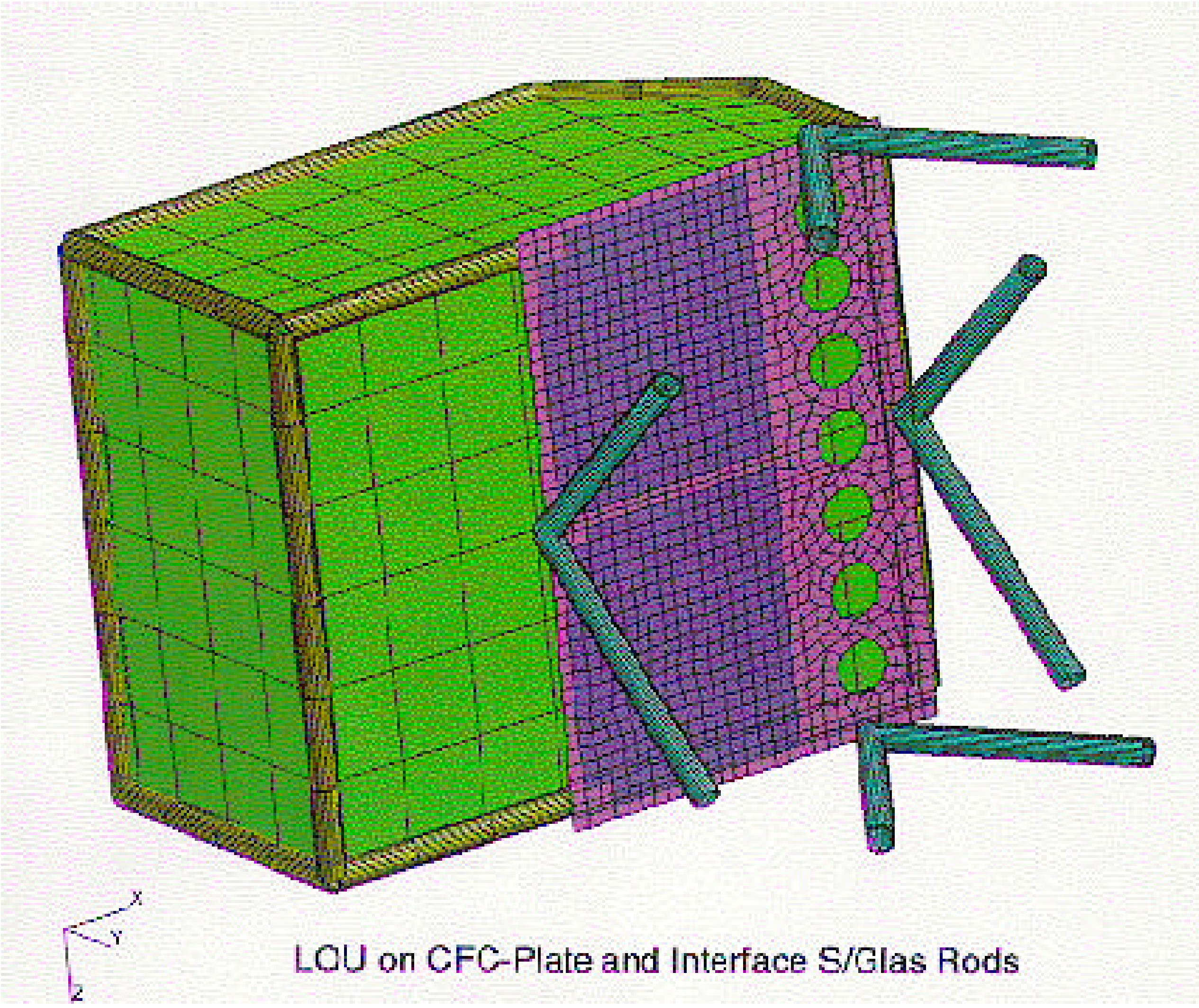


Fig. 7.1-3: LOU FE Model

7.1.3 Buffer Amplifier Unit

When using the same interface rods for the buffer amplifier unit with an supported mass of only 3.5 kg, then a 1. eigenfrequency of 220 Hz is obtained. The margins increase to MOS_{ult}=23.3 and MOS_{buckl}=39.1.

To reach at least 110 Hz as 1. eigenfrequency the minimum wall thickness is 0.2 mm. The margins against ultimate stress and buckling are MOS_{ult}=5.9 and MOS_{buckl}=10.0.

7.1.4. Overall PLM

The effect of increase of the higher mass of optical bench and instruments on the global eigenmodes of the payload module are analyzed by the unchanged PLM finite element model. The mass of the 1-mass point, which represents the instruments and the nonstructural mass of the optical bench plate is increased to a total mass of 247 kg.

To keep the eigenfrequency of the first axial mode at 43 Hz the cross-sections of the gfc and cfc straps are increased by 30%.

The idealization of the optical bench in the PLM model is not changed in this analysis. To get better and more reliable results an update of PLM finite element model should be done. This was not within the scope of this study.

7.2 THERMAL ANALYSIS

7.2.1 Thermal Requirements and Cooling Philosophy

The operating temperature levels of each instrument are summarized in Table 7.2-1. These temperatures shall be provided by the FIRST cryostat cooling system, which consists of the HeII tank and two interfaces at the GHe ventline. The temperatures of the external boxes, which are mounted outside on the CVV, are listed in Table 7.2-1, too. The boxes are wrapped in MLI and are thermally decoupled from the CVV by GFRP struts. The heat dissipation is rejected by individual radiators, see also section 7.2.5.

	Level 0	Level 1	Level 2	outside CVV
SPIRE	< 2 K	< 6 K (FPU structure)	< 15 K (filter box FTB)	
PACS	< 1.75K	< 4.3 K (FPU structure)	< 15 K (internal Assy.)	
HIFI	< 2 K	< 6 K (internal Assy.)	< 20 K (FPU structure)	
SPIRE BAU				120 K-150 K
HIFI LOUA				200 K
HIFI LOUX				120 K

Table 7.2.-1: Instrument Operating Temperatures and External Box Temperatures

High thermal conductivity copper (800 W/mK at 2 K) cooling straps are foreseen to connect the Level 0 instrument parts directly to the HeII tank. Aluminum or copper cooling straps with 140 W/mK at 2 K are foreseen as connection to the GHe Level 1 and Level 2 I/F. The connection sequence on the GHe ventline is SPIRE-PACS-HIFI for Level 1 followed by HIFI-SPIRE-PACS for Level 2..

The GHe ventline is isolated from the Optical Bench by CFRP brackets, and the Optical Bench itself is thermally decoupled from the warmer SFWK using stainless steel blades.
The cross-section of the tank straps has been increased as described in the chapter `structural analysis´.

7.2.2 Implementation of Instruments in FIRST Thermal Model

The simpified instrument thermal models are shown schematically in Fig 7.2.2-1 to Fig. 7.2.2-3. Each instrument temperature level is represented by one node. The thermal couplings between the different temperature levels and to the optical bench have been updated. The harness dimensions and dissipation is summarized in Table 7.2-2.

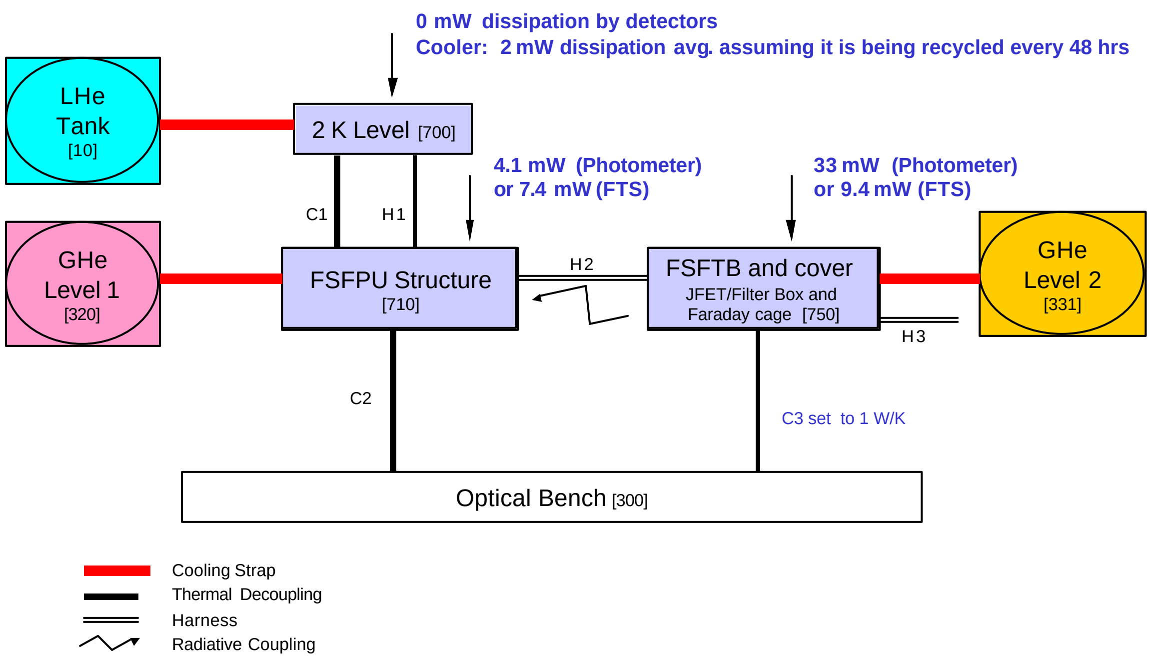


Fig. 7.2.2-1: Simplified Thermal Model of SPIRE Instrument (Feedhorn Option)

