Herschel/Planck

Instrument Interface Document

IID PART A

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepared/compiled by</td>
<td>Herschel/Planck Project Team Alcatel</td>
</tr>
<tr>
<td>Agreed by</td>
<td>Instrument PIs</td>
</tr>
<tr>
<td>Approved by</td>
<td>J.-J. Juillet Project Manager ASPI</td>
</tr>
<tr>
<td>Approved by</td>
<td>T.Passvogel Project Manager ESA/ESTEC/SCI/PT</td>
</tr>
</tbody>
</table>
# Distribution List

(Distribution in electronic format (Adobe PDF))

<table>
<thead>
<tr>
<th>Qty</th>
<th>Organisation</th>
<th>Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ESA</td>
<td>ESA</td>
</tr>
<tr>
<td>1</td>
<td>Prime Contractor / Planck PLM</td>
<td>Alcatel</td>
</tr>
<tr>
<td>1</td>
<td>Herschel EPLM</td>
<td>Astrium GmbH</td>
</tr>
<tr>
<td>1</td>
<td>SVM</td>
<td>Alenia</td>
</tr>
<tr>
<td>1</td>
<td>Herschel SPIRE</td>
<td>Univ.Cardiff/RAL</td>
</tr>
<tr>
<td>1</td>
<td>Herschel PACS</td>
<td>MPE</td>
</tr>
<tr>
<td>1</td>
<td>Herschel HIFI</td>
<td>SRON</td>
</tr>
<tr>
<td>1</td>
<td>Planck LFI</td>
<td>TESRE/CNR</td>
</tr>
<tr>
<td>1</td>
<td>Planck HFI</td>
<td>IAS</td>
</tr>
<tr>
<td>1</td>
<td>Planck Reflectors</td>
<td>DSRI</td>
</tr>
</tbody>
</table>
## Document Change Record

<table>
<thead>
<tr>
<th>Issue-Rev</th>
<th>Date</th>
<th>Version</th>
<th>Pages affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-0</td>
<td>01/09/2000</td>
<td>Initial Issue for ITT</td>
<td>New Document</td>
</tr>
<tr>
<td>2-0</td>
<td>31/07/2001</td>
<td>Issue for SRR</td>
<td>Complete Revision: Renaming of FIRST by Herschel. Changes made by change bars (including editorial changes).</td>
</tr>
</tbody>
</table>
# Table of Contents

1. **INTRODUCTION**

2. **APPLICABLE/REFERENCE DOCUMENTS**
   2.1 APPLICABLE DOCUMENTS
   2.2 REFERENCE DOCUMENTS
   2.3 LIST OF ACRONYMS

3. **KEY PERSONNEL AND RESPONSIBILITIES**
   3.1 ESA PERSONNEL
   3.2 CONTRACTOR PERSONNEL

4. **SATELLITE DESCRIPTION**
   4.1 INTRODUCTION
   4.2 SYSTEM DESCRIPTION
   4.3 Herschel PAYLOAD MODULE (FPLM)
   4.3.1 Herschel Telescope
   4.3.2 Helium Cryostat
   4.4 Planck PAYLOAD MODULE (PPLM)
   4.4.1 Planck Telescope and FPU
   4.4.2 PSVM Units
   4.5 SERVICE MODULES (SVM)
   4.5.1 Herschel Service Module
   4.5.2 Planck Service Module
   4.5.3 SVMs Subsystems
   4.6 OPERATING MODES
   4.6.1 Launch
   4.6.2 Herschel
   4.6.3 Planck

5. **INTERFACE WITH INSTRUMENTS**
   5.1 IDENTIFICATION AND LABELLING
   5.1.1 Project code
   5.1.2 Unit identification code
   5.1.3 Connector identification
   5.2 COORDINATE SYSTEM
   5.2.1 Spacecrafts Coordinate system
   5.2.2 Instrument unit coordinate system
   5.3 LOCATION AND ALIGNMENT
   5.3.1 Instrument location
   5.3.2 Instrument alignment
   5.4 EXTERNAL CONFIGURATION DRAWINGS
   5.5 SIZES AND MASS PROPERTIES
   5.5.1 Mass tolerances
   5.5.2 Centre of Gravity Location and Tolerances
   5.5.3 Moments of Inertia and Tolerances
   5.5.4 Overall Instrument Mass Allocation
   5.6 MECHANICAL INTERFACES
   5.6.1 Herschel Payload Module
   5.6.2 Planck Payload Module
   5.6.3 Service Modules
   5.7 THERMAL INTERFACES
5.7.1 Herschel Payload Module
5.7.2 Planck Payload Module
5.7.3 Service Modules

5.8 OPTICAL INTERFACES
5.8.1 Herschel Instruments
5.8.2 Planck Instruments

5.9 POWER
5.9.1 Thermal dissipation on Herschel Payload Module
5.9.2 Thermal dissipation on Planck Payload Module
5.9.3 Thermal dissipation on Herschel Service Module
5.9.4 Thermal dissipation on Planck Service Module
5.9.5 Power Supply - Load on main-bus

5.10 CONNECTORS, HARNESS, GROUNDING, BONDING
5.10.1 Connectors
5.10.2 Harness
5.10.3 Grounding and Isolation
5.10.4 Bonding

5.11 DATA HANDLING
5.11.1 Telemetry
5.11.2 SSR Mass Memory
5.11.3 Timing
5.11.4 Telecommands
5.11.5 Special signals
5.11.6 Interface circuits
5.11.7 Application Process Identifiers

5.12 ATTITUDE AND ORBIT CONTROL/POINTING
5.12.1 Terminology
5.12.2 Herschel Pointing Requirements
5.12.3 Planck Pointing Requirements
5.12.4 Herschel Scientific Pointing modes
5.12.5 Herschel Calibration - Star Tracker
5.12.6 On-Target Flag
5.12.7 Planck Reference Star Pulse
5.12.8 Herschel Slews
5.12.9 Planck Slews

5.13 ON-BOARD HARDWARE/SOFTWARE AND AUTONOMY FUNCTIONS
5.13.1 On-board hardware
5.13.2 On-board software

5.14 EMC
5.14.1 Electrical Interfaces
5.14.2 Harness, Connectors and Shielding
5.14.3 EMC Performance Requirements
5.14.4 Conducted Emission/Susceptibility
5.14.5 Radiated Emission/Susceptibility
5.14.6 Frequency Plan

5.15 INSTRUMENT HANDLING
5.15.1 Transport container
5.15.2 Cleanliness
5.15.3 Physical handling
5.15.4 Purging
5.15.5 Mechanism positions

6 GROUND SUPPORT EQUIPMENT
6.1 Mechanical Ground Support Equipment
6.2 Electrical Ground Support Equipment

6.3 Commonality
- 6.3.1 EGSE
- 6.3.2 Instrument Control and Data Handling
- 6.3.3 Other Areas

7 INTEGRATION, TESTING AND OPERATIONS

7.1 AIV Sequence Overview
- 7.1.1 Herschel AIV Sequence Overview
- 7.1.2 Planck AIV Sequence Overview

7.2 Integration
- 7.2.1 FPLM Integration
- 7.2.2 PPLM Integration
- 7.2.3 FSVM Integration
- 7.2.4 PSVM Integration
- 7.2.5 Herschel S/C PFM Integration
- 7.2.6 Planck S/C Integration

7.3 Herschel/Planck Testing
- 7.3.1 Herschel PLM CQM Testing
- 7.3.2 Herschel S/C CQM Testing
- 7.3.3 Herschel PLM PFM Testing
- 7.3.4 Herschel S/C PFM Testing
- 7.3.5 Planck PLM CQM Testing
- 7.3.6 Planck S/C CQM Testing
- 7.3.7 Planck PLM PFM Testing
- 7.3.8 Planck S/C PFM Testing

7.4 Operations

7.5 Commonality

8 PRODUCT ASSURANCE

9 DEVELOPMENT and QUALIFICATION

9.1 General
- 9.1.1 Definitions
- 9.1.2 Documentation

9.2 Model Philosophy
- 9.2.1 Spacecraft Models
- 9.2.2 Deliverable Instrument Models

9.3 Deliverable Instrument Test Plan
- 9.3.1 Instrument Verification
- 9.3.2 Instrument Scientific Performance Validation

9.4 Design and Analysis Requirements
- 9.4.1 Mechanical Design and Analysis
- 9.4.2 Thermal Verification Requirements
- 9.4.3 Mechanism Verification Requirements
- 9.4.4 Electrical and Software Verification Requirements
- 9.4.5 Radiation Environment Verification

9.5 Verification and Testing
- 9.5.1 General Test Requirements
- 9.5.2 Test Level Tolerances
- 9.5.3 Mechanical Verification and Testing
- 9.5.4 Thermal Verification and Testing
- 9.5.5 Mechanism Verification and Testing
- 9.5.6 EMC Verification and Testing
9.5.7 Qualification to the Radiation Environment

10 MANAGEMENT, PROGRAMME, SCHEDULE

10.1 General

10.2 Management
  10.2.1 ESA Responsibilities
  10.2.2 ESA Organisation
  10.2.3 Principal Investigator Responsibilities
  10.2.4 Instrument Team Organisation
  10.2.5 Formal Communication
  10.2.6 Financing

10.3 Project Control
  10.3.1 Project Control Objectives
  10.3.2 Project Breakdown Structures

10.4 Schedule Control
  10.4.1 Baseline Master Schedule
  10.4.2 Schedule Monitoring
  10.4.3 Schedule Reporting

10.5 Configuration Management
  10.5.1 Objectives
  10.5.2 Responsibilities
  10.5.3 Configuration Identification

10.6 Configuration Control
  10.6.1 Instrument Internal Configuration Control
  10.6.2 IID Configuration Control

10.7 Configuration Status Accounting

10.8 Reviews and reporting
  10.8.1 General
  10.8.2 Instrument Reviews

10.9 Instrument Progress Meetings

10.10 Reporting

10.11 Deliverable Items
  10.11.1 Mathematical Models
  10.11.2 Instrument Models

10.12 Review Data Packages

10.13 Baseline schedule
  10.13.1 Overall Herschel/Planck Baseline Schedule
  10.13.2 Baseline Schedule of Deliverables

Annex 1 Herschel Alignment Plan
Annex 2 HIFI LOU Alignment Plan
Annex 3 Planck Alignment Plan
Annex 4 Herschel Pointing Modes
1. INTRODUCTION

The purpose of the Instrument Interface Documents (IID’s) is to define and control the overall interface between each of the Herschel/Planck scientific instruments and the Herschel/Planck spacecraft.

The IID’s consist of two parts, IID-A and IID-B. There is one part A, covering the interfaces to all Herschel and Planck instruments, and one IID-B per instrument:

- The IID-A describes the implementation of the instrument requirements in the design of the spacecraft and will be a result of the spacecraft design activities performed by the Contractor.

- Each IID-B defines in its ‘interface’ section (chapter 5) the requirements of the instrument and the resources to be provided by the spacecraft. In its ‘performance’ section (last section of chapter 4) it defines the scientific performance requirements of the instrument as part of the scientific mission requirements and as agreed between the Principal Investigators and ESA.

After issue 2/0 by ESA the Contractor will be responsible for maintenance and configuration control of the IID’s in agreement with, and after approval by, the Instruments Principal Investigators and ESA.

In case of conflict between the contents of the IID-A and the IID-Bs, the agreement or definition in the IID-B shall take precedence.

The IID’s will not cover any of the interfaces of the Instrument Control Centres (ICC’s for Herschel), the Data Processing Centres (DPC’s for Planck) or the Herschel Science Centre (HSC).
2. APPLICABLE/REFERENCE DOCUMENTS

2.1. APPLICABLE DOCUMENTS

These documents contain requirements, specifications and rules imposed on the project in addition to the contents of the present document.

<table>
<thead>
<tr>
<th>AD number</th>
<th>Title</th>
<th>Reference number</th>
<th>Issue and Date</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Herschel Alignment Plan</td>
<td>Annex 1 to this doc.</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>02</td>
<td>HIFI LOU Alignment Plan</td>
<td>Annex 2 to this doc.</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>03</td>
<td>Planck Alignment Plan</td>
<td>Annex 3 to this doc.</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>04</td>
<td>HIFI IID-B</td>
<td>SCI-PT-IIDB/HIFI-02125</td>
<td>Latest issue</td>
<td>5.1, 5.5, 5.10, 5.15, 9.1, 9.5, 10.2, 10.11</td>
</tr>
<tr>
<td>05</td>
<td>PACS IID-B</td>
<td>SCI-PT-IIDB/PACS-02126</td>
<td>Latest issue</td>
<td>5.1, 5.5, 5.10, 5.15, 9.1, 9.5, 10.2, 10.11</td>
</tr>
<tr>
<td>06</td>
<td>SPIRE IID-B</td>
<td>SCI-PT-IIDB/SPIRE-02124</td>
<td>Latest issue</td>
<td>5.1, 5.5, 5.10, 5.15, 9.1, 9.5, 10.2, 10.11</td>
</tr>
<tr>
<td>07</td>
<td>HFI IID-B</td>
<td>SCI-PT-IIDB/HFI-04141</td>
<td>Latest issue</td>
<td>5.1, 5.5, 5.6, 5.10, 5.15, 9.1, 9.5, 10.2, 10.11</td>
</tr>
<tr>
<td>08</td>
<td>LFI IID-B</td>
<td>SCI-PT-IIDB/LFI-04142</td>
<td>Latest issue</td>
<td>5.1, 5.5, 5.6, 5.10, 5.15, 9.1, 9.5, 10.2, 10.11</td>
</tr>
<tr>
<td>09</td>
<td>Straylight Evaluation for Planck</td>
<td>PT-05985</td>
<td>23/06/98</td>
<td>5.8</td>
</tr>
<tr>
<td>10</td>
<td>ESA Packet Telemetry Standard</td>
<td>ESA-PSS-04-106</td>
<td>1 01/01/88</td>
<td>5.11</td>
</tr>
<tr>
<td>11</td>
<td>Packet Utilisation Standard</td>
<td>ECSS-E-70/41</td>
<td>April 1999</td>
<td>5.11</td>
</tr>
<tr>
<td>12</td>
<td>ESA Packet Telecommand Standard</td>
<td>ESA-PSS-04-107</td>
<td>1 02/04/92</td>
<td>5.11</td>
</tr>
<tr>
<td>13</td>
<td>Herschel Pointing Modes</td>
<td>Annex 4 to this doc.</td>
<td></td>
<td>5.12</td>
</tr>
<tr>
<td>14</td>
<td>ESA Software Engineering Standards</td>
<td>PSS-05-0</td>
<td>2 01/02/91</td>
<td>5.13, 10.11</td>
</tr>
<tr>
<td>15</td>
<td>Guide to applying ESA Software Standards to small projects</td>
<td>ESA-BSCC(96)2</td>
<td>May 1996</td>
<td>5.13</td>
</tr>
<tr>
<td>16</td>
<td>Herschel/Planck Operations Interface Requirements Document</td>
<td>SCI-PT-RS-07360</td>
<td>Latest issue</td>
<td>7.4</td>
</tr>
<tr>
<td>17</td>
<td>Herschel Science Implementation Requirements Document</td>
<td>PT-03646</td>
<td>Draft#3 30/09/97</td>
<td>7.4</td>
</tr>
<tr>
<td>18</td>
<td>Planck Science</td>
<td>PL-000249</td>
<td>Draft#2</td>
<td>7.4</td>
</tr>
</tbody>
</table>
2.2. REFERENCE DOCUMENTS

These documents contain additional or background information.

<table>
<thead>
<tr>
<th>RD number</th>
<th>Title</th>
<th>Reference number</th>
<th>Issue and Date</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Herschel Telescope Specification</td>
<td>SCI-PT-RS-04671</td>
<td>Latest issue</td>
<td>4.3</td>
</tr>
<tr>
<td>02</td>
<td>Planck Telescope Requirements Specification</td>
<td>SCI-PT-RS-07024</td>
<td>Latest issue</td>
<td>4.4</td>
</tr>
<tr>
<td>03</td>
<td>Herschel Payload Module / Focal Plane Unit</td>
<td>SPIRE/RAL/N/101_01</td>
<td>04/04/99</td>
<td>5.8</td>
</tr>
</tbody>
</table>

2.3. LIST OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABCL</td>
<td>As-Built Configuration List</td>
</tr>
<tr>
<td>ACMS</td>
<td>Attitude Control and Measurement Subsystem</td>
</tr>
<tr>
<td>AIV</td>
<td>Assembly, Integration and Verification</td>
</tr>
<tr>
<td>AME</td>
<td>Attitude Measurement Error</td>
</tr>
<tr>
<td>APE</td>
<td>Absolute Pointing Error</td>
</tr>
<tr>
<td>ARE</td>
<td>Absolute Rate Error</td>
</tr>
<tr>
<td>AVM</td>
<td>Avionics Verification Model</td>
</tr>
<tr>
<td>BEU</td>
<td>Back End Unit (LFI)</td>
</tr>
<tr>
<td>BOLA</td>
<td>Bolometer Amplifier (PACS)</td>
</tr>
<tr>
<td>CCB</td>
<td>Configuration Control Board</td>
</tr>
<tr>
<td>CCE</td>
<td>Central Check-out Equipment</td>
</tr>
<tr>
<td>CDMS</td>
<td>Command and Data Management Subsystem</td>
</tr>
<tr>
<td>CDMU</td>
<td>Central Data Management Unit</td>
</tr>
<tr>
<td>CIDL</td>
<td>Configuration Item Data List</td>
</tr>
<tr>
<td>CoG</td>
<td>Centre of Gravity</td>
</tr>
<tr>
<td>Co-I</td>
<td>Co-Investigator</td>
</tr>
<tr>
<td>CQM</td>
<td>Cryogenic Qualification Model</td>
</tr>
<tr>
<td>CVV</td>
<td>Cryostat Vacuum Vessel</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>DCCU</td>
<td>Dilution Cooler Control Unit</td>
</tr>
<tr>
<td>DDVP</td>
<td>Design, Development and Verification Plan</td>
</tr>
<tr>
<td>DPC</td>
<td>Data Processing Centre</td>
</tr>
<tr>
<td>DPOP</td>
<td>Daily Prime Operational Period</td>
</tr>
<tr>
<td>DTCP</td>
<td>Daily Tele-Communication Period</td>
</tr>
<tr>
<td>ECR</td>
<td>Engineering Change Request</td>
</tr>
<tr>
<td>EGSE</td>
<td>Electrical Ground Support Equipment</td>
</tr>
<tr>
<td>EM</td>
<td>Engineering Model</td>
</tr>
<tr>
<td>EMC</td>
<td>Electro-Magnetic Compatibility</td>
</tr>
<tr>
<td>EMI</td>
<td>Electro-Magnetic Interference</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>ESD</td>
<td>Electro Static Discharge</td>
</tr>
<tr>
<td>ESOC</td>
<td>European Space Operations Centre</td>
</tr>
<tr>
<td>ESTEC</td>
<td>European Space Research and Technology Centre</td>
</tr>
<tr>
<td>FCS</td>
<td>Flight Control System</td>
</tr>
<tr>
<td>FMECA</td>
<td>Failure-Modes, Effects and Criticality Analysis</td>
</tr>
<tr>
<td>FOV</td>
<td>Field Of View</td>
</tr>
<tr>
<td>FPU</td>
<td>Focal Plane Unit</td>
</tr>
<tr>
<td>FS</td>
<td>Flight Spare</td>
</tr>
<tr>
<td>GSE</td>
<td>Ground Support Equipment</td>
</tr>
<tr>
<td>HFI</td>
<td>High Frequency Instrument (Planck)</td>
</tr>
<tr>
<td>HIFI</td>
<td>Heterodyne Instrument for the Far Infrared</td>
</tr>
<tr>
<td>HK</td>
<td>House Keeping</td>
</tr>
<tr>
<td>HOB</td>
<td>Herschel Optical Bench</td>
</tr>
<tr>
<td>HPLM</td>
<td>Herschel Payload Module</td>
</tr>
<tr>
<td>HSC</td>
<td>Herschel Science Centre</td>
</tr>
<tr>
<td>HPLM</td>
<td>Herschel Payload Module</td>
</tr>
<tr>
<td>HSEC</td>
<td>Herschel Science Evaluation Committee</td>
</tr>
<tr>
<td>HSVM</td>
<td>Herschel Service Module</td>
</tr>
<tr>
<td>IAR</td>
<td>Instrument Acceptance Review</td>
</tr>
<tr>
<td>IBDR</td>
<td>Instrument Baseline Design Review</td>
</tr>
<tr>
<td>IHDR</td>
<td>Instrument Hardware Design Review</td>
</tr>
<tr>
<td>ICC</td>
<td>Instrument Control Centre</td>
</tr>
<tr>
<td>ICD</td>
<td>Interface Control Document</td>
</tr>
<tr>
<td>ICDR</td>
<td>Instrument Critical Design Review</td>
</tr>
<tr>
<td>IFAR</td>
<td>Instrument Flight Acceptance Review</td>
</tr>
<tr>
<td>IID</td>
<td>Instrument Interface Document</td>
</tr>
<tr>
<td>IIDR</td>
<td>Instrument Intermediate Design Review</td>
</tr>
<tr>
<td>ILT</td>
<td>Instrument Level Test</td>
</tr>
<tr>
<td>IST</td>
<td>Integrated Satellite Test</td>
</tr>
<tr>
<td>ISVR</td>
<td>Instrument Science Verification Review</td>
</tr>
<tr>
<td>ITT</td>
<td>Invitation To Tender</td>
</tr>
<tr>
<td>JFET</td>
<td>Junction Field Effect Transistor</td>
</tr>
<tr>
<td>LEOP</td>
<td>Launch and Early Orbit Phase</td>
</tr>
<tr>
<td>LISN</td>
<td>Line Impedance Stabilisation Network</td>
</tr>
<tr>
<td>LO</td>
<td>Local Oscillator (HIFI)</td>
</tr>
<tr>
<td>LOS</td>
<td>Line Of Sight</td>
</tr>
<tr>
<td>LOU</td>
<td>Local Oscillator Unit (HIFI)</td>
</tr>
<tr>
<td>LVDE</td>
<td>Low Vibration Drive Electronics</td>
</tr>
<tr>
<td>MGSE</td>
<td>Mechanical Ground Support Equipment</td>
</tr>
</tbody>
</table>
MLI  Multilayer Insulation
MOC  Mission Operations Centre
Mol  Moment of Inertia
MOS  Margin Of Safety
MPS  Mission Planning Subsystem
NCR  Non Conformance Report
OIRD  Operations Interface Requirements Document
OP  Observation Period
PACS  Photodetector Array Camera and Spectrometer
PCS  Power Control Subsystem
PDE  Pointing Drift Error
PFM  Proto Flight Model
PI  Principal Investigator
PLM  Payload Module
PM  Project Manager
PPLM  Planck Payload Module
PSEC  Plank Science Evaluation Committee
PSF  Point Spread Function
PSVM  Planck Service Module
PT  Product Tree
QLA  Quick Look Analysis (software)
RAM  Random Access Memory
RCS  Reaction Control Subsystem
RF  Radio Frequency
RFW  Request for Waiver
RH  Reference Hole
RPE  Relative Pointing Error
RTA  Real Time Assessment (software)
S/C  Spacecraft
SCOS  Spacecraft Control and Operations System
SFT  Short Functional Test
SIN  Straylight Induced Noise
SIRD  Science Implementation Requirements Document
SIST  Short Integrated Satellite Test
SLE  Standard Laboratory Equipment
SPIRE  Spectral and Photometric Imaging REceiver
SRPE  Spatial Relative Pointing Error
SSR  Solid State Recorder
SST  Stainless Steel
STM  Structural/Thermal Model
STMM  Simplified Thermal Model
SVM  Service Module
TBC  To be confirmed
TBD  To be determined
TCS  Thermal Control System
TM  Telemetry
TMM  Thermal Mathematical Model
TT&C  Telemetry, Tracking and Command
TTC  Telemetry, Tracking and Command
VSWR  Voltage Standing Wave Ratio
<table>
<thead>
<tr>
<th>WBS</th>
<th>Work Breakdown Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFE</td>
<td>Wave Front Error</td>
</tr>
</tbody>
</table>
3. KEY PERSONNEL AND RESPONSIBILITIES

3.1. ESA PERSONNEL

<table>
<thead>
<tr>
<th>NAME</th>
<th>RESPONSIBILITY</th>
<th>TELEPHONE</th>
<th>FAX</th>
<th>ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th. Paßvogel</td>
<td>Project Manager</td>
<td>Tel: +31-(0)71-5655962</td>
<td>Fax: +31-(0)71-5655244</td>
<td>ESTEC PO Box 299</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Email: <a href="mailto:tpassvog@estec.esa.nl">tpassvog@estec.esa.nl</a></td>
<td></td>
<td>2200 AG Noordwijk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The Netherlands</td>
</tr>
<tr>
<td>A. Heske</td>
<td>Payload Systems Engineer</td>
<td>Tel: +31-(0)71-5655467</td>
<td>Fax: +31-(0)71-5655244</td>
<td>ESTEC PO Box 299</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Email: <a href="mailto:aheske@estec.esa.nl">aheske@estec.esa.nl</a></td>
<td></td>
<td>2200 AG Noordwijk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The Netherlands</td>
</tr>
</tbody>
</table>

3.2. CONTRACTOR PERSONNEL

<table>
<thead>
<tr>
<th>NAME</th>
<th>RESPONSIBILITY</th>
<th>TELEPHONE</th>
<th>FAX</th>
<th>ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jean-Jacques Juillet</td>
<td>Project Manager</td>
<td>Tel:+33 49292 3423</td>
<td>Fax:+33492923010</td>
<td>Alcatel Space Industries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Email:jean-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:jacques.juillet@space.alc">jacques.juillet@space.alc</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>atel.fr</td>
<td></td>
<td>100, Bd du Midi, BP 99, 06156 Cannes La</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bocca Cedex FRANCE</td>
</tr>
<tr>
<td>Bernard Collaudin</td>
<td>Instrument Interface Manager</td>
<td>Tel:+33 4 9292 3021</td>
<td>Fax:+33 4 9292 3010</td>
<td>Alcatel Space Industries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Email:bernard.Collaudin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>@space.alcatel.fr</td>
<td></td>
<td>100, Bd du Midi, BP 99, 06156 Cannes La</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bocca Cedex FRANCE</td>
</tr>
</tbody>
</table>
4. SATELLITE DESCRIPTION

This chapter contains descriptive information and background data necessary to fully and mutually understand the interface constraints imposed by spacecraft. It is not to be considered as containing any requirement, nor to imply any particular interpretation or meaning other than the one explicitly stated in the other chapters of this document and is therefore not applicable in contractual sense.

4.1. INTRODUCTION

The Herschel/Planck programme combines two missions of the ESA Horizon 2000 Science Programme within one project.

Both missions perform astronomical investigations in the infrared, sub-millimetre and millimetre wavelength range:

- Herschel, the Far Infrared and Sub-millimetre Telescope (previously named FIRST), is a multi user observatory type mission;

- Planck (previously named COBRAS/SAMBA), is a Principal Investigator survey mission.

Both missions will be carried out with their specific spacecraft, and will be operated in a similar orbit around the second Lagrangian point L₂. The present concept is to have the two spacecraft launched on a single ARIANE 5 ESV-type launcher.

For the Herschel payload, composed of three instruments and mounted in the Herschel Payload module (HPLM), the Herschel spacecraft provides the environment for astronomical observations in the infrared wavelength range from 60 to 670 micron (480 GHz – 5 THz).

For the Planck payload, composed of two instruments and mounted in the Planck Payload Module (PPLM), the Planck spacecraft provides the environment for full sky surveys in the frequency range from 25 to 1000 GHz.

4.2. SYSTEM DESCRIPTION

The Herschel satellite configuration is completely modular and is made up of:

- the Herschel Payload Module (HPLM) which comprises the 3.5 meter Herschel telescope, the cryostat, the Herschel focal plane units inside the cryostat and the instrument units mounted externally on the cryostat

- the Herschel Service Module (HSVM) which comprises the conventional spacecraft subsystems, the “warm” instrument units and the sunshield.
The Planck satellite configuration shows a lower level of modularity due to the various connections between the cryogenic payload module and the units mounted on the payload module. However one can clearly distinguish

- the Planck Payload Module (PPLM) which comprises the Planck optical bench with the offset Aplanatic telescope and the two instruments focal plane unit, the SVM upper platform with the LFI Backend Unit and the HFI Readout Unit. The compressors of the sorption coolers, 4 K coolers and further cooler equipment is mounted on the PSVM radiator.

- the Planck Service Module (PSVM) which comprises, aside the conventional spacecraft subsystems and the “warm” instrument units and the solar array.

Figure 4.3.1-1 through Figure 4.3.1-3 show the general configurations of the Herschel and Planck satellites in the dual launch configuration (alcatel proposal baseline concept).

The selected satellite operational orbits are different Lissajous orbits around the second Lagrangian Libration Point (L₂) in the Earth/Moon - Sun system. This point lies approximately on the Earth-Sun line at 1.5 × 10⁶ km from the Earth in anti-Sun direction. Planck, due to stringent requirements on straylight, will be injected into a Lissajous orbit with a maximum sun-s/c-earth angle of 10°. Herschel will be sent into a larger Lissajous orbit.

Herschel will have a nominal lifetime of 3.5yrs from launch until end of mission, where the duration includes a maximum of 6 months for transfer to the operational orbit around L₂. Planck will have a lifetime which allows to carry out two full sky surveys (at least 95% of the whole sky) in the operational orbit around L₂, plus a maximum of 6 months for the transfer to the operational orbit.

The prime ground station is the 35 m station at Perth. The Kourou station may be used as emergency station. During normal operations the prime ground station will receive the spacecraft telemetry and up-link the telecommands during a period of 3 hours per day for each spacecraft (the Daily Telecommunications Period, DTCP).

Two different operation scenarios are foreseen:

- During the Herschel observation period of 21 hours per day the spacecraft will collect scientific data which will be stored in an on-board mass memory for transmission towards the ground station during the subsequent telecommunications phase. “Limited” scientific observations could also be conducted during the telecommunications period.

- For the Planck operation, the spacecraft will collect the scientific data 24 hours per day, which means that the observation phase will continue during the telecommunications period.

The telecommunications period will be used for up-linking the commands for later execution and dumping of the stored data.

The allocated time for the dump of the stored data is 3 hours for each spacecraft.
The data acquired at the ground station(s) from both spacecraft will be routed through ESA’s operational communications network to the Mission Operations Centre (MOC) at ESOC for subsequent storing and distribution to the Herschel Science Centre (HSC) and the Instrument Control Centres (ICC’s) or to the Planck Data Processing Centres (DPC).

Conversely, the HSC, ICC’s and DPC’s will provide the MOC with observation and instrument schedules, which inputs will be used by the Mission Planning System (MPS) at the MOC to prepare the command sequence to be up-linked to both spacecraft.

Figure 4.3.1-1: Herschel satellite
Figure 4.3.1-2: Planck Satellite.
Figure 4.3.1-3: Herschel/Planck Satellites in stacked Launch Configuration
4.3. Herschel PAYLOAD MODULE (HPLM)
The HPLM will accommodate all cold Herschel instrument units supplied by the Principal Investigators. The HPLM comprises the following two major elements, described in more detail below:

- the 3.5 m Herschel Telescope
- the Helium Cryostat.

The Herschel payload module configuration is shown in Figure 4.3.1-1.

