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B-1	x								26	x							
C-1	x								27	x							
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Table of Content

1 Introduction

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

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

Another constraint is that the alignment requirements are valid for in-orbit and cold conditions whereas the on-ground alignment can only be performed at warm conditions.

In this technical report we present the alignment concept for the Herschel payload taking into account the above mentioned constraints.

The Herschel Extended Payload Module is shown in Figure 1-1.

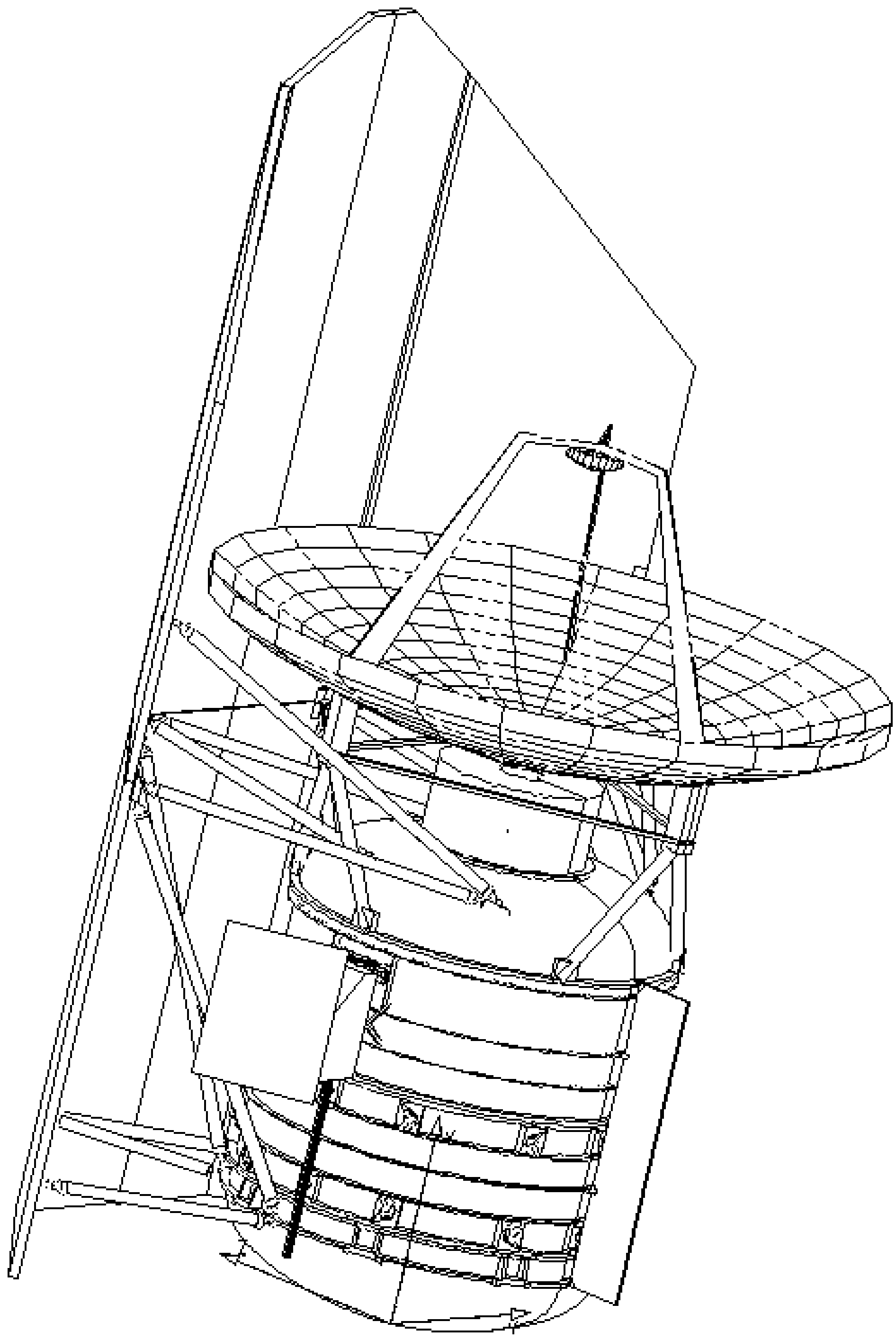

Figure 1-1: Herschel Extended Payload Module

2 Documents

2.1 Applicable Documents

[AD 1]	Instrument Interface Document IID Part A SCI-PT-IIDA-04624, Issue 1/0, dated 1.09.2000
[AD 2]	Instrument Interface Document Part B, Instrument HIFI SCI-PT-IIDB/HIFI-02125, Issue 1/0, dated 1.09.2000
[AD 3]	Instrument Interface Document Part B, Instrument PACS SCI-PT-IIDB/HIFI-02126, Issue 1/0, dated 1.09.2000
[AD 4]	Instrument Interface Document Part B, Instrument SPIRE SCI-PT-IIDB/HIFI-02124, Issue 1/0, dated 1.09.2000
[AD 5]	FIRST Telescope Specification SCI-PT-RS-04671, Issue 3/0, dated 2.05.2000

2.2 Reference Documents

[RD 1]	HIFI – LOU Alignment Plan (Annex 2 in IID Part A, SCI-PT-IIDA-04624, Issue 1/0, dated 1.09.2000)

3 Alignment Requirements

The alignment requirements for Herschel are defined in the documents [AD 1] through [AD 4]. There are two constraints:

- The alignment requirements listed in the above mentioned documents must be fulfilled in space.