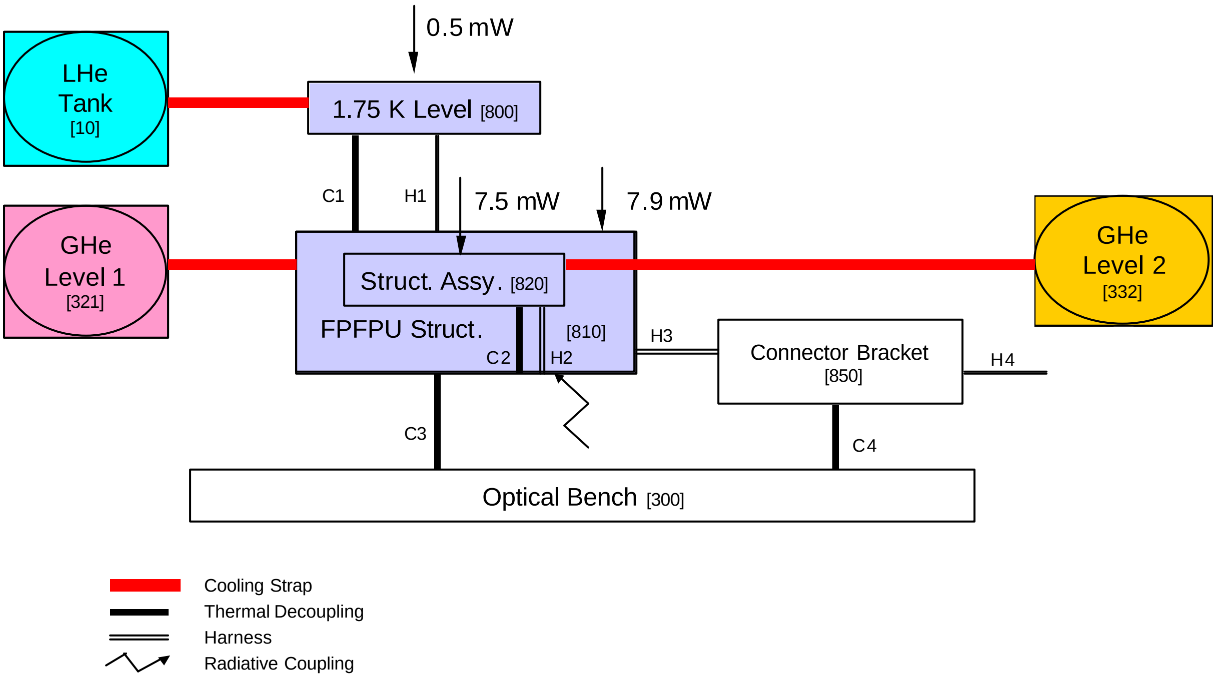


Fig. 7.2.2-2: Simplified Thermal Model of PACS Instrument

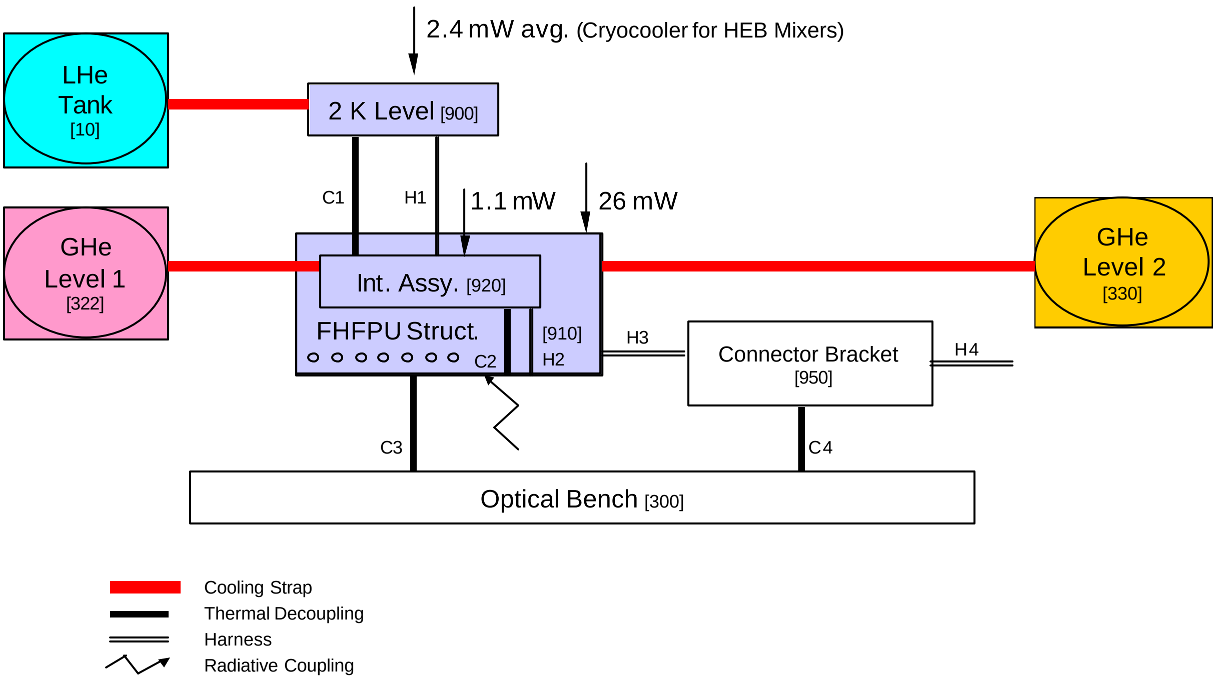


Fig. 7.2.2-3: Simplified Thermal Model of HIFI Instrument

Harness	Length	Dissipation	Stainl. St.	Brass	CuBe	PTFE	Kapton
	m	mW	mm^2	mm^2	mm^2	mm^2	mm^2
SPIRE H1	0.15	~0	6.72	-	-	-	106
SPIRE H2	0.15	~0	6.72	-	-	-	106
SPIRE H3	1.2	0.26	18.5	8.78	-	222	-
PACS H1	0.3 0.005	8µW ~0	0.064 0.58	- -	- -	0.17 -	- -
PACS H2	0.5	0.5	-	0.4	-	2	-
PACS H3	0.3	5.62	28.8	4.08	-	272	-
PACS H4	1.2	8.81	28.8	4.08	-	272	-
HIFI H1			1.11 mW/K @ 3.0 K including mechanical supports				
HIFI H2			0.73 mW/K @ 9.5 K including mechanical supports				
HIFI H3	0.3	2.85	15.2	0.54	0.34	58.7	-
HIFI H4	1.2	11.4	15.2	0.54	0.34	58.7	-
CVV–HS1	0.25	1.41	53.7	13.4	0.98	542.3	-

Note: 20% margin (cross section and dissipation) is included in CVV-HS1 and all H3 and H4

Table 7.2.-2: Harness Cross Sections used for Thermal Analysis

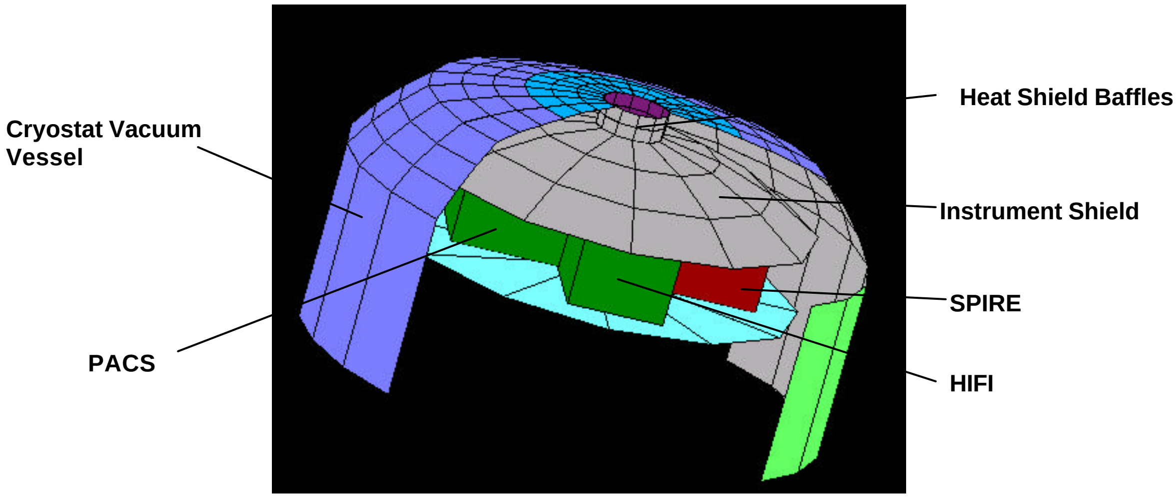
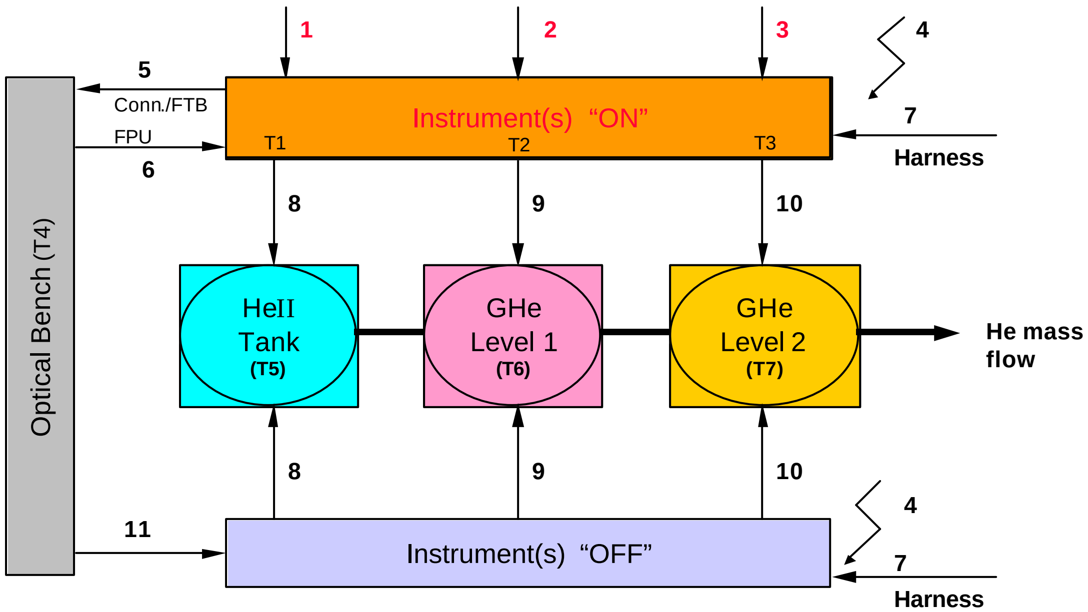