Figure 4.3.1-1: Herschel Payload Module.
4.3.1. Herschel Telescope
The telescope is an axi-symmetric, 3.5 m diameter Cassegrain telescope consisting of (RD 01):
- a primary reflector
- a secondary reflector
- a reflector support structure (tripod, bipods etc.,)
- an interface triangle (tbc) and mechanical fixation devices to the primary reflector
- baffles as necessary

A telescope heating system will be included for in-orbit contamination release from optical surfaces and for bake-out of the telescope.

The Sunshield, which is functionally part of the SVM, protects the telescope from direct solar radiation and provides a stable thermal environment, which minimise temperature variations across the telescope.

The opto-mechanical dimensions of the Herschel telescope are given in Table 4.3.1-1 and the configuration shown in Figure 4.3.1-1.

<table>
<thead>
<tr>
<th>Herschel Telescope Optical Parameters</th>
<th>Axi-symmetric 3.5 m diameter Cassegrain telescope</th>
<th>Specified tolerance or comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating wavelength</td>
<td>80-670 µm</td>
<td></td>
</tr>
<tr>
<td>Focal length</td>
<td>28500 mm</td>
<td>Tolerance 50 mm</td>
</tr>
<tr>
<td>f-number</td>
<td>f/8.68</td>
<td>Tolerance 0.02</td>
</tr>
<tr>
<td>Primary vertex to best focus</td>
<td>1050 mm</td>
<td>Tolerance 10 mm</td>
</tr>
<tr>
<td>Primary vertex to fixation plane</td>
<td>250 mm</td>
<td>Tolerance 1 mm (tbc)</td>
</tr>
<tr>
<td>Aperture stop</td>
<td>on M2</td>
<td></td>
</tr>
<tr>
<td>Field of View</td>
<td>0.25 deg</td>
<td></td>
</tr>
<tr>
<td>Area obscuration ratio (tripod + M2)</td>
<td>&lt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Overall WFE</td>
<td>&lt; 6 µm (rms)</td>
<td></td>
</tr>
<tr>
<td>Relative spectral transmission</td>
<td>&gt; 0.97 BOL</td>
<td>Non uniformity of relative spectral transmission &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.98 BOL (goal)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 0.95 EOL</td>
<td></td>
</tr>
<tr>
<td>Primary reflector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertex to telescope interface plane (tv)</td>
<td>250 mm</td>
<td></td>
</tr>
<tr>
<td>Vertex to paraxial focal plane (tf)</td>
<td>1050.16 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Distance M1 to M2</td>
<td>1588 mm</td>
<td></td>
</tr>
<tr>
<td>Radius of curvature</td>
<td>3500 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Conic constant</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>f-number</td>
<td>f/0.5</td>
<td></td>
</tr>
<tr>
<td>(Free) diameter</td>
<td>3500 mm</td>
<td>Tolerance 0, +2 mm</td>
</tr>
<tr>
<td><strong>Secondary reflector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Radius of curvature</td>
<td>345.2 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Conic constant</td>
<td>-1.279</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>308.1 mm</td>
<td>Tolerance 0.2 mm (tbc)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Image surface</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of curvature</td>
<td>- 165 mm</td>
<td></td>
</tr>
<tr>
<td>Conic constant</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>246 mm</td>
<td>Corresponds to 0.25 deg</td>
</tr>
<tr>
<td>Height above optical bench</td>
<td>202 mm</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.3.1-1: Herschel Telescope Opto-mechanical Dimensions**

The central hole diameter and the position of the triangle interface points and the M2 support structure dimensions will be given after the preliminary design activities.
Figure 4.3.1-1: Herschel Telescope Opto-mechanical Dimensions
4.3.2. Helium Cryostat

The Helium Cryostat of the HPLM accommodates the Herschel focal plane units (FPU) of the three scientific instruments:

- the Heterodyne Instrument for the Far Infrared (HIFI)
- the Photoconductor Array Camera and Spectrometer Instrument (PACS)
- the Spectral and Photometric Imaging Receiver (SPIRE).

The cryostat provides an adequate thermal environment to these focal plane units and provides the optical interface between the focal plane units and the telescope.

The Helium cryostat also provides interfaces with the HSVM, the Herschel Telescope, the sunshield and provides the mounting base for the three star trackers (tbc).

The cryostat consists of:

- Structural and insulation components featuring an outer vessel, a suspension system to minimise heat conduction from outer vessel to the cryogenically cooled elements and the adequate shielding and thermal insulation to minimise the heat radiation from the outer vessel to the cooled elements.

- A helium subsystem to provide the adequate cryogenic environment. This passive, single cryogen, cooling system features a main He tank, containing approximately 2560 litres of superfluid helium, a passive phase separator and the cryogenic components to operate it. It also features an additional helium tank designed to provide the required autonomy of the cryogenic system on the launcher.

- The Herschel Optical Bench (FOB), which accommodates the instrument Focal Plane Units in the Focal Plane Assembly (FPA) and provides the necessary thermal and structural interfaces.

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

The Cryostat also accommodates the following payload equipment:

- the Local Oscillator Unit (LOU) of the HIFI, its beam injection optics and the LOU wave-guides to the SVM
- the Bolometer Amplifier Unit (BOLA) of PACS

The PLM electrical subsystem harness provides all electrical connections between all electrical equipment in the Payload Module and between the Focal Plane Units and the warm electronics of the payload instruments.

The Helium Cryostat configuration is shown in Figure 4.3.2-1.
Figure 4.3.2-1: Herschel Payload Module

4.4. Planck PAYLOAD MODULE (PPLM)
The Planck Payload Module (PPLM) will accommodate the Planck instrument units supplied by the Principal Investigators. The Planck instruments are split into a common Focal Plane Unit (FPU) and HFI JFET box that shall be located close to the FPU, mounted to the Planck Telescope Support at 50-60K and ambient temperature units, mounted to the SVM panels.

The instruments elements mounted into the PPLM are directly and permanently connected to their counterparts in the PSVM and a clean separation is not possible. However, considering the mounting panels of the PSVM that carry these units as part of an extended Payload module, one can minimise the set of interfaces and achieve a nearly independent module. This can be integrated and tested separately.
from the rest of the spacecraft. It comprises the following major elements, described in more detail below:

- The Planck Telescope and the V-groove insulation system
- The PSVM upper Platform
- The PSVM Radiators panels, carrying the Sorption Cooler Compressors.

The “extended” PPLM exhibits the following external interfaces

- Mounting interfaces to the SVM
- Electrical interfaces between the electronic units mounted on the equipment platform and the corresponding units on the SVM panel.

The extended PPLM configuration is shown in Figure 4.3.2-1 below.

![Figure 4.3.2-1: Planck Payload Module](image-url)
4.4.1. Planck Telescope and FPU

The Planck Telescope Support Structure is the mounting base for the common Planck instrument FPU, HFI JFET box and the reflectors of the telescope.

The main parameters of the Planck telescope are given in Figure 4.4.1-1 below and in Table 4.4.1-1 (RD 02).

![Diagram of Planck Telescope and FPU](image)

- $Z_{M1}$ = Major axis of primary mirror
- $Z_{M2}$ = Major axis of secondary mirror
- RDP = Co-ordinate system of the detector reference plane
- $I$ = Intersection point of the major axes of primary and secondary mirror
- $Z_{bot}$ = distance between $O_{M1}$ and $I$
- $Z_{top}$ = distance between $I$ and $O_{M2}$
- $\Theta_1$ = angle between the major axes of primary and secondary mirrors
- LOS = Line of sight (-3.751° from $Z_{M1}$)

The secondary mirror is obtained by cutting the ellipsoid with a “cylinder” which has an elliptical base of 780.6 mm x 1018.6 mm. The axis of this “cylinder” is parallel to the major axis of the secondary ellipsoid.

![Diagram of secondary mirror cutting](image)

**Figure 4.4.1-1: Definition of design parameters of the Planck telescope**
Figure 4.4.1-2: Planck Telescope: Structure (upper) and conceptual view of spacecraft including V-Grooves (lower)
### Telescope

- **Telescope Angle of centre of FOV (line of sight) with Z\textsubscript{M1} Field of view:** -3.751° ± 5°

### Primary mirror

- **Surface shape:** Ellipsoid
- **Radius of curvature:** 1,440 mm, 1,500 mm
- **Real aperture dimensions in the rim plane:** 1555.98 mm x 1886.79 mm
- **Conic constant:** -0.869417
- **Offset distance at centre:** 1,038.85 mm

### Secondary mirror

- **Surface shape:** Ellipsoid
- **Radius of curvature:** 643.972 mm, -0.215424
- **Conic constant:** 1,018.6 mm
- **Major axis of projected contour:** 780.6 mm
- **Minor axis of projected contour:** 1,018.6 mm x 1,043.23 mm
- **Aperture dimensions in the rim plane offset distance at centre:** X\textsubscript{CM2} = -328.15 mm

### Relative position of primary and secondary mirrors

- **Angle between major axes (\(\Theta\)\textsubscript{1})**:
  - \(Z_{\text{top}}\)
  - \(Z_{\text{bot}}\)
  - 10.1°
  - 10.1°
  - 481.737 mm
  - 706.027 mm

### Position of reference detector plane with respect to the secondary axis system M2 (see Figure 4.4.1-2)

- **Position of centre of detector plane**:
  - \(X = -108.42\) mm
  - \(Y = 0\) mm
  - \(Z = -1,026.83\) mm
  - \(X = -108.42\) mm
  - \(Y = 0\) mm
  - \(Z = -1,026.83\) mm

- **Angle between \(Z_{\text{RDP}}\) and \(Z\text{m2} (\Theta\textsubscript{2})**:
  - -21.27°

### Notes:

1. In a plane perpendicular to the major axis of the primary ellipsoid
2. See figure for a sketch on how to derive the secondary mirror surface
3. Dimensions of apertures and contours are the optical definition. Physical dimensions of mirror shall take into account possible misalignments

---

### Table 4.4.1-1: Opto-mechanical Definition of the Planck Telescope

In order to provide the required temperatures at the Focal Plane Unit active cooling is implemented as part of the instruments. The active cooling units are mounted on dedicated PSVM radiator panels, and need a number of interfaces to the intermediate V-groove insulation system. These interfaces are thermal interfaces used for pre-cooling / thermalisation of the cooler pipes, harness and wave-guides and serve also as mechanical interfaces. The detailed interfaces are described in the respective chapter below.

#### 4.4.2. PSVM Units

The PSVM Upper Platform carries those ambient temperature units of the Planck instruments that are either required to be nearby the focal plane unit or that should not be disconnected after initial integration. Those units are the back-end unit of the LFI instrument and the Read-Out Unit of the HFI instrument.

Active cooling is required for both instruments and comprises the following sets of coolers:
- Sorption cooler (1 nominal and 1 cold redundant) for LFI cooling and HFI pre-cooling
- 4 K mechanical cooler for HFI and pre-cooling of dilution cooler
- HFI dilution cooler.

The sorption cooler compressors require a maximum temperature of 270 K and need dedicated radiator area. SVM panels are foreseen as Radiator.

The further units of the Planck instruments are placed mainly on other SVM panels (see Figure 4.3.2-1).
4.5. SERVICE MODULES (SVM)

4.5.1. Herschel Service Module

The Herschel Service Module (HSVM) consists of the following elements:
- a primary load carrying structure
- a secondary structure carrying units and parts of the subsystems necessary for the Herschel mission (current concept)
- a carrier structure between the Herschel and Planck satellite

The carrier structure is part of the HSVM, i.e. the separation interface is at the level of the upper platform of the Planck service module. (See Figure 4.5.3-1)

4.5.2. Planck Service Module

The Planck Service Module (PSVM) consists of the following elements:
- a load carrying primary structure, also supporting the Herschel spacecraft
- a secondary structure carrying the units and parts of the subsystems necessary for the Planck mission.

The PSVM provides the interface to the ARIANE V launcher. (see Figure 4.5.3-2)

4.5.3. SVM’s Subsystems

The HSVM and PSVM subsystems are:

4.5.3.1. Structure Subsystem

This subsystem provides the mechanical interface with
- the launcher (PSVM)
- the HSVM (stacked configuration)

It supports the SVM units and carries the PLM’s

4.5.3.2. Thermal Control Subsystem

The thermal control subsystem (TCS) maintains the required SVM and PPLM thermal environment for proper operations of equipment, taking into account the different environmental conditions.

4.5.3.3. Solar Array and Sunshield

The combined sunshield/solar array provides the necessary electrical power via a solar cell network and protects the payload module from direct solar radiation. For Herschel it is mounted on one side of the spacecraft. For Planck it is attached to the lower end of the PSVM.
4.5.3.4. Telemetry, Tracking and Command Subsystem

The Telemetry, Tracking and Command (TT&C) subsystems manage the reception and transmission of radio frequency signals for science and housekeeping data telemetry, telecommand and tracking. It is able to operate in both ways (up-link and down-link) during all mission phases when there is ground station contact. The frequencies are in the X-band frequency range.

4.5.3.5. Command and Data Management Subsystem

The Command and Data management Subsystem (CDMS) collects all telemetry data from the satellite. These data include the scientific data, the science instrument housekeeping (HK) and the spacecraft housekeeping data. The data will be conditioned, digitised and encoded for transmission to ground via the TT&C subsystem. The CDMS will also process the up-link command signals received by the TT&C subsystem and decode, validate and distribute the commands to the users for execution. During the observation period (OP) the collected telemetry data will be stored in a Solid State Recorder (SSR). During the Daily Telecommunications Phase (DTCP) the stored data, together with real time data, will be transmitted to ground.

The CDMS will be the source for:

- Telemetry and telecommand services to and from the ground station
- On-board timing and synchronisation
- Autonomous satellite monitoring and recovery
- Ground satellite checkout

The CDMS supports an average bit rate of the instruments during scientific observations as defined in 5.11.

4.5.3.6. Power Control Subsystem

The Power Control Subsystem (PCS) conditions, controls and distributes the electrical power generated by the solar array to all payload instruments and spacecraft subsystems/units.

4.5.3.7. Attitude Control and Measurement Subsystem

The Attitude Control and Measurement Subsystem (ACMS) provides the hardware and associated on-board software to acquire, control and measure the attitude of the satellite during all mission phases and modes according to the system requirements. The attitude and orbit control thrusters, used as actuators, are part of the Reaction Control Subsystem (RCS), but their operation is controlled by the ACMS.

The ACMS comprises the following elements:

- attitude sensors for attitude measurement during all mission phases
- actuators to generate control torques for attitude manoeuvres and for compensation of perturbing torques
- electronics and software to manage the attitude measurement and control functions, to detect and isolate failures and reconfigure if necessary, and to provide the interfaces with the CDMS and TT&C subsystems.
4.5.3.8. Reaction Control Subsystem
The reaction control subsystem comprises the propellant storage tanks, pipes, necessary valves and pressure transducers and the thrusters. The thrusters are commanded by the ACMS.

4.5.3.9. Harness
The SVM harness provides all electrical connections between all electrical equipment in the service module. It includes harnesses for power supplies, signals and pyrotechnic pulses. It includes also harnesses for connections with the PPLM, the HPLM, the umbilicals and test connectors.

The layout of the Herschel and the Planck SVM are given in Figure 4.5.3-1 and Figure 4.5.3-2.
Figure 4.5.3-1: Herschel Service Module (typical)
Figure 4.5.3-2: Planck Instrument deployment on SVM (typical)
4.6. OPERATING MODES

4.6.1. Launch
During Launch of the two satellites the scientific instruments will be switched off. If required, power will be provided to the active coolers of the Planck instruments for the launch lock mode.

4.6.2. Herschel
The Herschel spacecraft will be three axes stabilised. The instantaneous sky coverage is defined by the allowed sun aspect angles of ±30° in the x-z plane and ±5° in the y-z plane.

The orbit operation is characterised by the observation time and the down-link time. The duration of the Observation Periods will be 21 hours during which the scientific data will be stored on-board. During the DPOP the spacecraft will support a number of scientific pointing modes, such as fine pointing, raster scanning and line scanning modes (see annex 4).

The spacecraft supports the Herschel instrument operation with any instrument in prime mode. Furthermore, if PACS is in prime mode SPIRE could be in parallel mode, taking observations but not perturbing in any way the prime instrument.

At the end of the Observation Period the stored data will be sent to ground and the observation/schedule parameters for the next 48 hrs will be up-linked. Within this period also spacecraft operations like reaction wheel unloading and star-tracker calibration checks will be performed. The spacecraft can support, during this time period, limited instrument operations. In addition, a serendipity mode could be defined, where either PACS or SPIRE will be operated in a fixed configuration during a slew from one target to the next.

4.6.2. Planck
The Planck observation programme basically consists of two scans of the full sky each carried out over the period of half an orbit around the sun and as such covering the full sky. The satellite is spinning with one revolution per minute around the –x-axis that is pointing continually to the sun. In order to properly cover the full sky, the spin axis is repointed to up to 10° from the sun direction.

The instruments will take data for the full 24-hour period and the data will be stored on-board. As for the Herschel spacecraft the data will be sent to ground within a period of nominally 3 hours, the down-link time. The spacecraft will support, during this time period, full instrument operations.

The spacecraft supports the Planck instruments being operated simultaneously. However, it is also possible to operate only one instrument. In this case, the operating instrument may be allocated the sum of the data rates of LFI and HFI nominal allocation.
5. INTERFACE WITH INSTRUMENTS

Spacecraft resource allocations, as specified for the scientific instruments in this chapter, are based on present knowledge.

After initial issue by ESA, the contractor will be responsible to maintain the IID-A in line with the requirements as defined in the IID-Bs and in agreement with ESA.

5.1. IDENTIFICATION AND LABELLING

Each instrument unit is required to bear a unit identification label containing the following information:

- Project code
- Unit identification code
- Model (e.g. AVM, CQM, PFM, FS)

The identification label shall be attached to each instrument unit at a location that guarantees maximum visibility. The location and content of the instrument unit’s identification label shall be shown on the external configuration drawing(s) of the respective unit. The identification label shall be clearly legible.

5.1.1. Project code

For each instrument the Project code, which is the normal reference used for routine identification in correspondence and technical descriptive material, is defined in chapter 5.1 of the IID’s part B (AD 04,05,06,07,08).

5.1.2. Unit identification code

The unit Identification code is allocated in accordance with a computerised configuration control system and also for connector and harness identification purposes. The first 5 characters of this code are the allocated Project code. The unit identification code is composed of 3 parts:

- 2 characters for instrument identification, i.e. FH, FP and FS for the Herschel instruments, PH and PL for the Planck instruments
- 3 characters for unit identification, e.g. FPU, FCU, DPU, SPU
- 2 characters for model identification, i.e. AV for Avionics Model, CQ for Cryo-Qualification Model, PF for Proto-Flight Model, FS for Flight Spare Model.

For connector and harness this code is limited to the characters up to unit identification, followed by the connector identification (see below)

5.1.3. Connector identification

Each equipment box is required to bear visible connector identification labels closely adjacent to the appropriate connector. Spacecraft philosophy is to locate a “J” character to all units fixed (hard mounted) connectors and a “P” character to all harness mounted connectors, followed by a 2-digit number. Each unit is treated individually in this respect, starting at “J01” for unit fixed connectors.
For full connector identification these three alphanumeric characters are preceded by the S/C identification code of the instrument unit, e.g. connector “J03” on box the SPIRE FPU will have the full reference “FSFPUJ03”, the mating harness connector will have the reference “FSFPUP03”.

Since the S/C identification code already appears on the unit identification label however, unit fixed connectors are not required to bear the full connector identification code; in the example above “J03” would suffice. The same rules apply for supplied instrument interconnect harnesses, and harness from an instrument EGSE if it requires connection to test connectors on an instrument unit.

The location and content of the above described identification labels shall be included in the external configuration drawing.
5.2. COORDINATE SYSTEM

5.2.1. Spacecraft Coordinate system

The basic co-ordinate system shall be a right-handed Cartesian system with its origin located at the point of intersection of the longitudinal launcher axis and the satellite/launcher (for Planck), and the satellite to satellite (for Herschel) separation plane.

For Herschel the positive X-axis shall be along the nominal optical axis of the Herschel telescope, towards the target source. The Z-axis is in the plane normal to the X-axis such that nominally the Sun will lie in the XZ-plane (zero roll angle with respect to the Sun), positive towards the Sun. The Y-axis completes the right-handed orthogonal reference frame.

Figure 5.2.1-1: Definition of Herschel spacecraft axes

For Planck the X-axis is the nominal anti-sun direction, i.e. the spin axis. The Planck telescope line of sight, which is defined as the direction in which the projection of the main mirror rim is circular, is tilted 85° from the X-axis in the Z direction.
The Z-axis is in the plane normal to the X-axis such that nominally the telescope line of sight will lie in the XZ-plane, positive towards the target source. The Y-axis completes the right-handed orthogonal reference frame.

Figure 5.2.1-2: Definition of Planck spacecraft axes

The X-axes of both satellites nominally coincide with the longitudinal launcher axis.

5.2.2. Instrument unit co-ordinate system

In order to provide a reference for the Instrument Focus (Focal Plane Units), Centre of Gravity (CoG) and (possibly) Moment of Inertia (MoI) measurements, each instrument unit is required to have a right-handed Cartesian system as described in 5.2.1. Its origin shall be in a reference hole (RH) in the unit mounting plane, which is the attachment to the S/C. The RH is defined as one of the unit fixation holes.

The principal axis of the instrument units shall be parallel to those of the S/C co-ordinate system, as far as practical.

The instrument unit co-ordinate system and the RH location shall be defined in the unit’s external configuration drawing.
5.3. LOCATION AND ALIGNMENT

5.3.1. Instrument location

5.3.1.1. Herschel Instruments

The Herschel instruments are located in the cryostat on the optical bench (Focal Plane Units, SPIRE JFET and RF filter Module), mounted to the cryostat (PACS Bolometer Amplifier Unit (BOLA) and the HIFI Local Oscillator Unit and Wave-guides) and on the SVM (Electronic units).

The instrument units shall be compatible with maximum instrument envelopes as defined in Figure 5.3.1-1 and in Table 5.3.1-1.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Max. envelope</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Bench</td>
<td>Non symmetric, See Figure 5.3.1-1</td>
<td>All FPU's (including SPIRE JFET and RF filter module)</td>
</tr>
<tr>
<td>Cryostat</td>
<td>TBD</td>
<td>To be agreed upon on a case by case basis (includes LOU, wave-guides and PACS BOLA)</td>
</tr>
<tr>
<td>SVM</td>
<td>TBD</td>
<td>To be agreed upon on a case by case basis</td>
</tr>
</tbody>
</table>

Table 5.3.1-1: Maximum allocated envelope for Herschel instruments
Figure 5.3.1-1: Maximum allocated envelope for the Herschel FPU’s, for Instrument dimensions see IID-B
5.3.1.2. Planck Instruments

The Planck instruments are treated in a slightly different way to the Herschel instrument units. The combined HFI and LFI Focal Plane Unit is mechanically mounted to the Planck telescope structure. Connected to the FPU via wave-guides and cooling lines are the ambient temperature elements of the instrument coolers and the LFI Backend Unit. There is a predefined maximum distance between the FPU and the HFI JFET box and Readout Electronics.

All the above units, as they are strongly linked to the FPU, are treated in a dedicated way, different to “normal” warm boxes. Although they are physically mounted to the SVM they are logically considered part of the PPLM, i.e. they are discussed as “PPLM warm units”.

The “normal” electronic boxes are treated in a more general way as SVM units.

The instruments shall be compatible with maximum instrument envelopes as defined in Table 5.3.1-2.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Max. envelope</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPU on Planck telescope support structure</td>
<td>400 x 426 x 600 mm³</td>
<td>HFI/LFI merged FPU*</td>
</tr>
<tr>
<td>PPLM Warm Units</td>
<td>TBD</td>
<td>To be agreed upon on a case by case basis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Includes sorption coolers, 4 K cooler, dilution cooler, LFI backend unit, HFI JFET box and Readout Electronics and all elements between optical bench and upper SVM)</td>
</tr>
<tr>
<td>SVM Units</td>
<td>TBD</td>
<td>To be agreed upon on a case by case basis</td>
</tr>
</tbody>
</table>

Table 5.3.1-2: Maximum allocated envelope for Planck instruments

Note: * The mounting struts from the telescope structure to the FPU are not included in this envelope, but are part of the FPU and are delivered by the instrument.

5.3.2. Instrument alignment

5.3.2.1. Herschel Focal Plane Units

The alignment of the Herschel telescope to the Herschel Optical Bench reference is defined in the Herschel Alignment Plan (AD 01, see Annex).

The requirements for the FPU’s are included in the Herschel alignment plan, where references are required on the outer surface of the box. The focal plane units will be aligned w.r.t. a reference point on the Herschel optical bench during integration of the unit. The actual position of the focal plane unit on the optical bench will not be measured directly after integration, but will be calculated via the measurement reference on the optical bench.
5.3.2.2. Local Oscillator Alignment

To align the HIFI Focal Plane Unit with the local oscillator with the required precision will need at least two visible-light windows in the Herschel cryostat. Natural positions for these two windows would be adjacent to the first and last of the seven sub-millimetre windows, in positions 0 and 8. Alignment cubes (with reflecting surfaces for orientation and crosses for position reference), mounted on the +Z and −Z faces of the LOU and of the FPU, shall be used. For the critical alignments (rotations around the X and Z axes and translations parallel to the X and Z axes) the +Y and/or −Y faces of the alignment cubes can be used. After having sighted the FPU cubes with theodolites through the visible-light windows in the cryostat wall, the LOU can be aligned with its alignment cubes. If the cubes on the LOU are partially transparent then the alignment can also be checked after integration by measurements along the Y axis through the cubes on the LOU and through the two alignment ports. However, in cryogenic instrument-level tests, with the FPU at 15 K and with the LOU at 150 K or 180 K, it will be very difficult to check the alignment of the two units. For that reason HIFI proposes to use a special camera system to monitor the alignment of the two units. It is planned to monitor the alignment of the LOU with the FPU at all stages of ground testing. The camera system will consist of two pieces of special ground support equipment mounted temporarily on the LOU. The same equipment will (have to) be used when mapping the LOU beams and the FPU LO ports at the interface plane between LOU and FPU (see also Annex, AD 02).

5.3.2.3. Planck Focal Plane Unit

The alignment of the Planck FPU w.r.t. the Planck telescope and the Planck spacecraft reference system is defined in the Planck alignment plan (AD 03, see Annex).
5.4. EXTERNAL CONFIGURATION DRAWINGS

For each instrument unit, a configuration drawing is required to establish the mechanical interfaces with the spacecraft structure, harnesses and thermal hardware. These drawings shall contain the following information:

- Dimensions and associated tolerances (at ambient and operational temperatures)
- Identification of a reference hole
- Mounting hole pattern dimensions and hole patterns
- Dimensions of mounting feet and contact area
- Spot-faced area for seating of the mounting screw washers (if and where applicable)
- Dimensions and location of dowel pins (where applicable)
- Mass and associated tolerances
- Location, type and function of all connectors
- Identification of non-flight items
- Location of unit and connector identification labels
- Details of instrument provided mounting hardware, thermal/electrical isolation provisions
- Location and routing of any harness, interconnecting modules of a “stacked” box configuration
- Location of cold strap interfaces to Helium tank, level 1 and level 2 (see Table 5.7.1-1)
- Calculated Centre of Gravity location in instrument unit co-ordinate system and Moments of Inertia and its co-ordinate system if different from instrument unit co-ordinate system
- Location of transport/storage purging connections (if applicable)
- Material of housing and surface finish
- Roughness of contact area
- Eigen-frequency if below 140 Hz (warm units only)
- Base plate material
- Surface properties (IR Emissivity and Solar absorptance if external location)
- Specific heat (J/Kg/K) (calculated or measured)

Drawings shall clearly specify the unit they represent and the responsible design authority; they shall be subject to a properly controlled numbering and revision updating system. Each revision of a drawing shall be accompanied by a list detailing all changes that have been incorporated since the previous revision, either on the drawing itself, or on an accompanying revision change sheet.

Drawings shall be submitted to the Project as computer readable and editable files together with one hard copy of each file.

The Metric Standard (SI-SYSTEM INTERNATIONAL) shall be used for design and manufacturing of all instruments. For components and equipment, the dimensions shall be given in millimetres and the angles in degrees.
5.5. SIZES AND MASS PROPERTIES

5.5.1. Mass tolerances
- Cryogenic Qualification Model (CQM): The mass of each of the CQM units shall be within 1% or 100 grams (whichever is less) of the estimated mass for that unit. On no account shall the instrument unit mass exceed the Project agreed maximum for that unit, current at the time of delivery to the Project.

- Proto-Flight Model (PFM): The mass of each of the PFM units shall be within 1% or 100 grams (whichever is less) of the estimated mass for that unit. On no account shall the instrument unit mass exceed the Project agreed maximum for that unit, current at the time of delivery to the Project.

- Flight Spare (FS): In order to ensure free interchangeability of PFM and FS units the mass of each of the FS units shall be within 1% or 100 grams (whichever is less) of the mass measured for the equivalent PFM units.

5.5.2. Centre of Gravity Location and Tolerances
In interpreting the figures below, the Centre of Gravity (CoG) should be taken not to include any external harness or connectors other than those hard-mounted on the unit.

- Cryogenic Qualification Model (CQM): The CoG of each unit shall be within a sphere of 2.0 mm radius around the best estimated location given in the unit’s external configuration drawing, current at the time of delivery to the Project. Following delivery of the CQM units to the Project, the external configuration drawings of the unit shall be updated to show the actual CoG location based on QM experience.

- Proto-Flight Model (PFM): The CoG of each unit shall be within a sphere of 2.0 mm radius around the best estimated location given in the unit’s external configuration drawing, current at the time of delivery to the Project. These shall be the drawings updated from CQM experience.

- Flight Spare (FS): In order to allow free interchangeability of PFM, or CQM, and FS units, the CoG of the FS shall be within a sphere of 1.0 mm radius around the CoG measured for the other models.

5.5.3. Moments of Inertia and Tolerances
Nominal Moments of Inertia (MoI) of each unit are recorded in the IID’s part B (AD 04,05,06,07,08) The value of all instrument models must not deviate from the nominal value by more than 10 %. Calculated values may be supplied for units for which the MoI is lower than 0.1 kg m². The MoI must be measured to an accuracy of ±5 %.

5.5.4. Overall Instrument Mass Allocation
Depending on the development status of the instrument the following mass margin philosophy shall apply:
5.5.4.1. Herschel Instruments

The maximum allocated mass for the Herschel Instruments is 415 kg.

This total mass is distributed to the three Herschel instruments with the following allocations:

- **HIFI**: 192 kg
- **PACS**: 133 kg
- **SPIRE**: 90 kg.

The present distribution of the instrument mass to the different interfaces in the system is as given in Table 5.5.4-1.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Max. allocated Mass [kg]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Bench</td>
<td>179</td>
<td>All FPU’s (including SPIRE JFET and RF filter module)</td>
</tr>
<tr>
<td>Cryostat</td>
<td>35</td>
<td>Includes a Bolometer Amplifier Unit and the HIFI Local Oscillator Unit (with radiator)</td>
</tr>
<tr>
<td>SVM</td>
<td>201</td>
<td>Warm units of all three instruments and Local Oscillator Unit wave-guides</td>
</tr>
<tr>
<td>Total</td>
<td>415</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.5.4-1: Distribution of Herschel Instrument Mass

The margin philosophy to be applied by the instruments is outlined in paragraph 5.5.4. The instruments shall provide in the IID-B the instrument current estimated mass per unit and the related margin.

5.5.4.2. Planck Instruments

The maximum allocated mass for the Planck Instruments is 445 kg.