- The requirements are valid for operational conditions (FPU at appr. 15K and LOU at appr. 100K), whereas the alignment will be carried out at ambient conditions. Only a check of the actual alignment is possible in operational conditions

An alignment concept and overall alignment strategy which takes into account the above mentioned constraints will be discussed in the next chapters.

The alignment requirements are as follows:

3.1 Axial Focus Alignment

The absolute focus alignment between the telescope focal plane and each instrument shall be ≤ ± 11mm. This is shared between the different interfaces as follows:

- **Instrument alignment w.r.t the OB**
  The instruments shall be mounted on the OB with an accuracy of ≤ ± 3mm in axial direction. The instrument internal alignment is in the responsibility of the instrument manufacturers and the internal error does not belong to the 3mm. TBC by Alcatel.

- **Optical bench w.r.t. the CVV**
  The Optical Bench shall be mounted w.r.t. the CVV with an accuracy of ≤ ± 5mm.

- **Telescope w.r.t. the CVV**
  The alignment accuracy of the telescope w.r.t. the CVV shall be ≤ ± 9mm. This value includes ± 5mm variation during one orbit above 40000km altitude.

3.2 Lateral Focus and Tilt Alignment

The overall tilt error shall be smaller than 12 arcmin (cone angle). This error corresponds to a lateral misalignment of 16mm. The overall tilt error has to be shared by several contributions and split between lateral and tilt requirements.

The following table shows “reasonable numbers” for the individual contributions and shows the requirements for lateral and tilt alignment (based on ISO experience):

Alignment Step	Axis (arcmin)	Lateral (mm)	ResultingTilt (arcmin)
Instrument adjustment w.r.t. OB 1)	8	3	9.11
OB w.r.t. CVV	1	0.5	1.2
Telescope knowledge	NA	1	1.5
PLM / Telescope adjustment	1	1	1.8
Telescope stability	NA	0.1	0.1
Instrument stability 2)			
PLM stability (ISO type)	0.4	0.3	0.6
Total			9.5

Table 3.2-1: Summary of Lateral and Tilt Alignment Requirements

1) It is assumed that the instrument internal alignment accuracy does not contribute to this value. If this is true, remark 2) is also obsolete. TBC by Alcatel

2) Included in instrument adjustment

A distance of 2288mm between secondary mirror and focal plane has been assumed.

We understand Table 3.2-1 as reasonable breakdown of the overall requirement of 12 arcmin between lateral and tilt values. The system level requirements are fulfilled as long as the 12 arcmin value has been achieved, even if some figures are greater than in Table 3.2-1. TBC by Alcatel.

3.3 Roll Requirement

The roll error shall be less than 1 degree. This requirement is not shared between the different interfaces.

3.4 LOU to HIFI Alignment Requirements

The alignment requirements for the LOU w.r.t. the HIFI FPU have been taken from the document [AD 2]

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

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

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

The alignment requirements for the LOU w.r.t. the HIFI FPU must also be satisfied for ground tests of e.g. the coupling of the LOU to the mixers inside the FPU (TBC by HIFI).

Stability Requirements for LOU w.r.t. HIFI

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

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

4 Herschel Alignment Concept

In this chapter we provide a description of the Herschel alignment concept. The alignment concept described below is chosen such, that except the LOU alignment camera conventional alignment tools can be used.

The internal instrument and telescope alignment are under the responsibility of the manufacturers and are not covered within this document.

The three Herschel instruments HIFI, PACS and SPIRE must be placed precisely at the telescope focus. Therefore an instrument alignment must be performed w.r.t. the telescope focus during the system level integration activities.
During the Herschel integration, however, the telescope is the last subsystem which will be mounted outside and upon the cryostat. At this integration stage the cryostat cover is already closed and therefore the optical reference from the instruments can no longer be seen. Consequently the instruments must be aligned to a common intermediate optical reference to which the telescope is aligned later on. The integration and alignment steps are as follows:

1. Mounting of a reference cube at the optical bench.

2. Integration of the three instruments onto the optical bench. Each instrument is equipped with an alignment cube to represent its internal alignment (see Figure 4-1).

3. Alignment measurement of the instruments w.r.t. the OB reference cube as shown in Figure 4-2 to know the actual orientation (position and angle). This measurement will be performed with the OB on a laboratory table. 1)

4. Integration of the OB into the cryostat.

5. Alignment measurement of OB reference cube w.r.t. a reference cube mounted outside the CVV (see Figure 4-3).

6. Closing the CVV cover, evacuation and cool down.

7. Re-adjustment of the tank straps and alignment control using the special camera proposed by HIFI

8. Telescope integration.

9. Alignment measurement of the telescope reference cube w.r.t. the CVV cube as shown in Figure 4-5.

Remark:

1) It is also possible to integrate the instruments onto the OB in case the OB is already mounted inside the cryostat.