Fig. 7.2.2-4: Thermal Geometry Model of Optical Bench with Instruments

Steady State Analysis Results

The following different steady state instrument operation cases have been investigated:

- SPIRE operation, feed horn and CEA option (Fig. 7.2.3-2)
- PACS operation (Fig. 7.2.3-3)
- HIFI operation (Fig. 7.2.3-4)
- SPIRE and PACS operating simultaneously (Fig. 7.2.3-5)
- all instruments are switched off, i.e. no dissipation (Fig. 7.2.3-6)
- instruments are operating with average dissipation, i.e. one third of nominal (Fig. 7.2.3-7)



1	Dissipation on Level 0 instrument(s) part, i.e. < 2 K level
2	Dissipation on Level 1 instrument(s) part
3	Dissipation on Level 2 instrument(s) part
4	Radiation from instrument environment (other instruments, instrument shield, baffles,...)
5	Heat flow from instrument connector bracket (or FTB in case of HIFI) to optical bench
6	Heat flow from optical bench to the colder FPU housing
7	Dissipation and heat flow across harness from heat shield 1
8	Heat flow across cooling strap to HeII tank (Level 0)
9	Heat flow across cooling strap to GHe Level 1
10	Heat flow across cooling strap to GHe Level 2
11	Total heat flow (connector + FPU) from optical bench to the non-operating instrument(s)
T1	Temperature of Level 0 instrument(s) part
T2	Temperature of Level 1 instrument(s) part
T3	Temperature of Level 2 instrument(s) part
T4	Temperature of Level optical bench
T5	Temperature of HeII tank (Level 0)
T6	Temperature of GHe Level 1 heat sink
T7	Temperature of GHe Level 2 heat sink

Fig. 7.3.2-1: Heat Flow Chart Principle for Instruments Operation (see Fig. 7.3.2-2 to 7.3.2-6)

The corresponding heat flow charts (Fig. 7.2.3-2 to Fig. 7.2.3-6) follow the same principle for all operation cases investigated. The chart principle is explained in Fig. 7.2.3-1. The charts show the temperatures and the heat flow rates from and into the operating instrument(s), as well as for the instrument(s) which are not operating. The instruments internal heat exchanges are not shown. The heat flow rates into the three heat sink levels generate the He mass flow, and thus the lifetime.

For SPIRE there are several options existing (Feedhorn, CEA, GSFC) and for each option there are two operation modes, the Photometer and the Spectrometer mode. For each temperature level, the higher dissipation of the corresponding mode has been taken as worst case. Since the GSFC option have lower dissipation rates compared to the other ones, this option has not been investigated.

For the two detector options calculated for SPIRE the inputs into the HeII tank for the Feedhorn option are 2.8 mW from SPIRE and 2.5 mW from the non-operating PACS and HIFI, i.e. in total 5.3 mW. This results in a gas flow of 2.486 mg/s. For the CEA option the inputs are 7.5 mW from SPIRE and 1.7 mW from PACS and HIFI, i.e. in total 9.2 mW. This results in a gas flow of 2.437 mg/s which is lower than for the feedhorn option. This is caused by the fact that the higher dissipation on level 2 (33.2 mW for the feed horn option instead of 0.2 mW for the CEA option) increases the temperature of the GHe flow and leads to higher heat shield temperatures. This further increases the radiative and conductive parasitic heat flow into the HeII-tank and consequently the mass flow.

As presented in Fig. 7.3-2 to Fig. 7.3-4, all instrument temperatures are within the allowed range, except, if PACS and SPIRE are operating together. In this case the PACS Level 1 temperature increases to 5.0 K (see Fig. 7.3.2-5) and thus exceeds the limit of 4.3 K. This, however, can be easily amended by connecting the PACS Level 1 cooling strap first to the GHe ventline and/or by increasing the conductance of this cooling strap.

For an average instrument dissipation, i.e. each instrument operates 1/3 of the time, the average Helium mass flow is 2.4527 mg/s (see Fig. 7.3.2-7), which corresponds to about 4.3 years lifetime. If PACS and SPIRE are simultaneously operating for 2/3 of the time and HIFI 1/3 of time, the average Helium mass flow increases to 2.5610 mg/s, which reduces the overall lifetime by about 65 days.

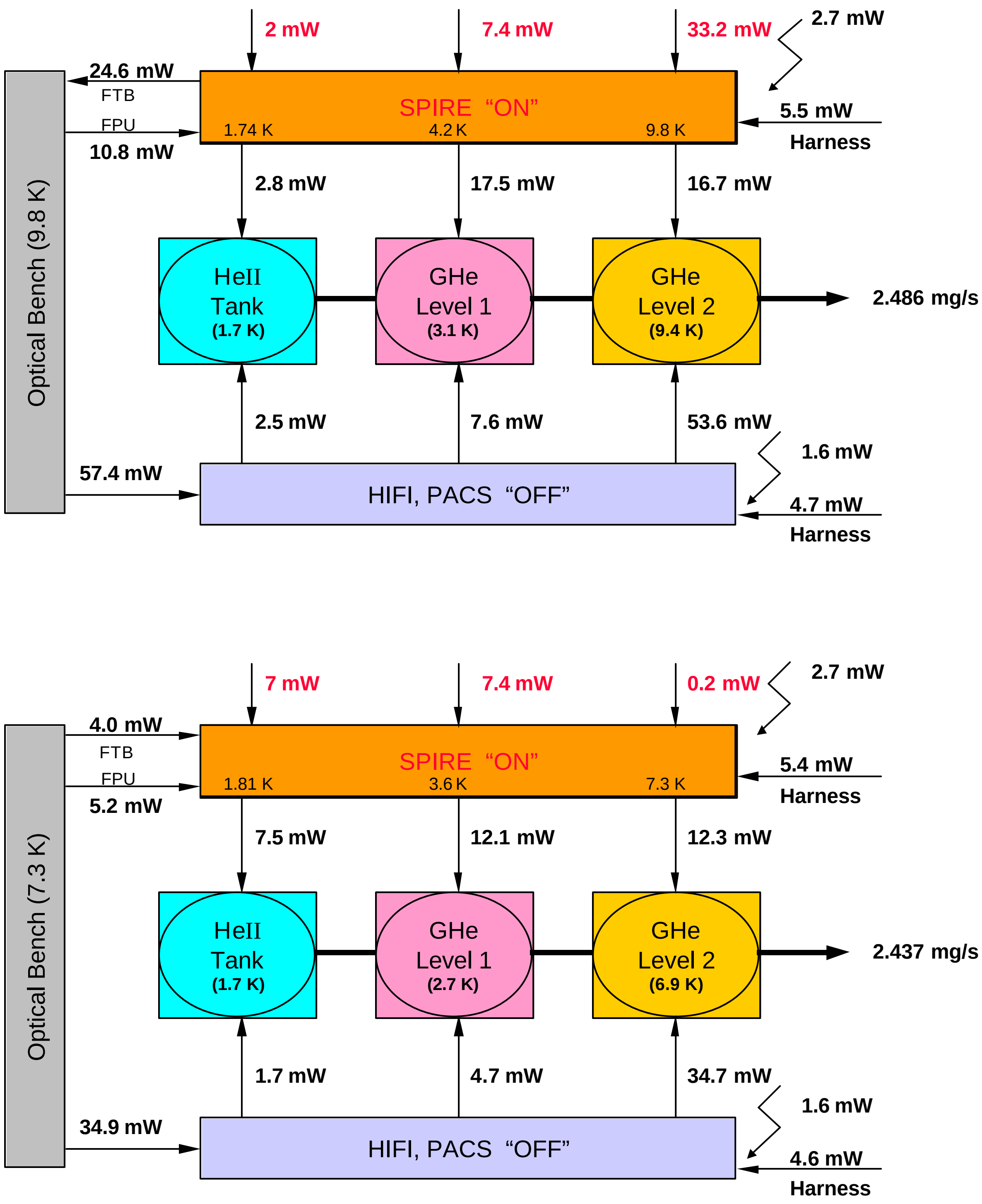


Fig. 7.3.2-2: Temperature Distribution and Heat Flow Chart for SPIRE Operation, Feedhorn Option (top) and CEA Option (bottom)