This total mass is distributed to the two Planck instruments and the sorption cooler with the following allocations:

- **LFI**: 89 kg
- **HFI**: 244 kg
- **Sorption cooler**: 112 kg.
The present distribution of the instrument and cooler mass to the different interfaces in the system is as given in Table 5.5.4-2.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Max. allocated Mass [kg]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planck Telescope Structure</td>
<td>62</td>
<td>HFI/LFI merged FPU, incl. HFI JFET and RF filter Unit</td>
</tr>
<tr>
<td>PPLM and SVM Warm Units</td>
<td>383</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>445</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.5.4-2: Distribution of Planck Instrument Mass

The margin philosophy to be applied by the instruments is outlined in paragraph 5.5.4. The instruments shall provide in the IID-B the instrument current estimated mass per unit and the related margin.
5.6. MECHANICAL INTERFACES

5.6.1. Herschel Payload Module

The following mechanical interfaces of the Herschel Payload Module (HPLM) to the instruments are discussed:

- Focal plane units to Herschel optical bench
- SPIRE JFET and RF filter module to optical bench
- HIFI LOU to cryostat vacuum vessel
- PACS Bolometer Amplifier Unit to cryostat vacuum vessel
- HIFI LOU wave-guides to cryostat vacuum vessel

5.6.1.1. Herschel Focal Plane Units

- The focal plane units of the Herschel instruments shall exhibit a standard mechanical interface to the Herschel optical bench.

The Instrument shall provide a hole in the instrument mounting foot and for a dowel pin. The diameters of these are to be specified in due course.

The number of fixation points is different for each experiment: PACS 6, HIFI 3 and SPIRE 3 or 4.

The reference plane for fixation interface is at the upper surface of the Optical Bench (at station x = 2000 mm for current cryostat design).

For each instrument one reference hole has to be defined from y =0 and z =0, where it is recommended to have the reference hole as close as possible to the centre of the OB (y=0, z=0) and on the y or z-axis. All other fixation points shall be located w.r.t the instrument reference point.

The fixation principle shall be similar for all three instruments. A typical example is given in Figure 5.6.1-1, where for all fixation points a central hole $\varnothing$ 12 H7 (tbc) and a screw pattern of 4 screws M6 size is provided.

All holes on OB are fixed –there will be no provisions for compensation of thermal displacements. Provisions for alignment adjustment and thermal displacements shall be done on instrument side.
The thermal contact conductivity to the Optical Bench is defined in chapter 5.7. The mounting hardware will be furnished by the spacecraft for the integration of the focal plane units on the Herschel optical bench. The fixation of the instruments shall be accessible from the $+x$ side. It shall be possible to mount and dismount each focal plane unit independent from the other ones. The position of the holes of the FPU shall be within a tolerance of 0.1 mm (tbc) between different models (CQM, PFM and FS). The co-planarity of the interfaces to the FPU’s on the optical bench will be within less than 0.1 mm (tbc) between any two mounting interfaces of all three FPU’s and between 0.1 mm (tbc) between two mounting interfaces of each individual FPU under all conditions. Therefore no additional forces due to thermal expansion shall be applied to the optical bench. To avoid such additional forces, e.g. struts or sliding bolts can be used. The co-planarity of the interfaces of one FPU shall be lower than 0.05 mm (tbc). The co-planarity requirements hold for room as well as for cryogenic temperatures.

5.6.1.2. SPIRE JFET and RF filter Module
The SPIRE JFET and RF filter module need a dedicated interface to the optical bench. The design of the unit has been selected such as to minimise the impact on the cryostat design.
The unit is mechanically attached to the optical bench by a set of 4 screws (tbc) at the outer rim of the unit. The concept is shown in Figure 5.6.1-2.

Figure 5.6.1-2: Mechanical Interface of SPIRE JFET and RF filter Module to Optical Bench

The mounting interface shall provide for mechanical and thermal interface.

The differential thermal expansion of the unit compared to the mounting interface, the optical bench, shall be considered in the design of the unit.

The SPIRE JFET and RF filter module shall provide 4 mounting holes. The mounting hardware is provided by the spacecraft. The position of the holes of the SPIRE JFET and RF filter module shall be within a 0.1 mm tolerance between different models (CQM, PFM and FS).

The interfaces to the electrical connectors shall be at the side of the unit that is the easiest accessible. No special mechanical fixations of the connectors, except mounting screws, are required.

5.6.1.3. HIFI Local Oscillator Unit

The mechanical interface of the HIFI local oscillator unit to the spacecraft is at the level of the local oscillator unit, i.e. the s/c is providing the mounting interface as the mechanical and thermal interface of the unit. A layout of the Local Oscillator Unit is given in Figure 5.6.1-3.
The Local Oscillator Unit shall provide a hole in the mounting foot of diameter tbd and for a dowel pin of diameter tbd. A typical example of a mounting concept is given in Figure 5.6.1-3.

Figure 5.6.1-4: Mechanical Interface of HIFI LOU to LOU Mounting platform
The thermal contact conductivity to the LOU Mounting platform is defined in chapter 5.7.

The mounting hardware will be furnished by the spacecraft for the integration of the LOU on the LOU Mounting platform.

The position of the holes of the LOU shall be within a tolerance of 0.1 mm (tbc) between different models (CQM, PFM and FS).

The co-planarity of the interfaces of the LOU shall be lower than 0.05 mm (tbc).

Note that the unit will be mounted under ambient temperature conditions. The mechanical loads, e.g. during launch will be at ambient temperature conditions, whereas the alignment will be provided only during operational conditions of the spacecraft, i.e. with a cryostat temperature of around 80 K and a local oscillator temperature at around 150 K.

5.6.1.4. PACS Bolometer Amplifier Unit

The mechanical interface of the Bolometer Amplifier Unit (BOLA) to the spacecraft is at the level of the BOLA, i.e. the s/c is providing the mounting platform as the mechanical and thermal interface of the unit.

The mechanical interfaces of the BOLA shall be as defined for the SVM units in paragraph 5.6.3 below.

The thermal contact conductivity to the BOLA Mounting platform is defined in chapter 5.7.

The mounting hardware will be furnished by the spacecraft for the integration of the BOLA on the BOLA mounting platform.

5.6.1.5. HIFI LOU Wave-guides

The wave-guides, 14 in total, start at the bottom of the LOU and are routed directly to the LSU on the SVM, via intermediate structure and radiator. The fixation hardware will be provided by the spacecraft. This structure will be used to support the LOU Harness.
5.6.2. Planck Payload Module

The following mechanical interfaces are discussed in this paragraph to the Planck instruments:

- Focal Plane Unit to Planck Telescope Structure
- PPLM warm units
- Pipes/wave-guides.

5.6.2.1. Planck Focal Plane Unit

The Planck focal plane unit is mounted to the Planck Telescope structure via a set of 6 (tbc) CFRP struts, being part of the FPU. This mounting concept is designed to:

- Mechanically hold the FPU, achieving the proper eigen-frequency
- Thermally isolate the FPU from the Telescope support structure
- Allow adjustment of FPU around nominal position of 3 mm (tbc)
- Achieve a positive fixation (not friction dependent)
- Allow for differential expansion between the focal plane unit and the Planck Telescope Structure, e.g. during cool-down.

The position of the FPU interface struts on the Planck Telescope structure is defined in Figure 5.6.2-1.
Figure 5.6.2-1: Interface position of the Planck FPU Interface Supports

The mounting hardware to the Planck Telescope Structure, i.e. screws/bolts/washers will be furnished by the spacecraft for the integration of the focal plane unit.

The different models of the FPU (CQM and FM) shall be compatible with the interface position of the holes at the Planck Telescope Structure.

The co-planarity of the interfaces to the FPU Interface Supports on the Planck Telescope structure will be within less than tbd mm between any two mounting interfaces of the FPU under all conditions.

There are no mechanical interfaces provided by the spacecraft other than to the FPU Interface Supports, i.e. the wave-guides of LFI are assumed to be mechanically fixed to the FPU.

There are no mechanical interfaces provided by the spacecraft to the cooler pipes at the level of the Planck Telescope Structure. Further fixation of the cooler pipes is covered in chapter 5.6.2.2 below.

5.6.2.2. PPLM Warm Units

In this paragraph only the mechanical interfaces of the PPLM warm units are discussed.
Figure 5.6.2-2: SVM and PPLM warm units
The following units are to be considered:

### 5.6.2.2.1. Sorption coolers Compressors

The sorption cooler compressor assemblies are two cold redundant, sets of units that exhibit mechanical interfaces to the main Planck spacecraft radiator. The mounting requirements are defined in Figure 5.6.2-3. Specific thermal interface requirements that are necessary to evacuate the dissipated power from the units are defined in chapter 5.7. The pipes from/to the sorption cooler is treated like harness, i.e. mechanical fixation will follow those requirements, no special thermal interface requirements are considered on the spacecraft radiator. The spacecraft will define the routing of the lines. The lines and thermalisation devices will be provided by the instrument. The fixation hardware will be provided by the spacecraft.

![Figure 5.6.2-3: Mounting for Sorption Coolers compressors and Electronics](image-url)
5.6.2.2.2. Sorption cooler electronics

The SCE units are two identical boxes, proposed by LFI to be located on the upper platform of the SVM, adjacent to the sorption cooler compressor assemblies to minimise the lengths of interconnecting cables. The SCE have no special thermal interface requirements. The position of the SCE units on the SVM is given in Figure 5.6.2-3. The mechanical fixation will follow the same rules as SVM units. The fixation hardware will be provided by the spacecraft.

5.6.2.2.3. 4 K cooler

The 4 K cooler is a set of units that exhibit standard mechanical interfaces to the spacecraft. The units are mounted on the spacecraft radiator. Mounting rules as for SVM units apply. No specific thermal interface requirements are necessary to evacuate the dissipated power from the unit. The pipes from/to the 4 K cooler compressors is treated like harness, i.e. mechanical fixation will follow those rules, no special thermal interface requirements are considered on the spacecraft radiator. The spacecraft will define the routing of the lines. The lines and thermalisation devices will be provided by the instrument. The fixation hardware will be provided by the spacecraft. The spacecraft will not provide any further mechanical interface/fixation to the 4 K cooler. The spacecraft will define the exact position of the cooler on the spacecraft radiator.

Figure 5.6.2-4: Interface drawing for the 4K Cooler units on the SVM panel.
5.6.2.2.4. Dilution cooler

The dilution cooler consists of the $^3$He and $^4$He bottles, the necessary valves and pipes. The mounting interfaces to the bottles are tbd. The spacecraft will define the position of the bottles. The pipes and valves from the bottles are treated like harness, i.e. mechanical fixation will follow those rules, and no special thermal interface requirements are considered on the equipment platform. The spacecraft will define the routing of the lines. The lines and thermalisation devices will be provided by the instrument. The fixation hardware will be provided by the spacecraft. The spacecraft will not provide any further mechanical interface/fixation to the dilution cooler.

![Diagram](image)

**Figure 5.6.2-5: Interface drawing for Dilution units on SVM O.1K Dilution panel (view from inside SVM)**

*Remark: It is suggested to HFI to change the dimensions of the DCCU and Filling & venting Panel to avoid cutting the SVM shear webs. Suggestion: DCCU Base 670x600mm, Filling & venting panel: Base 350x600mm. Height=260mm for both.*

5.6.2.2.5. LFI backend unit

The LFI backend unit is connected via the wave-guides with the LFI part of the FPU. The spacecraft has defined the position of the backend unit on the upper platform of the SVM. The location w.r.t. the FPU is given in Figure 5.6.2-6 and Figure 5.6.2-8. The wave-guide routing is treated in a dedicated way and defined in paragraph 5.6.2.3 below.
The mechanical fixation will follow the rules as for SVM units and no special thermal interface requirements are considered on the SVM platform. The fixation hardware will be provided by the spacecraft.

**Figure 5.6.2-6: Location of LFI backend unit and REBA**

**HFI Readout Electronics**

The JFET box is required to be at a maximum distance of 0.5 m from the FPU. The spacecraft has defined the position of the JFET box on the PLM. The location w.r.t. the FPU is given on Figure 5.6.2-7.

For the mechanical fixation will follow the rules as for SVM units and no special thermal interface requirements are considered on the SVM platform. The fixation hardware will be provided by the spacecraft.
Figure 5.6.2-7: Location of HFI JFET box, and routing of the HFI Harness (inside bellow Diam. 25mm)

Figure 5.6.2-8: SVM upper panel: Location of LFI-BEU and HFI-PAU (View from top)
5.6.2.3. Pipes / Wave-guides

This paragraph defines the mechanical interfaces of the instrument hardware other than harness that has to be routed from the PPLM warm units to the Planck FPU, i.e.:

5.6.2.3.1. Sorption cooler pipes

The pipes of the sorption cooler starts at the compressor assembly on the SVM radiator and is routed from this platform via the SVM upper platform to the V-groove shields and finally to the Planck FPU. The routing and the position of the routing is defined by the spacecraft and shown in Figure 5.6.2-10. The length of this pipes as defined in the IID B (AD 08) is followed. The mounting interfaces for the routing are standard interfaces not defined separately. The thermal interfaces at the V-groove shields that form also the mechanical interface are defined in paragraph 5.7 below. It is not planned to support the pipes mechanically between the thermal fixation at the shields.
Figure 5.6.2-10: Routing of the Sorption Cooler Pipes from Compressor Assembly to the FPU (typical)
5.6.2.3.2. 4 K cooler

The pipes of the 4 K cooler start at the compressors, mounted to the SVM radiator, is routed to the cooler’s ancillary unit from where it is routed via the V-groove shields to the FPU. The routing and the position of the routing are defined by the spacecraft. The maximum length of this part of the line is defined in the IID B (AD 07). The mounting interfaces for the routing are standard interfaces not defined separately. The thermal interfaces at the V-groove shields that form also the mechanical interface are defined in paragraph 5.7 below. It is not planned to support the pipes mechanically between the thermal fixation at the shields.

Figure 5.6.2-11: Interface drawing for Sorption cooler pipes.
5.6.2.3. Dilution cooler

The pipes of the dilution start at the supply bottles on the Planck equipment platform, is routed to the dilution cooler control unit from where it is routed via the V-groove shields to the FPU. The routing and the position of the routing are defined by the spacecraft. The maximum length of this part of the line is defined in the IID B (AD 07). The mounting interfaces for the routing are standard interfaces not defined separately. The thermal interfaces at the V-groove shields that form also the mechanical interface are defined in paragraph 5.7 below. It is not planned to support the pipes mechanically between the thermal fixation at the shields.

Figure 5.6.2-12: 4K cooler Pipes routing on the V-Groove Shields.
5.6.2.3.4. LFI wave-guides

The wave-guides are 2 bundles and start at the back end unit on the SVM upper platform and are directly routed to the FPU unit. The routing is illustrated in Figure 5.6.2-14 and interface drawing is shown on Figure 5.6.2-15 below. Forbidden areas (stay-out zones) are shown on Figure 5.6.2-16. The routing and positioning are defined by the instrument. The maximum length of this part of the line is defined in the IID B (AD 08). The spacecraft will not provide mounting interfaces between the two units for the wave-guides.
Figure 5.6.2-14: Routing of the wave-guides

Figure 5.6.2-15: Wave guides interface drawing
Figure 5.6.2-16: Wave-guides envelope volume.

For all above described elements it has to be noted that the spacecraft provides a mechanical stability such that differential movement of below 3 mm in any direction between the FPU and the BEU will be guaranteed.

5.6.3. Service Modules

5.6.3.1. Functional requirements:

Attachment points shall provide a controlled contact between the unit and the structure for the purpose of mechanical fixation and thermal control as well as electrical bonding of the unit.

5.6.3.2. Design requirements:

The attachment points shall be designed according to Figure 5.6.3-1. Boxes with a mass less than 1.5 kg shall not have more than 4 attachment points. For boxes with a mass above 1.5 kg and a structural and dynamic requirement for more than 4 points, the number of attachment points has to be approved by the Project.
For highly dissipative units the number and location of attachment points shall be based on thermal considerations.

Each attachment point shall have a fixation hole and one of these holes shall be identified as the Reference Hole, it shall be marked with a capital R in the configuration drawing. The box co-ordinates and the centre of mass co-ordinates shall be related to this reference hole. The positive X-axes of the unit and the S/C shall be parallel and in the same orientation as far as reasonable.

The distance D between two adjacent attachment points shall be \( 300 > D > 30 \) mm.

The distance of each attachment hole centre w.r.t. the Reference Hole, shall be within a 0.2 mm diameter circle centred on the theoretical position.

The attachment points and the clearance for mounting shall be dimensioned as shown in Figure 5.6.3-1. No part of the box shall be in the volume above the attachment points indicated as “free access required”. The contact area shall be specified in the configuration drawing for each attachment point. The attachment point edge shall be rounded-off to a minimum radius of 0.2 mm to avoid structural damage.

The co-planarity of the attachment points shall be within 0.1 mm/100 mm.

Each box on the SVM shall have an eigen-frequency of \( > 140 \) Hz.
Figure 5.6.3-1: Definition of attachment points of SVM mounted units and dimensioning requirements
5.7. THERMAL INTERFACES

5.7.1. Herschel Payload Module

The resources provided by the cryostat and the details of the interfaces are defined below for the different thermal interfaces to the instruments:

- Focal plane units to Herschel cryostat
- SPIRE JFET unit to optical bench
- HIFI Local oscillator unit to cryostat vacuum vessel
- PACS Bolometer Amplifier Unit to cryostat vacuum vessel

5.7.1.1. Focal Plane Units

The focal plane units of the Herschel instruments are mechanically mounted to the Herschel optical bench and shall exhibit standardised thermal interfaces. Three different thermal interface levels have been defined (see Table 5.7.1-1), where for each instrument the maximum temperature at the respective interface unit is identified.

<table>
<thead>
<tr>
<th>Thermal Interface</th>
<th>Maximum temperature [K]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIFI</td>
<td>PACS</td>
</tr>
<tr>
<td>Level 0</td>
<td>2</td>
<td>1.75</td>
</tr>
<tr>
<td>Level 1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Level 2</td>
<td>20</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Table 5.7.1-1: Definition of thermal interface levels

The identified thermal interfaces are detailed below:

5.7.1.1.1. Mounting interface of the focal plane unit to the optical bench

The optical bench will be thermally linked to level 2. The primary thermal link of the instruments to this temperature level will be by means of standardised straps (see Figure 5.7.1-1 and Figure 5.7.1-2). There is no thermal specification on the instruments on these interfaces, however the implementation selected by the instrument shall be properly defined and reflected in the thermal model of the FPU.

5.7.1.1.2. Level 2 interface

The requirement of this temperature to be below the maximum temperature given in Table 5.7.1-1 is valid for the instrument dissipation as given in paragraph 0. The interface of the instrument to level 2, delivered by the venting Helium, is a direct interface with the cryostat. The interface shall be at the level of the focal plane unit.
The thermal link will be provided by the spacecraft. The focal plane interface layout is defined in Figure 5.7.1-1. The instrument defines the location of this interface on the side faces of the unit. In case electrical insulation of the thermal connection from the structure is required, this has to be implemented as part of the focal plane unit. Since level 2 is achieved by the Helium vent-line coming from the Helium II tank and passing level 1 before, the spacecraft will not provide any type of thermal stabilisation of the interface temperature. For the design of the instrument and the evaluation of transient behaviour in the instrument it can be assumed that the mass flow through the interface pipes will be constant in orbit.

Figure 5.7.1-1: Level 1 and 2 interfaces (thermal link) to FPU

5.7.1.1.3. Level 1 interface
The requirement of this temperature to be below the maximum temperature given in Table 5.7.1-1 is valid for instrument dissipation as given in paragraph 0. The interface of the instrument to the level 1, delivered by the venting Helium, is a direct interface with the cryostat. The interface shall be at the level of the focal plane unit. The thermal link will be provided by the spacecraft. The focal plane interface layout is defined in Figure 5.7.1-2. The instrument defines the location of this interface on the side faces of the unit. In case electrical insulation of the thermal connection from the structure is required, this has to be implemented as part of the focal plane unit.
Since level 1 is achieved by the Helium vent-line coming from the Helium II tank, the spacecraft will not provide any type thermal stabilisation of the interface temperature. For the design of the instrument and the evaluation of transient behaviour in the instrument it can be assumed that the mass flow through the interface pipes will be constant in orbit.

**Figure 5.7.1-2: Mounting concept for thermal link (standard ISO)**

### 5.7.1.4. Level 0 interface

The requirement of this temperature to be below the maximum temperature given in Table 5.7.1-1 is valid for instrument dissipation as given in paragraph 0. The interface of the instrument to the level 0 is a direct interface with a thermal link to the Helium II tank of the cryostat. The interface shall be at the level of the focal plane unit. The thermal link will be provided by the spacecraft. The focal plane interface layout is similar to the level 1 and 2 interface (see Figure 5.7.1-1) where an increased interface area of the strap will be necessary (tbc). The instrument defines the location of this interface on the side faces or the bottom plate of the unit. In case electrical insulation of the thermal connection from the structure is required, this has to be implemented as part of the focal plane unit.

Level 0 is achieved by the temperature of the Helium II in the main tank. The requirement is an upper limit and the actual temperature will be below. The stability of the Helium temperature will be achieved by passive means. For the layout of the instrument and the evaluation of transient behaviour in the instrument it can be assumed that the Helium temperature is stable with a tbd mK variation per hour on a time-scale of days.

During recharging of the sorption coolers of PACS and SPIRE, the peak power dissipated by the instruments is much higher than the average power dissipation to the main tank. The temperature stability as given above will not achieved be during these periods.
5.7.1.5. **Environment/radiative thermal interface**

The environment temperature of the focal plane units is defined by the temperature of the surrounding instrument shield (maximum 2 K above the optical bench temperature and emissivity of 0.05), the optical channel from the telescope to the instruments and the optical channels from the LOU windows to the HIFI FPU. These optical channels will be designed to fulfill the straylight requirements, but no thermal load requirements are placed on their design except that the above temperature levels are fulfilled including the thermal load from these interfaces.

5.7.1.2. **SPIRE JFET and RF filter Module**

The SPIRE JFET and RF filter module does exhibit a specific thermal interface to the optical bench. The unit shall be designed such that the maximum thermal load during operation as defined in paragraph 5.9 will not be exceeded, assuming the interface to the optical bench being ideally thermally connected, i.e. infinite thermal conductance.

5.7.1.3. **Local Oscillator Unit**

The thermal interface of the local oscillator unit to the cryostat shall be a non-conductive one and only via the fixation struts. The fixation struts are provided by the spacecraft. The radiative heat exchange from the Local Oscillator Unit to the spacecraft will be minimised by design of the cryostat and of the LOU (MLI). The absolute temperature of the unit shall be minimised by means of appropriate radiative areas to space using a radiator, part of the LOU. The allocated volume for the unit including the potentially necessary radiator(s) is given in paragraph 5.3.1.1. For the design of the unit an equivalent radiative environment temperature will be given (average of space & Spacecraft radiative boundary environment. The current estimation is about 90K. The unit shall not require any active thermal control. The maximum dissipation of the unit shall be as given in paragraph 5.9.

![TBD](image)

Figure 5.7.1-3: Thermal interface of LOU

5.7.1.4. **PACS Bolometer Amplifier Unit**

The thermal interface of the Bolometer Amplifier Unit to the spacecraft shall be a conductive one and only via the fixation struts. The fixation struts, respectively a mounting plate are/is provided by the spacecraft. The radiative heat exchange from
the Bolometer Amplifier Unit to the spacecraft will be minimised by design of the cryostat. The absolute temperature of the unit shall be minimised by means of appropriate radiative areas to space. The unit shall not require any active thermal control. The maximum dissipation of the unit shall be as given in paragraph 5.9.

5.7.1.5. LOU Wave-guides

The LOU wave-guides, routed directly from LSU on SVM to LOU on cryostat, will be supported from the SVM and will be equipped of a radiator. This frame will also support and heat sing the LOU harness.

5.7.1.6. Instrument Harness

Herschel instrument harness is procured and integrated by the Herschel PLM contractor. As the harness is a potential bypass from SVM (room temperature) down to the coldest zone inside the Cryostat, as the number of cables is very important, the harness has to be optimised for electrical and thermal performances. This paragraphs summarises the material cross sections, thermal conduction and joule effect dissipations, as estimated from the sections 5.10.2 of the IID-B’s

<table>
<thead>
<tr>
<th>FIRST</th>
<th>from</th>
<th>to</th>
<th>SVM to local oscillator</th>
<th>SVM to BAU</th>
<th>BAU to CVV</th>
<th>Inside CVV</th>
<th>Inside FPU</th>
<th>K</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIFI</td>
<td>length of cable</td>
<td>2.0m</td>
<td>2.0m 0.2m 2.0m 0.25m 0.5m 0.5m 0.5m m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># cables</td>
<td>1230</td>
<td>section steel</td>
<td>19.54</td>
<td>19.64 19.64 19.64 19.64 - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>152</td>
<td>section brass</td>
<td>4.57</td>
<td>2.34 2.34 2.34 2.34 - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>152</td>
<td>section insulator</td>
<td>171.61</td>
<td>141.40 141.40 141.40 141.40 - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>152</td>
<td>Section CuBe</td>
<td>-</td>
<td>0.28 0.28 0.28 0.28 - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>152</td>
<td>Section Cu</td>
<td>3.69</td>
<td>- - - - - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># wave guides</td>
<td>14</td>
<td>Section Waveguides (Steel)</td>
<td>55.67</td>
<td>- - - - - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dissipation in cable</td>
<td>2 774.09</td>
<td>30.78 2.97 5.76 5.76 5.76 - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conduction harness</td>
<td>148.31</td>
<td>56.29 60.20 1.19 0.06 - - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduction wave-guides</td>
<td>56.19</td>
<td>- - - - - - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissipation + Conduction</td>
<td>2 922.41</td>
<td>87.07 63.17 6.95 5.82 - - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE</td>
<td>length of cable</td>
<td>2.0m</td>
<td>2.0m 0.2m 2.0m 0.25m 0.5m 0.5m 0.5m m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># cables</td>
<td>1116</td>
<td>section steel</td>
<td>- - 55.63 55.63 55.63 49.81 5.4944 mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>491</td>
<td>section brass</td>
<td>- - 0.87 0.87 0.87 - - - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>491</td>
<td>section insulator</td>
<td>- - 388.92 388.92 388.92 330.20 326.39 - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dissipating in cable</td>
<td>-</td>
<td>9.64 0.95 1.84 0.0017 0.00012 - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conduction</td>
<td>-</td>
<td>95.30 105.11 1.88 0.075 0.012 - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissipation + Conduction</td>
<td>95.30 105.11 1.88 0.075 0.012 - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS</td>
<td>length of cable</td>
<td>2.0m</td>
<td>2.0m 0.2m 2.0m 0.25m 0.5m 0.5m 0.5m m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># cables</td>
<td>2110</td>
<td>section steel</td>
<td>12.62 7.28 24.59 31.87 31.87 16.56 7.48 mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>286</td>
<td>section brass</td>
<td>- - 2.92 2.92 2.92 0.06 - - - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>286</td>
<td>section insulator</td>
<td>103.18 53.18 191.46 244.64 244.64 106.63 55.08 - mm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dissipating in cable</td>
<td>9.82</td>
<td>87.78 6.39 12.33 0.0013 0.000022 - mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conduction</td>
<td>17.22</td>
<td>67.91 86.68 1.71 0.0252 0.0019 mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissipation + Conduction</td>
<td>27.04</td>
<td>135.69 93.07 14.04 0.00265 0.00019 mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># cables</td>
<td>4456</td>
<td>Dissipation in cable</td>
<td>2774.1</td>
<td>4.9 0.0 36.1 3.4 6.6 1.9 0.000049 mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Shields</td>
<td>929</td>
<td>average harness dissipating</td>
<td>148.3</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total conduction</td>
<td>17.2 16.2 219.5 252.0 4.8 0.2 0.0138 mW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This table has been established on the basis of the harness input provided by the instruments in IID-Bs 1/0 and will be updated following revised inputs from the instruments.

Figure 5.7.1-4: Thermal impact of Herschel instrument harness

5.7.2. Planck Payload Module

The resources provided by the Planck Payload Module and the details of the interfaces are defined below for the different thermal interfaces to the instruments:
An overview of the thermal design and interfaces is given in Figure 5.7.2-1.

**Figure 5.7.2-1: Planck PLM Thermal Interfaces Schematic**

### 5.7.2.1. Focal Plane Unit

The combined focal plane unit of LFI and HFI is mechanically mounted to the Planck telescope support structure. The thermal interface parameters of this mechanical interface to the Planck telescope support structure is shown in Figure 5.7.2-1. However, at present it can be assumed that an ideal thermal contact will be achieved at the interface point at the telescope support.

Another thermal interface of the FPU to the optical bench is thermal connection of the HFI JFET unit. This unit is mounted as well to the telescope support frame. It needs to be thermally coupled to the radiator and mechanically isolated from the spacecraft. The maximum supported heat load is given in paragraph 5.9.
The environment/radiative thermal interface to the focal plane is given by the surface properties and the temperature of the inner enclosure of the Planck Telescope Baffles bench. The details of these parameters are given in Figure 5.7.2-2.

Figure 5.7.2-2: Thermal interface of the JFET Unit of HFI to the telescope support structure
Figure 5.7.2-3: Thermal environment of PPLM Baffles to FPU (continuous red line is low emissivity (Polished Al coating), Dashed blue line is radiator Area (Black open honeycomb)

5.7.2.2. Planck Instrument Units on Spacecraft Radiator

In this paragraph the thermal interfaces of the units mounted on the s/c radiator are discussed.

The following units are to be considered:

5.7.2.2.1. Sorption cooler

The sorption cooler is dissipating several hundred Watts and needs a specific thermal interface to evacuate the dissipated power from the unit. The mounting interface is defined in Figure 5.6.2-3 and the thermal dissipation is listed in section 0.

5.7.2.2.2. 4 K cooler

The 4 K cooler compressor, ancillary panel, and electronics are directly hard mounted on a dedicated radiator (see Figure 5.6.2-4), allowing to evacuate directly the heat to space.

5.7.2.2.3. Dilution cooler
The dilution cooler consists of the $^3$He and $^4$He bottles, the necessary valves and pipes.

5.7.2.3. Pipes / Wave-guides / Harness

This paragraph defines the thermal interfaces of the instrument hardware other than harness, that has to routed from the Planck SVM radiator equipment, respectively the SVM upper platform to the Planck FPU, i.e.:

5.7.2.3.1. Sorption cooler pipes

At the level of the v-groove shields, the instrument will provide heat exchangers for the sorption cooler pipes. The thermal interface of the heat exchanger is defined by the spacecraft and is tbd. The spacecraft does not provide any further thermal interface to the pipes.

5.7.2.3.2. 4 K cooler pipes

At the level of the v-groove shields, the instrument will provide heat exchangers for the 4 K cooler pipes. The pipes are currently connected only on the 50 K Shield (See Figure 4.3.1-1). It is recommended to have also a thermal heat sink on 150K and 100K shields, to reduce the load on the 50K radiator.

5.7.2.3.3. Dilution cooler

At the level of the v-groove shields, the instrument will provide heat exchangers for the dilution cooler pipes. The dilution cooler pipes are heat sunk on each V-Groove shields (see Figure 5.6.2-13).

5.7.2.3.4. Wave-guides

Each of the bundles of the wave-guides has dedicated thermal interfaces at the v-groove shields. The thermal interface of the heat exchangers is defined by the spacecraft. The properties of the interfaces are tbd. Typical interface is shown on figure 5.7.2.-4

5.7.2.3.5. Harness

The Planck cryo-harness is provided by the instruments, and integrated by the Planck Payload contractor. In this section, the thermal impact of the harness are estimated, from the description given in the IID-B, § 5.10.2.