To compensate for the variation in focal length and manufacturing tolerances the telescope and the instruments shall be delivered with shimming plates TBC. The shimming plates can also be used for angular corrections if necessary. The decision whether the shimming plates for the instruments are needed depends on the alignment budget. The actual alignment budget which takes into account the in-orbit effects (see chapter 6) is in preparation. With the new budget we will decide if the shimming plates are needed.

Dowel pins mounted at the OB and the telescope I/F to the CVV shall serve as alignment reference to allow to find the alignment position again after removing of the instruments or the telescope (e.g. for insertion of new shims).

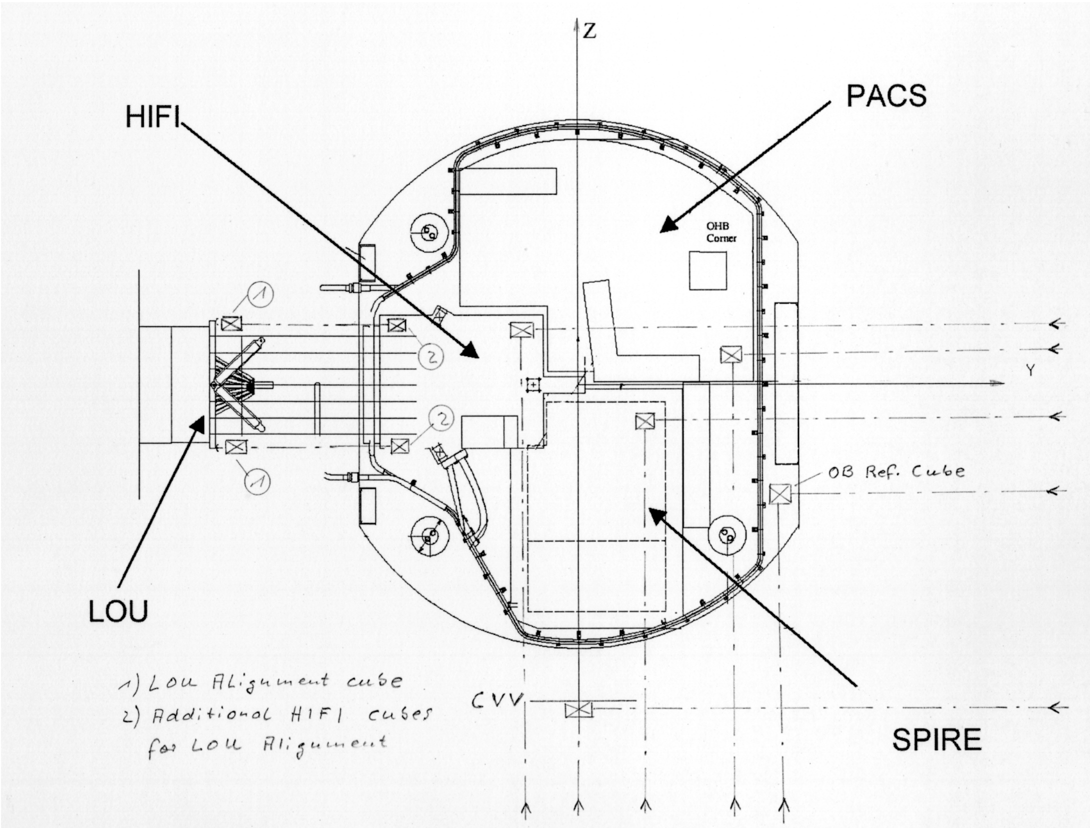

Figure 4-1: Alignment References

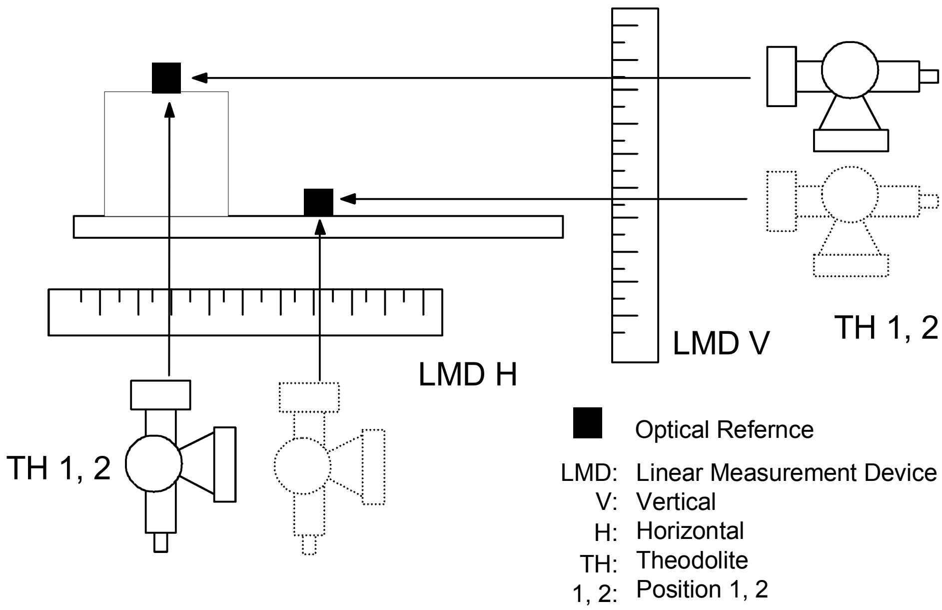

Figure 4-2: Instrument Alignment w.r.t. Optical Bench

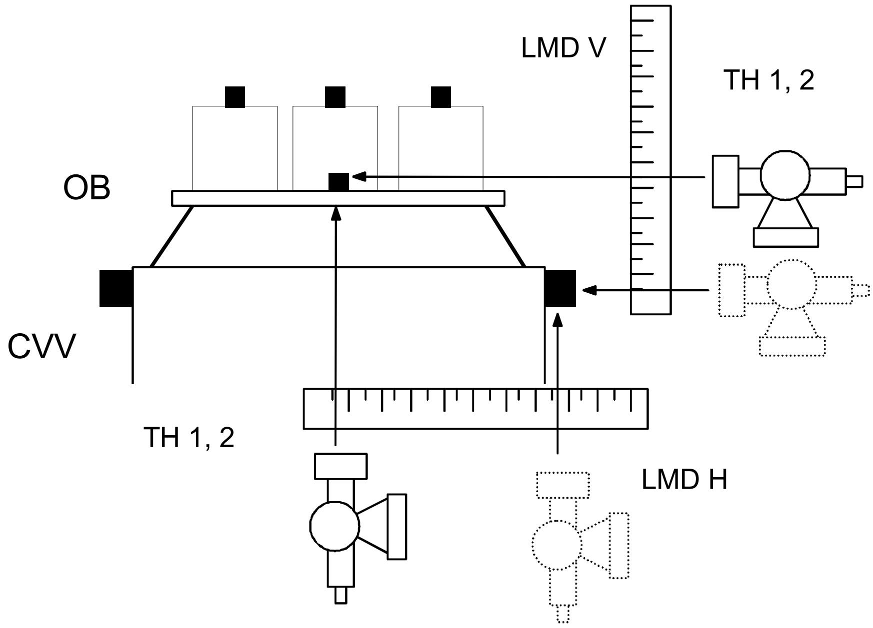

Figure 4-3: Optical Bench Alignment w.r.t. CVV

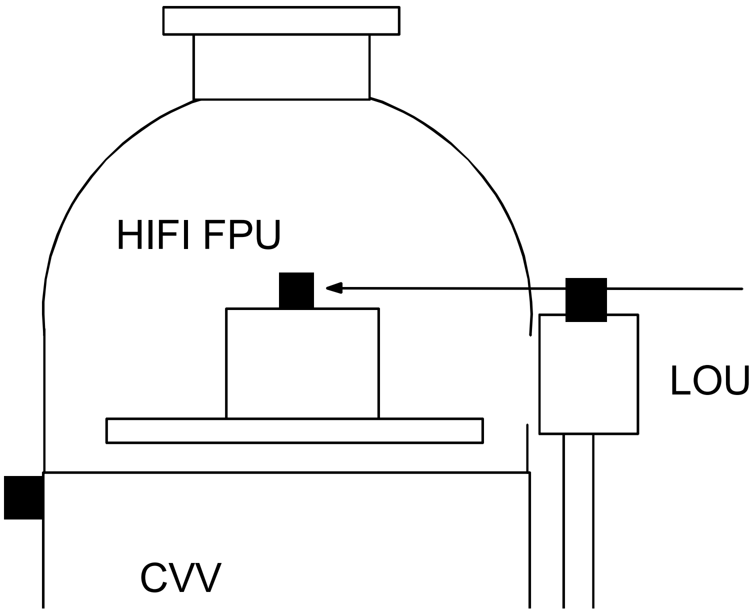

Figure 4-4: LOU Alignment w.r.t. HIFI
(With the LOU Camera proposed by, HIFI TBC by HIFI)