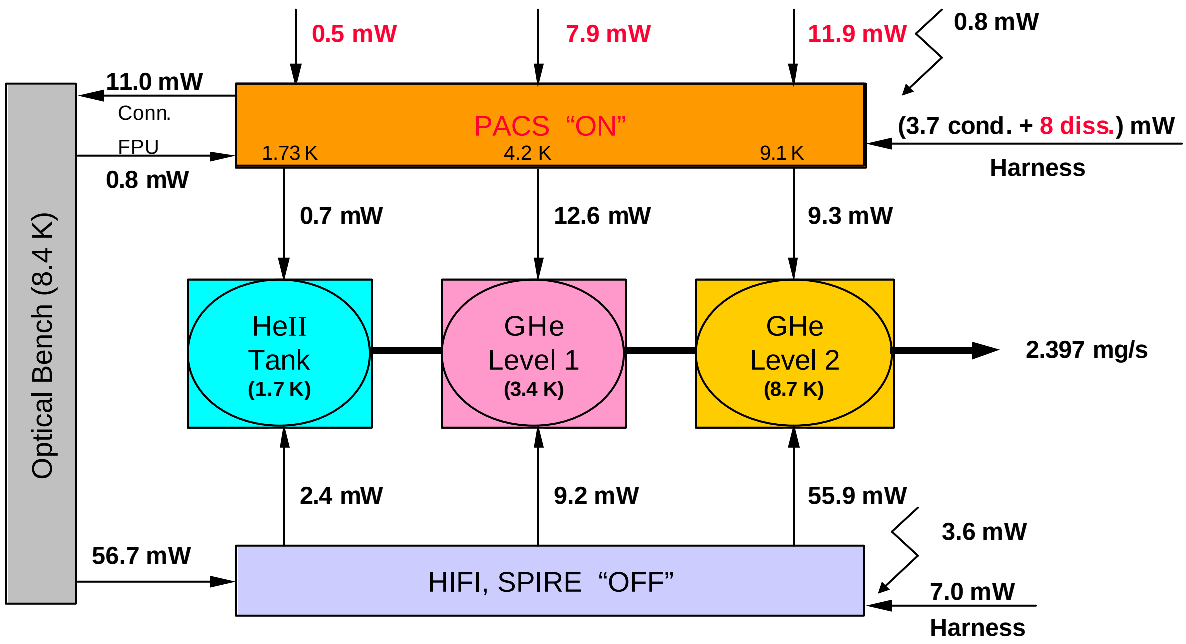


Fig. 7.3.2-3: Temperature Distribution and Heat Flow Chart for PACS Operation

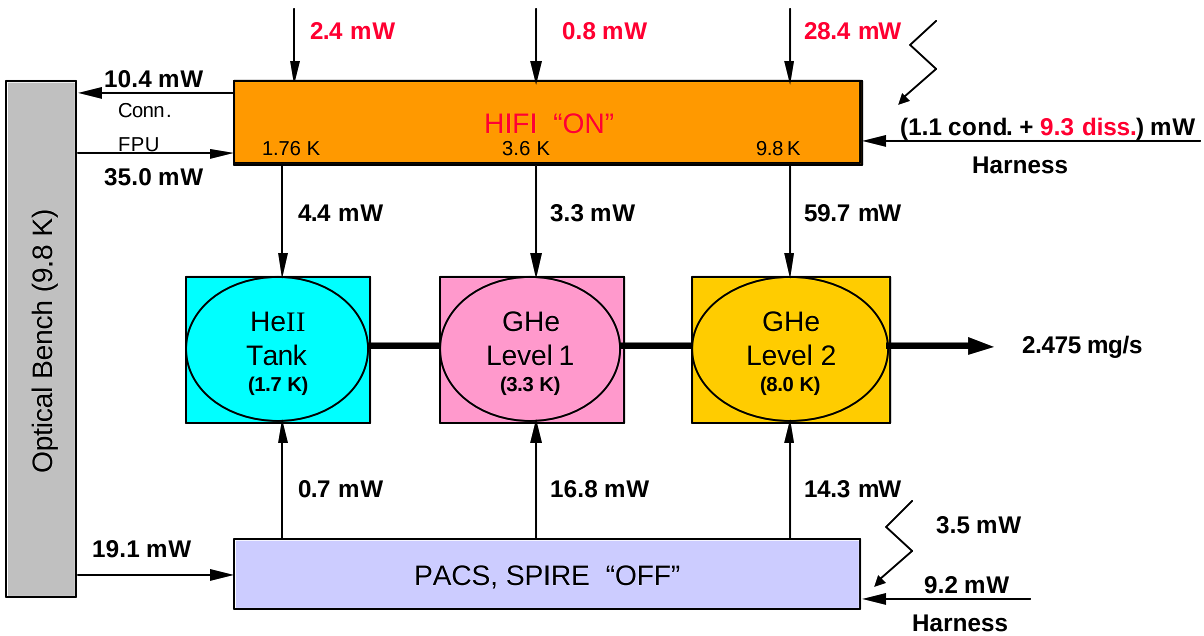


Fig. 7.3.2-4: Temperature Distribution and Heat Flow Chart for HIFI Operation

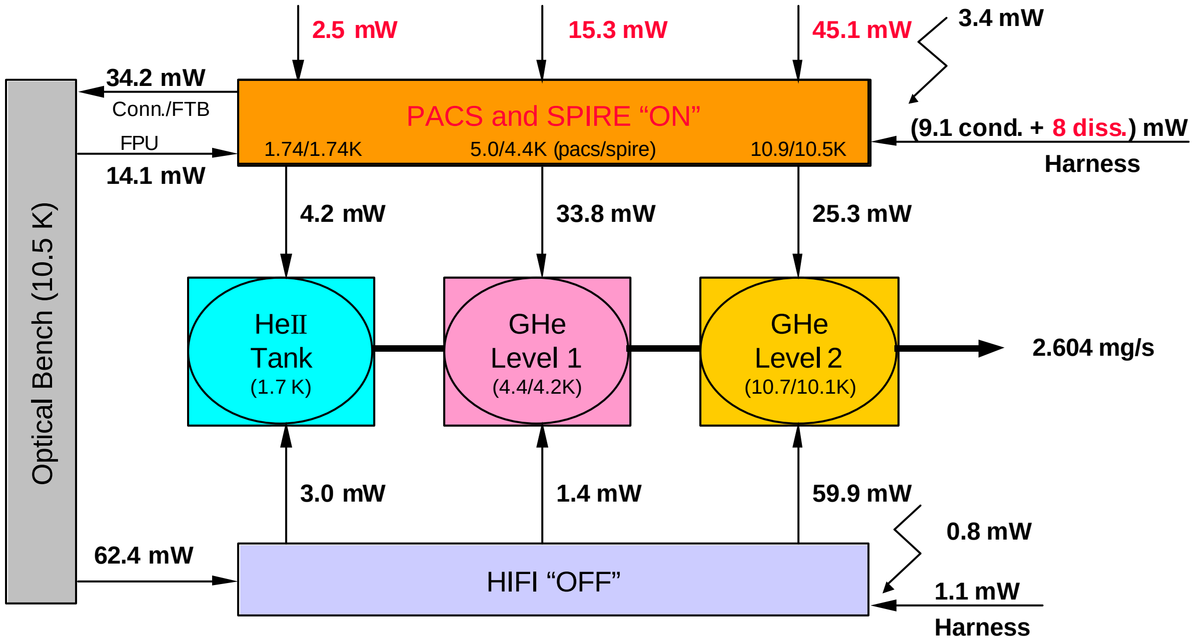


Fig. 7.3.2-5: Temperature Distribution and Heat Flow Chart for Simulateous Operation of PACS and SPIRE (Feedhorn Option)

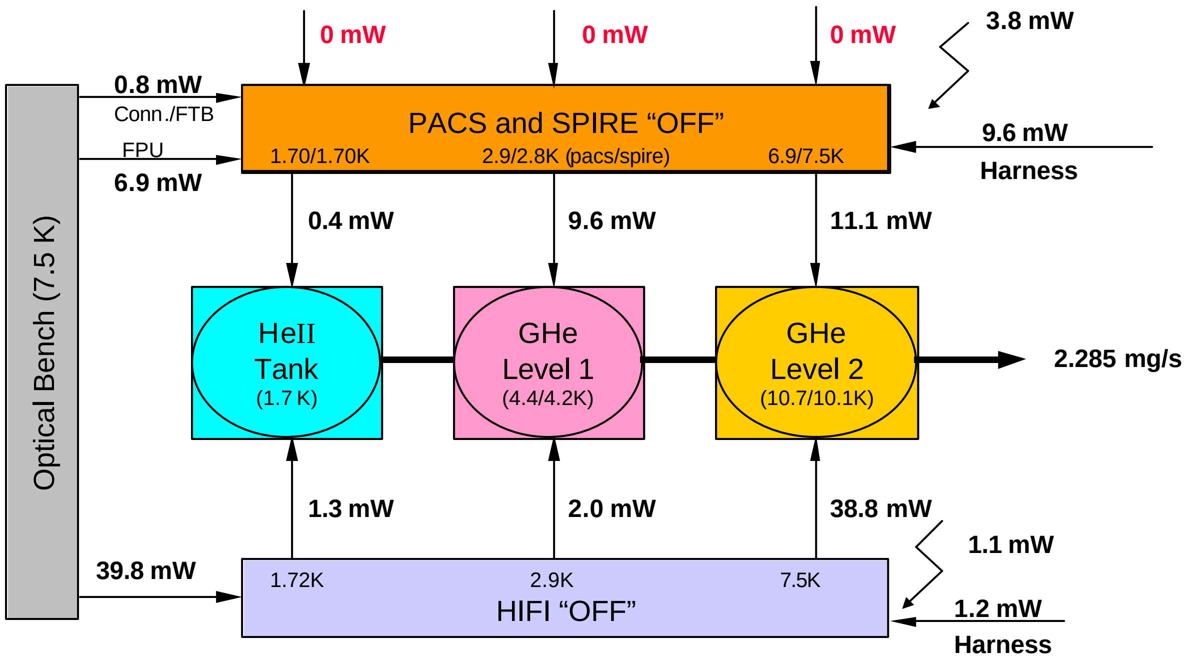


Fig. 7.3.2-6:Temperature Distribution and Heat Flow Chart for all Instruments in Off Mode