Figure 5.7.2-5: Thermal impact of Planck instrument harness
This table has been established on the basis of the harness input provided by the instruments in IID-Bs 1/0 and will be updated following revised inputs from the

<table>
<thead>
<tr>
<th>Planck</th>
<th>SVM-Outer shield</th>
<th>Outer shield-Medium shield</th>
<th>Medium shield-Radiator</th>
<th>Radiator-LFI</th>
<th>LFI-HFI</th>
<th>HFI</th>
<th>HFI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td>300K</td>
<td>150K</td>
<td>100K</td>
<td>60K</td>
<td>20K</td>
<td>4K</td>
<td>1.6K</td>
</tr>
<tr>
<td>to</td>
<td>150K</td>
<td>100K</td>
<td>60K</td>
<td>20K</td>
<td>4K</td>
<td>1.6K</td>
<td>0.1K</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LFI harness</th>
<th>length of cable</th>
<th>section steel</th>
<th>0.30m</th>
<th>0.20m</th>
<th>0.20m</th>
<th>0.20m</th>
<th>mm2</th>
</tr>
</thead>
<tbody>
<tr>
<td># cables 996</td>
<td>length of cable</td>
<td>section brass</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>mm2</td>
</tr>
<tr>
<td># shields 34</td>
<td>length of cable</td>
<td>section insulator</td>
<td>2.385</td>
<td>2.347</td>
<td>2.309</td>
<td>2.271</td>
<td>mm2</td>
</tr>
<tr>
<td># shield 0.0</td>
<td>length of cable</td>
<td>Section Gold 0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>mm2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wave guides</th>
<th>length of wave guide</th>
<th>dissipation in Harness</th>
<th>52.0</th>
<th>22.5</th>
<th>20.9</th>
<th>48.4</th>
<th>mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section Steel 184.7</td>
<td>184.7</td>
<td>184.7</td>
<td>184.7</td>
<td>184.7</td>
<td>mm2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Gold 1.1</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>mm2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total LFI</th>
<th>Conduction + Dissipation</th>
<th>4085.3</th>
<th>774.4</th>
<th>432.5</th>
<th>227.9</th>
<th>mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFI harness</td>
<td>length of cable</td>
<td>section steel</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td># cables 879</td>
<td>length of cable</td>
<td>section brass</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.29</td>
</tr>
<tr>
<td># shields 74</td>
<td>length of cable</td>
<td>section insulator</td>
<td>93.1</td>
<td>93.1</td>
<td>93.1</td>
<td>50.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total HFI</th>
<th>Conduction + Dissipation</th>
<th>167.1</th>
<th>64.9</th>
<th>34.6</th>
<th>163.1</th>
<th>mw</th>
</tr>
</thead>
</table>

| Sorption Cooler | length of cable | section steel | 25.3 | 24.9 | 24.5 | 24.1 | mm2 |
| # cables 996 | length of cable | section brass | 0.3 | 0.5 | 0.5 | 0.5 | mm2 |
| # shields 34 | length of cable | section insulator | 238.5 | 234.7 | 230.9 | 227.1 | mm2 |
| # shield 0.0 | length of cable | Section Gold 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | mm2 |

<table>
<thead>
<tr>
<th>total Sorption</th>
<th>Conduction + Dissipation</th>
<th>3839.1</th>
<th>649.4</th>
<th>346.6</th>
<th>163.1</th>
<th>mw</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Total Planck</th>
<th>total dissipation</th>
<th>59.4</th>
<th>26.6</th>
<th>24.6</th>
<th>50.9</th>
<th>mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total conduction</td>
<td>4193.0</td>
<td>815.3</td>
<td>451.7</td>
<td>195.5</td>
<td>1.7</td>
<td>mw</td>
</tr>
<tr>
<td>Total harness</td>
<td>4252.4</td>
<td>841.3</td>
<td>476.3</td>
<td>246.5</td>
<td>3.4</td>
<td>mw</td>
</tr>
</tbody>
</table>

5.7.3. Service Modules
The nominal temperature range for units mounted onto the Herschel or Planck SVM are defined in Table 5.7.3-1. Acceptance temperatures are 5°C below minimum and 5°C above maximum operating temperatures. Qualification temperatures are 10°C below minimum and 10°C above maximum operating temperatures. Instrument units that are not compliant with the nominal temperature ranges shall be clearly identified in the IID-B

<table>
<thead>
<tr>
<th>SVM Unit</th>
<th>Operating</th>
<th>Start-up</th>
<th>Switch-off</th>
<th>Non-operating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. °C</td>
<td>Max. °C</td>
<td>°C</td>
<td>°C</td>
<td>Min. °C</td>
</tr>
<tr>
<td>-15</td>
<td>45</td>
<td>-30</td>
<td>50</td>
<td>-35</td>
</tr>
</tbody>
</table>

Table 5.7.3-1: Nominal Temperature Limits for SVM mounted Instrument Units

The contact area between boxes and structure shall be at the area of the mounting feet. This area shall be flat with no protrusion below the mounting plate.
All units operating in the 270-350K range shall have a flat base-plate contact: these are all the dissipating units i.e. those where the skin dissipated power of faces not in contact with support structure is more than 50W/m$^2$.

In the case of a flat base-plate contact area, this area must meet the following requirements:
- Flatness of 0.1mm/100mm (for mounted box and structure)
- Roughness < 3.2micron
- Use of an inter-filler or equivalent

5.7.3.1. Thermal stability
For Herschel it is not envisaged that the spacecraft will provide any resources to maintain a thermal stability of better than 3K/hour, with a goal of 1K/hour. Should a warm unit or parts thereof have more stringent requirements on the stability the means (such as cooling device or heaters) shall be provided by the instrument respecting the mass limits given above in this chapter.
5.8. OPTICAL INTERFACES

5.8.1. Herschel Instruments

5.8.1.1. Herschel Telescope Interfaces

The Herschel telescope is described in chapter 4.3.1.

The optical interfaces are controlled via a set of mechanical interfaces defined w.r.t. spacecraft co-ordinates. The focal plane units will be mechanically mounted to the Herschel optical bench. This optical bench is aligned to the telescope in accordance with the alignment requirements as defined in Annex 1.

- pupil: limited by the secondary reflector
- aperture stop: at the secondary mirror
- unvignetted telescope field of view: +/- 0.25°
- linear central obscuration: less than 3%
- system f/D (D = effective aperture): 8.68
- diffraction limits of telescope: at 150 microns (goal: 80 microns)
- relative spectral transmission: 97% at BOL
- nominal operational temperature: 70 – 90 K
- early orbit contamination release phase: up to at least 313 K for a minimum duration of three weeks
5.8.1.2. Herschel Straylight

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

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

**Scattered light (source outside the telescope FoV)**

Taking into account the worst combination of the Moon and the Earth positions w.r.t. the LOS of the telescope with maximal:
- Sun - S/C - Earth angle of 37º
- Sun - S/C - Moon angle of 47º
- Sun - S/C - LOS angle of 60º to 120º,
  the straylight shall be: $< 1.0\%$ of background radiation induced by self-emission of the telescope.

**Sources inside FOV:**

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

**Self-emission**

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

For each of the seven LO beams a window with 30 mm free aperture will be provided in the cryostat wall. The design and mounting layout is shown in Figure 5.8.1-1. The LOU is aligned with the cryostat according to requirements given in 5.3 above.

Figure 5.8.1-1: Design and layout of cryostat vacuum feedthroughs

5.8.2. Planck Instruments

5.8.2.1. Planck Telescope Interfaces

The Planck telescope is described in chapter 4.4.1. Further interface relevant characteristics are:

The telescope operates at a temperature between 45K and 60K.
The Planck telescope is an offset Aplanatic telescope. Its main characteristics are:

- focal length: 1800 mm
- maximum field of view: ±5°
- optical quality: tbd variation w.r.t. the ideal
- positioning of optical elements:
  - the position of the optical elements especially the secondary versus primary and the focus position are given in Figure 5.8.2-1 below

The telescope LOS will remain within 0.5° of the nominal direction considering the mechanical, thermal and radiation environment.

The optical interfaces are controlled via a set of mechanical interfaces defined w.r.t. spacecraft co-ordinates. The focal plane unit will be mechanically mounted to the Planck telescope support.

Figure 5.8.2-1: Planck Telescope Positioning of Optical Elements
5.8.2.2. Planck Straylight

The Straylight is defined for the Planck instruments as the radiative power that reaches a detector within its RF bandwidth, and that does not originate from sources close to the main beam.

For Planck, the detectors consist of either bolometers or HEMT amplifiers. Straylight induces a signal in the detector that is indistinguishable from signals induced by sources located in the main beam. Variations in straylight are a source of noise in the detector (the Straylight Induced Noise, or SIN) that cannot be separated from intrinsic detector noise or from variations in the sources of interest (those in the main beam).

Straylight coming into the focal plane can have two distinct origins:

- Sources external to the spacecraft in the far-field of the telescope
- Spacecraft self emission sources

Sources external to the spacecraft in the far field of the telescope

External straylight in the millimetre and sub-millimetre wave range is dominated by four extremely bright sources: the Sun, the Earth, the Moon and the Milky Way. Large angle off-axis rejection is determined mainly by the telescope shield’s shape and size.

The system rejection at the detectors for Sun, Earth, Moon at worst case locations will be, at least:

30 GHz: -91 dB, -78 dB and -71 dB respectively.
100 GHz (HFI): -91.5 dB (-99 dB), -78.5 dB (-86 dB) and -71.5 dB (-73 dB) respectively
353 GHz: -92 dB (-108 dB), -79 dB (-95 dB) and -72 dB (-81 dB) respectively.
857 GHz: -98 dB (-122 dB), -85 dB (-109 dB) and -78 dB (-95 dB) respectively.

1) The requirement for the Milky Way is of order ~65 dB from peak but is driven by the telescope in free-standing configuration.
2) The values between brackets shall be taken as goals

Spacecraft self emission sources

Thermal emission from all components of the spacecraft (including telescope, FPU, shield, SVM, baffles etc.) produces a signal which is not easily distinguishable from signals due to sources in the main beam. The time variation of the straylight signal from these sources is due to fluctuations in the temperature of emissive components.

The Amplitude Spectral Density (ASD) at the bolometer (HFI) or cold LNA (LFI) of any signal due to fluctuating thermal emission from a S/C element that couples radiatively into payload detectors, shall be as specified below for each of the five
defined individual frequencies, taking into account the power transfer function between the radiating source and the detectors.

The ASD (in Watts/√Hz) of each frequency component between 0.01 Hz and 100 Hz shall be such that:

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>ASD [Watt/√Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>&lt; 3.4 E-18 X</td>
</tr>
<tr>
<td>100 (LFI)</td>
<td>&lt; 1.1 E-17 X</td>
</tr>
<tr>
<td>100 (HFI)</td>
<td>&lt; 2.1 E-18 X</td>
</tr>
<tr>
<td>353</td>
<td>&lt; 1.8 E-18 X</td>
</tr>
<tr>
<td>857</td>
<td>&lt; 2.2 E-17 X</td>
</tr>
</tbody>
</table>

Note:
X is equal to one for any frequency component \( f_0 \) of the fluctuation source synchronous with the Planck S/C spinning rate (i.e. multiple of \( f_{\text{spin}} = 1 / 60 \text{ Hz} \)). Otherwise, \( X = (B \times t_{\text{obs}} \times \Delta f) \), where \( \Delta f = f_0 - k \times f_{\text{spin}} \) and \( k \) is chosen to minimise \( \Delta f \).

\( t_{\text{obs}} = 3600 \times \text{FWHM} / 2.5 \text{arcmin} \), and FWHM is the angular resolution of the antenna radiation pattern in arc minutes.

In order to enable calculation of the straylight, the position, orientation and beam characteristics of the five horns in the focal plane at 30, 100, 353 and 857 GHz, together with their frequency bandwidth are as follows:

### Parameters defining the horns:
The tables below give the characteristics of the realistic corrugated Horns that will be used for the evaluation of the Planck straylight analysis.

<table>
<thead>
<tr>
<th>horn-identifier</th>
<th>x (mm)</th>
<th>y (mm)</th>
<th>z (mm)</th>
<th>phi (deg)</th>
<th>theta (deg)</th>
<th>psi (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFI 857</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HFI 353</td>
<td>-2.74E+01</td>
<td>-5.99E+01</td>
<td>1.50E+02</td>
<td>165.70</td>
<td>30.57093</td>
<td>-1.92</td>
</tr>
<tr>
<td>LFI 100</td>
<td>-8.97E+01</td>
<td>8.07E+01</td>
<td>1.18E+02</td>
<td>-156.24</td>
<td>23.90021</td>
<td>1.84</td>
</tr>
<tr>
<td>LFI 30</td>
<td>-1.25E+02</td>
<td>1.23E+02</td>
<td>9.08E+01</td>
<td>-141.78</td>
<td>22.32231</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Positions of the horns in the global coordinate system:

### Horn-identifier	| taper (db @22 deg) | aperture D (mm) | Beamwidth (deg) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HFI 857</td>
<td>-36</td>
<td>8.2</td>
<td>3.5</td>
</tr>
<tr>
<td>HFI 353</td>
<td>-36</td>
<td>8.2</td>
<td>8.4</td>
</tr>
<tr>
<td>LFI 100</td>
<td>-30</td>
<td>19.5</td>
<td>11.4</td>
</tr>
<tr>
<td>LFI 30</td>
<td>-30</td>
<td>51</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Electromagnetic parameters defining the horns.
### 5.9. POWER

#### 5.9.1. Thermal Dissipation on Herschel Payload Module

The maximum thermal dissipation supported by the spacecraft at the different interface levels of the Herschel Payload module are defined in the table below.

#### Summary

<table>
<thead>
<tr>
<th>Level</th>
<th>Average Maximum dissipation [mW]</th>
<th>Maximum Peak dissipation [mW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>10</td>
<td>tbd</td>
</tr>
<tr>
<td>Level 1</td>
<td>25</td>
<td>tbd</td>
</tr>
<tr>
<td>Level 2</td>
<td>50</td>
<td>tbd</td>
</tr>
<tr>
<td>Outside CVV</td>
<td>7250</td>
<td>tbd</td>
</tr>
</tbody>
</table>

#### Level 0

<table>
<thead>
<tr>
<th>Instrument/Mode</th>
<th>Maximum Average load [mW]</th>
<th>Maximum Peak load [mW]</th>
<th>Maximum Peak Energy [Ws]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIRE/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/PACS</td>
<td></td>
<td></td>
<td></td>
<td>Parallel mode tbc</td>
</tr>
<tr>
<td>HIFI/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIFI/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Level 1

<table>
<thead>
<tr>
<th>Instrument/Mode</th>
<th>Maximum Average load [mW]</th>
<th>Maximum Peak load [mW]</th>
<th>Maximum Peak Energy [Ws]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIRE/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/PACS</td>
<td></td>
<td></td>
<td></td>
<td>Parallel mode tbc</td>
</tr>
<tr>
<td>HIFI/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIFI/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Level 2

<table>
<thead>
<tr>
<th>Instrument/Mode</th>
<th>Maximum Average load [mW]</th>
<th>Maximum Peak load [mW]</th>
<th>Maximum Peak Energy [Ws]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIRE/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE/PACS</td>
<td></td>
<td></td>
<td></td>
<td>Parallel mode tbc</td>
</tr>
<tr>
<td>HIFI/Prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIFI/No prime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cryostat Vacuum Vessel

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOU/On</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOU/Off</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOLA/On</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOLA/Off</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.9.1-1: Maximum thermal dissipation at the Herschel Payload Module

5.9.2. Thermal Dissipation on Planck Payload Module

The maximum thermal dissipations supported by the spacecraft at the different interface level of the Planck Payload module are defined in the table below.

<table>
<thead>
<tr>
<th>Planck FPU</th>
<th>V-Groove 3 (Cold)</th>
<th>V-Groove 2 (Medium)</th>
<th>V-Groove 1 (Warm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2930</td>
<td>1320</td>
<td>7150</td>
</tr>
<tr>
<td>HFI</td>
<td>620</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>JFET Dissipation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harness (Conduction (*)+Dissipation)</td>
<td>40</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Cooler pipes 0.1K (Cond (*)+ Enthalpy)</td>
<td>170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooler pipes 4K (Cond(*) + Enthalpy)</td>
<td>260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFI</td>
<td>610</td>
<td>560</td>
<td>5370</td>
</tr>
<tr>
<td>Dissipation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harness (Cond(*)+Dissip)</td>
<td>100</td>
<td>60</td>
<td>730</td>
</tr>
<tr>
<td>Wave-Guides (Cond(*)+ Dissip + Rad)</td>
<td>510</td>
<td>500</td>
<td>4640</td>
</tr>
<tr>
<td>Sorption cooler</td>
<td>1380</td>
<td>500</td>
<td>860</td>
</tr>
<tr>
<td>Cooler Pipes (Cond(*) + Enthalpy)</td>
<td>1380</td>
<td>500</td>
<td>860</td>
</tr>
<tr>
<td>Harness (Cond(<em>)+Dissip) (</em>**)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPLM</td>
<td>320</td>
<td>240</td>
<td>870</td>
</tr>
<tr>
<td>Supports</td>
<td>220</td>
<td>70</td>
<td>530</td>
</tr>
<tr>
<td>Harness (Cond(*)+Dissip) (**)</td>
<td>100</td>
<td>170</td>
<td>340</td>
</tr>
</tbody>
</table>

Table 5.9.2-1: Maximum thermal dissipation on the Planck Payload Module

* Conduction / radiation allocation on level (i) represent the summ of the heat coming from level i+1 minus the one leaving to level i-1
** Includes provision for Decontamination heaters on mirrors
*** sorption cooler harness included with pipe

These Heat losses allocations are Maximum Values acceptable by the Planck Payload.
This mean that the instrument estimated dissipations or losses should include 20% of design margin before reaching these values.
With these allocations, the calculated temperature at the sorption cooler interface is 52K ±7K
5.9.3. Thermal Dissipation on Herschel Service Module

The maximum and minimum thermal dissipations supported by the Herschel spacecraft at the interface level of the warm boxes to the HSVM are defined in the table below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HIFI</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACS</td>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRE</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.9.3-1: Maximum and minimum thermal dissipation of warm boxes on HSVM.

5.9.4. Thermal Dissipation on Planck Service Module

The maximum and minimum thermal dissipations supported by the Planck spacecraft at the interface level of the warm boxes to the PSVM are defined in the table below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LFI</td>
<td>74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorption Cooler</td>
<td>655</td>
<td>950</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HFI</td>
<td>255</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.9.4-1: Maximum and minimum thermal dissipation of warm boxes on PSVM

5.9.5. Power Supply - Load on main-bus

The total electrical power provided by the spacecraft to the instruments will be limited as in the following Table 5.9.5-1:

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Instrument</th>
<th>Maximum Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel</td>
<td>SPIRE</td>
<td>100</td>
</tr>
<tr>
<td>Herschel</td>
<td>PACS</td>
<td>100</td>
</tr>
<tr>
<td>Herschel</td>
<td>HIFI</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Planck</td>
<td>LFI</td>
<td>74</td>
</tr>
<tr>
<td>Planck</td>
<td>Sorption Cooler</td>
<td>655</td>
</tr>
<tr>
<td>Planck</td>
<td>HFI</td>
<td>255</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1000</td>
</tr>
</tbody>
</table>

Table 5.9.5-1: Loads on Main Bus

Peak power, as defined in 5.9.1.6 below, will be given in the IID-Bs.
5.9.5.1. Bus voltage

The spacecraft power supply subsystem will provide: The distribution, protection and switching of a 28V DC main power bus to the users.

Each of the scientific instruments will have to incorporate its own converter(s) (compatible with the main bus characteristics) to generate the required secondary voltages.

5.9.5.2. Main Bus characteristics

The instruments shall be designed to operate with nominal performance within the following steady state voltage limits:

<table>
<thead>
<tr>
<th>Line</th>
<th>Minimum Voltage</th>
<th>Maximum Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Bus</td>
<td>26 V</td>
<td>29 V</td>
</tr>
</tbody>
</table>

Table 5.9.5-2: Bus Voltage

In addition, all the users of these power lines shall safely survive any standing or fluctuating voltage in the full range 0 V to 35V.

5.9.5.3. Dynamic behaviour

5.9.5.3.1. Transient

The equipment shall operate with nominal performance when subject to a transient superimposed on the steady state bus as described in paragraph 5.14.3.8. This requirement accounts for potential transients caused by remote equipment's (susceptibility).

5.9.5.3.2. Ripple and Spikes

The equipment shall operate with nominal performance when subject to the following main bus conditions:

- 140 mVpp Main Bus ripple
- 240mVpp Commutation spikes.

5.9.5.4. Power Distribution

Power is switched and distributed to instruments on protected output lines by means of Latching Current Limiters [LCL’s].

If the LCL limitation level is exceeded the LCL will limit the current and reduce the voltage at that user’s input. Therefore, except for the inrush, the user’s instantaneous current demand shall never exceed the limitation level of the related LCL. If the limitation extends beyond the LCL trip-off time, the LCL will trip off and power will be disconnected from that user.
Use of fuses shall be avoided. If absolutely needed, use of fuses shall be justified and request submitted to ESA for approval.

5.9.5.5. Bus Impedance

The bus impedance mask at the user interface is:

![Bus Impedance User Side](image)

**Figure 5.9.5-1**: Bus impedance vs. Frequency

Each instrument shall not be susceptible to voltage transients induced by its own current transitions, when connected to a 28Vdc voltage source (+2%, -1%) with the output impedance reported above. This requirement shall be verified during the electrical functional testing.

5.9.5.6. Power Demand

5.9.5.6.1. Average

The average power is defined for an equipment as the maximum average power drawn from its dedicated power lines in the worst case conditions.

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

5.9.5.6.2. Long Peak

To be defined as a long peak, the power demand shall last less than 5 minutes per 24 h (cumulated duration of individual peaks if any) and more than 100 ms.
The peak value is defined as the integral mean during a period of 100 ms shifted to any point in time where the integral will yield a maximum.

5.9.5.6.3. Short Peak
To be defined as a short peak, the power demand shall last less than 100 ms.

The peak value is defined as the integral mean during a period of 1 ms shifted to any point in time where the integral will yield the maximum.

5.9.5.6.4. Inrush Current
Inrush current is limited by the spacecraft PDU LCL to a maximum of 1.5 times the short peak value. At LCL switch-on the inrush current is limited by the PDU LCL as well as the inductance in the user input circuit.

Inrush current is limited by the PDU LCL to a value between the instantaneous peak value and 1.5 times the instantaneous short peak value.

Inrush current duration is set the PDU LCL. To prevent LCL trip-off users shall limit the inrush current duration to a maximum change of $5A \times \text{msec (tbc)}$.

LCL users shall limit the rate of change of inrush current to $1A/\mu\text{sec}$.

5.9.5.6.5. Load Current Transitions
The instantaneous rate of change ($dI/dt$) shall not exceed $5.10^4 \text{ A/s}$. Pulse repetition frequency shall not exceed 1 Hz unless confined to the limits of admissible ripple current.

5.9.5.6.6. Initial Electrical Status
After being switched OFF for a minimum period of 10 sec and when switched on, equipments shall have an initial electrical status (except for latching relays if used), which is reproducible and identified

This status shall be safe; i.e. no degradation of nominal performance shall be caused if this initial status is kept for an unlimited time.

5.9.5.6.7. Interface Circuits
TBD

5.9.5.7. Instrument Converter Synchronisation
The converters shall be free running at nominal frequency $131kHz +/-10\%$ (TBC).

5.9.5.8. Pyrotechnic Devices
NA

5.10. CONNECTORS, HARNESS, GROUNDING, BONDING

5.10.1. Connectors
Connectors provide a low-impedance path for all wires and a low-impedance bond when an outer shell is used.
5.10.1.1. Connector types

For non-coaxial connections at non-cryogenic temperatures CANNON-ITT connectors of type DxA are defined. (x = A, B, C, D or E).

At cryogenic temperatures CANNON-ITT micro-miniature connectors, MDM xx, SL2-A 174 are defined. The maximum number of pins for these connectors shall be 37, the number of rows shall be 2.

For coaxial connections at TBD temperatures TBD connectors are defined. For tri-axial connections, as used by PACS, at TBD temperatures TBD connectors are defined, where three adjacent pins may be used instead of tri-axial connectors.

5.10.1.2. Connector characteristics

- Connectors shall be clearly identified to prevent incorrect mating.
- The housing of connectors shall be electrically connected to the unit structure.
- All connectors supplying power shall have socket contacts.
- Flight-quality connectors shall be protected against frequent mating/demating operations by connector savers. These savers shall be supplied with the instrument.
- Connectors shall be mechanically locked to prevent inadvertent disconnection.
- All units shall use dedicated connectors for the different signal categories as defined in chapter 5.10.2.4
- Separate connectors shall be used for each of the redundant system, subsystem or unit branches.

5.10.1.3. Connector mounting

- Equipment and bracket mounted connectors shall be located in easily accessible positions.
- The physical position is to be indicated on the External Configuration Drawings and must be compliant with the minimum distances between connectors and mounting plane as given in Figure 5.10.1-1.
- Any additional specific requirements (e.g. minimum distance between two units facing each other) shall be identified in the IID-B by the instrument.
5.10.2. Harness

5.10.2.1. S/C harness
The S/C harness provides the interconnection between the instruments and two other subsystems, i.e. the Power subsystem and the Data-handling subsystem. The harness will be part of the SVM, delivered through the S/C contractor, manufactured to agreed standards and specifications, compatible with the characteristics of the source and destination. A so-called harness list specifies source and destination to the level of unit, connector and pin. Instrument teams will have to provide their inputs to the harness list by pin function definitions for instrument connectors to the Power and the Data Handling subsystems. Pin functions will be defined in part B of the IID’s (AD 04,05,06,07,08). Some general design criteria are given in 5.10.2.4.

5.10.2.2. Instrument harness
The “warm” harness, i.e. the interconnect harness between the various “warm” instrument units will be delivered by the instrument teams, manufactured to agreed standards and specifications, compatible with the characteristics of the source and destination. Instrument teams will have to provide a harness list, which specifies source and destination to the level of unit, connector and pin. This harness list will be defined in part B of the IID’s (AD 04,05,06). As the layout of the instrument units as well as the S/C mounting platform is unknown, harness length and routing are presently TBD. Some general design criteria are given in 5.10.2.4.

The wave-guides between the Herschel HIFI LOU unit at the Herschel CVV and Local Oscillator Control Unit on the SVM are considered part of the instrument and will be defined in the IID B (AD 04).

5.10.2.3. Cryo harness
The interconnect harness between the cold units (FPU’s, JFET modules, Herschel CVV mounted units, Planck warm PPLM units) and the “warm” SVM units of the instruments, the cryo harness, will nominally be manufactured and delivered through the Contractor, based on the requirements in chapter 5.10 of the IID-B’s (AD 04,05,06,07,08). Provisions by instrument teams may be agreed on a case-by-case basis. Some general design criteria are given in 5.10.2.4.
5.10.2.4. Design criteria

Signals between subsystems can be divided into the following categories:

- Supply lines from power source to the users.
- Digital signals.
- Signals sensitive with respect to EMC (analogue signals)

Signals of each of these categories shall be handled as follows:

- Separation of categories shall be retained up to and inclusive of the interface connector
- Separate bundles shall be used for each of the redundant systems, subsystems and unit branches
- Twisted wires shall be routed through a connector on adjacent pins

The number of different types of cables shall be minimised and cable types used for the ISO mission shall be used as a baseline

Instruments shall provide free areas for fixation and routing of harness on instruments

Instruments shall identify harness bundles to be separated where critical connections shall clearly be identified:
- signal
- power
- redundancy for harness routing
- optical bench connectors and low number of CVV connectors

The distance between the MDM connectors and space for mounting/dismounting, when it is still on the spacecraft, has to be taken into.

For Herschel the estimated harness length from the instruments to the optical bench connectors is between 0.3 m and 1 m (depending on the location of the instrument connectors); from the optical bench to the SVM it is 5 m. With the harness resistance given in Table 5.10.2-1, the estimated resistance from the OB connectors via CVV to the SVM is 600 $\Omega$ (for SST AWG 38), plus 120 $\Omega$ from the instruments to the OB connectors (for SST AWG 38).

<table>
<thead>
<tr>
<th>Material</th>
<th>Gauge</th>
<th>Ohmic resistance $[\Omega/m]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST</td>
<td>AWG 38</td>
<td>120</td>
</tr>
<tr>
<td>Brass</td>
<td>AWG 38</td>
<td>10</td>
</tr>
<tr>
<td>Brass</td>
<td>AWG 30</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 5.10.2-1: Cable definition

The table below gives the format for the harness specification (minimum information required).
5.10.3. Grounding and Isolation

5.10.3.1. Grounding Concept
The local grounding concept of the Subsystem shall be “Distributed Single Point Grounding” (DSPG) system. As a consequence of this grounding philosophy one secondary power output shall not be distributed to more than one unit.

5.10.3.2. Return Path
The spacecraft structure shall not be used as return path for power and signals.

5.10.3.3. Grounding to Structure
The grounding to structure shall not depend on the configuration of the electrical design.

Commentary: The principle here is to realise a single point grounding of each independent power network and galvanic isolation between those networks.

5.10.3.4. Isolation between Primary Power lines and the Structure of the Hosting Spacecraft
Equipment using primary DC power shall maintain at least 1 MΩ DC isolation shunted by not more than 50 nF between:

- Primary power high line and structure.
- Primary power return line and structure.

before any grounding of the primary reference is made.

5.10.3.5. Isolation between Primary Power lines and Secondary Power Lines
Secondary power lines, inherently galvanic-isolated from the primary power by DC-to-DC converters or isolation transformers, shall maintain an isolation of at least 1 MΩ shunted with a capacity less than 5 nF between primary power return lines before any grounding of the secondary reference is made.

Commentary: In case DC-to-DC converters are manufactured “ad hoc” for specific applications, it is recommended to use static shields between primary and secondary windings of the transformer. It would reduce the capacitive coupling between primary and secondary side. This static shield should be connected to the primary power return line via a low inductance strap.

5.10.3.6. Secondary Power Grounding
Each user secondary power return shall be connected to a single ground (ground point/ground plane). This ground point/ground plane shall be connected to chassis.
5.10.3.7. Grounding for Equipment Distributing Secondary Power
When a single converter via multiple windings supplies one or more equipments, the secondary power network shall be grounded to a single location within the supplied unit(s).
Deviation from the above requirement shall be assessed on a case by case basis and approved by the ESA.

5.10.3.8. Secondary Power Reference Separation
Secondary references and secondary power returns shall never be connected together.

5.10.3.9. Secondary Power Lines Isolations
When the secondary power return is disconnected from the ground, the isolation between the secondary power return and the equipment chassis shall be at least 1 MΩ shunted by not more than 50 nF.

5.10.4. Bonding
The bonding rules given below are fully applicable to the instrument units mounted on the SVM. For cryogenic units the rules given below shall be used as a reference, however, specific solutions can be implemented on a case by case basis.

5.10.4.1. Fault Current
Bonding provisions and bonding interfaces shall be designed to carry fault currents of 1.5 times the subsystem equipment protection device rating for an infinite time without damage and thermal hazard. Magnesium shall not be used as path for fault currents.

5.10.4.2. Lifetime
Bonding provisions and bonding interfaces shall be designed to be corrosion resistant, i.e. to maintain their performance in the specified environment and operations for the specified lifetime. Bonding of dissimilar materials shall be avoided (same group in the electrochemical series) unless special precautions are taken to avoid stress corrosion.