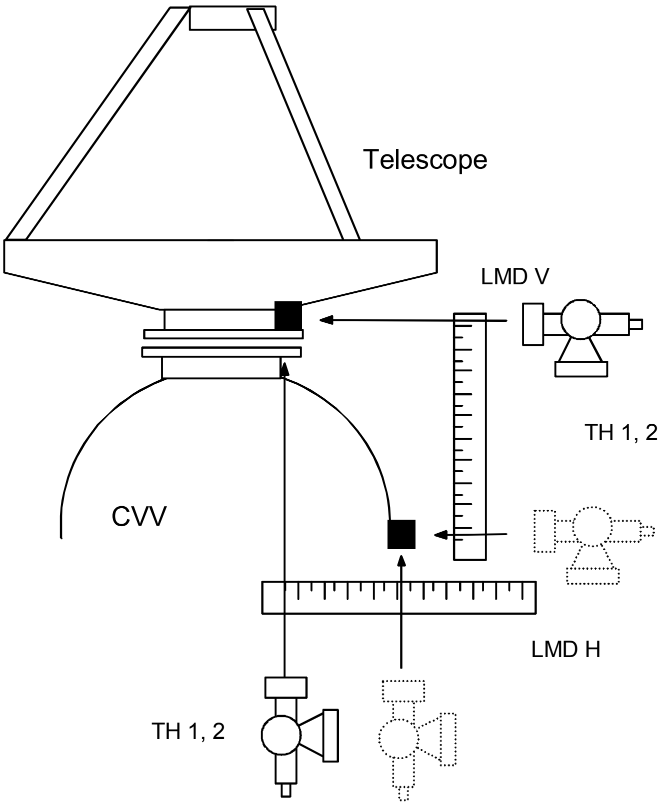

Figure 4-5: Telescope Alignment w.r.t. CVV Reference Cube

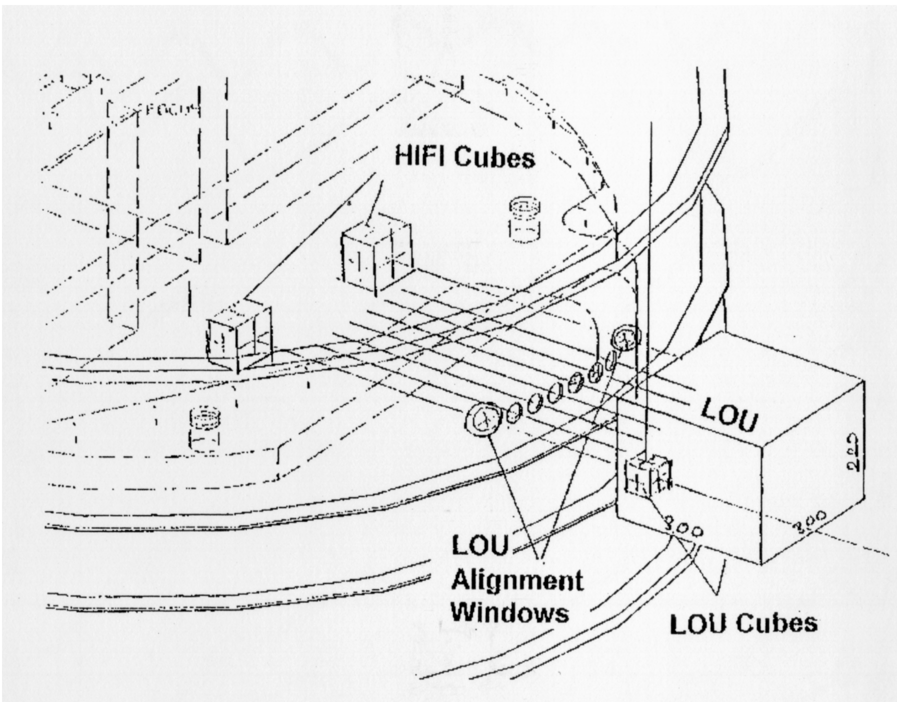

Figure 4-6: Detection of HIFI using the LOU Alignment Windows

The alignment cube position of the instruments, OB, CVV and telescope will be defined in chapter 7.

The alignment measurements can be subdivided into two major categories:

- Linear measurements (axial and lateral)
- Angular measurements (tilt and roll).

The angular alignment is subdivided into tilt measurements (rotation about the y and z axes) and roll measurements (rotation about the S/C x axis). For both measurements standard optical cube and autocollimation techniques will be used. To allow this two sides of an optical reference cube must be accessible as a minimum. One side for the rotation about the y axis and the other for the rotation about the z axis. The roll measurement can be performed from both sides.
In chapter 7 we will define for all measurements the direction from which the alignment measurements will be performed during system level alignment. The internal instrument alignment shall be performed from the same directions.

Angular Measurements

Because autocollimation measurements are standard this chapter gives only a short description. A theodolite is set in autocollimation at the first reference cube (for example OB). A second theodolite (or the same) is set in autocollimation w.r.t. the second reference cube (for example instrument). The difference from both readings gives the angle between both reference cubes taking into account the theodolite internal horizontal calibration (for rotation about the y and z axes). For roll measurements an additional outer reference such as an angular transfer prism must be used as reference for both measurements (to transfer the angular measurements from one cube to the other).

The use of an angular transfer prism is explained as an example for the roll measurement of an instrument w.r.t. the OB reference cube (see Figure 4-8). A theodolite is set in autocollimation w.r.t. the OB reference cube. The theodolite is then rotated by 90° in order to adjust the angular transfer prism (rotation of the ATP about the x axis until autocollimation is achieved). This defined direction can be picked up by a second theodolite performing autocollimation w.r.t. the ATP. Rotating this theodolite by 90° and looking in autocollimation onto the instrument reference cube determines the angular difference between the OB reference cube and the instrument.

Linear Measurements

For the linear measurements in focus direction and laterally all reference cubes shall have cross hairs. For the position measurements a linear measurement device will be used. The same device will be used for measurements in x- and y-z direction. It works as follows:

A scale tape (steel) is mounted onto a rail under a defined mechanical tension (spring load). On the tape surface are engraved code bars which provide an absolute linear position code. The actual position is defined by aiming sequentially at position reference cubes with cross hair on the PLM and an alignment target at the linear measurement device with a theodolite. The actual position is read by a scanning head and shown on a display. Figure 4-7 shows a typical linear measurement device and Figure 4-8 its application for a lateral measurement.