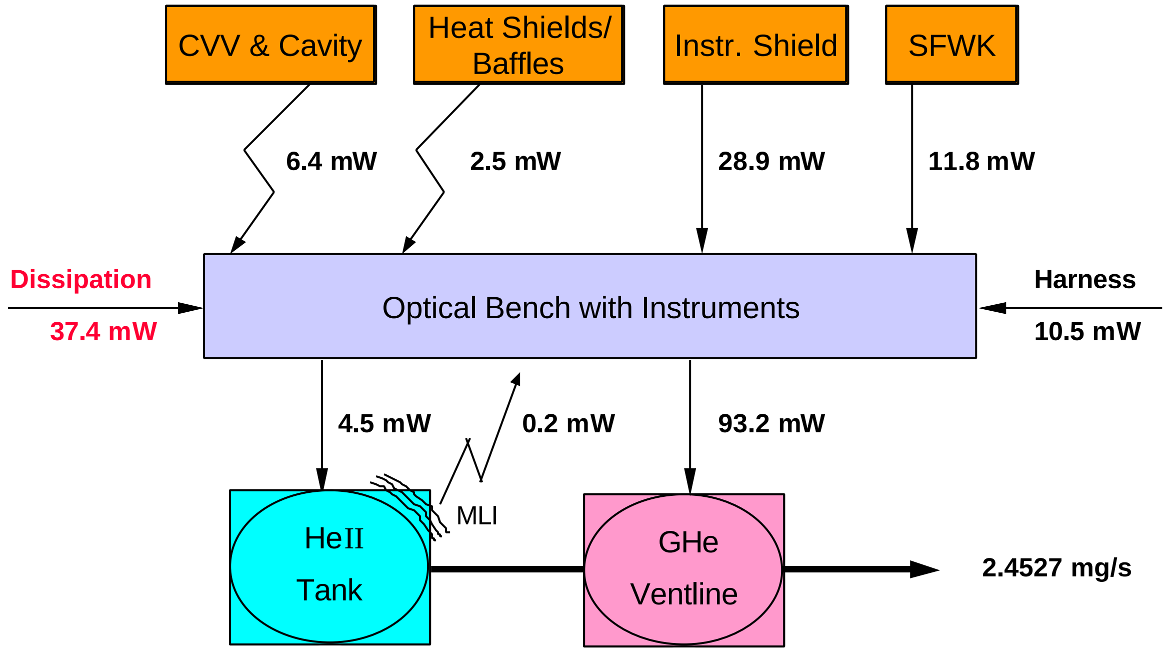


Fig. 7.3.2-7: Heat Flow Chart of Optical Bench for Average Instrument Dissipation

<u>Sensitivities</u>

To investigate the impact of changes in instrument data on the lifetime, the following sensitivities have been analysed:

Increase SPIRE instrument heatload by 30%:	2.5474 mg/s	(-37 days)
Add 10 mm² brass harness between CVV and HIFI:	2.7018 mg/s	(-128 days)
Add 9.4 mW to connector bracket (HIFI on):	2.5140 mg/s	(-24 days)

7.2.3 Transient Analysis with Typical SPIRE Timeline

To investigate the impact of instrument operations on the thermal stability of the three levels within the FIRST cryostat, a typical timeline for SPIRE operation has been provided by RAL /7/. Two examples of mode changes are described in RD /7/, the sorption cooler recycling and changing from photometer to spectrometer operation. For the transient calculations the average He-massflow of 2.4527 mg/s has been fixed.

The Level 0 input power profile for cooler recycling and the resulting temperature profile of the Level 0 instrument part is shown in Fig. 7.2.4-1. During cooler recycling there is a high power peak at the begin followed by a 90 mW dissipation for 30 minutes. The Level 0 temperature in that case is 2.8 K.

The Level 1 input power profile for transition from Photometer to Spectrometer operation and the resulting temperature profile of the Level 1 instrument part is shown in Fig. 7.2.4-2. The temperature variation on Level 1 is in a range of about 0.6 K. Since the cooler recycling is completed in this case, there is no dissipation on Level 0 during this time. However, due to the instrument internal thermal couplings, there is an impact also on the Level 1 instrument part, which is presented in Fig. 7.2.4-3 together with the corresponding heat load to the HeII tank. The temperature variation on Level 0 in this case is within a range of less than 4 mK.

The corresponding power profile and its impact on Level 2 (JFET filter box) is shown in Fig. 7.2.4-4.

An extraction out of Fig. 7.2.4-2 and Fig. 7.2.4-3 representing the mirror drive operation is given in Fig. 7.2.4-5 in detail. It shows the power input on Level 1 for the mirror drive and the resulting temperature on Level 1, as well as the impact on the instrument Level 0 temperature.

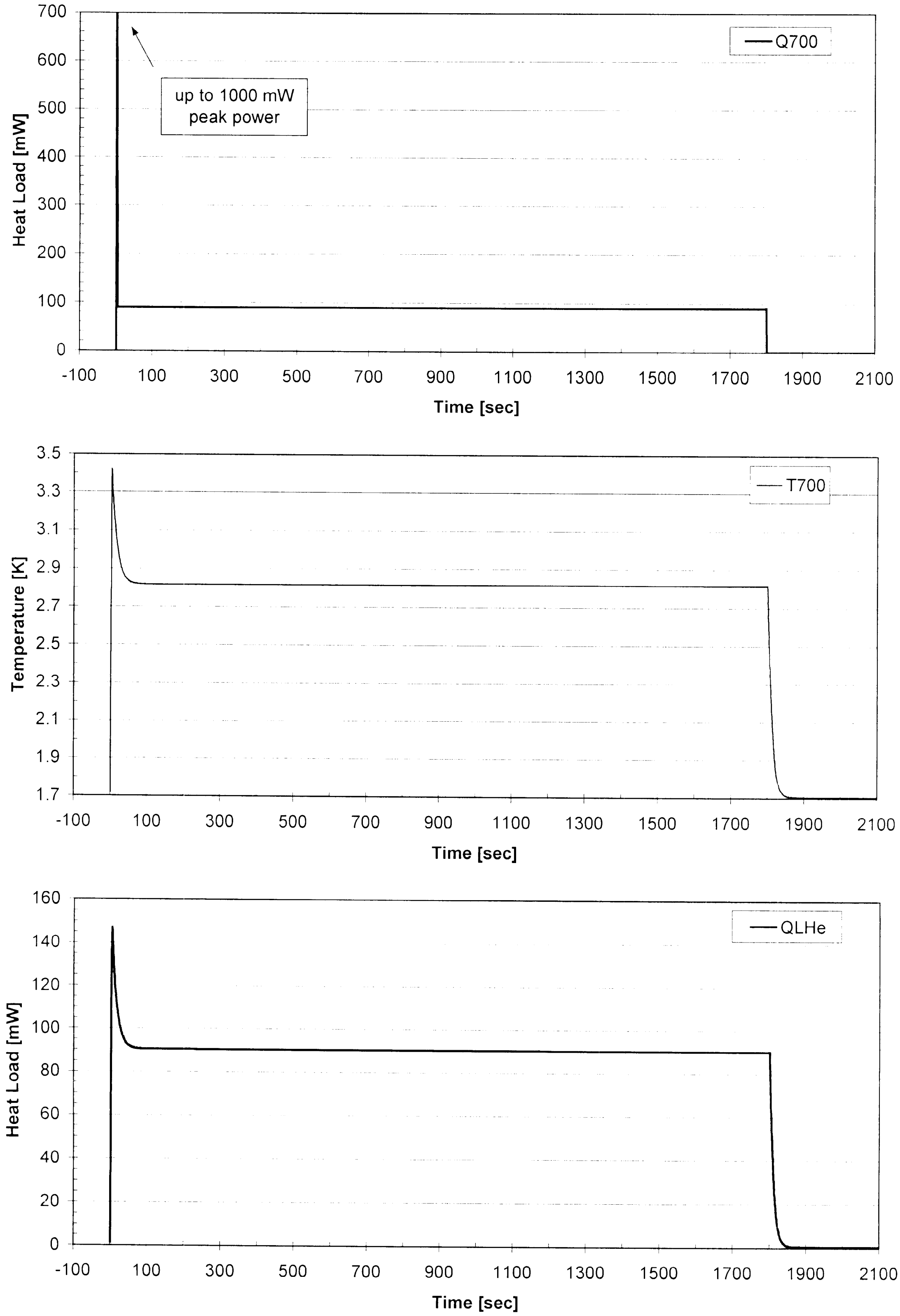


Fig. 7.2.4-1: Timeline for Sorption Cooler Recycling, Power Dissipation (top), Level 0 Temperature (mid) and Heat Flow into HeII Tank (bottom)