5.10.4.3. Direct and Indirect Bonding
The use of conductive mounting surfaces (i.e. direct metal-to-metal contact) is the preferred method of bonding. Use of bonding straps (indirect bonding) is regarded as last resort and shall be reserved for demonstrated cases of impossibility (e.g. vibrations, thermal insulation, etc).

5.10.4.4. Bonding of Equipment to Structure
Equipment cases shall eventually be bonded to the structure of the hosting spacecraft via the equipment mounting feet. The contact area of the bottom side of each foot shall not be less than 1 cm². The DC resistance between the equipment chassis and the hosting spacecraft structure shall not exceed 10 mΩ.
This level applies for both directions of polarity across the bond.

5.10.4.5. Bonding of Equipment Thermally Insulated from the Structure.
Equipment that must be thermally isolated from the spacecraft structure shall be provided with a bonding strap on the case for electrical connection to the spacecraft...
structure. The strap shall be made of beryllium-copper or aluminium solid form (i.e. not a braid or flexible wire) and with rectangular cross section. Its length to width ratio shall be less than 5:1 and the thickness shall be at least 0.5 mm. The contact area at both the ends of the strap shall be at least 1 cm². The DC resistance between the equipment chassis and the hosting spacecraft structure via the bonding strap shall not exceed 10 mΩ.

This level applies for both directions of polarity across the bond.

5.10.4.6. Characteristics of the Bonding Surfaces
Flat, clean and conductive surfaces shall be used for bonding. The permitted surface finishes are:
- Clean metal (except magnesium)
- Gold plate on the base metal
- Alodine 1200 or similar according to MIL-C-5541

Any other anti-corrosion finish (e.g. anodic film), grease, paint, lacquer and other high resistance properties shall be removed from the facing surfaces before bonding. Abrasives that may cause corrosion if embedded in the metal or that may damage the internal structure of the material and degrade its structural integrity shall not be used.

5.10.4.7. Unstable bonding
Anti-friction bearings, wire-mesh vibration cushion mounts, lubricated bushing etc. shall not be used to implement bonding. Bolts and screws shall not be used as intentional grounding path.

5.10.4.8. Compression Fasteners
Bonding connection shall not be compression fastened through non-metallic materials.

5.10.4.9. DC Resistance between Adjacent Faces of Equipment Chassis
The DC resistance between any two adjacent faces of the equipment chassis shall not exceed 2.5 mΩ. This level applies for both directions of polarity across the bond.

5.10.4.10. Bonding Lug
To allow bonding tests during both the system integration and the subsystem equipment EMC test campaign, each unit shall provide a bonding lug. This shall consist of a stud M4 x 6 located close to the mounting plane. The bonding lug shall be easily accessible when the unit is integrated on the spacecraft and shall be clearly marked on the mechanical interface drawings. The DC resistance between this stud and the underside of the mounting feet shall not exceed 2.5 mΩ for both directions of polarity.

5.10.4.11. Serial Connection of Bonding Strap
Serial connection of two or more bonding straps is not permitted.

5.10.4.12. Secondary Power Reference
The DC impedance between the unique secondary power reference inside the equipment and the bonding lug shall be less than 5 mΩ. The secondary power
reference shall be connected to the equipment chassis via a low inductance strap, whose length shall not exceed 3 cm.

5.10.4.13. Bonding of Equipment not performing electrical functions.
Devices not performing any electrical function shall be bonded to the spacecraft structure via a DC resistance not exceeding 10k Ω.
5.11. DATA HANDLING

The Command Data Management Subsystem (CDMS) is organised around the Central Data Management Unit (CDMU) and terminals.

On one hand the CDMU interfaces with the telecommunication subsystem and is in charge of ground command decoding, validation reporting and distribution, and payload science data and housekeeping telemetry emission (including data acquisition, encoding and formatting). On the other hand the CDMU interfaces with the remaining of the satellite via terminals connected to a communication bus. The interface to the instruments is performed by terminals. The type of terminal is defined in paragraph 5.11.6.

5.11.1. Telemetry

The data of the instruments will be categorised in science data and instrument housekeeping data. The science data will not be processed by the Mission Operation Centre (MOC) but will be stored and made available to the Instruments Control Centres (ICC’s) for Herschel and Data Processing Centres (DPC’s) for Planck. The instrument housekeeping data will be processed by the MOC to ensure the health and safety of the instruments. The science and instrument housekeeping data must be formatted following the Packet Telemetry Standard and the rules of the Packet Utilisation Standard (AD10 and AD11). However, a specific Herschel/Planck Packet Structure ICD (AD21) defines all the applicable rules and the acquisition mechanism and the Packet Utilisation Standard services applicable to Herschel and Planck.

The CDMS shall hence have the capability to:

- acquire experiment data from instruments
- store experiment data during non visibility period and visibility period
- transmit the stored data and real time ones to the ground.

The total instrument average data rate over 24hrs – including science and periodic and non-periodic HK data and formatting overheads for TM packets - must not exceed 100kbits/s for Herschel and for the Planck mission, compatible with the link margins and formatting requirements. Burst Data rate up to 300kbps can be handled for a short time not exceeding TBD seconds.

For Herschel, the allocation for the instrument being in prime mode is 96kbits/s, the data rate for each of the other instruments, not in prime mode and thus generating only housekeeping data, shall not exceed 2kbits/s each.

The science and housekeeping data are acquired continuously and down-linked during the visibility periods (DTCP).

During non-visibility periods, TM packets from instruments and platform are transmitted to a storage unit; this transmission can be performed through either dedicated links or through the satellite bus.

During visibility periods, data from the instruments S/C are always stored in the storage unit and are transmitted in real time multiplexed with dumped data from
storage unit. The storage unit is partitioned into two parts: one for the housekeeping data, the other for instrument science data.

The spacecraft will support the following telemetry mode during the various phases of the mission:

- real time housekeeping data (spacecraft and payload)
- real time science + real time housekeeping data
- real time housekeeping data + dump of the on-board mass memory
- real time housekeeping + real time science + dump of the on-board mass memory

5.11.2. SSR Mass Memory
The Solid State Recorder (SSR) can store instrument science and housekeeping data of 48 hrs.

The storage unit will have the capability to support simultaneous read and write operations during visibility periods.

5.11.3. Timing
A unique on-board time, the TAI (Temps Atomique International – ref. 1958 January epoch), is maintained at spacecraft level and distributed to the instruments in order to time-tag their data, which will be embedded in their telemetry packets.

5.11.4. Telecommands
The telecommands will be formatted according to the ESA Packet Telecommand Standard and the rules of the Packet Structure ICD (AD 12 and 21). The instrument is expected to receive command packets. For specific applications (power on/off for example) discrete commands are envisaged.

The total telecommand rate will be shared between spacecraft and instruments commanding. It can be assumed that 50 bits/s (TBC) to be distributed to the instruments, on average. The maximum telecommand rate will be 4 kbits/s. The maximum command rate to the instrument will be 2 TC packets per instrument per second.

Over the 3 hours daily contact the spacecraft commanding will have priority over other tasks.

5.11.5. Special signals

5.11.5.1. Synchronisation Signal

A redundant, electrically isolated synchronisation signal with a frequency of 131072Hz and an overall stability of better than $1 \times 10^{-8}$ over 30 days will be delivered to each instrument.
5.11.5.2. Herschel Mission
Attitude information including an “On Target Flag” will be routed between ACMS and the instruments on the data bus (TBC, might be replaced by a hardware signal, to achieve the timing accuracy).

5.11.5.3. Planck Mission
The ACMS will provide the reference star event from the star mapper at which the field of view moved across the reference star. A spin reference message will be sent to the instruments on the data bus. (TBC, might be replaced by a hardware signal, to achieve the timing accuracy).

5.11.6. Interface circuits
The interface circuits for the spacecraft data bus have been defined according to MIL 1553 B. The S/C data bus will provide routing of the instrument TM packets up to 300kbps maximum, and it will support delivery of TC packets to each instrument at the maximum rate (see above). Details of the data protocol and interface are defined in AD21.

Each second a time re-synchronisation is foreseen.

5.11.7. Application Process Identifiers
A range of typically 8 Application Process Identifiers (APID’s) will be allocated to each instrument to support its TM/TC communication needs. The exact range is specified for each instrument in the Packet Structure ICD (AD 21). Different APID’s shall be allocated for Housekeeping and Science TM packets. Details of the APID allocation shall be specified in the IID-Bs.
5.12. ATTITUDE AND ORBIT CONTROL/POINTING

5.12.1. Terminology
The following terminology is used:

- **Absolute Pointing Error (APE):** is the angular separation between the commanded direction and the instantaneous actual direction.

- **Pointing Drift Error (PDE):** is the angular separation between the short time average pointing direction during some time interval and a similar average pointing direction at a later time.

- **Relative Pointing Error (RPE):** is the angular separation between the instantaneous pointing direction and the short time average pointing direction at a later time.

- **Attitude Measurement Error (AME):** is the instantaneous angular separation between the actual and the measured pointing direction. This performance requirement is referred to as "a posteriori knowledge".

- **Absolute Rate Error (ARE):** is the difference between the actual and the controlled angular rate about the satellite spin axis.

In addition, for the Herschel Mission, the following “unconventional” term is defined which is specifically applicable to modes where a number of pointings are commanded relatively close to each other (e.g. for raster pointing):

- **Spatial Relative Pointing Error (SRPE):** is the angular separation between the average orientation of the satellite fixed axis and a pointing reference axis which is defined relative to an initial reference direction.

In addition, for the Planck mission the following term is defined which is specifically applicable to efficiently cover portions of the sky which have been ‘missed’, by returning to a previous pointing with an accuracy compatible with the normal scan width:

- **Pointing Reproducibility Error (PRE):** is the angular separation between the average actual pointing direction at one time and the achieved average pointing of that same commanded direction at a later time. The PRE is given over 20 days.

The pointing requirements specified below refer to the instruments Line of Sight of the instruments. The error in determining the absolute attitude of a detector line of sight, using a detector dedicated calibration source, will be assumed to be less than 50% of the AME.

Unless otherwise specified, the pointing error specifications are expressed as half-cone angles of the optical axis and half-angles around the optical axis. They are specified at a temporal probability level of 68%, which implies that error will be less than the requirements for 68% of the time.
5.12.2. Herschel Pointing Requirements

During all scientific observation modes requiring periods of stable pointing, the pointing requirements with the goals as specified in the Table 5.12.2-1 below will be met with a single calibration once per 24 hours.

Note that the definition applied to requirements and goals is:

- Requirements: performance to be satisfied under all applicable conditions and margins
- Goals: performance to be satisfied under restricted, but specified, conditions and without margins

<table>
<thead>
<tr>
<th>ERROR</th>
<th>Line of sight (arcsec)</th>
<th>Around line of sight (arcmin)</th>
<th>Goals for line of sight (arcsec)</th>
<th>Goals around line of sight (arcmin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APE</td>
<td>≤ 3.7</td>
<td>3.0</td>
<td>≤ 1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>APE scanning</td>
<td>≤ 3.7 + 0.05 w</td>
<td>n.a.</td>
<td>≤ 1.5 + 0.03 w</td>
<td>n.a.</td>
</tr>
<tr>
<td>PDE(24 hours)</td>
<td>≤ 1.2</td>
<td>3.0</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>RPE (1 min) pointing</td>
<td>≤ 0.3</td>
<td>1.5</td>
<td>≤ 0.3</td>
<td>1.5</td>
</tr>
<tr>
<td>RPE (1 min) scanning</td>
<td>≤ 1.2</td>
<td>1.5</td>
<td>≤ 0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>AME pointing</td>
<td>≤ 3.1</td>
<td>3.0</td>
<td>≤ 1.2</td>
<td>3.0</td>
</tr>
<tr>
<td>AME scanning</td>
<td>≤ 3.1 + 0.03*w</td>
<td>3.0</td>
<td>≤ 1.2 + 0.02*w</td>
<td>3.0</td>
</tr>
<tr>
<td>AME slew</td>
<td>≤ 10</td>
<td>3.0</td>
<td>≤ 5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Note: w is the scan rate in arcsecond/second

Table 5.12.2-1: Herschel Pointing requirements

In consecutive pointings within 4 x 4 degrees spherical area, the SRPE of all pointings following the initial pointing, as referred to the average (barycentre) pointing direction of the first pointing will be less than 1arcsec.

5.12.3. Planck Pointing Requirements

During the sky survey mode, the pointing requirements are as specified in the Table 5.12.3-1 below:
<table>
<thead>
<tr>
<th>ERROR</th>
<th>Line of sight (arcmin)</th>
<th>Around line of sight (arcmin)</th>
<th>Goals for line of sight (arcmin)</th>
<th>Goals around Line of Sight (arcmin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APE</td>
<td>&lt; 37</td>
<td>&lt; 37</td>
<td>&lt; 25</td>
<td></td>
</tr>
<tr>
<td>PDE (24 hours)</td>
<td>&lt; 6.2</td>
<td>&lt; 6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPE (55 min)</td>
<td>&lt; 1.5</td>
<td>&lt; 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AME</td>
<td>&lt; 1</td>
<td>&lt; 6</td>
<td>&lt; 0.5</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>PRE (20 days)</td>
<td>&lt; 2.5</td>
<td>&lt; 37</td>
<td>&lt; 0.5</td>
<td>&lt; 3</td>
</tr>
</tbody>
</table>

**Table 5.12.3-1: Planck Pointing requirements**

The spin axis motion about the spacecraft X-axis pointing to the Anti-Sun will be at constant rate of 1 rpm (6°/sec), where the direction (sense of rotation) will be unique throughout the mission.

The spacecraft will be capable of re-pointing the spin axis to +/- 10° away from the sun.

Between 2 consecutive re-orientation manoeuvres, the spin rate drift or fluctuation over one hour will be less than 10⁻⁴ rpm.

The Absolute Rate Error about the satellite spin axis will be better than 5.4 arcmin/sec.

**5.12.4. Herschel Scientific Pointing modes**

For Herschel the following scientific pointing modes will be provided:
- Fine Pointing
- Raster Pointing
- Line Scanning
- Tracking of Solar System Objects
- Position Switching
- Nodding

These modes are described in the document: Herschel Scientific Pointing Modes, in the annex to this document.

**5.12.5. Herschel Calibration - Star Tracker**

To establish the offset angle between the Herschel star tracker and the lines of sight of the instruments, the spacecraft will perform a calibration of not longer than 10 min every 24 hours.
The spacecraft will communicate, on-board and to ground, a request for pointing correction from the prime instrument. After the reception of pointing correction from the instrument, the spacecraft will autonomously readjust its position accordingly. The correction will only be allowed within predefined boundaries, which will be updateable from ground.

5.12.6. On-Target Flag
For the Herschel mission a “on target flag” will be generated when the commanded target has been acquired. This flag will be accessible to all three instruments simultaneously. The flag will be transmitted by the CDMS in less than one second after the ACMS computer predicts that the spacecraft is actually pointed in the required direction within a ground programmable accuracy.

5.12.7. Planck Reference Star Pulse
For the Planck mission the ACMS will provide the reference star signal.

For the Planck mission the ACMS will deliver the precise instant (± 1.5 msec) at which the field of view of the star mapper moved across the reference star and transmit it to ground.

The reference star pulse and precise instant as above described will be distributed to the Planck instruments with maximum delay of 5 msec.

5.12.8. Herschel Slews
A slew is used to change the satellite pointing from a current point to the next point. The maximum slew rate will be 7 degrees/min (or larger) for slews longer than 16 arcmin. For smaller angles (φ in arcsec) the time to acquire the target will be:
- maximum: 10+sqrt(2φ) sec
- goal: 5+sqrt(φ) sec

It will be possible to change via command the slew rate between 0.1 arcmin/s and 1 arcmin/s with a resolution of 0.1 arcmin/s.

The Absolute Rate Error about the scan axis will be better than 1% of the demanded rate but not less than 0.1 arcsec/s.

It will be possible to complete a slew of 90 degrees (or more) in 15 min, including settling time.

5.12.9. Planck Slews
The spacecraft will be capable of re-orienting the Spin-axis in accordance with the following requirements:
- frequency: one manoeuvre every 45 min throughout nominal lifetime (on average),
- amplitude: 3 arcmin in any direction
- accuracy: 0.4 arcmin (amplitude and direction, 68% probability level)
The duration of such re-orientation, including the settling time, will be 5 min or less (elapsed time during which pointing requirements cannot be met).

For a spin axis reorientation not part of the Planck scanning law the rate of such a reorientation will be at least 0.5arcmin/s.

To the Planck APE and PDE requirements the spacecraft design will utilise a maximum of +/-10% tuning of the amplitude of the manoeuvre needed to execute the nominal sky scanning law; i.e. no dedicated slew manoeuvres will be required.

5.13. ON-BOARD HARDWARE/SOFTWARE AND AUTONOMY FUNCTIONS

5.13.1. On-board hardware
TBD

5.13.2. On-board software
Instrument on-board software shall comply with the ESA software standard PSS-05-0 and amended by the “Guide to applying the ESA software engineering standards to small software projects” BSSC(96)2

After launch on-board software maintenance is a possible tool to overcome unforeseen situations or failures of the instruments. Commonality and standardisation of on-board software and its development and verification tools, in particular also with other PI's developing instruments for the same satellite, will significantly ease the in-flight maintenance. The PI is therefore requested to:

- use a preferred (TBD) language for on-board software coding
- standardise the software and development and verification tools
- be in close contact with other PI's

In-flight maintenance furthermore requires that functionally distinct areas of memory shall be assigned to:

- programme code
- fixed constants
- variable parameters

It shall be possible to modify individual software parameters or constants by command from the ground.

Information to indicate all actions of operational significance taken by on-board software in a complete, unambiguous and timely manner shall be available in the telemetry.

5.13.2.1. Software interfaces
The sole instrument on-board software interface with the spacecraft is through the software of the Central Data Management Unit (CMDU)
5.13.2.2. Process control
The control processes managed by an on-board application are defined in the OIRD (AD16).

5.13.2.3. On-board memory loading
It shall be possible to load any memory area from the ground.

Any telecommand packet needed to up-link any area of memory shall be self-consistent in that:
- a successful load shall not depend on previous packets
- if a packet is rejected, it may be up linked on its own at a later time (see AD16)

5.13.2.4. On-board memory dumping
Any memory area shall be accessible for dumping on ground request.

The dump request shall specify the start address and length of the dump

Only a single command packet shall be required, even if several telemetry packets are required to convey the dumped area to the ground (see AD 16).

5.13.2.5. Autonomy functions
During all mission phases, the spacecraft including instruments will be capable of operating nominally without ground contact for a period of 2 days without interrupting the planned operations. If no ground command has been received by the spacecraft since more than a ground programmable time, the spacecraft will go into a safe mode. It will be possible to exit from autonomy mode by ground command.

The more general autonomy requirements is given in the OIRD (AD 16).

The purpose of the survival mode is to maintain a safe spacecraft including instruments after a major on-board failure or a violation of the attitude constraints or loss of ground contact.

Once activated, the survival mode will maintain a safe attitude within the constraints allowing a continuous supply of power, maintaining a stable thermal environment compatible with the spacecraft and instrument requirements and ensure a two way communication link with the ground station when coverage is available for at least housekeeping telemetry data and commanding and the spacecraft and instruments in safe conditions.

It will be possible to enter the survival mode by ground command and exit only by ground command.

It will be possible that the survival mode is initiated automatically on-board and is maintained without any ground contact for at least seven days. The survival mode will not rely on any RAM stored data.
The instruments will have to define a safe configuration for the stand-by and survival mode.
5.14. EMC

The extremely low detector output voltages and the complexity of the spacecraft necessitate a careful design of the grounding, electrical interfaces and other EMC related parameters to assure mutual compatibility between instruments and the rest of the spacecraft.

To achieve this compatibility, the following preliminary guidelines have been established:

- separate power and data connectors
- separate interconnecting harnesses where required
- separate signal and primary power (28 Volt) ground
- use filters to reduce conducted emission and susceptibility levels
- isolate detector housing and electronics boxes from electrical signals
- twist and shield wires in the interconnect harness
- provide good and reliable bonds between the various parts of an electronics box and also to the mounting platform
- select power converter frequency outside detector-signal bandwidth

At the moment no detailed requirements have been established for DC magnetic requirements, however the following measures should be taken:

- local strong (> 10 Oersted) DC hard-magnetic fields should be avoided or compensated by proper component arrangement to achieve self-cancellation.
- the use of very soft magnetic materials with high permeability should be avoided as far as possible and practicable

Exact values for the various parameters are currently being defined. To this effect it is planned to set-up a so-called frequency plan.

5.14.1. Electrical Interfaces

This section provides the EMC/EMI requirements for the Subsystem electrical interfaces to accomplish grounding requirements, to enhance Electromagnetic Compatibility and to maintain the necessary common methodology and implementation within the Project.

The internal interface arrangement (i.e. the interfaces inside the same equipment) shall follow the rules established for external interfaces (i.e. interfaces between different equipment) to the maximum extent possible.

5.14.1.1. Signal Interface Grounding

For external interfaces, all the signal driver outputs shall be referenced to the signal ground and all the input terminals of the signal receivers shall be isolated from the ground. Only exceptions are the RF interfaces using coaxial cables and the low-level telemetry and telecommand lines that are permitted to have single/ended-single/ended interface (as dictated by the PSS).
5.14.1.2. Signal Isolation (Common Mode Isolation)

The receiver interface circuitry shall be designed to provide isolation between its input terminals and the receiver grounding reference that shall not be less than the mask given in Figure 5.14.1-1.

![Common Mode Signal Isolation](image)

**Figure 5.14.1-1: Common mode Signal Isolation versus frequency**

5.14.1.3. Signal Reference

Signals shall never use the primary power ground as reference. The secondary power reference shall constitute the user signal reference unless a further galvanic isolation stage is implemented.

5.14.1.4. Allowed Interface Topologies

The allowed interface topologies are listed in Table 5.14.1-1:
<table>
<thead>
<tr>
<th>TYPE OF INTERFACE</th>
<th>TRANSMITTER</th>
<th>RECEIVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analogue, Unit/Subsystem, ext.</td>
<td>Balanced</td>
<td>Differential</td>
</tr>
<tr>
<td>Digital, Unit/Subsystem, ext.</td>
<td>Single-ended</td>
<td>Differential</td>
</tr>
<tr>
<td></td>
<td>Single-ended</td>
<td>Opto-coupler</td>
</tr>
<tr>
<td></td>
<td>Single-ended</td>
<td>Isolation Transformer</td>
</tr>
<tr>
<td>Digital, unit/subsystem, Sync &amp; clock</td>
<td>Balanced</td>
<td>Differential</td>
</tr>
<tr>
<td>signals, unit, ext.</td>
<td>Balanced</td>
<td></td>
</tr>
<tr>
<td>RF Transmission (coaxial cable)</td>
<td>Single Ended</td>
<td>Single ended</td>
</tr>
</tbody>
</table>

Table 5.14.1-1: Allowed interface topologies.

Exception to the above Table 5.14.1-1 is the low-level telemetry and telecommand lines (as specified in the PSS), that are permitted to have the single-ended /single-ended topology.

5.14.1.5. Noise Immunity
Discrete and digital interfaces shall be designed for noise immunity with both level and time discrimination.

5.14.1.6. In Band Response
Analogue and digital circuits shall be designed to not respond to signals out of their own intentional frequency bandwidths.

5.14.1.7. In Band Transmission
The transmission bandwidths shall be limited to the minimum extent possible.

5.14.1.8. Filter Location
Filters shall be placed at the source end of the interface if it is dictated so by the receiver time response or if additional noise suppression is required.

5.14.2. Harness, Connectors and Shielding

5.14.2.1. Definition of EMC Classes
Power and signal lines shall be grouped into the following EMC classes:

- Class 1: Primary/Secondary Power
- Class 2: Digital Signals
- Class 3: Low Level Sensitive Analogue Signals
- Class 4: RF Signals (via coaxial cables, tri-axial cables, etc).

5.14.2.2. Wire/Bundle Coding
Wires/Cables belonging to the same EMC class can be assembled together in a bundle. In any case cable bundles or separate wires shall be coded reporting the EMC classes of the circuits which it contains. The wire type, twisting, shielding and
shield grounding requirements shall be reflected on all the schematics, wiring diagrams and Interface Control Documents in which the circuit appears.

5.14.2.3. Cable Separation of Different EMC Classes
Bundles belonging to different EMC Classes shall be routed separately. Bundles belonging to class 2, 3 and 4 shall be shielded and separated by metallic barriers. The height of those barriers shall not be less than the largest cable bundle diameter requiring separation. If separation barriers are not practical, the bundles shall be separated by at least 10 cm. This requirement is not applicable to the subsystem equipment internal cabling or close to connector brackets.

5.14.2.4. Harness Routing and Crossing
All cable bundles shall be routed as close as possible to the hosting Spacecraft structure, which constitutes the ground plane. Where bundle must cross each other, the crossing angle between different categories shall be as close as possible to 90°.

5.14.2.5. Twisting
Twisting of the active wire around its relevant return wire shall be used in order to reduce magnetic susceptibility and emission. In case several lines share the same return line they shall be twisted with the return line. The minimum twist rate shall be as specified in Table 5.14.2-1:

<table>
<thead>
<tr>
<th>AWG Size Number</th>
<th>Minimum Twist/meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>28</td>
<td>35</td>
</tr>
</tbody>
</table>

*Note: One twist is a full rotation around the cable axis.*

Table 5.14.2-1: Minimum Twist Rate

If different AWG (> 28) are used that are not reported in the above Table 5.14.2-1, they shall be twisted in such a way to preserve the mechanical characteristics of the wires.

5.14.2.6. Pin Allocation on Connectors
Allocation of wires with different EMC Classes to the same connector shall be avoided to the maximum possible extent. When wires with different EMC Classes have to be allocated to the same connector, they shall be physically separated as much as possible within the connector.
The intermediate spare pins on the equipment connector shall be shorted together and eventually connected to the ground plane via the Equipment connector shell.
5.14.2.7. Twisted Wire Allocation
Conductors of a twisted wire shall be allocated to adjacent pins.

5.14.2.8. Tri-axial Cable
Tri-axial cables, if any, shall use the centre and the inner shield conductor for unbalanced transmission, referenced to the ground plane at a single point with the outer shield multiple-point grounded as an over-shield.

5.14.2.9. Shield Coverage
Uninterrupted shields, unless at connector location, with at least 85% optical coverage shall be used. The maximum unshielded length of wire at the connectors shall not exceed 3 cm. Shields shall not intentionally carry current (i.e., they shall not be the return path for power and signal) except for coaxial cables used with RF.

5.14.2.10. Cable Shield Terminations
Cable shield shall be grounded at both the ends to the equipment case at each end. The preferred method of grounding shields is through a conductive backshell that makes good electrical contact to the equipment case.

5.14.2.11. DC Resistance between Cable Shield and Connector Back-shell
The DC resistance between any shield and the connector backshell shall be less than 5 mΩ.

5.14.2.12. DC Resistance between the Back-shell and the Structure
The DC resistance between the plug connector backshell and the structure in the vicinity of the equipment shall be less than 10 mΩ.

5.14.2.13. Shield Insulation
Individual shields shall be insulated to prevent uncontrolled grounding.

5.14.2.14. Shield Termination of Overall Shield
Overall shield shall always be circularly terminated or shield terminations shall be within the connector backshell.

5.14.2.15. DC Resistance between Shield Ground Pin and Equipment Chassis
If the shielding ground is implemented via dedicated pin, the DC resistance between any shield ground pin and the equipment chassis shall not exceed 5 mΩ. The connection of the shield ground pin to case shall be as short as possible. The maximum allowable length is 3 cm.

5.14.2.16. Non-RF Shield Termination of individual Wire Shields
Where dictated for practical reasons, up to 4 (four) shield may be grouped together on one ground wire for termination, but daisy chaining for shield termination is prohibited. The shielding termination shall be as low inductive as possible, however not exceeding 5 cm in length.
RF backshells with individual shield ground provisions shall be used for multiple RF shield terminations, with the maximum termination length not exceeding 5 cm.
5.14.2.17. Shielding through Intermediate Connectors
When intermediate connectors are used, shields shall be individually continued via the intermediate connector pins while shielding for RF wires or overall shields shall be circularly terminated to the RFI backshells.

5.14.2.18. Conductive Caps
All electrical connectors not engaged shall be covered with a conductive cap..

5.14.2.19. Equipment Chassis Apertures
The equipment case shall not contain any apertures other than those that are essential for connectors, sensor viewing or out-gassing vents. If out-gassing vents are required, they shall be as small as possible (less than 5 mm diameter) and shall be located close to the equipment mounting plane, i.e. the spacecraft structure ground.

5.14.2.20. Grounding Diagram
Grounding diagrams shall be established at both Equipment and Subsystem level. The minimum extent of each diagram shall be:

1) Primary/secondary power grounding.
2) Interface circuit grounding.
3) EMI filters.
4) Shielding Grounding
5) Equipment Grounding
6) Principal Interface Circuit Diagram

5.14.3. EMC Performance Requirements

Commentary: Some EMC performance requirements depend strongly on both the power quality and on the power system architecture (e.g. protection provisions, power regulation, voltage etc.), especially as far as conducted requirements are concerned. Moreover, radiated EMC performance requirements need tailoring to particular frequency notches typical of the hosting spacecraft. This information may not be available at the time of the design.

The EMC requirements specified in the following paragraphs have been derived and tailored to meet the demands of most spacecraft known to the writer that could accommodate the Subsystem. They also allow a strict control of the EMC quality of the Subsystem per se.

Those requirements have been specified with the idea of avoiding unnecessary stringent demands that might impact costs and technical solutions. However, the requirements might be further refined as soon as information on the hosting spacecraft will be known. Presently, the ESA Power Standards are assumed as a reference.

Specific requirements are made applicable to equipment or subsystem in order to enhance meeting the spacecraft overall compatibility requirement. These
requirements are normally applicable at the equipment level, however they can be made applicable to a set of equipment which operates together (i.e. Subsystem level). When the following requirement state that they are applicable to subsystem equipment, it should be understood that the requirement could be applicable at either the equipment or subsystem level. The levels are applicable when the subsystem equipment is set to the operational condition yielding the maximum emission.

5.14.3.1. Conducted Emission on Power Lines

Conducted emissions on power lines generated by the subsystem equipment shall be controlled as follows:


Narrow Band conducted emission Differential Mode in the frequency range 30 Hz ÷ 50 MHz generated by the subsystem equipment on each primary power line shall not exceed the following adjustable limit:

A. For nominal DC input current less than 1 A, use the curve of fig. 5.14.3-1 as shown.

B. For nominal DC input current greater than 1 A, the curve of fig. 5.14.3-1 shall be relaxed by the factor $10 \log [I \,(A)]$. $I \,(A)$ is the nominal input current in Ampere.

![Figure 5.14.3-1: Narrow Band Conducted Emission Current – Differential Mode](image)
5.14.3.1.2. **Conducted Emission on Primary Power Lines, Frequency Domain, Common Mode, NB**

Narrow Band conducted emission Common Mode in the frequency range 10 kHz ÷ 50 MHz generated by the subsystem equipment on the primary power lines shall not exceed the following adjustable limit:

A. For nominal DC input current less than 1 A, use the curve of fig. 5.14.3-2 as shown.

B. For nominal DC input current greater than 1 A, the curve of fig. 5.14.3-2 shall be relaxed by the factor 10*log [I (A)]. I (A) is the nominal input current in Ampere.

![Fig. 5.14.3-2 – Narrow Band Conducted Emission Current – Common Mode](image)

**5.14.3.1.3. Current Ripple, Time Domain, Differential Mode**

Differential mode, time domain current ripple and spikes on the primary power bus of the subsystem equipment shall be:

A. For nominal DC input current less than 1 A:

Ripple: less than 20 mA<sub>pp</sub>.
Spikes, including ripple: less than 60 mA<sub>pp</sub>.