This linear measurement device is already available at Astrium. The length is appr. 2m. It has been designed and successfully used for XMM and is now in use for METOP. The measurement accuracy achieved was ± 0.2mm, but depends on calibration. Errors introduced by non perfect alignment of the linear measurement device w.r.t the relevant alignment axis defined by the PLM must be considered additionally.

Some modifications concerning the LMD support structure are necessary to use the LMD for axial and lateral measurements.

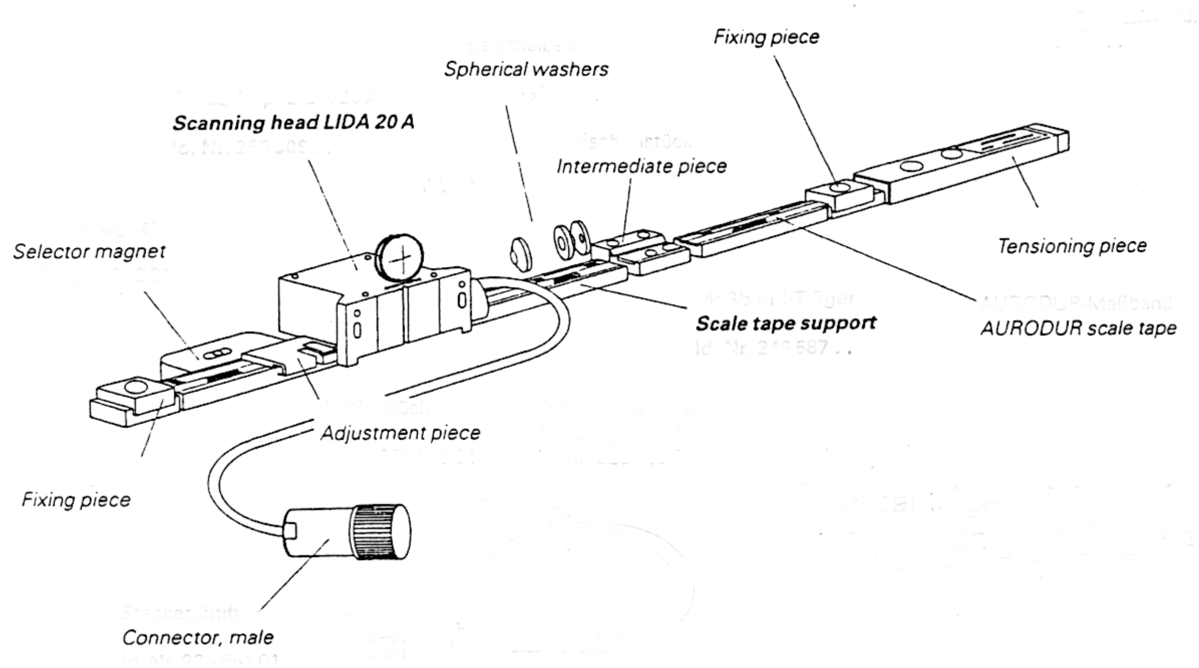

Figure 4-7: Linear Measurement Device

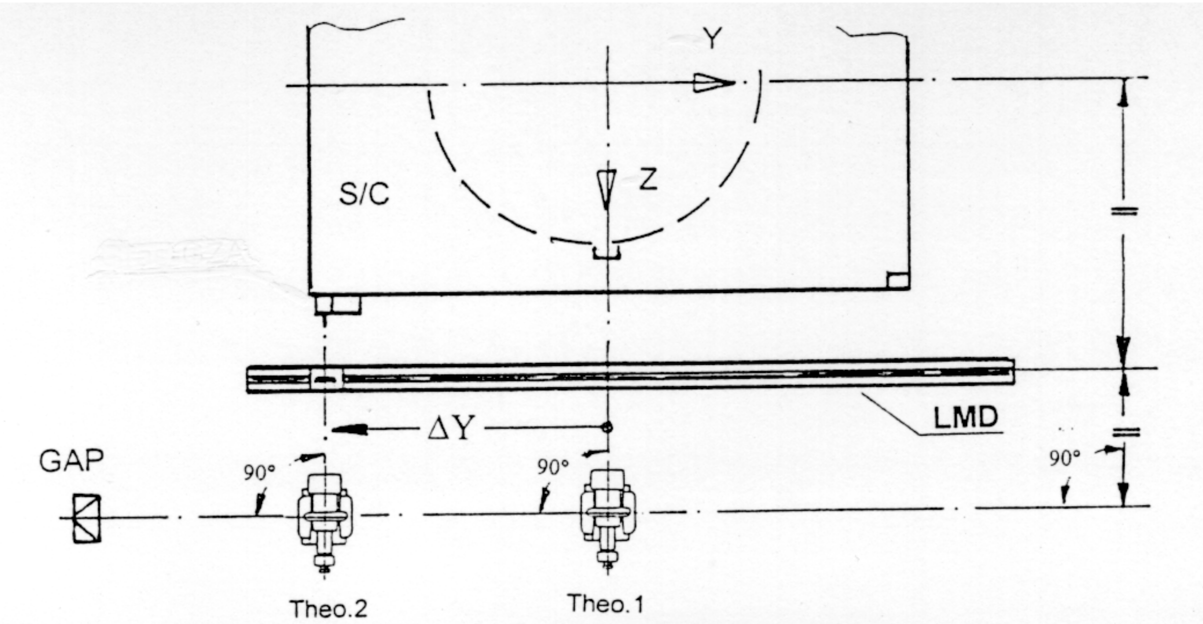

Figure 4-8: Lateral Distance Measurement using a LMD

5 Alignment Plan

This chapter defines the alignment philosophy and the measurements which will be performed with the individual models. During the on-ground alignment two constraints must be taken into account:

1. The alignment requirements are valid for in-orbit conditions

2. The alignment requirements are specified for operational conditions, whereas the alignment can only be performed at ambient conditions.

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

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

These effects must be determined and have to be pre-compensated by a corresponding offset on-ground.

For the initial alignment performed with the EQM this offset must be determined theoretically and confirmed during testing.
Effects due to temperature and pressure change can be confirmed during on-ground testing, however, the gravity release effect can only be determined theoretically. Restrictions must also be made for the testing of the temperature change.

Alignment of the Herschel PLM has to be performed in various steps.

5.1 EQM Alignment

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

.....PLM Integration→Alignment→Closing Cryostat→Evacuation→Alignment check →

Cooling→Alignment check→Other Tests.....

Only the alignment relevant steps have been shown. The complete test plan is shown in the relevant AIV documentation.

The main tasks are the following:

- Early verification of the alignment
- Verification of pressure and temperature change effects on alignment (with an outer CVV temperature at 300K)
- Lessons learned with the EQM can already be applied for the STM
- No end to end test seems possible but: switching on the LOU and determine the signal strength at HIFI will verify correct alignment of LOU w.r.t. HIFI (this is only possible if the LOU can be sub-cooled to orbit representative temperatures)
- Risk reduction for the STM and FM programme

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

Two alignment cameras are mounted temporarily on the LOU allowing to monitor simultaneously tilt and offsets (two cameras are needed to determine the rotation about the y axis). A distance measurement in y direction is not possible, however, the distance requirement w.r.t. this axis is very comfortable (± 15mm for LOU w.r.t. HIFI FPU), so that we can rely on the mathematical model for this direction TBC. For the lateral instrument alignment w.r.t. the telescope focus this will be checked in the course of phase B.

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

5.2 STM Alignment

The STM serves for the qualification of the structure. Therefore the alignment shall be checked before and after the environmental testing. Furthermore, the effect on alignment due to outer CVV temperature change can be verified with the STM inside the TV chamber.

The main tasks are as follows:

- Qualification of the structure (stability)
  (Alignment measurement before and after the environmental tests)

- Verification of the temperature change w.r.t. outer CVV temperature (TV chamber)

- Confirmation of the mathematical model

The actual test sequence is as follows (only alignment related steps - this sequence might be changed in the relevant AIV documents):

.....PLM Integration→Alignment→Closing Cryostat→Evacuation→Warm vibration

→Alignment check → Cooling→Alignment check→Telescope integration

→ Telescope alignment→.....→Cold vibration→Alignment check→Telescope

deintegration→.....→TB/TV test→Alignment check→.....

Monitoring of the alignment stability also in the TV chamber will be performed using the dedicated HIFI alignment camera TBC.

Please note: There is no possibility to measure the shift in y direction, however, the alignment requirement in this direction is very comfortable (± 15mm) and we can rely on the mathematical model TBC.

5.3 PFM Alignment

For the PFM a validated and accepted alignment procedure is already approved with the EQM and the STM.

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

.....PLM integration→Alignment→Evacuation→Alignment check→Warm vibration

→Cooling→Alignment check→.....→Telescope integration→Telescope alignment

→.....→Cold vibration→Alignment check→.....→TB/TV test→Alignment check→.....

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

6 Alignment Budget

In the previous chapters a Herschel alignment concept has been described for distance and angular measurements. In this chapter it shall be shown which individual errors contribute to the overall achievable alignment accuracy and which alignment accuracy can be achieved with the proposed alignment method. The result will be compared with the alignment requirements shown in chapter 3.

The following main error sources have been identified as single contributions to the overall alignment error:

- On-Ground Alignment
  The achievable on-ground accuracy includes all measurement and adjustment errors occurring during on-ground integration and alignment procedures. The instruments internal alignment accuracy is not under Astrium responsibility and therefore not covered here.

- Vacuum and Temperature effects on-ground
  Comprises all errors that will occur during cryostat evacuation and cool-down.

- Launch and initial orbit
  Includes all error sources originating from the launch loads and the differences between the on-ground alignment conditions and the in-orbit environmental conditions. The following error sources will be considered:

  - Gravity release
  - Atmospheric pressure from 1bar to 0bar
  - Initial temperature change (outer CVV temperature)

- Thermal Stability
  Covers the drift errors as specified by the instruments within certain time intervals and long term variations during the mission.