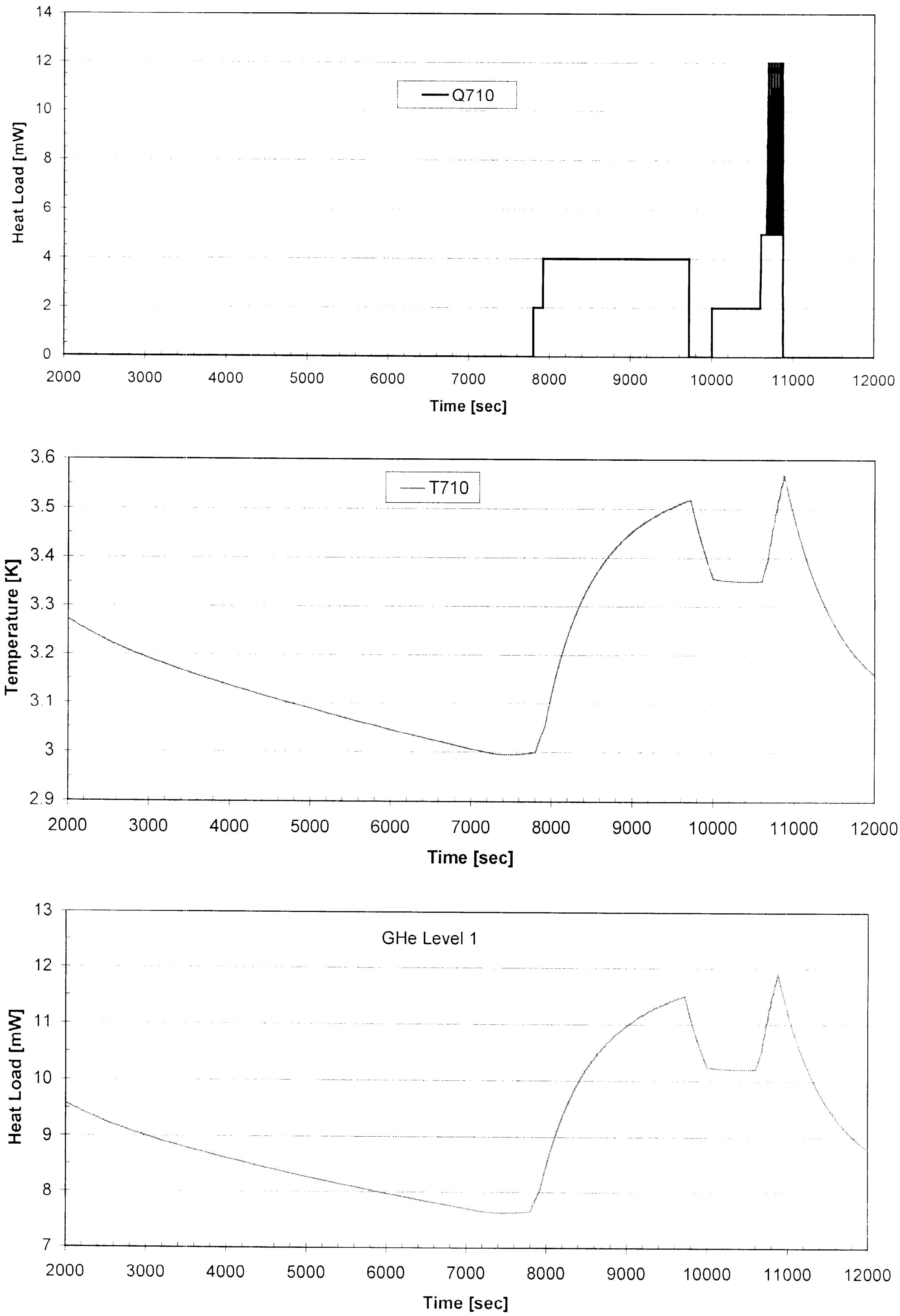
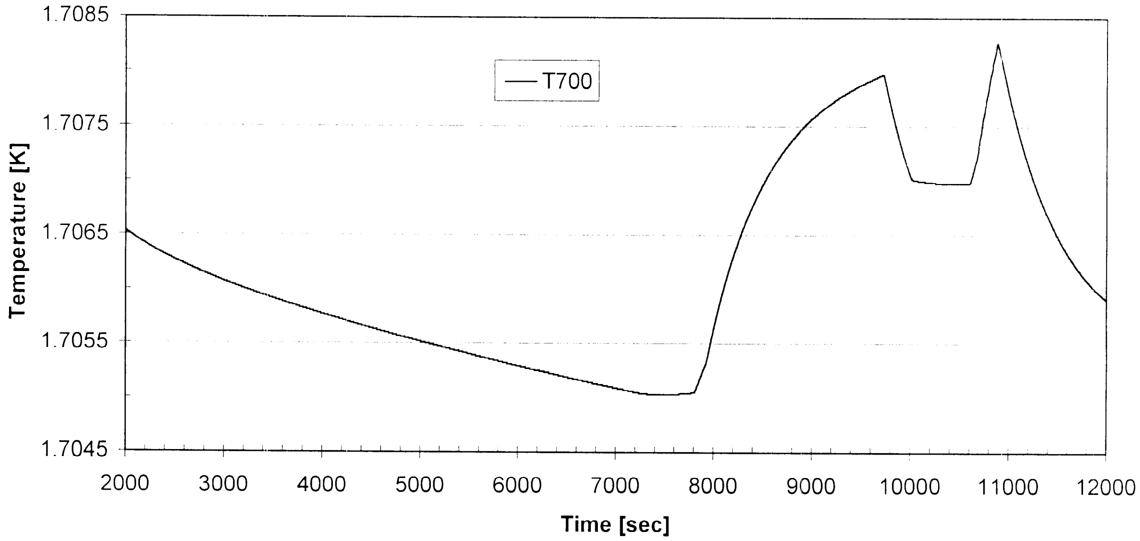


Fig. 7.2.4-2: Transition from Photometer to Spectrometer Operation. Level 1 Dissipation (top), Temperature (mid) and Heat Flow into GHe Ventline (bottom)



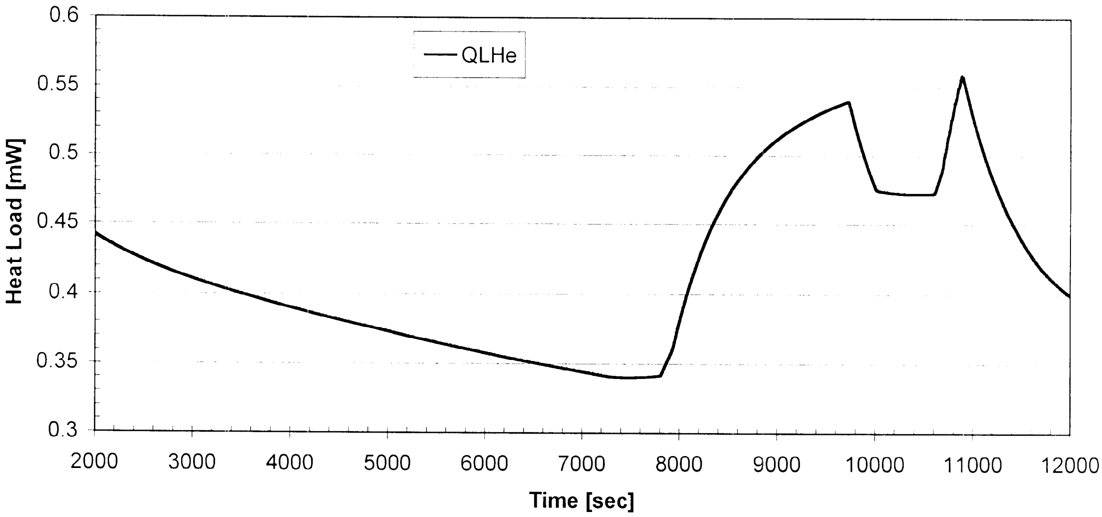


Fig. 7.2.4-3: Transition from Photometer to Spectrometer Operation. Level 0 Temperature (top) and Heat Flow into HeII Tank (bottom)