B. For nominal DC input current greater than 1 A:

Ripple: relax 20 mA<sub>pp</sub> by a factor \(\sqrt{I (A)}\), I (A) being the nominal input current in Ampere.
Spikes, including ripple: relax 60 mA<sub>pp</sub> by a factor \(\sqrt{I (A)}\), I (A) being the nominal input current in Ampere.
Ripple and spikes shall be measured on both the primary and return lines with at least 50 MHz bandwidth.

5.14.3.2. Conducted Emission Common Mode Current on Signal Bundles
The Conducted Emission Common Mode on individual Signal Bundles of the subsystem shall be measured from 10 kHz to 50 MHz. Measurement shall be used to establish the limits for Conducted Susceptibility Common Mode current injection on the same bundles.

5.14.3.3. Conducted Susceptibility Power Lines – Differential Mode – Steady State
The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its specification when sinusoidal voltages with amplitude specified in Fig.5.14.3-3 is injected into the subsystem equipment power leads in the frequency range 30Hz-50MHz. The frequency sweep rate shall not be faster than 5 min/decade.

**Conducted Susceptibility Power - DM**

![Graph showing conducted susceptibility power levels](image)

Fig. 5.14.3-3 – Conducted Susceptibility Power Lines – Differential Mode

In the frequency range 50 kHz – 50 MHz, the applied sinusoidal voltage shall be 1 kHz amplitude modulated (30% AM).

The requirement shall be considered to have been met when:

1) Frequency range 30 Hz – 50 kHz
The specified test voltage level cannot be generated but the injected current has reached 1 A\textsubscript{rms} and the subsystem equipment is still operating without malfunctions within its specified tolerances.

2) Frequency range 50 kHz – 50 MHz

A power source of 1 Watt, 50 Ω impedance cannot develop the required voltage at the equipment power input terminals and the subsystem equipment is still operating without malfunctions within its specified tolerances.

5.14.3.4. Conducted Susceptibility Power Lines – Common Mode – Steady State

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when a sinusoidal common mode signal is injected in both the subsystem equipment power leads via Bulk Current Injection (BCI) until:

A) 2 V\textsubscript{pp} is achieved between return line and chassis.
B) A maximum of 1 A\textsubscript{pp} is achieved

5.14.3.5. Conducted Susceptibility Common Mode Current on Signal Bundles

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when a sinusoidal common mode current of amplitude 6 dB higher than the common mode measurement (specified in the paragraph 5.14.3.2) is injected into the signal bundles.

5.14.3.6. Conducted Susceptibility Common Mode Voltage on Signal Reference – Steady State

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when sinusoidal voltages with 2 V\textsubscript{pp} amplitude are applied between the subsystem equipment signal reference and the ground plane in the frequency range 50 kHz – 50 MHz. The sweep rate shall not be faster than 5 min/decade.

5.14.3.7. Conducted Susceptibility Common Mode Voltage on Signal Reference - Transient

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when transient voltages typically shaped as shown in 5.14.3-5 are applied between the equipment signal reference and the ground plane.

With reference to Fig. 5.14.3-5, the peak amplitude shall be calibrated to ± 3 V and \( T_2 \) shall be between 150 ns and 250 ns when the source having output impedance of 50 Ω is connected to a 50 Ω resistor. Then the source is applied to the equipment after it is detached from the ground plane. The pulse repetition frequency of the waveform shall range from 5 Hz to 10 Hz and the test duration shall be at least 5 minutes.
5.14.3.8. Conducted Susceptibility on Power Lines – Transients

**Differential Mode**

The unit shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when transient voltages typically shaped as shown in Fig. 5.14.3-4 are superimposed on the steady state bus voltage at the unit input power leads. With reference to Fig. 5.14.3-4 the peak amplitude shall be ±2.5V, the rise time between 10µs and 100µs, the flat portion of the pulse ≈ 300µs and the time constant 2ms. The pulse repetition frequency of the waveform shall range from 5 Hz to 10 Hz and the test duration shall be at least 5 minutes.

![Fig. 5.14.3-4 – Typical transient waveform for DM Transient on PL](image)

**Common Mode**

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when transient voltages shaped as shown in Fig. 5.14.3-5 are applied between the power return line and the unit case. With reference to Fig. 5.14.3-5 the peak amplitude shall be 28 V, the rise time less than 100ns and the length (Td) at least 5µs. Repetition rate shall range from 5 Hz to 10 Hz and the test duration shall be at least 5 minutes.

![Fig. 5.14.3-5 – Typical transient waveform for CM Transient](image)
5.14.3.9. NB E-Field Radiated Emission

**Commentary:** The following requirements assume that the instruments OFF when the spacecraft is connected to the launcher and therefore do not account for specific frequency notches that may be requested by the hosting spacecraft and launcher. The requirement is defined here for the frequency range 14 kHz – 18 GHz. If the instruments are ON then the requirements given the ARIANE 5 User Manual plus any requirements from the spacecraft shall be applicable.

Narrow-band electric fields generated by the subsystem equipment and measured at 1 m distance shall not exceed the limits shown in Fig. 5.14.3-6 in the frequency range 14kHz – 18GHz:

![NB Radiated Emission - E Field](image)

**Fig. 5.14.3-6 – Narrow-Band Radiated Emission Limit – E Field.**

5.14.3.10. NB E-Field Radiated Susceptibility

**Commentary:** The following requirement does not account for specific frequency notches that may be requested by the hosting spacecraft. This information will be unequivocally available when the launch opportunity will be defined.

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when it is irradiated with 2 V/m, 1 kHz amplitude modulated (30% AM), in the frequency range 14 kHz – 18 GHz.
5.14.3.11. H Field Radiated Emission

Narrow-band electric fields generated by the subsystem equipment and measured at 1 m distance shall not exceed the limits shown in Fig. 5.14.3-7 in the frequency range 30Hz – 50KHz.

![NB Radiated Emission - H Field](image)

**Fig. 5.14.3-7 – Narrow-Band Radiated Emission Limit – H Field.**

*Commentary:* Requirements on Pulsed Magnetic field are currently (TBC). If dictated so, they can be introduced at a later version of this document.

5.14.3.12. H Field Radiated Susceptibility

The subsystem equipment shall not exhibit any malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification when it is irradiated with a magnetic field of 140dBpT in the frequency range 30Hz–

5.14.3.13. Arc Discharge Susceptibility

No malfunction, degradation of performance or deviation beyond the tolerance indicated in its individual specification shall occur when the subsystem equipment and its interface lines are exposed to a repetitive electrostatic arc discharge of at least 5.6 mJ energy/ 15 kV. For conducted test only, if damage risks are envisaged for interface circuits, the voltage can be reduced down to 4 kV but the energy shall remain 5.6mJ.
5.14.4. Conducted Emission/Susceptibility
The results of a dedicated questionnaire elaborated by ESA in conjunction with the instrument teams are currently under evaluation and will be formalised in this chapter in due time.

5.14.5. Radiated Emission/Susceptibility
The results of a dedicated questionnaire elaborated by ESA in conjunction with the instrument teams are currently under evaluation and will be formalised in this chapter in due time.

5.14.6. Frequency Plan
The results of a dedicated questionnaire elaborated by ESA in conjunction with the instrument teams are currently under evaluation and will be formalised in this chapter in due time.
5.15. INSTRUMENT HANDLING

5.15.1. Transport container

5.15.1.1. Focal Plane Unit
For all deliverable units, transport containers shall be provided.
The containers shall be vacuum tight, be purged and slightly over-pressurised with dry nitrogen gas. The containers shall be equipped with a mounting platform supported by a shock absorber.
Shock recorders shall be mounted at a TBD location.
The containers shall be made of material compatible with cleanliness requirements. The IID-B (AD 04,05,06,07,08) shall list size and mass of the containers as well as the overall mass including the instrument package.

5.15.1.2. Warm electronic units and interconnecting harness
For all deliverable units, transport containers shall be provided.
The containers shall be slightly over-pressurised with dry nitrogen gas, if necessary.
Hygrometry will be recorded with witness devices.
The containers shall be equipped with a mounting platform supported by a shock absorber.
Shock recorders shall be mounted at a TBD location.
The containers shall be made of material, compatible with cleanliness requirements for these units.
The IID-B (AD 04,05,06,07,08) shall list size and mass of the containers as well as the overall mass including the instrument package.

5.15.2. Cleanliness

5.15.2.1. Focal Plane Unit
The Focal Plane Unit container may only be opened in a clean room environment of class 100 (TBC) with a relative humidity of 50 %.
Any other requirements shall be specified in the IID-B (AD 04,05,06,07,08).

5.15.2.2. Warm electronic units and interconnecting harness
The Warm Electronics container may only be opened in a clean room environment of class 100 000 with a relative humidity of 50 %.
Any other requirements shall be specified in the IID-B (AD 04,05,06,07,08).

5.15.3. Physical handling

5.15.3.1. Focal Plane Unit
The EGSE software shall provide locks that prevent powering of critical components at ambient temperature.

Maximum rates of FPU warm-up and cool-down shall be specified in the IID-B (AD 04,05,06,07,08).
Any other requirement shall be specified in the IID-B (AD 04,05,06,07,08).
5.15.3.2. Warm electronic units and interconnecting harness
Standard handling precautions shall be observed.

5.15.4. Purging

If it is demonstrated that during system level ground tests purging is absolutely necessary the PI shall provide an instrument purging plan, to be part of the IID-B which shall establish
• definition of purging connection
• detail purging requirements and procedures
• assistance in commissioning purging procedures

During the final phase of launch preparations the performance of purge operations on a regular basis may violate safety procedures and hence be impossible.

5.15.5. Mechanism positions
Sometimes mechanisms should be placed in a certain position, to avoid possible damage caused by vibration during transport. Should this be the case then this position shall be listed in the IID-B (AD 04,05,06,07,08)
6. GROUND SUPPORT EQUIPMENT

6.1. Mechanical Ground Support Equipment

Mechanical Ground Support Equipment (MGSE) is the total of the mechanical equipment or special tools necessary to support instrument (at system, subsystem, unit level) related activities, such as:

- instrument handling and integration into the Payload Module (PLM) or parts thereof other than standard space industry equipment or tools
- instrument testing after its integration into the PLM and at level of the complete satellite
- instrument protection against the environment at the various integration and test sites (normally class 100000 clean room conditions)

This MGSE shall be supplied in sufficient quantities (normally one per instrument model) to ensure efficient integration and testing of the various satellite models.

6.2. Electrical Ground Support Equipment

Electrical Ground Support Equipment (EGSE) is the total of the instrument specific electrical equipment necessary to support testing and operational activities of the instrument at various levels.

The Herschel/Planck instrument teams have identified an EGSE implementation, which provides maximum reuse of resources (see below), since that system will also be used both during instrument-level testing, system level tests and in the operational phases of the mission (see IID-Bs).

6.3. Commonality

Taking into account that it is a fundamental design goal of the Herschel/Planck mission that commonality should be pursued to the maximum extent possible, the Herschel instrument teams have been actively engaged in investigating such possibilities.

6.3.1. EGSE

It has been agreed that a common EGSE system could be developed as a collaborative effort between instrument groups.

In addition, it has been agreed that this system would be applicable at various times during all the phases of the mission listed below:

- Subsystem Level Testing
- Instrument Level Testing
- Module and System Level Testing
- In-orbit instrument commissioning
- Performance Verification
- Routine operations
In the interests of minimising the cost and maximising the reliability of such a system through the different phases the EGSE will:

- be based on SCOS 2000 – this system will be used in the ground segment by the MOC for controlling the satellite. The cost of the system (essentially free), its proven use in similar situations for other space projects and the support provided by ESOC, contribute to a cheaper and more reliable system.

- use the same interfaces between the EGSE and other systems, in order to improve reliability through reuse throughout the mission.

- Provide a constant implementation of the
  - Man Machine Interfaces
  - Data Archiving and Distribution facilities
  - On-board Software Management
  - On-board Maintenance (e.g. Software Development Environment, Software Validation Facility)
  - Common User Language (for Test procedures and in-orbit operations)

6.3.2. Instrument Control and Data Handling
All three Herschel instruments are using the same supplier (IFSI) for their on-board control and data handling hardware and software systems, which interface to the spacecraft. This has ensured commonality in the areas of;
- on-board microprocessors
- instrument internal interfaces
- On-board Programming language
- Software Development Environments
- Software Validation Facilities
In addition, the on-board software provides commonality in its non instrument-specific functions. A common instrument commanding scheme has also been agreed and will be implemented by the instrument teams.

6.3.3. Other Areas
Other areas of possible commonality will be addressed by working groups set up as and when necessary. These may cover:

- Follow up on Herschel Common Science System data base activities
- A common approach to IA/QLA systems.
7. INTEGRATION, TESTING AND OPERATIONS

Information in this chapter covers all instrument-related activities after the acceptance of the instruments by ESA and hand-over to the Contractor.

7.1. AIV Sequence Overview

7.1.1. Herschel AIV Sequence Overview
The Herschel AIV sequence consists as far as related to the instruments of three separate test campaigns, two related to tests with the PLM, i.e. inside the cryostat and one separate for the AVM testing. This is directly reflected in the instrument hardware model philosophy. It is assumed that there is a dedicated electrical model of the spacecraft, the avionics model, containing among others the CDMS, the ACMS the instrument AVMs and the associated EGSE. In order to allow compatibility test of the CQM instrument units a dedicated test cryostat is provided. This test is off-line the spacecraft development sequence.

Two test campaigns can therefore be identified w.r.t. the activities on the Herschel Instruments that will be in the Herschel PLM:

- Herschel Instrument CQM compatibility test – integration of the CQM units in a test cryostat (ISO cryostat) – compatibility test
- PLM FM integration and test – integration with complete PFM SVM – System PFM tests

7.1.2. Planck AIV Sequence Overview
The Planck AIV sequence consists of two main test sequences or test campaigns and reflects the corresponding hardware model philosophy. It is assumed that there are two separate hardware models of the Payload module and one proto-flight model (PFM) of the SVM, including their respective EGSE. The PFM SVM is assumed to be used in the early test phase with the first hardware model of the Payload Module, the Cryogenic Qualification Model (CQM) and later, when equipped with flight equipment with the flight model of the PLM.

The two test campaigns can therefore be identified w.r.t. the activities on the PLM:

- PLM CQM integration and test – integration with PFM SVM structure – System STM tests
- PLM FM integration and test – integration with complete PFM SVM – System PFM tests
7.2. Integration

Procedures detailing the individual integration steps will be prepared and reviewed in due time.

7.2.1. HPLM Integration

7.2.1.1. HPLM CQM Integration

This paragraph reflects the integration of the CQM instruments into the test cryostat. It is assumed here that the ISO QM cryostat will be used for this test campaign.

The integration of the CQM instruments into this test cryostat starts with the open cryostat that has been adapted to this test before. The interface for the optical bench is the same as for Herschel. The Herschel upper bulkhead has been reproduced for his test and will be mounted after integration of the FPU’s.

The integration flow of the instruments starts with mounting of the FPU’s on the optical bench and is considered completed with the closure of the cryostat at ambient temperature.

The major steps that can be identified are:
- Instrument integration to optical bench (mechanical/thermal and electrical)
- Instrument ambient temperature functional check (no alignment, expected that mechanical adjustment is sufficient)
- Closure of optical bench (mechanical and straylight – specifically w.r.t. LOU windows and filters)
- MLI closure for optical bench
- Subsequent integration (shield by shield)
- Integration of cryostat vacuum vessel outer shell upper part (connection of He filling/venting system, leak test of the He system after connection)
- Integration of cryostat cover dummy
- Closure of the cryostat and integral leak test of the cryostat vacuum vessel, pre-evacuation of the system
- Transport of cryostat from integration area to test area and preparation for CQM instrument testing.

The integration is assumed to be similar to the final PFM integration sequence and is therefore not described in detail (see next paragraph).

7.2.1.2. HPLM PFM Integration

The integration of the instruments to the Herschel cryostat starts with the open cryostat at the completion of the earlier test phase, the STM programme, where instrument dummies are mounted in the PFM cryostat. The major tests completed at that point in time are:
- cryostat thermal characterisation (lifetime, ground hold time)
- cryogenic operations verification (bake out, cooling, filling He II production, pressure drop…)
- qualification level vibration
- alignment verification and procedure development
- warm up.

The integration flow of the instruments starts with mounting of the FPU’s on the optical bench and is considered completed with the closure of the cryostat at ambient temperature.

The major steps that can be identified are:
- Instrument integration to optical bench (mechanical/thermal and electrical)
- Instrument ambient temperature functional check (no alignment, expected that mechanical adjustment is sufficient)
- Closure of optical bench (mechanical and straylight – specifically w.r.t. LOU windows and filters)
- MLI closure for optical bench
- Subsequent integration (shield by shield)
- Integration of cryostat vacuum vessel outer shell upper part (connection of He filling/venting system, leak test of the He system after connection)
- Integration of FM cryostat cover
- Closure of the cryostat and integral leak test of the cryostat vacuum vessel, pre-evacuation of the system
- Transport of cryostat from integration area to test area and preparation for PLM testing.

The sequence assumes the use of class 100 clean room and cleanliness control procedures similar to the integration of the ISO system.

The following assumptions are used for the planning:

7.2.1.2.1. Instrument integration to optical bench and Instrument Integrated Satellite Test (IST) at ambient temperature (functional check)

Each instrument is mounted separately to the optical bench. It is assumed that no alignment activities are necessary, the mechanical mounting is sufficiently accurate. The integration is done according common practice on ESD protection in the class 100 clean-room. The thermal links are integrated from the tank, resp. the cooling loops. The harness is integrated from the optical bench interface connector to the FPU’s. The further harness throughout the cryostat is assumed to have already been integrated and validated prior to the instrument arrival. After connection of the harness to the FPU and through the complete cryostat it is foreseen to perform an Instrument ambient temperature IST, instrument by instrument, at ambient temperature. In order to provide protection from straylight through the local oscillators optical channels a dedicated input port baffle for HIFI is integrated at this step.

7.2.1.2.2. Closure of optical bench

After completion of the above the optical bench can be closed. This is basically just putting the shield around the instruments. At this stage it is expected that we need a
type of verification of the IR tightness of the system with the exception of the optical channel. The optical entrance is closed off, together with the LO filters and the “sealing” interfaces are illuminated (visual) while having still optical sensors in the optical bench/shield cavity. The validation of this integration approach is considered part of the CQM test sequence, so has been validated following the same lines.

7.2.1.2.3. MLI closure for optical bench and subsequent shields integration

The closure of the cryostat is systematic integration of the shields and closure of the MLI between the upper conical shield and the cylindrical part of the cryostat. One major element during the integration is the control and achievement of the cleanliness requirements.

7.2.1.2.4. Integration of cryostat vacuum vessel outer shell upper part

After integration of the insulation system the outer shell can be integrated. Besides the mechanical integration at the outer cylinder the connection of He filling system has to be performed with the corresponding leak test of the He system.

7.2.1.2.5. Integration of FM cryostat cover

The cryostat cover is mounted on top of the system with the opening mechanism. In this case it is the FM cover system. The system that was mounted beforehand is a qualification model, which is now taken for refurbishment as FS. The integration is completed by a functional test. Since the cover has to be opened later in the test sequence this needs to be verified also here.

7.2.1.2.6. Closure of the cryostat and completion of integration

Upon completion of the cover integration the system is closed and ready for the integral leak test of the insulation system. The cryostat is pre evacuated and integral leak test performed. The system is now ready for transport from the integration area to the test area and the start of the test sequence.

The remaining items for integration are the cavity on top of the cryostat and the connection of the vent gas piping to the cavity. This is carried out later in the sequence, since not compatible with the cryogenic instrument test.

7.2.1.2.7. Transport of cryostat

The transport of the cryostat from the class 100 clean room to “normal” (class 100.000) clean-room conditions is the last activity of the integration sequence.
7.2.2. PPLM Integration
The PPLM integration will be defined in due course in line with the instrument definitions and needs given in the IID B’s and the progress of the spacecraft and PPLM design activities in the industrial phase B.

7.2.3. HSVM Integration
The HSVM integration will be defined in due course in line with the instrument definitions and needs given in the IID B’s and the progress of the spacecraft and HSVM design activities in the industrial phase B.

7.2.4. PSVM Integration
The PSVM integration will be defined in due course in line with the instrument definitions and needs given in the IID B’s and the progress of the spacecraft and PSVM design activities in the industrial phase B.

7.2.5. Herschel S/C PFM Integration
After transport and unpacking of the cryostat the system integration can start. It is assumed that the SVM for Herschel has already been integrated and validated. The remaining items to be integrated can be listed as:

- Herschel telescope
- External structures
- Herschel Sunshield
- Service module with PLM.

The complete integration is performed with the He tank of the cryostat at normal pressure conditions, i.e. at 4.2 K. One filling is expected during the integration period. The total available time for integration without filling would be only 2 months, what is too short for the complete integration activity.

Additional explanations for each of the major integration steps:

7.2.5.1. Integration of the telescope
The cryostat has been unpacked and is on mounted to the MGSE in the clean room. The telescope is mounted together with the PLM to telescope interface struts. Some special protection is applied to the telescope to avoid contamination. The external references of the telescope will be adjusted to the PLM reference. The thermal insulation/heating of the telescope will be mounted now, after completion of the mechanical/optical integration. The alignment measurement to the Local oscillator and the external cryostat reference provides the basis for the later comparisons. It is not planned to perform any real telescope performance measurements now, e.g. measurement of the WFE.

7.2.5.2. External structures
The activities foreseen comprise among others the integration of the external insulation of the cryostat on the front side, i.e. the side facing the sunshield, the upper conical part and the lower interface to the SVM. This includes, to partially mount already now the interfaces to the supporting struts for the sunshield.
Depending on the design of this supporting system the supporting system also provides interface points to the star-trackers. During these activities the cryostat will be refilled to 100 % with He I. The activities include mounting of the cryogenic GSE, filling and partial removal of the GSE. During these times the system needs to be connected to EGSE for control and commanding. The instruments need not be connected during this period. The ambient temperature units of the instruments as coming from the PLM PFM test sequence need to be mechanically and electrically (functionally) integrated to the Herschel SVM to be ready for the integration of the SVM to the PLM.

7.2.5.3. Integration Herschel Sunshield

The sunshield fixation design is expected to have mechanical interfaces only to the cryostat. This allows the "stand alone" integration without the SVM. The duration of the integration depends on the actual design. It has been assumed here that the sunshield consists of several panels that need to be integrated sequential with insulation material (MLI) to be mounted to each of the panels after mechanical integration. This is considered not yet an optimum design approach.

7.2.5.4. Integration of the Service Module with PLM

The integration of the SVM includes the mechanical mounting and the electrical integration. This requires lifting of the cryostat with the 3.5 m telescope on top and the sunshield attached on one side. It includes the integration and de-integration of the necessary MGSE for lifting. At the end of the integration steps the system is expected to be mounted on the lower interface adapter, the cylindrical ring to the Planck S/C.

7.2.6. Planck S/C Integration

The Planck spacecraft integration will be defined in due course in line with the instrument definitions and needs given in the IID B’s and the progress of the spacecraft and HSVM design activities in the industrial phase B.

7.3. Herschel/Planck Testing

After completion of the integration, be it at the level of the HPLM, PPLM, HSVM, PSVM, Herschel S/C or Planck S/C, a series of verification tests will be carried-out. Each test will be defined in detail in a test procedure to be written by the Contractor, based on instrument group inputs. It will be reviewed and approved by the Herschel/Planck project group.

7.3.1. Herschel PLM CQM Testing

The test configuration is defined in line with the integration sequence as given in paragraph 7.2.1.1 above, i.e.:

The test cryostat is the ISO QM Cryostat. The dimensions allow to mount the Herschel optical bench on top of the ISO spatial framework. This optical bench is assumed to be 100 % the Herschel bench, including thermal, electrical and optical interfaces. The upper part of the Herschel cryostat will be copied for this test, i.e. we assume to get the optical bench shield, three conical shields and the
outer bulkhead of Herschel. For the instruments there is no difference to the real Herschel cryostat. The harness would be the Herschel harness with feedthroughs at the same or nearly the same place. The BOLA and the LOU will be mounted to the outside with representative struts. The LOU will be mounted within a test cryostat (tbc), provided by the instrument, to achieve near orbital temperature conditions. The cryostat cover will be there, i.e. either the Herschel qualification model or a GSE cover for the test. The outer, upper part of the cryostat allows mounting of a GSE cavity to produce low temperature background to simulate orbital background conditions. The orbital mass flow rate of about 2.5mg/s is further assumed to be reached for this test (at least for the instrument test periods)

The outer cryostat harness will be electrically representative to the “real” Herschel harness.

The instrument warm units will be mounted on an electrically representative plate (grounding etc.).

The instrument units will be connected to a functionally representative CDMS and Power S/S. Further the EGSE deployment is assumed to be the same as in the “real” system, respectively the PLM level testing.

The total system will be deployed in a clean-room (standard class) and the test carried out with the CVV at ambient temperature environment.

7.3.1.1. Herschel PLM CQM Test Sequence

The test sequence below has been defined in co-operation with the Herschel instrument teams. This paragraph in the IID A provides the overall test sequence, the test objectives, estimated durations, however, does not include details of the instruments. These details together with specific instrument test objectives and requirements are given in the corresponding paragraph in the IID-B’s.

The test sequence consists of the following major steps:
- Alignment check after integration
- Evacuation and cool-down
- Alignment check cold
- Thermal Sensitivity Tests
- Instrument Tests (Integrated System Tests, IST’s)
- Instrument EMC tests (conducted)
- Warm up and alignment check.

One major objective of the CQM Test Sequence is the development and execution of Instrument IST’s as a reference for PFM testing.
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Duration [days]</th>
<th>Objective</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration</td>
<td>N/A</td>
<td>Interface verification, mounting of FPU's</td>
<td>For CQM the HiFi cleanliness requirements can be reduced LOU has been prechimmed</td>
</tr>
<tr>
<td>Alignment check instrument FPU's, LOU to HIFI FPU</td>
<td>1</td>
<td>Pre-alignment of optical bench prior to cool-down, validate procedure</td>
<td></td>
</tr>
<tr>
<td>Evacuation of cryostat</td>
<td>3</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Alignment check instrument FPU's, LOU to HIFI FPU</td>
<td>1</td>
<td>Change of alignment due to evacuation validate procedure</td>
<td></td>
</tr>
<tr>
<td>Cool-down and filling (controlled cooling speed - if needed)</td>
<td>10</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Alignment check instrument FPU's, LOU to HIFI FPU</td>
<td>1</td>
<td>Change of alignment due to cool-down validate procedure</td>
<td>Assume that there is a GSE on top of the cryostat that allows viewing the optical bench for alignment or the alignment is carried out through the LOU alignment windows An optical dummy instead of LOU is an option for monitoring</td>
</tr>
<tr>
<td>He II Production</td>
<td>5</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Thermal Tests (heat lift at each stage, time constant)</td>
<td>5</td>
<td>Characterise optical bench behaviour, input to thermal model correlation</td>
<td></td>
</tr>
<tr>
<td>Instrument Test HIFI</td>
<td>3</td>
<td>Verification of FPU thermal behaviour Determination of stray-light and standing waves between telescope, FPU and LOU Verification of telescope-FPU-LOU alignment accuracy, changes in alignment as function of temperature changes as well as alignment procedures and tools</td>
<td>Note: Standing waves to LOU tbd, to telescope not feasible, alignment tests should not be part of this test, but test should be to its majority serve for instrument functional and performance tests All tests are to be carried out in a representative configuration and subject to representative environments. For almost all HiFi units a Q-model standard appears available</td>
</tr>
<tr>
<td>Mount GSE cavity, open cover and provide dark background</td>
<td>2</td>
<td>Verify GSE and procedure</td>
<td></td>
</tr>
<tr>
<td>Instrument Test PACS</td>
<td>3</td>
<td></td>
<td>All testing of PACS in the cryogenic environment of CQM test will require a representative thermal background radiation as can be expected from the real telescope. The actual background radiation expected needs to be discussed with PACS. For recycling of the sorption cooler the</td>
</tr>
<tr>
<td>Sequence</td>
<td>Duration [days]</td>
<td>Objective</td>
<td>Remarks</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>cryostat needs to be tilted by 20 degrees.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument Test SPIRE</td>
<td>3</td>
<td></td>
<td>For recycling of the sorption cooler the cryostat needs to be tilted by 20 degrees. For testing of the FTS tilting up to 90 degrees might be required</td>
</tr>
<tr>
<td>Instrument Test PACS/SPIRE Parallel mode</td>
<td>1</td>
<td></td>
<td>Details of this mode will be defined in due course</td>
</tr>
<tr>
<td>Instrument Test HIFI (EMC)</td>
<td>2</td>
<td>Early determination of Flight Instrument EMI susceptibility (radiated and conducted)</td>
<td>Note: It is expected that the effect of standing waves to LOU might not be measurable and to the Herschel telescope will not be measurable. Radiated testing is expected not to be compatible with facility, SVM s/s will not be fully represented (high level of representation of the SVM optimises the value of these tests. This applies also to the availability of a transponder)</td>
</tr>
<tr>
<td>Instrument Test PACS (EMC)</td>
<td>2</td>
<td></td>
<td>Note, the most sensitive mode of PACS also depends on the amount of thermal background falling into the instrument. In case the background is too high, this needs to be discussed with PACS.</td>
</tr>
<tr>
<td>Instrument Test SPIRE (EMC)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close Cover, remove cavity</td>
<td>1</td>
<td>Verify GSE and procedure</td>
<td></td>
</tr>
<tr>
<td>Warm up to He I temperatures</td>
<td>1</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Depletion of He</td>
<td>3</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Warm up to ambient</td>
<td>5</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Alignment check instrument FPU's, LOU to HIFI FPU</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressurisation</td>
<td>1</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Alignment check instrument FPU's, LOU to HIFI FPU</td>
<td>1</td>
<td>Final check</td>
<td></td>
</tr>
<tr>
<td>De-integration</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3.1-1: Herschel Payload CQM Test sequence

7.3.2. Herschel S/C CQM Testing
At present no test are defined on Herschel S/C level with the CQM instruments.

7.3.3. Herschel PLM PFM Testing
The test sequence in after integration considers the following major stages:
- Evacuation and bake out
- Alignment checks of the FPU’s
- Cool-down of the system and filling with He I
- Alignment check after cooling
- He II production and complete filling
- Integrated Module Test
- Transport to system AIV

As can be seen the test sequence is dominated by activities that are related to the payload. Since the same cryogenic system has already been verified in the STM sequence the task to do here for the cryostat is reduced to validating that the performance is the same, i.e. that there is no degradation. The telescope is not planned to be mounted in this sequence, as part of the PLM activities, but as part of the system activities. As a performance test of the three instruments is foreseen, it has been assumed that the units outside the cryostat (BOLA and LOU) have been fully integrated, the control electronics are available and can be connected to appropriate EGSE. In this sequence there are a number of parallel activities, therefore further explanations are given for each step.