A preliminary Herschel alignment budget has been presented in the Astrium proposal. At this time it is still valid, but an update is in preparation. Please note, that the budget shown in the proposal does not include all of the above listed error contributions, but they will be implemented in the next update. The update will be based on a thermal mechanical model which considers the above mentioned effects besides the achievable on-ground alignment accuracy.

7 Alignment References

In this chapter the alignment references for each instrument or H/W will be defined for which alignment is required.

The exact position of the alignment reference cubes can only be determined after finalisation of the optical bench design. The positions will be implemented in the next update of this document.

7.1 Instruments

Each instrument has to be equipped with an external reference cube with cross hair representing its optical axis (position and direction). After finalisation of the OB design, the position of the reference cubes will be defined and the accessibility during system level tests will be checked. The positions as already proposed by the instruments will be maintained as far as possible.

To measure all relevant parameters, Rx, Ry, Rz, Tx, Ty, Tz, two sides of the reference cubes must be accessible as a minimum. The accessible and therefore used sides during system level alignment will be defined in the course of phase B.

To maintain the full traceability from the CCD position to the telescope focus the same reference sides shall be used by the instruments for their internal alignment.

7.1.1 HIFI

Position of reference cube for OB alignment is TBD.

For the LOU alignment HIFI must be equipped with two additional alignment cubes which shall be visible from -y side. Position TBD

7.1.2 PACS

Position of reference cubeTBD

7.1.3 SPIRE

Position of reference cube TBD

7.2 Optical Bench

The three instruments will be mounted on the OB outside the cryostat and aligned to an OB reference cube.

The position of the OB reference cube is TBD.

7.3 Cryostat Vacuum Vessel

After integration of the OB into the cryostat the OB will be aligned w.r.t. the CVV. Therefore the CVV will be equipped with a reference cube mounted at the circumference of the CVV cylinders upper part. The exact position is TBD. The CVV cube serves also as reference for the OB and the telescope accommodation after the cryostat cover has been closed. The cube faces represent the nominal direction of the telescope optical axis. For axial and lateral alignment they shall be equipped with cross hairs at known positions in CVV coordinates.

7.4 Telescope

After the cryostat has been closed the telescope can be integrated. For alignment w.r.t. the CVV cube the telescope shall be equipped with a reference cube located nearby the interface triangle at a stable position. For axial and lateral alignment the reference cube must provide cross hairs.

The exact position of the reference cube is TBD.

7.5 Alignment Windows

For the LOU alignment w.r.t. the HIFI FPU two alignment windows in the cryostat are needed. Suitable positions for these two windows would be adjacent to the first and last of the seven submillimeter windows, in position 0 and 8.

Exact position and window diameter is TBD.

No further alignment windows in the cryostat are needed with the proposed alignment concept.

8 Alignment Support Equipment

The alignment concept proposed above is chosen, that standard laboratory products can be used to a large extend. Most of the equipment is already available at Astrium, but needs to be adapted for Herschel. In the following table the main equipment needed for Herschel system level alignment activities is shown.

Nr.	Qty	Equipment	Description	Available	Procurement
1	1	Optical Table	For instrument alignment w.r.t. OB 1)	x	
2	2	Theodolite	Wild T2000 S or equivalent	x	
3	1	Linear Measurement Device	For axial and lateral distance measurements	x	
4	2	Angular Transfer Prism	As reference for azimuth	x	
5	2	LOU Alignment Camera	LOU alignment and alignment monitoring		2)
9	Appr.20	Alignment reference cubes	For OB, CVV......		x
6	1	Support Structure for LMD	For vertical and horizontal measurements	3)	
7	1	Tripod	For Theodolite Height appr. 7m		4)
8	1	Adjustable support for PLM or use of a rotary table	For precise levelling of the PLM		5)
9	1	Adapter	For SVM I/F		x
10	1	Adapter	For PLM I/F		x
11	1	Cherry Picker			6)

Table 8-1: Alignment Equipment List (preliminary)

1) Only needed in case of pre-alignment of the instruments w.r.t. the OB

2) It is assumed that the LOU alignment w.r.t. the HIFI FPU can be performed with the LOU Camera TBC by HIFI. If not possible additional OGSE could be necessary.

3) Made with X95 System TBC

4) It will be clarified if the ERS or METOP tripod is available

5) It will be checked if the ERS rotary table is available. At this time it will be used by METOP

6) Will be procured with the MGSE Batch

9 Abbreviations

AD	Applicable Document
AIV	Assembly Integration Verification
CVV	Cryostat Vacuum Vessel
EQM	Engineering Qualification Model
FPU	Focal Plane Unit
HIFI	Heterodyne Instrument for FIRST
IID A	Instrument Interface Document (Part A)
IID B	Instrument Interface Document (Part B)
H/W	Hardware
I/F	Interface
LOU	Local Oscillator Unit
LMD	Linear Measurement Device
OB	Optical Bench
OGSE	Optical Ground Support Equipment
PACS	Photoconductor Array Camera & Spectrometer
PFM	Proto Flight Model
PLM	Payload Module
RD	Reference Document
S/C	Spacecraft
SPIRE	Spectral & Photometric Imaging Receiver
STM	Structural Thermal Model
TBC	To Be Confirmed
TBD	To Be Determined