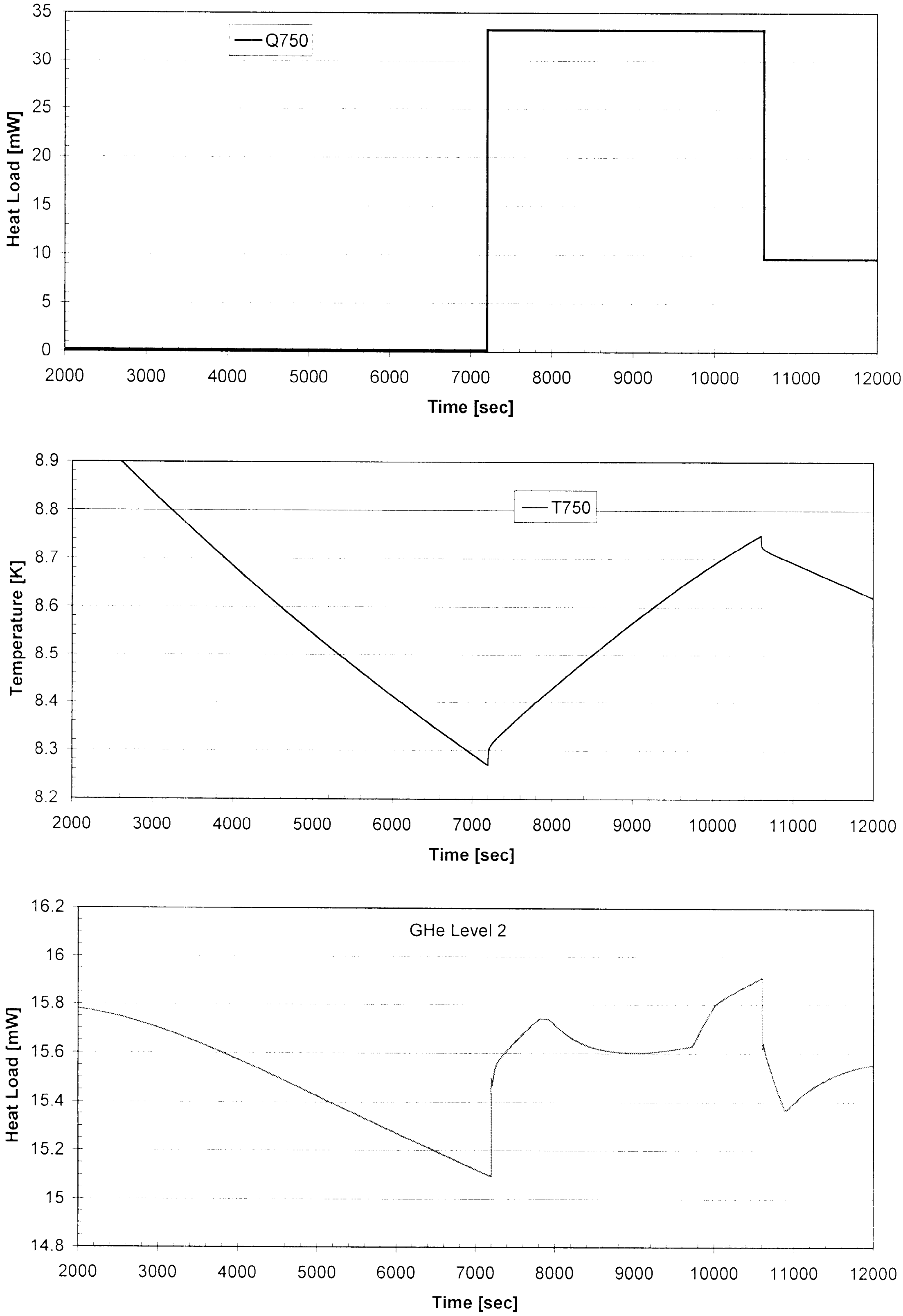


Fig. 7.2.4-4: Transition from Photometer to Spectrometer Operation. Level 2 Dissipation (top), Temperature (mid) and Heat Flow into GHe Ventline (bottom)

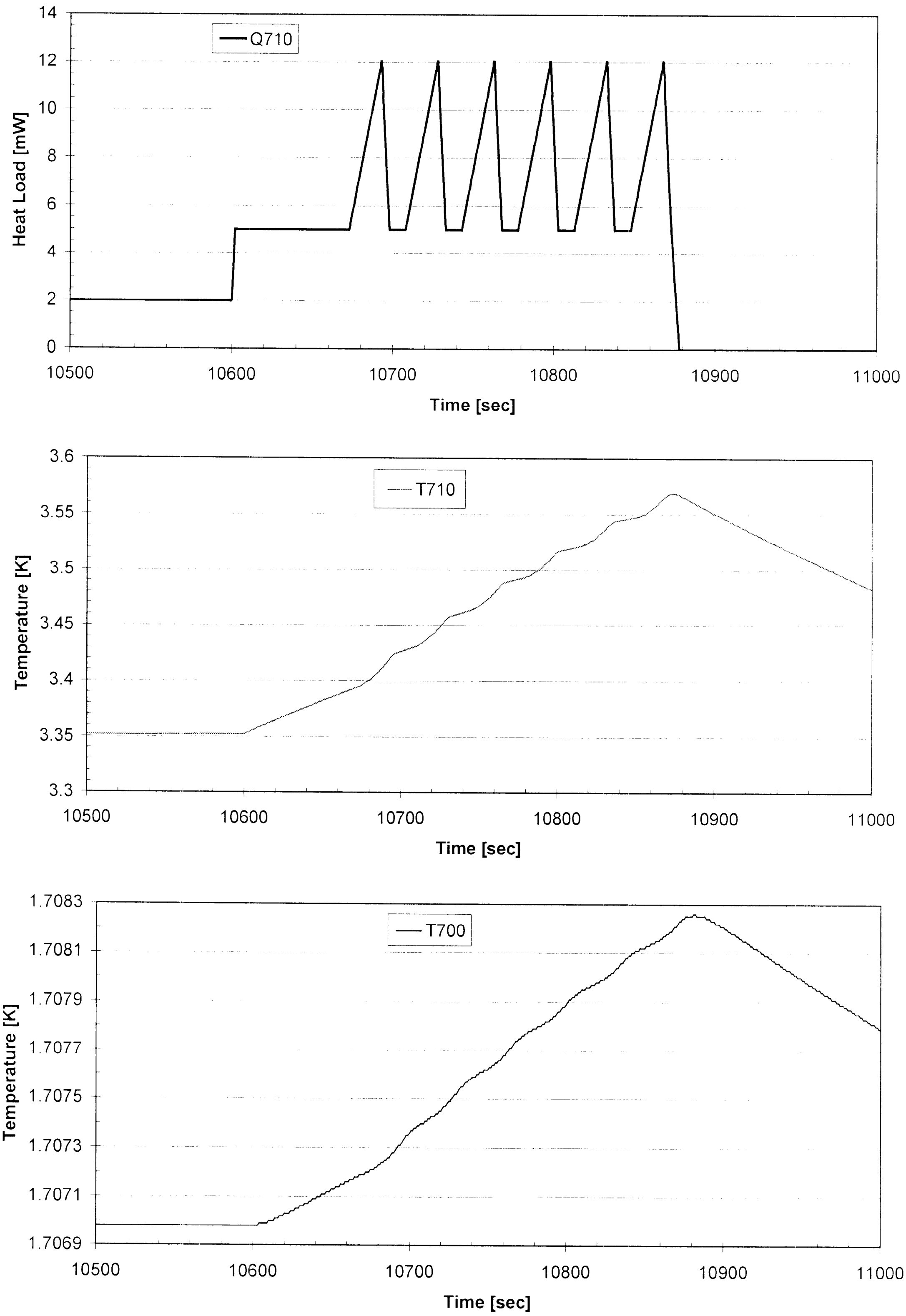


Fig. 7.2.4-5: Mirror Drive Spectrometer Operation (Detail out of Fig. 7.2.4-3). Level 1 Dissipation (top), Level 1 Temperature (mid), Level 0 Temperature (bottom)

7.2.5 Implementation of LOU and BAU in FIRST Thermal Model

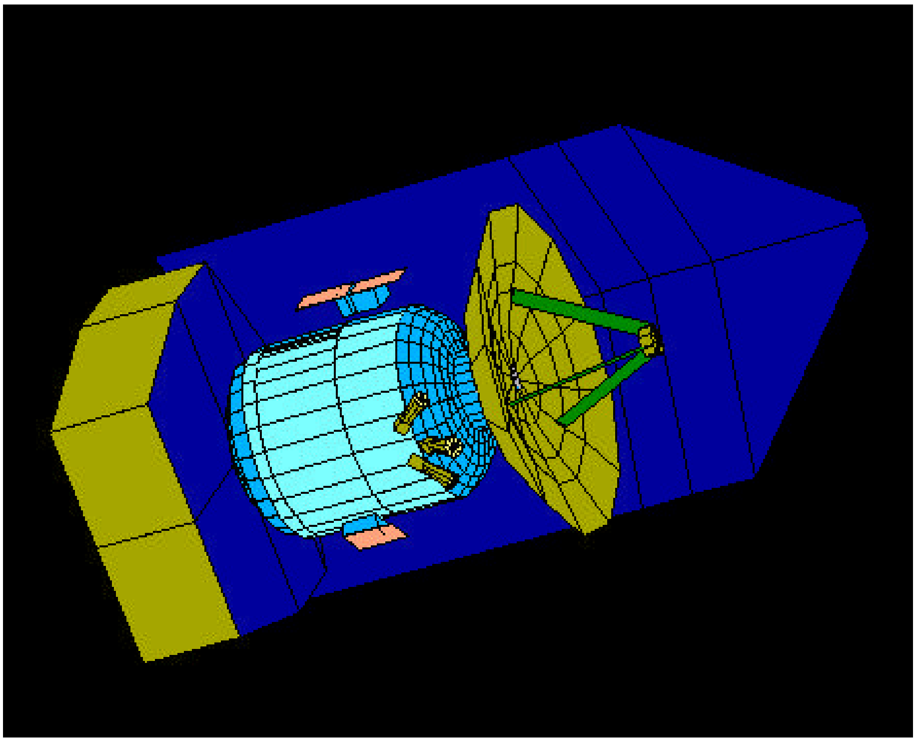
The geometrical configuration of the LOU and BAU in the FIRST thermal model is shown in Fig. 7.2.5-1. The BAU and LOU boxes are mounted outside the CVV by means of GFRP struts. The LOU is subdivided in an amplifier unit LOUA and a multiplexer unit LOUX. The warmer LOUA is attached on the LOUX box with GFRP supports. All boxes and radiator rear sides are wrapped in MLI. Further thermal design details are listed in following Table 7.2-4.