7.3.3.1. Evacuation and bake out
The cryostat is on its MGSE in the clean room and the vacuum pumps are finally connected (should be mounted already since needed for pre-evacuation). The Helium venting system is connected to high temperature Helium or eventually Nitrogen flow that increases the temperature of the Helium tank and piping to around 80°C. This is done in a controlled manner, to keep the instrument units always at the highest temperature (avoid to collect contamination). The purpose of the bake-out is twofold, on one side removal of contamination from the system on the other hand removal of water from the MLI to increase the later low temperature performance. As a parallel activity to the evacuation and bake out the GSE cavity is mounted on top of the cryostat. This cavity is planned to be designed for alignment and test purposes and allows opening of the cryostat cover with vacuum in the system or even when filled with Helium. It is not clear whether this could be a multi-purpose GSE cavity or whether it is simpler to use more than one but simpler systems. The local oscillator unit and the buffer amplifier unit are mounted as a parallel activity.

7.3.3.2. Alignment checks of the FPU's
The FPU position is now measured through the opened cover and alignments via the cryostat suspension system is performed. The other expected alignment measurement is via the local oscillator alignment windows into the HIFI. The alignment is measured w.r.t. a cryostat fixed reference system.

7.3.3.3. Cool-down of the system and filling with He I
The system is evacuated and aligned, so, it is time to cool the system to cryogenic temperatures. It is expected that this have to be done in a controlled way, i.e. with the instrument cool-down rate controlled and the instruments as the warmest element in the system. The cover would be kept closed during this activity. The system is filled up to 100 % filling level at He I temperature.
7.3.3.4. Alignment check after cooling

The FPU position is now measured through the, again, opened cover. The cryostat suspension pre-tensioning system (GSE) can now be removed. At this point the alignment of the local oscillator unit is performed, first via measurements of the FPU and LOU relative alignment through the dedicated alignment windows.

7.3.3.5. He II production and complete filling

As a preparation of the integrated module test, the temperature of the Helium tank is reduced to 1.6 K and the tank filled up completely. This is done in a sequential way, i.e. pumping the tank, filling, pumping, etc. The final condition is that the He II tank is filled with He at around 1.6 K and the instruments “see” the “real” expected environment. During this time, as a parallel activity, the electrical connection can be made to the warm electronic units. The integration of the wave-guides from the local oscillator to the warm control unit is performed in parallel. The external cryostat harness is expected to come completely new for the FM and is also integrated in parallel (already during the above activities, but need to ready now). The GSE cavity could, at this point, be exchanged, if one would go for different GSE items. The definition of the cavity for the integrated module test would be such as to simulate/provide a low temperature background to the instruments, similar to the orbit case. Since later the telescope will be mounted to the cryostat, this is the only point in time of the FM sequence, where such low temperature background could be provided.

7.3.3.6. Integrated Module Test

The integrated module test is the full performance and functional test of the instruments, instrument by instrument and together. This includes the capability of the set-up to recycle the instrument sorption coolers. It has to be assumed that the procedures have already been validated with the CQM, so this test sequence is for validation and not procedure development. However, note that this is the first time that the PFM instruments are together in the proper environment. During this test some information is obtained on the performance of the cryostat, w.r.t. temperatures and lifetime, but this is gathered as a separate information and should not drive or dominate any of the sequences. At the end of the test sequence the He bath is heated to ambient pressure (He I) and prepared for transport. At the end of the sequence the flight cavity is mounted to the cryostat and connected to the He vent-line system.

7.3.3.7. Transport to system AIV

It is not expected that the cryostat tests be carried out at the same facility as the system integration and tests (planned to be at ESTEC). So the cryostat has to be transported to the system test facility. This means packing into the container and shipment. The cryostat without the telescope is still compatible with road transport.

7.3.4. Herschel S/C PFM Testing

After completion of the system integration the final test sequence can start. The sequence consists of all necessary major tests for system verification:
- Alignment and Cryostat refilling
- Integrated satellite test
- System Validation Test (ESOC Compatibility Test)
- Vibration test
- Acoustic noise test
- Alignment checks (telescope/spacecraft)
- EMC test
- Thermal Vacuum and Thermal Balance test
- System Validation Test II

The main tests in this sequence are the integrated satellite test, the mechanical and the thermal tests. Some additional information to the different elements of the test flow are given below:

7.3.4.1. Alignment and Cryostat refilling
As a first step after system integration, the alignment of the different elements is verified and the system prepared for the integrated satellite test. This includes mounting of the cryogenic GSE, filling the system with He I, He II production and He II top-up. At the completion of this activity, the system is ready for functional test of the integrated spacecraft.

7.3.4.2. Integrated Satellite Test
The integrated system is, for the scientific instruments, similar to the previously performed integrated module test, however, with different thermal background for the focal plane instruments (cryostat cover closed). Further to the instrument tests, the total integrated spacecraft is tested at this stage.

7.3.4.3. System Validation Test (ESOC Compatibility Test)
This system validation test has been included at two stages of the Herschel System test phase. The main purpose of these tests is the verification of the ground segment operations with the real flight hardware system.

7.3.4.4. Vibration test and Acoustic noise test
The mechanical system verification is performed through a three-axis sine vibration test and the acoustic noise test. The vibration test is performed with normal He I in the system. Consequently the He II conditions are given up and the system is heated to He I conditions and transported to the test facility. In order to achieve proper conditions the He II tank is filled prior to each run to the nominal launch conditions, i.e. > 98% filling level. After completion of each axis vibration and the acoustic test, short functional tests demonstrate the health of the system and the instruments.

The mechanical test sequence is completed by alignment checks afterwards. These are alignment checks of the instruments to the telescope and the spacecraft
elements to each other. The system is transported at completion of the sequence back to the main test room for He II production and filling.

7.3.4.5. EMC test
The system test sequence assumes that the system radiative EMC test is conducted with He II conditions, however in a launch autonomy mode configuration. This means that the bath is kept at He II temperatures (< 2 K), but closed off and the cooling of the other instrument stages is performed from the auxiliary tank. In order to achieve the necessary thermal inertia the He II tank is completely filled at temperatures below 1.7 K then closed and the auxiliary tank filled with normal He. The total available duration in this configuration is given by the launch autonomy capacity of six days. Each 48 hours refilling of the auxiliary tank has to be foreseen. The system is transported in autonomy configuration to the acoustic facility and then tested. After completion of the test the system is transported back to the main test floor for preparation for the main thermal test.

7.3.4.6. Thermal Vacuum and Thermal Balance test
The thermal test is the last main test in the Herschel test sequence. During this sequence also the cool-down of the cryostat shall be verified. Therefore the He II bath is re-pumped to launch conditions and the system brought to launch autonomy configuration. For the integration into the facility it is assumed that this can be done in the Herschel system configuration, i.e. no dismounting of any equipment is necessary. The spacecraft integration and removal into and out of the facility is considered one of the most complicated integration sequences and need proper and detailed preparation. The actual facility test duration is taken long enough to perform the electrical functional tests of the spacecraft, integrated system test for the instruments and to verify adequate cool-down/transient behaviour of the cryostat and the telescope. The telescope bake-out is demonstrated as one of the “side” tests in the first week of the thermal test. It is not planned to open the cryostat cover during this test, i.e. the thermal background from the thermal shield in the cover will be above the orbit conditions. At completion of the actual test the system is removed from the facility for the second ground segment compatibility test and preparation of the system for the carrier test programme.

7.3.5. Planck PLM CQM / STM Spacecraft Testing
The test sequence after completion of the integration of the PLM CQM considers the following major test steps:
- Telescope Alignment Check
- Functional Test of the instruments
- Mating Planck PLM on SVM -> Planck STM Spacecraft
- Vibration Test
- Telescope Alignment Check
- Functional Test of the instruments
- Cryogenic Test
- Telescope Alignment Check
- Functional Test of Instruments
- Spacecraft and PPLM disassembly
As can be seen the test sequence is dominated by activities that are related to the telescope and the payload. As a functional test of the two instruments is foreseen, it has been assumed that the control electronics are available and can be connected to appropriate EGSE. Further explanations are given for the above steps.

7.3.5.1. Telescope Alignment Check
The alignment of the telescope is measured w.r.t. a PLM fixed reference system after integration of the telescope with the PLM structure. The alignment to the FPU is measured via external references on the telescope, the PLM and the FPU.

7.3.5.2. Instrument Integrated Satellite Tests (ambient)
All instrument units that are mounted to the Payload module are properly integrated and connected. Instrument units, that are later mounted on the SVM, might be replaced by functional EM’s or the Avionics models (AVMs). The PLM is mounted in its MGSE in the clean-room.
The integration of the PLM has been completed with all thermal and structural hardware of the PLM.
The IST of the instruments at this stage is limited by the instrument verification possibilities at ambient temperature.

7.3.5.3. Vibration Test
The complete Planck STM satellite assembly will be structurally tested, i.e. via 3-axis vibration test. A short version of the instrument IST’s as described above and the alignment checks are clearly verification elements.

7.3.5.4. Cryogenic Test
The cryogenic qualification is expected to be the most demanding test of the CQM sequence. The objectives of this test are the verification of the passive thermal concept of the PLM (incl. its sensitivity) and the verification of the performance of the active coolers of the instruments. Further objectives of this test are the assessment of the thermal response of the radiators to temperature level and the correlation of the results with the thermal model. Once the proper temperatures at the FPU are achieved an extended instrument functional/performance test is performed. In order to achieve the test objectives it is expected that the facility provides adequately low background for the FPU. During this test a limited EMC test (limited by the capabilities inside a facility) is carried out.

The expected overall configuration and an integration and test sequence is outlined below. This description is a result of a working group activity with ESA, LFI, HFI and facility representatives from CSL. The anticipated test sequence, with test objectives and estimated duration is outlined in paragraph 7.3.5.5.1 below. Information on
details of the instrument test sequences and needs are given in corresponding paragraphs in the LFI and HFI IID-B’s.

It is assumed that all instrument coolers have passed successfully a leak test after completion of the PPLM CQM vibration test. The overall configuration includes the PPLM only, i.e. not the full SVM. The need to simulate for thermal reasons the “real” SVM structure is not clear at present and has to be evaluated from the detailed design of Planck in line with the objectives of the test. The instruments, consisting out of the CQM units and the corresponding AVM units to operate the CQM’s, are all compatible with the vacuum facility and mounted in an electrically representative manner to the PPLM. The interfacing spacecraft units, i.e. the CDMS and the power units are functionally representative to the Planck SVM units and could be located outside the facility. It is assumed that these units will be operated by a (reduced) version of the system EGSE and that the instrument EGSE will interface to this system EGSE in the same way as in the PFM program. The facility will provide a venting/collection system for the helium of the dilution cooler. This pipes will be routed from the PPLM to the outside of the facility and connected to a recollection system provided by HFI. The Helium tanks for the dilution cooler are inside the facility filled to a level necessary for the completion of this test (e.g. up to 100 bars). It is assumed that the most practical way to cool the sorption cooler compressors in the facility will be by radiative means, i.e. the sorption cooler will “view” a LN$_2$ cooled panel. Compensation heaters on the sorption cooler radiator panel allow for temperature control when the cooler is switched off or to perform tests at different temperatures of the radiator panel.

It appears that the best configuration for the telescope is to have the primary mirror facing downwards to ground. A small shroud in front of the focal plane units and connected to a helium cooling loop is implemented to provide the cold background for the instrument performance test and form the inner, coldest part of the shroud system. A further shroud that will be during test at 20 K (“20 K shroud”) is mounted around the PPLM, starting at the level of the upper face of the SVM (some mm clearance only) and completely closing off all PPLM elements. A further shroud that is mounted around this 20 K shroud completes the shroud system for the test.

7.3.5.4.1. Cryogenic Test – Sequence

The test sequence below has been defined in co-operation with the Planck instrument teams. This paragraph in the IID A provides the overall test sequence, the test objectives, estimated durations, however, does not include details of the instruments. These details together with specific instrument test objectives and requirements are given in the corresponding paragraph in the IID-B’s
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Duration [days]</th>
<th>Objective</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration</td>
<td>N/A</td>
<td></td>
<td>See general definition in paragraph above</td>
</tr>
<tr>
<td>Ambient. Functional</td>
<td>5</td>
<td>Go ahead for test (up to detectors, coolers)</td>
<td>Dilution cooler pipes (exhaust), pre-cooling line for dilution connected</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Instruments, Non-op substitution heaters and thermistors all functional,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Micro vibration level (test chamber environment and pumps, shrouds, 4K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>compressors, etc...) at HFI Focal Plane Unit less than TBD, required for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>operation of dilution cooler</td>
</tr>
<tr>
<td>Shrouds closure</td>
<td>1</td>
<td></td>
<td>PPLM – 20k shroud – down to SVM shield</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(closed optically)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Telescope” Background shield in front of FPU</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(4K Shield)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SVM shroud (LN2) closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mounting at SVM – I/F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Consider evacuation ports</td>
</tr>
<tr>
<td>Facility Pump down</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient leak test</td>
<td>1</td>
<td>Facility leak tight</td>
<td>Helium leaks from pipes/shrouds have to be discriminated from specimen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instrument pipes/coolers leak tight,</td>
<td>out-gazing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure vibration level on HFI FPU</td>
<td>Leak level smaller than 10e-8 mbar l/sec (integral facility)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vibration level at LFI interface and telescope frame – measured by</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>instruments &lt; 10e-3 g</td>
</tr>
<tr>
<td>Short Ambient functional test</td>
<td>N/A</td>
<td>Go-ahead for test</td>
<td></td>
</tr>
<tr>
<td>Facility Ready for test</td>
<td>N/A</td>
<td>Go-ahead for test</td>
<td></td>
</tr>
<tr>
<td>Bake out</td>
<td>2</td>
<td>Condensation prevention, water release for facility</td>
<td>Passive Bake out – shrouds heated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SVM temperature control by EGSE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HFI units max $T^\circ$ as per instrument IID-B</td>
</tr>
<tr>
<td>Cool-down of facility</td>
<td>1</td>
<td>PPLM cool-down sequence (instruments off, substitution heaters</td>
<td>Shroud (outer to inner) temperatures:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and thermistors ON)</td>
<td>LN2/20K/20K (possibly pre-cooling of PPLM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Strain gages on Wave-guides/Pipes and other instrumentation as long as</td>
<td>4 K shroud needs to be “black” at HFI/LFI wavelength!</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not affecting the test)</td>
<td>Small shroud in front of the FPU! (temperature stability to be considered)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Validate cool-down transient modelling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HFI 0.1K plate de-clamping creates FPU 4K stage cooling slope discontinuity (T° TBD, below 77K )</td>
</tr>
<tr>
<td>Contamination release test</td>
<td>3</td>
<td>Demonstration of in flight heating system</td>
<td>SVM temperature control by EGSE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HFI units max $T^\circ$ as per instrument IID-B</td>
</tr>
<tr>
<td>Sequence</td>
<td>Duration [days]</td>
<td>Objective</td>
<td>Remarks</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------</td>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Cool-down of PPLM</td>
<td>5</td>
<td>PPLM cool-down sequence (instruments off, substitution heaters and thermistors ON)</td>
<td>Shroud temperatures LN2/20K/20K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PPLM “final” temperature</td>
<td></td>
</tr>
<tr>
<td>Low temperature stable</td>
<td>2</td>
<td>Sensitivity tests on PLM</td>
<td>100 mK stability level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planck telescope temperature and gradients</td>
<td>Step response of PPLM temperatures on dissipation of PLM items</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Damping functions (thermal) of PLM structures</td>
</tr>
<tr>
<td>Switch on sequence instruments</td>
<td>N/A</td>
<td></td>
<td>Criteria for switch on to be completed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(By-pass loop for HFI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sorption Cooler radiator $T^\circ &lt; 270 K$,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Colder V-groove colder than 60K (TBC)</td>
</tr>
<tr>
<td>- Sorption on</td>
<td>2</td>
<td>Stop Sorption Cooler System (SCS) non-op substitution heaters,</td>
<td>Shroud temperatures LN2/20K/4 K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch SC Electronics ON,</td>
<td>Sorption cooler – 20/18K (No dummy loads on liquid reservoirs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perform SCS initial checks,</td>
<td>Liquid Reservoir 1(LR1) $T^\circ &lt; 19 K$ (TBC), LR1 $T^\circ$ oscillation smaller than 0.1K peak-to-peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Start SC Compressor,</td>
<td>Observe coldest V-groove $T^\circ$ change after SCS ON,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch Liquid Reservoir 3 heater ON when LR3 $T^\circ$ reaches 22K TBC,</td>
<td>Same for 270K radiator (TBC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>As soon as Sorption Cooler is operational</td>
<td>HFI will have a dedicated pre-cooling loop, to be connected thermally to the 4 K stage for pre-cooling of the inside of HFI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>start HFI pre-cooling loop with 20K helium (with “4K Shroud” gas)</td>
<td>Measure temperature fluctuations of the shields (v-grooves)</td>
</tr>
<tr>
<td>- LFI on</td>
<td>1</td>
<td>LFI functional test : connect facility “4K shroud” to liquid helium supply,</td>
<td>Shroud temperatures LN2/20K/4 K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch LFI non-op heaters OFF,</td>
<td>Observe SCS cold end $T^\circ$ change as dissipation in LFI Front End Unit is increased,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decrease LR3 heating prior to switching HEMP’s ON, etc…</td>
<td>Observe coldest V-groove $T^\circ$ new equilibrium (including at Sorption Cooler pre-cooling exchanger level)</td>
</tr>
<tr>
<td>- HFI on</td>
<td>1</td>
<td>Stop non-op heaters before each unit switch-on,</td>
<td>Shroud temperatures LN2/20K/4 K</td>
</tr>
<tr>
<td>- 4 K cooler on</td>
<td></td>
<td>Switch HFI DPU ON,</td>
<td>To measure 4K cool-down duration do not use HFI pre-cooling loop during this phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch Readout Electronics ON,</td>
<td>LFI &quot;4K&quot; reference loads reach 4.8K plus TBD,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch 4K Cooler Drive Electronics ON,</td>
<td>Facility &quot;4K shroud&quot; at 4K plus TBD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observe 4K Cooler Cold End $T^\circ$ decrease,</td>
</tr>
<tr>
<td>Sequence</td>
<td>Duration [days]</td>
<td>Objective</td>
<td>Remarks</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>Measure vibration level on HFI FPU, Perform 4K Cooler Compressor switch-on procedure, Measure vibration level on HFI FPU</td>
<td></td>
<td></td>
<td>$T^\circ$ change on Focal Plane Unit 20K stage and LFI &quot;4K&quot; reference loads, $T^\circ$ change on coldest V-groove</td>
</tr>
<tr>
<td>LFI functional test II</td>
<td>4</td>
<td></td>
<td>Shroud temperatures LN2/20K/4K variation of &quot;4K&quot; shroud temperature for change in background for LFI 4K loads at about 4.8K HFI still cooling</td>
</tr>
<tr>
<td>HFI cool-down - parallel to above</td>
<td>N/A</td>
<td>Parallel LFI performance test (use available time), Start Dilution Helium flow (1.6K JT operating), Adjust HFI Dilution Cooler Helium isotopes mixture ratio</td>
<td>Shroud temperatures (LN2/20K/4K, 4K for pre-cooling HFI) Maximum vibration for 0.1K cooler = 10e-3 g measure at the LFI interface Observe HFI FPU 4K, 1.6K and 0.1K stages cool-down</td>
</tr>
<tr>
<td>Instruments cold (operational)</td>
<td>N/A</td>
<td></td>
<td>Shroud temperatures LN2/20K/4K HFI bolometers at less than 105 mK TBC</td>
</tr>
<tr>
<td>- HFI functional test</td>
<td>3</td>
<td>verify compatibility</td>
<td>Shroud temperatures LN2/20K/4K Measure signal detected by different HFI 0.1K detectors Observe HFI Focal Plane Unit $T^\circ$ variation over Sorption Cooler beds switching period and other duration's</td>
</tr>
<tr>
<td>Contingency</td>
<td>2</td>
<td></td>
<td>as part of this test run the 4K cooler in a noisy mode (EMC and vibration wise) test switches in LFI</td>
</tr>
<tr>
<td>- EMC – conductive test</td>
<td>4</td>
<td>verify EMC behaviour</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td>- LFI switch off/HFI stand alone</td>
<td>2</td>
<td>Perform LFI switch-off sequence, Simulate LFI dissipation by non-op heaters (including in Focal Plane Unit), Perform HFI stand alone test,</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td>LFI switch on again</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- SCC radiator temperature change</td>
<td>1</td>
<td>Effect on 4K Cooler &quot;18K&quot; pre-cooling temperature</td>
<td>Shroud temperatures LN2/20K/4K 4K pre-cooling temperature variation should be about 1K for 10K on 270K radiator</td>
</tr>
<tr>
<td>Sequence</td>
<td>Duration [days]</td>
<td>Objective</td>
<td>Remarks</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Cooler Failure tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4K cooler off</td>
<td>1</td>
<td>Increase of HFI FPU 0.1K, 1.6K, 4K</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LFI performance degradation for 4K failure,</td>
<td>Observe HFI FPU T° increase for 24 h duration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch 4K compressor OFF,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch corresponding substitution heater ON</td>
<td></td>
</tr>
<tr>
<td>4K cooler on</td>
<td>1</td>
<td>Return to 4K in HFI,</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perform 4K cooler switch-on procedure,</td>
<td>Dilution 4K heat exchanger back to &quot;4K&quot;, Do not wait for HFI FPU internal T° return to 1.6 and 0.1K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch 4K compressor ON,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch corresponding substitution heater OFF</td>
<td></td>
</tr>
<tr>
<td>20K off</td>
<td>1</td>
<td>Temperature control SVM SCC radiator?</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warm up of FPU/PPLM (for failure case)</td>
<td>observe 4K cold end loss of cooling power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch Sorption Cooler OFF</td>
<td>Monitor HFI FPU temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch corresponding substitution heaters ON</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warm up 4K shroud</td>
<td></td>
</tr>
<tr>
<td>4K off</td>
<td></td>
<td>Controlled switch off,</td>
<td>Shroud temperatures LN2/20K/4K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch 4K Cooler OFF,</td>
<td>Monitor HFI FPU temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch corresponding substitution heaters ON</td>
<td>LFI taking data but not driving the test</td>
</tr>
<tr>
<td>0.1K off</td>
<td>1</td>
<td>Controlled switch off,</td>
<td>Shroud temperatures LN2/20K/20K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch Dilution Cooler OFF</td>
<td>Monitor HFI FPU temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch corresponding substitution heaters ON</td>
<td>LFI taking data but not driving the test</td>
</tr>
<tr>
<td>LFI off</td>
<td>N/A</td>
<td>Controlled switch off</td>
<td>Shroud temperatures LN2/20K/20K</td>
</tr>
<tr>
<td>HFI off</td>
<td>N/A</td>
<td>Controlled switch off</td>
<td>End: FPU = 50K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Define how to accelerate/monitor HFI Focal Plane Unit internal warm-up</td>
</tr>
<tr>
<td>Facility Warm Up</td>
<td>5</td>
<td>Tbd “thermal inertia/damping tests”</td>
<td>Criteria to start facility re-pressurisation without danger for HFI FPU are TBD (FPU internal T°, pressure increase speed)</td>
</tr>
</tbody>
</table>
Table 7.3.5-1: Planck PLM CQM test sequence

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Duration [days]</th>
<th>Objective</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequential heat up of the system with instruments and telescope driving the warm up</td>
<td></td>
<td>Sequential heat up of the system with instruments and telescope driving the warm up</td>
<td></td>
</tr>
<tr>
<td>Short ambient functional test</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Removal from the facility</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.3.5.5. Ambient RF test
Ambient RF test is performed at Planck RFQM levels with telescope QM and instrument RF mock-ups (made by the prime).

7.3.6. Planck S/C CQM Testing
This is covered in the previous section.

7.3.7. Planck PLM PFM Testing
The PLM PFM test sequence is to a major extent a repeat of the CQM sequence, however, now with the Flight model instrument units.

The test sequence after integration is identical to the CQM sequence and considers the following major test steps:

- Telescope Alignment Check
- Functional Test of the instruments

7.3.7.1. Functional Test of the instruments
All instrument units that are mounted to the Payload module are properly integrated and connected. Instrument units that are later mounted on the SVM might be mounted on some MGSE, but are expected to be the real FM units. The PLM is mounted in its MGSE in the clean room.

The integration of the PLM has been completed with all thermal and structural hardware of the PLM.

The IST at this stage is limited by the instrument verification possibilities at ambient temperature.

7.3.8. Planck S/C PFM Testing
After completion of the PLM FM integration the Planck spacecraft will be fully integrated with the SVM PFM and the system tests will be carried out. Since this is...
the first fully representative Planck S/C system a number of system tests will be
carried out for the first time. The test sequence envisaged is:

- Integration of Planck S/C
- Alignment Check
- Integrated Satellite Test
- System Validation Test
- Vibration Test
- Acoustic Noise test
- Alignment Check
- EMC test
- TV test
- Alignment Check
- System Validation Test

The test durations are adapted to the needs of a FM sequence, i.e. the objective is
changed from qualification to acceptance. This means in some areas a reduction in
duration since the demonstration can be limited. It has been assumed that control
electronics are available and can be connected to appropriate EGSE.

The main tests in this sequence are the integrated satellite test, the mechanical and
the thermal tests. Some additional information to the different elements of the test
flow are given below:

7.3.8.1. Alignment
As a first step after system integration, the alignment of the different elements is
verified and the system prepared for the integrated satellite test. At the completion of
this activity, the system is ready for functional test of the integrated spacecraft.

7.3.8.2. Integrated Satellite Test
The integrated satellite test is, for the scientific instruments, similar to the previously
performed integrated module test, however, at this stage at ambient temperature.
Further to the instrument tests, the total integrated spacecraft is tested at this stage.

7.3.8.3. System Validation Test (ESOC Compatibility Test)
The system validation test has been included at two stages of the Planck System
test phase. The main purpose of these tests is the verification of the ground
segment operations with the real flight hardware system.

7.3.8.4. Vibration test and Acoustic noise test
The mechanical system verification is performed through a three-axis sine vibration
test and the acoustic noise test. After completion of each axis vibration and the
acoustic test, short functional tests demonstrate the health of the system and the
instruments.
The mechanical test sequence is completed by alignment checks afterwards. These
are alignment checks of the instruments to the telescope and the spacecraft
elements to each other.
7.3.8.5. **EMC test**
The system test sequence assumes that the system radiative EMC test is conducted at ambient temperature conditions for the instruments.

7.3.8.6. **Thermal Vacuum, Thermal Balance and PPLM Cryogenic test**
The thermal test is the last main test in the Planck test sequence. During this sequence also the cool-down of the PLM will be measured. The actual facility test duration is taken long enough to perform the electrical functional tests of the spacecraft, integrated satellite test for the instruments and to verify adequate cool-down/transient behaviour of the Planck PLM. At completion of the actual test the system is removed from the facility for the second ground segment compatibility test and preparation of the system for the carrier test programme.
The cryogenic test is limited to the functional verification of the PLM thermal control and the proper operation of the active coolers of the instruments. Once the proper temperatures at the FPU are achieved an instrument functional test is expected to be performed.

7.4. **Operations**
Requirements in the OIRD and the SIRDs (AD 16,17,18) apply.

7.5. **Commonality**
For the activities in chapters 7.2 and 7.3 commonality shall be pursued as per the applicable parts of chapter 6.3.
8. PRODUCT ASSURANCE

Product assurance requirements are given in AD 19.
9. DEVELOPMENT and QUALIFICATION

9.1. General
The PI shall, in a systematic manner, verify the instrument design and build status against each requirement in the IID-A and Bs (AD 04,05,06,07,08)

This section establishes the verification requirements for the qualification and flight certification of the instrument units also giving specific test levels and durations and describing acceptance test and analytical methods for implementation of these requirements.

The PI shall include in the Design Development and Verification Plan the tests and analyses that collectively demonstrate that hardware and software complies with the requirements.

The plan shall allow the overall approach to accomplish the instrument qualification and acceptance programme. The interaction of the test and analysis activity shall be described.

9.1.1. Definitions
The following definitions are to be used:

9.1.1.1. Design Qualification Verification:
Tests and analyses intended to demonstrate that the item will function with performance specifications under simulated conditions more severe than those expected from ground handling, launch and orbital operations. The purpose is to uncover deficiencies in design and method of manufacture and is not intended to exceed design safety margins or to introduce unrealistic modes of failure.

9.1.1.2. Acceptance Verification:
Tests intended to demonstrate that hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies, and normally to provide the basis for delivery of an item under terms of a contract or agreement.

9.1.1.3. Functional Tests:
The operation of a unit in accordance with defined operational procedures to determine that functional performance is within the specified requirements.

9.1.1.4. Performance verification:
Determination by test, analysis, or a combination of the two that the complete instrument or instrument unit can operate as intended in a particular mission: this includes proof that the design of the complete instrument or instrument unit has been qualified and that the particular item has been accepted as compliant to the design and ready for flight operations.
9.1.1.5. Thermal Balance Test:
A test conducted to verify the adequacy of the Thermal Model, the adequacy of the thermal design, and the capability of the thermal control system to maintain thermal conditions within established mission limits.

9.1.1.6. Thermal Cycling Tests:
Tests to be conducted to verify that the instrument or instrument unit can withstand without degradation of its performance thermal cycles under vacuum.

9.1.1.7. Thermal Vacuum Test:
A test to demonstrate the validity of the design in meeting functional goals: it also demonstrates the capability of the test item to operate satisfactorily in vacuum at temperatures based on those expected for the mission. The test can also uncover latent defects in design, parts and workmanship.

9.1.1.8. Thermal Shock Test:
A test to be conducted to verify that the instrument or the instrument unit can withstand without degradation a cool down from room temperature.

9.1.1.9. Static Loads:
The maximum combination (longitudinal and lateral) of static loads which acts on an instrument, during the various segments of the flight profile. It consists of steady state accelerations (e.g. due to engine constant thrust or lateral wind loads) and quasi-static loads which are structure borne loads generated by the launch vehicle in the low frequency (less than 100 Hz) range (e.g. engine cut-off loads or wind gusts).

9.1.1.10. Sine Vibration Test:
A test to demonstrate that the instrument can withstand the mechanical environment of the low frequency (less than 100 Hz) sinusoidal and transient vibrations. This test can also be used to demonstrate compatibility with the static loads.

9.1.1.11. Acoustic Random Vibration:
An environment induced by high-intensity acoustic noise associated with various segments of the flight profile: it manifests itself throughout the instrument in the form of directly transmitted acoustic excitation and as structure-borne random vibration excitation.

9.1.1.12. Integrated Satellite Test (IST):
The detailed demonstration that the instrument and their units meet there performance requirements in all operational modes.
9.1.1.13. **Short Functional Test (SFT):**
The correctness of the instrument functions, for instance after a transport, is the objectives of the SFT.

9.1.1.14. **Electromagnetic Compatibility (EMC):**
The condition that prevails when various electronic devices are performing their functions according to design in a common electromagnetic environment.

9.1.1.15. **Electromagnetic Interference (EMI):**
Electromagnetic energy that interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical equipment.

9.1.1.16. **Electromagnetic Susceptibility:**
Undesired response by a component, instrument or system to conducted or radiated electromagnetic emissions.

9.1.2. **Documentation**
The following plans, procedures, and reports are requested to document the instrument environmental verification programme.

These documents shall be prepared by the instrument teams and are under their responsibility.

The test procedures and test reports shall be available on request and will be part of the Qualification or Acceptance Data Package.

9.1.2.1. **Design Development and Verification Plan**
A design development and verification plan (DDVP) shall be prepared and shall describe the overall approach to accomplish the instrument qualification and acceptance programme. When appropriate, the interaction of the test and analyses activity shall be described. The overall logic shall be clearly established.

For each analysis activity, the plan shall include objectives of the mathematical model with underlying assumptions. The DDVP shall be supported by the procedures and reports.