Item	Node	Material / Component	Mass	Size	Dissipat.	Emiss.
LOUX (multiplier)	4200	thermally equivalent to Al	7.5 kg	Box: (270x220x357)mm	1 W	
	4210	MLI				0.15
	4250	Radiator		0.2 m²		0.9
		8 GFRP struts on CVV		cross sect.: 8x47mm², l=177mm		
		14 St.St. WR10 Waveguides to LOUA		14 x WR10 (17mm²), l=50mm		
LOUA (amplifier)	4300	thermally equivalent to Al	2.3 kg	Box: (110x220x357)mm	12 W	
	4310	MLI				0.15
	4350	Radiator		0.2 m²		0.9
		6 GFRP supports on LOUX		cross sect.: 6x20mm², l=50mm		
	4360	14 Al WR28 Waveguides to SVM *	1.8 kg	14 x WR28 (360mm²) *, l=2.3m		
		6 GFRP Waveguide supports on CVV		cross sect.: 6x30mm², l=50mm		
BAU	4700	thermally equivalent to Al	3 kg	Box: (360x150x380)mm	2.5 W	
	4710	MLI				0.15
	4750	Radiator		0.2 m²		0.9
		8 GFRP struts on CVV		cross sect.: 8x21mm², l=177mm		

*) stainless steel waveguides with 0.15 mm wall thickness have been investigated as option

Table 7.2-4: Item List for External Boxes Thermal Model

The analysis results are presented in Fig. 7.2.5-3 for the baseline aluminum waveguide version (red) and for a stainless steel waveguide version (black). Due to the high conductance of the aluminum waveguides. a high heat flow from the warmer SVM and LOUA is conducted to the CVV via the waveguide GFRP supports. Compared to a stainless steel waveguide solution, the lifetime is reduced by about 15 days. Therefore, it is recommended to use a low conductivity waveguide material, such as stainless steel, invar, titanium or GFRP.



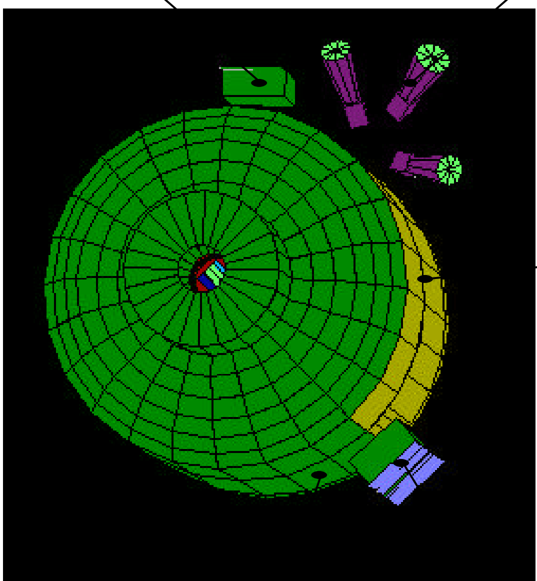


Fig. 7.2.5-1: Thermal Geometry Model of CVV with External Boxes

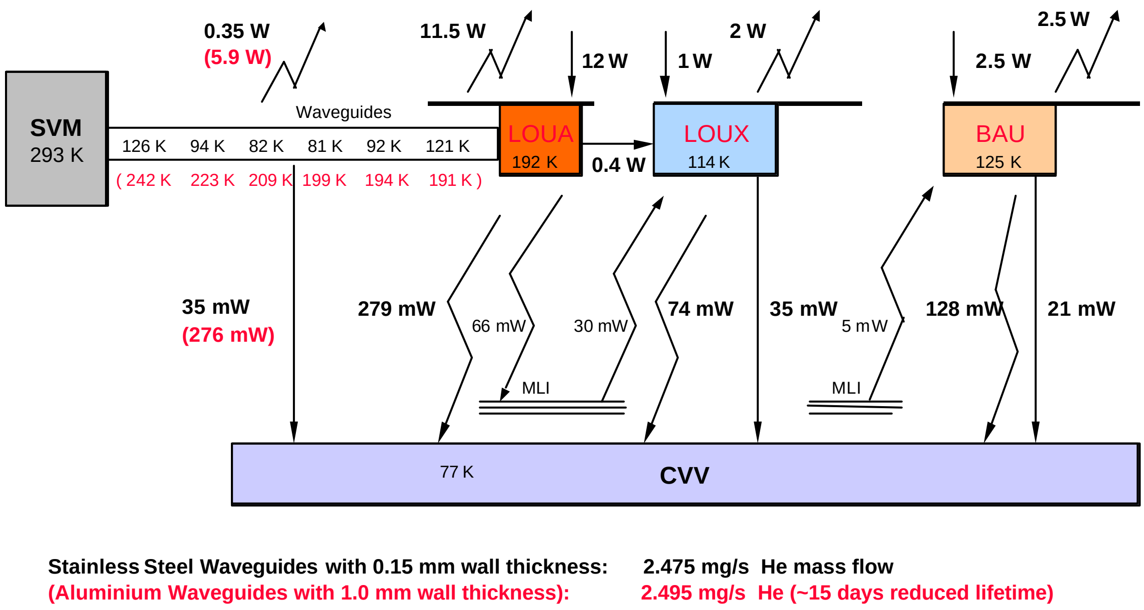


Fig. 7.3.5-2: Temperature Distribution and Heat Flow Chart of LOU and BAU

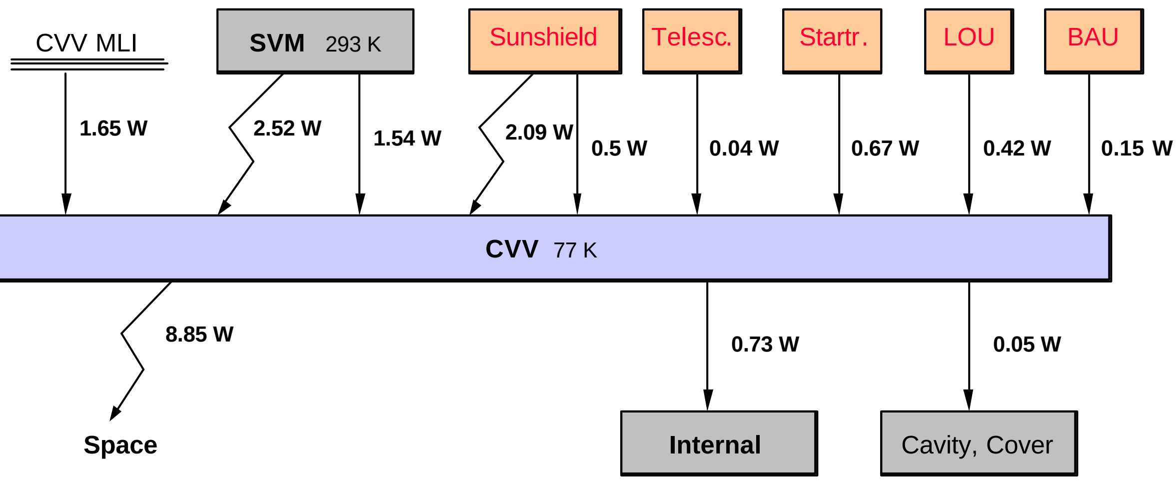


Fig. 7.3.5-3: Heat Flow Chart of CVV for Average Instrument Dissipation (stainless steel waveguide version)

8. Budgets

8.1 Mass Budget

Due to the increased instrument mass and volume the following masses have been adapted:

Item	Nominal Mass [kg]	Mass incl. margin
Optical Bench:	54	64.8
Common Instrument Shield:	10	11.5
Cryo Harness:	8	9.6
BAU Plate and Fixation H/W	4	4.8

The total nominal PLM mass (without scientific instruments, LO,BAU, Startracker and Telescope) is increased from 1356.9 kg to 1406.9 kg.

8.2 Massflow/ Lifetime

The average massflow is 2.45 mg/s, which corresponds to about 4.3 years lifetime for a HeII-volume of 2560 l.
Taking into account the estimated increased brass cross-section and ohmic dissipation (tbc) for the HIFI harness the lifetime is clearly reduced to about 3.7 years.

9. Inputs to IID A update

For update of the IID A the following input is provided:

- Mech./thermal interfaces of FPUs:

Fig. 5.1-2: Arrangement of FPU´s – top view
Fig. 5.1-3 : Arrangement of FPU´s – side view (from–y-side)
Fig. 5.1-4: Arrangement of FPU´s – side view (from –z-side)
Principles for instrument fixation on the OB with Fig. 5.1-5: Sketch of instrument fixation
Fig. 5.1-6: Connection of instruments to He-ventline (level 1 and level 2)
Fig. 5.1 - 7: Standard ISO mounting concept

- Local Oscillator:

Fig. 5.2-1: LO Installation Layout
Fig. 5.2-3: LO vaccum feedthroughs

- Cryostat:

Harness General design rules (see chapter 6)
Structural Models of Instruments shall be provided in NASTRAN
For Thermal Mathematical Models the following informations are required:

- material, cross-sections, length of all relevant suspensions
- dissipations (average and vs. time) on different stages
- harness properties (material, cross-section, length, current, duty-cycle)
- material of the various temperature stages for transient calculations
- thermo-optical properties of surfaces

10. Conclusions

The present FIRST instrument design has been implemented. The Instrument I/F to the PLM have been further detailed in this study. But since the instrument design is still in progress and there are even different options for one instruement, some important points remain open as e.g. distance between instruments, position of instrument connectors, optimization of harness for updated harness tables, harness routing. The cryostat performance, which is significantly affected by the updated instrument requirements, has been checked.
It is strongly recommended to continue with detailing of the instrument interfaces and supporting the instrument development.