9.1.2.2. **Test Matrix**
In addition to the DDVP, the PI shall provide a test matrix that is in essence a synthesis of the verification programme. The test matrix summarises all the tests that will be performed on each instrument unit. The purpose of the matrix is to provide a ready reference to the contents of the test program in order to identify easily the deviations that could be requested. It has also the purpose of ensuring that flight hardware has been exposed to various environmental tests that are sufficient to demonstrate acceptable workmanship.
In addition, the matrix shall provide traceability of the qualification heritage of hardware. All models shall be included in the matrix that shall be prepared in conjunction with the DDVP.

9.1.2.3. Test Procedures
For each verification test activity conducted at the instrument level, test procedures shall be prepared that describe the test objectives and success criteria, the configuration, the test article, and how it fits in the DDVP.

The procedures shall contain all details which are necessary to make meaningful interpretations of the results, such as test parameters, instrumentation, monitoring, data collection, post-test verifications (alignment). It shall also address safety and contamination control provisions.

Test procedures shall be provided to ESA for review prior to tests.

9.1.2.4. Test Reports
After each instrument verification activity has been completed a test report shall be submitted. The report shall describe the most significant results, comparison of the measured parameters with requirements or allocations and the degree to which the initial objectives were accomplished.

In addition all as run procedures, test and analysis data shall be retained for review. Every failure shall be reported through an NCR (non-conformance report) in accordance with QA provisions.

9.2. Model Philosophy

9.2.1. Spacecraft Models

9.2.1.1. Model Philosophy at Spacecraft Level
The Herschel/Planck Project is based on a reduced model philosophy, focused on those aspects of the development which present the highest uncertainties. The dedicated structural model at system level is deleted. No thermal test at system level will take place before the PFM.

The main models at system level are: An Avionics Model (AVM), a Cryogenic Qualification Model (CQM) and the Proto-flight Model.

Module level tests are envisaged, to cover instrument and module integrated performance uncertainties

- A Planck Payload Module Cryogenic Qualification Model (CQM) to undergo mechanical and thermal validation tests. HFI and LFI will undergo a cryogenic compatibility test.

- A set of Herschel focal plane units Cryogenic Qualification Models, to undergo a compatibility test in cryogenic conditions, using a modified ISO cryostat.
A scheme of this S/C level model philosophy is shown in Table 9.2.1-1.

Table 9.2.1-1: S/C level model philosophy

The purpose of the system level AVM is to gain early confidence of the correct interactions and interfacing of the elements of the system, including those units of the instrument which interface with the various spacecraft subsystems.

The Proto-flight Model is the only fully representative model of Herschel or Planck and will be subjected to a full set of tests at qualification levels (proto-flight approach).

9.2.1.2. Model Philosophy at Instrument level

Each instrument has its own critical areas and specific needs. ESA therefore expects each PI to define a set of development tests and their related hardware, software and support equipment to demonstrate progressively during the development period that all scientific and technical requirements are met (see Table 9.2.1-2).

The Design and Development Plan (DDVP) of the instrument will therefore consider and integrate these development tests and the needs of the tests at system level. Table 9.2.1-2 lists the models required for each class of instrument units.

The AVM and PFM units, when delivered to ESA, will not be returned to the PI’s.

<table>
<thead>
<tr>
<th>Development</th>
<th>AVM</th>
<th>CQM</th>
<th>FM/PFM</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel FPU’s</td>
<td>TBD</td>
<td>Sim’s</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Herschel Warm Electronics</td>
<td>TBD</td>
<td>Yes</td>
<td>TBD</td>
<td>Yes</td>
</tr>
<tr>
<td>Herschel HIFI LOU</td>
<td>Yes</td>
<td>TBD</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Herschel PACS BOLA</td>
<td>TBD</td>
<td>Sim’s or H/W</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PLANCK HFI/LFI FPU’s</td>
<td>TBD</td>
<td>Sim’s</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PLANCK HFI/LFI coolers</td>
<td>TBD</td>
<td>Sim’s</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PLANCK HFI/LFI/Coolers</td>
<td>TBD</td>
<td>Yes</td>
<td>TBD</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: Sim’s stands for Simulators
TBD’s will be defined in the DDVP
9.2.2. Deliverable Instrument Models

9.2.2.1. Avionics Model
The AVM system test objectives are:

- verification of all electrical and software interfaces
- verification of subsystem and instrument functional performance within system environment
- qualification of on-board software
- verification of system performance
- verification of operational procedures.

The instrument AVM units therefore have to have the following built standard:

- electronics flight standard except for parts. Commercial parts have to be of same technology, same supplier as FM parts
- mechanisms flight representative for electrical actuators
- software flight standard.
- form, fit and function of the flight model
- software of flight quality must be able to be run.

In order to save cost the AVM hardware contents may be reduced by reducing redundancy:

- cold redundant units or channels may be deleted if no automatic switch-over function is involved
- multiple redundancy of hot redundant units or modules may be reduced by electrical dummies (to e.g. dual redundancy) if compatible with the AVM test objectives
- simulators may be supplied of units not directly interfacing with spacecraft subsystems. The level of these simulators, to be agreed with ESA, will allow verification of the correct execution of the flight procedures.

9.2.2.2. Cryogenic Qualification models
Because of their new development status and/or of the criticality of their performance to the flow of the AIV program, specific units will deliver CQM models for the assembly tests at payload module level.

These are:
- Herschel focal plane units (HIFI, PACS and SPIRE), HIFI LOU, PACS BOLA
- Planck focal plane unit (HFI and LFI)
- Planck coolers (HFI and LFI)

The cryogenic qualification models standard will be the same as flight models. It has been agreed that for PLM or S/C testing the AVM units could be used to control the CQM units. The AVM’s will be taken from the AVM test sequence for this period.
9.2.2.3. Flight Model

The PFM system test objective is the qualification of spacecraft system by functional and environmental tests. The PFM units therefore shall have full flight standard verified by formal functional and environmental acceptance tests.

9.2.2.4. Flight spares

The FS objectives are:
- replacement of failed or damaged equipment at integration and launch site.

The FS units have to have the following built standard:
- full flight standard verified by formal acceptance tests.

In order to save cost the FS units:
- may be derived from refurbished cryogenic qualification units if flight worthiness can be agreed,
- may be reduced to repair kits for repair at manufacturer’s site if predetermined turnaround time of one month is ensured for unit repair after failure.

This approach has to be agreed with the project office on a case by case basis.

9.3. Deliverable Instrument Test Plan

9.3.1. Instrument Verification

The different types of instrument models and sub-units which will be used at system level will, as a minimum, be required a set of tests, necessary to insure that they will be able to perform correctly and reliably their functions within the overall system.

For each type and model instrument the following minimum set of tests are requested (aside the verification of the performance requirements defined per each instrument see § 9.3.2).

- AVM:

<table>
<thead>
<tr>
<th>AVM</th>
<th>Electrical Functional (1)</th>
<th>Flight SW</th>
<th>Limited EMC (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel FPU (Sim’s)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herschel Warm Electronics</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Herschel HIFI LOU (Sim’s)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herschel PACS BOLA (Sim’s)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANCK FPU HFI/LFI (Sim’s)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANCK Coolers (Sim’s)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANCK HFI/LFI Warm Electronics</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Sim’s stands for simulators
Note:
Functional tests will be run with procedures validated before the delivery to the system tests. Conductive EMC tests, as a minimum, will be those representative and coherent with the simulator standard.

- CQM/PFM:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel FPU</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Herschel Warm Electronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herschel HIFI LOU</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Herschel PACS BOLA</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>PLANCK FPU HFI and LFI</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PLANCK Coolers</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PLANCK HFI/LFI/Coolers</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

* Those instruments or part of them which have delivered a qualification unit, will be allowed to be tested at acceptance level.

9.3.2. Instrument Scientific Performance Validation
Each instrument shall carry out the verification steps required to insure that the scientific performance of his/her instrument is met. The instruments performance validation shall also include a proper calibration of the instruments or the units.

9.4. Design and Analysis Requirements

9.4.1. Mechanical Design and Analysis

9.4.1.1. General Requirements
A series of tests and analyses shall be conducted to qualify the design of the hardware, to verify the stiffness and mechanical environment requirements as well as the general requirements.

9.4.1.2. Mechanical Models and Analyses
Structural analysis of instrument units shall be performed in order to show that the stiffness and mechanical environment requirements as well as general requirements and shall be performed in NASTRAN. The structural analysis shall include stress and
dynamic analysis. Requirements on the standards of the mechanical mathematical models will be detailed in tbd documents.

9.4.1.2.1. Detailed Stress Analyses

The stress analysis shall demonstrate that the instrument unit can withstand the limit loads factored by the appropriate safety factors. The analysis results shall be compiled in a technical note with at least:

- a description of the configuration analysed with reference to interface controlled drawings,
- a description of the mathematical finite element model and/or of the assumptions taken to verify the structure,
- a description of all possible loading cases and an identification of the design driving load cases or load combinations,
- a detailed description of the most loaded elements listed with relevant stresses, and the loading cases that generated them,
- a list of the materials and structural components with characteristics data sheets (including long-life effects under space environment),
- a set of tables showing, for each structural element, the maximum value on each type of stress or combination of them with the allowable value, and the load case that determines it together with its margin of safety.

9.4.1.2.2. Dynamic Analyses

The dynamic analysis shall be performed to demonstrate that the instrument and/or unit meets the stiffness requirements.

Furthermore, it shall be detailed enough to predict the dynamic loads which size the structural elements, the interface loads and the notching necessary in the dynamic tests input spectrum.

When mechanisms are part of the unit, different models shall be developed to account for the various configurations (stowed, fully deployed ...).

The analysis results shall be compiled in a technical note with at least:

- a description of the configuration analysed with reference to interface controlled drawings,
- a description of the mathematical finite element model and/or the definition of the assumptions and reductions introduced in the analysis,
- a description of the checks performed on the model to verify its quality (e.g. rigid body modes, residual forces),
- a list of eigen-frequencies with relevant mode type and associated modal effective masses,
- plots and listings of eigen-vectors.

And when necessary:

- frequency response analysis
- acoustic response analysis
- shock response analysis.
9.4.1.2.3. Safety Factors and Sizing Factors

Following safety factors are defined for the dimensioning of the equipment to cover uncertainties of load factor evaluation, material data and analysis as well as to avoid undesirable influences of manufacturing tolerances. They shall be applied to the design limit loads, yield against permanent deformation, ultimate against rupture and loss of functionality.

<table>
<thead>
<tr>
<th>Item</th>
<th>Yield SF</th>
<th>Ultimate SF</th>
<th>Buckling SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional metallic materials</td>
<td>1.1</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Unconventional materials</td>
<td>1.4</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Inserts and joints</td>
<td>1.5</td>
<td>2.0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

9.4.1.2.4. Design Limit Loads

The limit loads shall be applied for the structural design considering in addition the safety factors defined in 9.4.1.2.3:

<table>
<thead>
<tr>
<th>Location</th>
<th>Case</th>
<th>Longitudinal [g]</th>
<th>Lateral [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel Optical Bench Instr.</td>
<td>1</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>Herschel CVV LOU</td>
<td>1</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>Herschel CVV BOLA</td>
<td>1</td>
<td>20g (any direction)</td>
<td></td>
</tr>
<tr>
<td>Herschel SVM</td>
<td>1</td>
<td>25g (any direction)</td>
<td></td>
</tr>
<tr>
<td>Planck LFI/HFI (FPU)</td>
<td>1</td>
<td>20g (any direction)</td>
<td></td>
</tr>
<tr>
<td>Planck HFI JFET box</td>
<td>1</td>
<td>25g (any direction)</td>
<td></td>
</tr>
<tr>
<td>Planck Sorption Cooler Compressor Assembly</td>
<td>1</td>
<td>25g (any direction)</td>
<td></td>
</tr>
<tr>
<td>Planck SVM and BEU</td>
<td>1</td>
<td>25g (any direction)</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.4.1-1: Limit Loads for Herschel and Planck Instruments units

9.4.1.2.5. Stiffness Requirements

The structural stiffness of the instruments FPU’s shall be designed so that both the longitudinal eigenfrequency and lateral eigenfrequency is greater than 100 Hz. In hard-mounted condition all other units shall be designed with eigenfrequencies (any axis) above 140 Hz.

Resonances of internal items (e.g. PCBs, CCD benches shall be at least one octave above these frequencies to avoid coupling).
Note: Above mentioned levels cover the instrument global design. However, resonances can lead to important responses under random test conditions. This shall be covered by local sizing for the specified random test levels.

9.4.1.2.6. Structural Design Margins
All structural elements shall be designed to exhibit a positive margin of safety (MOS) after application of the relevant safety factors (yield and ultimate) for all worst load cases. The margin of safety is defined as the ratio of the allowable load (or stress) to the applied load (or stress):

\[ MOS = \frac{\text{Allowable Load (or Stress)}}{\text{Applied Load (or Stress)}} - 1 \]

9.4.1.3. Validation of Dynamic Mathematical Model
The unit structural mathematical model shall be updated if necessary according to test results and supplied to ESA in order to run meaningful system analyses. This validation may be performed either through a specific modal survey test or a low level sine test whichever is the most practical and efficient. All the modes observed during the test will be identified by their mode shape, their frequency and their damping ratio. The predicted modes of the Structural Mathematical Model (SMM) shall be correlated / updated against modes whose effective mass is greater than 10% of the rigid body mass. Local modes which require secondary notching shall be included whatever the effective mass. After validation, the SMM shall still describe the main nodes up 150 Hz.

9.4.2. Thermal Verification Requirements

9.4.2.1. General Requirements
An appropriate set of tests and analyses shall be conducted by the PI to demonstrate the following instrument capabilities:

- the satisfactory performances of all the instrument units in vacuum within the qualification or acceptance operating temperature range,
- the capability of the instrument units to withstand without degradation, the qualification or acceptance non operating temperature range and the switch-on minimum temperature,
- the ability of the internal thermal design of the instrument units to guarantee the required temperatures on internal critical items from the specified interface temperature at reference point and thermal environment of each instrument unit taking into account the repartition of heat sources,
the quality of the workmanship and the selected materials to pass thermal cycle test. In addition, the test must show the adequacy of the thermal mathematical model with the hardware thermal behaviour and the accuracy of the thermal predictions.

9.4.2.1.1. Definition of the Thermal Environment
The thermal design of the instruments and their units shall be compliant with the thermal interface temperature ranges defined in IID-B.

9.4.2.1.2. Thermal Models and Analyses
Each instrument unit must be modelled by a Thermal Mathematical Model (TMM) under PI responsibility. All the thermal mathematical models are delivered to ESA to be incorporated in the general spacecraft thermal mathematical model. A tbd software shall be used for all the thermal mathematical models. The degree of detail (i.e. number of nodes and conductors, etc.) shall be at least sufficient to show that all interface requirements are met. The model shall allow to perform transient analyses, hence a thermal capacity must be allocated to each node. Heat dissipation shall be identified in each operating mode. In case of an instrument unit with a large number of operating modes, the number of these operating modes can be reduced for thermal modelling purposes, in agreement with ESA.

In particular, the following information is required:

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

The PI shall give a description of the configuration, the interface control drawing as well as all the assumptions and simplifications used for modelling. The accuracy of all the thermal mathematical model shall be demonstrated by the PI using simple reference thermal loads (type of test tbd by PI with ESA agreement). A Simplified Thermal Mathematical Model (STMM) with tbd thermal nodes must be provided by the PI on request from ESA.

9.4.2.2. Validation of the Thermal Mathematical Models
The unit thermal mathematical model shall be updated if necessary according to test results of the thermal vacuum and thermal balance tests and supplied to ESA in order to run meaningful system analyses. The level of required agreement between the mathematical model prediction and the test results will be agreed upon after completion of instrument design.
9.4.3. Mechanism Verification Requirements

9.4.3.1. General Requirements
All subassemblies featuring parts moving under the action of command able internal forces shall be considered as mechanisms. They include all hold-down and release mechanisms, hinges, actuators and latches which are required for latching, alignment, positional control etc. of subsystems.

9.4.3.1.1. Performance and Functional Requirements
Each mechanism shall be analysed functionally and the following information shall be at least supplied:

- a detailed description of the mechanisms, with particular reference to its discrete components (bearings, actuators, switches) and to its operational/ safety features,

- a detailed description of the operating modes with reference to ground and orbital activations,

- a definition of operating loads in various configurations with a clear definition of analysis assumptions. In particular, the functional analysis shall include the effects of the worst environmental conditions that could produce distortions or changes in clearance between movable parts (e.g. thermal gradient through bearings),

- a Failure Modes, Effects and Criticality Analysis (FMECA) defining the failure modes and the functional margins of safety against each of them,

- a performance description of the control system which includes the mechanisms.

9.4.3.1.2. Design Requirements
In addition to the functional requirements for the mechanisms, the following design specifications shall be taken into account by the PI’s:

- the design of the mechanisms shall comply with the general requirements for mechanisms (ECSS-E-30A Part 3),

- a detailed stress analysis of the mechanisms shall be established taking into account the applicable thermal environment and the safety factors and sizing factors defined in § 9.4.1.2.3.

- Margins of safety will be evaluated,

- stiffness requirements shall be established and demonstrated compatible with the structural and functional needs for all the envisaged configurations of the mechanisms,
- Sliding surfaces shall be avoided, only lubricants which are compliant with ESA PA requirements shall be allowed,

- The lifetime of the mechanism shall be evaluated and demonstrated/qualified using representative samples with acceptable safety factors.

The mathematical models of mechanisms shall comply with paragraph 4.2 of ECSS-E-30A Part 3.

**9.4.3.1.3. Mechanism Kinematics Mathematical Models**

The following mathematical models shall be established for the mechanisms:

- Structural models representative of the different configurations of the mechanisms,

- Thermal models representative of the different configurations of the mechanisms,

- Dynamical models representative of the various envisaged displacements and capable of describing the Kinematics and Dynamical Variables of the mechanisms with respect to time and taking into account ground and in orbit environmental conditions including mechanical shocks,

- Models establishing the maximal/minimal driving forces/torques compared to the worst realistic combinations of resistive forces/torques in both static and dynamic conditions.

**9.4.3.2. Validation of the Mechanism Mathematical Models**

The different mathematical models used for the evaluation of the mechanism shall be updated if necessary according to test results of performance/functionality and lifetime tests.

**9.4.4. Electrical and Software Verification Requirements**

**9.4.4.1. General Requirements**

All electrical functions and on-board software of the units and the instruments shall be verified and qualified.

**9.4.4.2. Integrated System Tests**

The Integrated System Test (IST) shall be a detailed demonstration that the hardware and software meet their performance requirements within allowed tolerances. The test shall demonstrate operations of all redundant circuitry. It shall also demonstrate satisfactory performance in all operational modes. The initial IST shall serve as a baseline against which the results of all later IST’s can be readily compared.

The test shall also demonstrate that when provided with appropriate stimuli, performance is satisfactory and outputs are within allowed limits.
A limited version of the IST may be used in cases where comprehensive performance testing is unwarranted or impracticable. This limited version, Short Integrated System Test (SIST), shall be a subset of the IST and could for example be performed before, during and after environmental tests, as appropriate, in order to demonstrate that functional capability has not been degraded by the environmental tests.

9.4.4.3. Short Functional Tests
The purpose of the Short Functional Test (SFT) is to prove the correctness of the principal instrument functions via its housekeeping values. No connection for test signals, such as stimulation or calibration signals, is foreseen. This type of test will be applied for instance after transport and shall not exceed a duration of 30 minutes per instrument. Normally instrument personnel are not required to attend the tests, which will be carried out by the Contractor, following procedures agreed with the PI.

9.4.4.4. Software Verification

9.4.4.4.1. General and Design Requirements
The general requirements for the development of the software dedicated to the instruments are as follows:

- The instrument on board software shall be verified and qualified before launch.
- The on board software shall follow the requirements as defined in 5.13.2 above.
- The software development includes also ground software needed to support the validation and qualification of the on board software of the instruments.
- The software verification shall be included in the instrument DDVP. Software tests shall be documented in line with the documentation requirements defined in tbd.

As a general rule no untested software shall be used on any instrument model.

9.4.4.4.2. Software Verification
The detailed software verification approach is tbd.

The instrument software deliveries are linked to the delivery of the instrument units.

9.4.5. Radiation Environment Verification

9.4.5.1. Radiation Environment
Although, after the LEOP, the spacecraft will not traverse the Earth’s radiation belts, the spacecraft and its components will be exposed to energetic protons and heavy ions from solar flares and cosmic rays.

The principal radiation effects are:
9.5. Verification and Testing

9.5.1. General Test Requirements

- **Verification approach:**

  The instrument units belong in general to the category of new design equipment with performances to be fully demonstrated by both qualification and acceptance. Qualification acquisition through different models shall require ESA approval.

- **Test Sequences:**

  No specific environmental test sequence is required. But the test programme should be arranged in a way to best disclose problems and failures associated with the characteristics of the hardware and the mission objectives. It is strongly recommended that the vibration/acoustic test precede the thermal vacuum test unless there is an overriding reason to reverse that sequence. Functional tests shall be performed before and after each test sequence and will be detailed in the DDVP.

- **Test facilities:**

  The facilities shall be capable of maintaining operating conditions that ensure safe testing of the units, with special emphasis on cleanliness. Facility performance should be checked prior to any major test.

- **Test documentation:** see 9.1.2

9.5.2. Test Level Tolerances

For the mechanical and thermal tests, the following test tolerances are applicable, unless otherwise specified:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remark</th>
<th>Tolerances</th>
</tr>
</thead>
</table>
| Temperature (ambient)            | Tmax and Tmin are the max. and min. nominal temperatures for a specific test | Tmax: +0°C … +3°C  
Tmin: -0°C … -3°C                |
<p>| Temperature (cryogenic)          |                                                                        | To be tailored to test and temperature range |
| Pressure                         | Equal or above 0.1 mbar; Below 0.1 mbar:                               | 10%                                |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remark</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Humidity</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Sinusoidal Vibrations</td>
<td>Acceleration Frequency above 50 Hz</td>
<td>+/- 10% ± 2%</td>
</tr>
<tr>
<td>Random Vibrations</td>
<td>Power spectrum density (50 Hz or narrower):</td>
<td>±1.5 dB ± 3 dB ± 1.5 dB</td>
</tr>
<tr>
<td></td>
<td>20 to 500 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500 to 2000 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall g RMS</td>
<td></td>
</tr>
<tr>
<td>Static Force</td>
<td></td>
<td>± 5%</td>
</tr>
<tr>
<td>Acoustic</td>
<td>see tolerances in</td>
<td></td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>±0.05xA where A is peak response from semi-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sinusoidal shock pulse</td>
<td></td>
</tr>
</tbody>
</table>

For the mass properties measurements, the following tolerances apply:

| Weight                     | ± 1%                                        |
| Centre of Gravity          | ± 1%                                        |
| Moments of Inertia         | ± 5%                                        |

For the electromagnetic compatibility, the following tolerances apply:

| Voltage Amplitude          | 5% of the peak value                       |
| Current Amplitude          | 5% of the peak value                       |
| RF Amplitude               | tbd                                         |
| Frequency                  | tbd                                         |
| Distance                   | tbd                                         |

For the magnetic properties, the following tolerances apply:

| Mapping distance measurement: | tbd                                         |
| Displacement of assembly Centre of Gravity (COG) from rotation axis: | ± 5 cm                                     |
| Vertical displacement of single probe centre line from COG assembly: | ± 5 cm                                     |
| Mapping turntable angular displacement: | tbd                                         |
| Magnetic field strength:     | tbd                                         |
| Repeatability of magnetic measurements (short term): | tbd                                         |
| De-magnetising and magnetising field level: | tbd                                         |

Table 9.5.2-1: Test Level Tolerances
9.5.3. Mechanical Verification and Testing

Mechanical testing shall be performed to show that the CQM unit meets the stiffness and environment mechanical requirements or that the FM unit is acceptable for flight.

9.5.3.1. Mass, Moment of Inertia, Centre of Gravity

The PI shall verify that all units comply with the requirements of interface control documents, that fixation points have the correct position and definition within specified tolerances. When necessary, 3D control results of the unit interface shall be supplied.

The PI shall provide the following unit properties:
- Mass
- Moments of inertia
- Position of the centre of gravity

Except for mass and when tight balancing is required the other properties may be determined by analysis.

9.5.3.2. Quasi Static Test and Strength Tests

The main objective of this test is to demonstrate that the load carrying structure is able to withstand the flight limit loads without rupture, collapse, damage, permanent deformation or misalignment.

Amplitude (g level) is the flight limit loads factored by the qualification or acceptance factor (see 9.4.1.2.3)

The test is not required in the following cases:
- if analysis demonstrates positive margin of safety against the limit loads
- if the test is being covered by the sine vibration test at low frequency.

9.5.3.3. Sine Vibration Tests

Sinusoidal tests are required to demonstrate that the instrument units can survive all stressing events whether during launch, handling, transportation or the S/C AIV program.

9.5.3.3.1. General Requirements

9.5.3.3.1.1. Facility

The vibration test facility and procedure shall satisfy the following minimum requirements:
- the shaker shall have at least 20% margin with respect to the maximum expected interface load,
- the control equipment shall be able to maintain the specified tolerances,
- the data handling equipment shall be sized according to the requested instrumentation.
- in case of unexpected incidents, smooth abort shall be programmed
all test incidents shall be reported and fully explained before going on with the test sequence.
- blank test using the item fixture is not mandatory but is strongly advised.

9.5.3.3.1.2.  Test facility cleanliness

Every precaution shall be taken to avoid contamination by oils, greases... The test should take place in a class 100,000 clean room or better. A protection shall be used if needed.

9.5.3.3.1.3.  Fixture requirement

The Unit shall be hard mounted on a stiff fixture by all its spacecraft attachment points. The PI will be responsible for the definition and procurement of the test fixture. The design of the fixture shall guarantee that the major modes of the unit are not modified (as a typical value, frequency shifts should be less than 5 % on the lower frequency modes).

9.5.3.3.1.4.  Configuration

The unit shall be vibrated in the launch configuration, except possibly for thermal hardware (MLI) when it does not contribute to the test article stiffness. All non-flight items shall be removed except for optical cubes, which may be needed to monitor the unit alignment and any other low weight instrumentation control equipment.

9.5.3.3.1.5.  Vibration and control equipment

To control the vibration level applied to the test specimen, at least 2 three-axis accelerometers shall be rigidly attached on the test fixture near the specimenfixture interface and shall be aligned with the excitation axis.

Accelerometers shall be calibrated for frequency response in the range 5-2000 Hz.

9.5.3.3.1.6.  Recording instrumentation

All tests shall be fully recorded and records be properly labelled. All accelerometers shall be calibrated and show linear response in the range 5-2000 HZ for amplitudes up to 1.25 times the maximum expected during the tests. Some carefully selected accelerometers will be used for automatic notching and abort in order to protect the test article.

9.5.3.3.2.  Sine Vibration Test Levels and Duration

*Note: The values below have been derived from an early system level frequency response analysis and are considered conservative.*
Steps are initiated within the project to further evaluate these values with the intention to reduce them.

Qualification levels are specified in the table below.
Sweep rate: 2 Oct./min

<table>
<thead>
<tr>
<th>Location</th>
<th>Axis</th>
<th>Frequency</th>
<th>Level (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel</td>
<td>FPU</td>
<td>Longit. 5 – 40 Hz 40 – 100 Hz</td>
<td>20 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral 5 – 100 Hz</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>LOU</td>
<td>Longit. 5 – 80 Hz 80 – 100 Hz</td>
<td>25 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral 5 – 100 Hz</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>BOLA</td>
<td>Long/Lat 5 - 100 Hz</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>SVM</td>
<td>Long/Lat 5 - 100 Hz</td>
<td>25</td>
</tr>
<tr>
<td>Planck</td>
<td>FPU</td>
<td>Long/Lat 5 – 100 Hz</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>JFET</td>
<td>Long/Lat 5 – 100 Hz</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>SCC and BEU</td>
<td>Long/Lat 5 – 100 Hz</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>SVM</td>
<td>Long/Lat 5 – 100 Hz</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 9.5.3.3.2

Acceptance levels are to be derived by dividing the qualification levels by a factor 1.5.
Acceptance sweep rate is 4 Oct./min.

Low level sine test shall be performed to determine resonance frequencies to evaluate the behaviour of the test fixture and item integrity. Resonance search shall be carried out before and after vibration test for each axis between 5 to 2000 Hz with a level of 0.5 g (sweep rate: 2 oct/min).

9.5.3.4. Random Vibration Tests

Note: The values below have been derived from an early system level analysis and are considered conservative. Steps are initiated within the project to further evaluate these values with the intention to reduce them.

Qualification levels are specified in the table below. Duration: 2 min. per axis.
<table>
<thead>
<tr>
<th>Location</th>
<th>Axis</th>
<th>Frequency</th>
<th>Level</th>
<th>$g_{RMS}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FPU</strong></td>
<td>Long/Lat</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>5.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.05g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>LOU</strong></td>
<td>Normal to own radiator plane</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>7.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.10g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>Other axes</strong></td>
<td></td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>5.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.05g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>BOLA</strong></td>
<td>Long/Lat</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>5.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.05g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-1000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>SVM Units</strong></td>
<td>Normal to fixation plane</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.30g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-1000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>Other axes</strong></td>
<td></td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>5.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.05g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-1000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>FPU and JFET</strong></td>
<td>Long/Lat</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>7.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.09g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>BEU, SCC and SVM units</strong></td>
<td>Normal to fixation plane</td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.30g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
<tr>
<td><strong>Other axes</strong></td>
<td></td>
<td>20-100 Hz</td>
<td>+6 dB/Oct</td>
<td>5.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 Hz</td>
<td>0.05g$^2$/Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-2000 Hz</td>
<td>-6 dB/Oct</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.5.3.4.2

Acceptance levels are to be derived by dividing the qualification levels by a factor 2.25. Acceptance duration is 1 min. per axis.

Low level sine test shall be performed to determine resonance frequencies to evaluate the behaviour of the test fixture and item integrity. Resonance search shall be carried out before and after vibration test for each axis between 5 to 2000 Hz with a level of 0.5g (sweep rate: 2 oct/min).
9.5.3.5. Acoustic Tests

The levels below are extracted from the ARIANE 5 Users Manual. Relevance level: 2

<table>
<thead>
<tr>
<th>Octave Band Centre Frequency (Hz)</th>
<th>Qualification level (dB)</th>
<th>Acceptance level (dB)</th>
<th>Test Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>132</td>
<td>128</td>
<td>-2g+4</td>
</tr>
<tr>
<td>63</td>
<td>134</td>
<td>130</td>
<td>-1g+3</td>
</tr>
<tr>
<td>125</td>
<td>139</td>
<td>135</td>
<td>-1g+3</td>
</tr>
<tr>
<td>250</td>
<td>143</td>
<td>139</td>
<td>-1g+3</td>
</tr>
<tr>
<td>500</td>
<td>138</td>
<td>134</td>
<td>-1g+3</td>
</tr>
<tr>
<td>1000</td>
<td>132</td>
<td>128</td>
<td>-1g+3</td>
</tr>
<tr>
<td>2000</td>
<td>128</td>
<td>124</td>
<td>-1g+3</td>
</tr>
<tr>
<td>Overall level</td>
<td>146</td>
<td>142</td>
<td></td>
</tr>
</tbody>
</table>

Duration 2 min 1 min

9.5.3.6. Shock Test Levels

The defined shock response spectrum is applicable to the instrument of Planck and to the Herschel instruments mounted inside the SVM. It is to be applied along all three axes.

Figure 9.5.3.6-1 Shock Response Spectrum.
The present assumptions are based on Herschel and Planck in a “Carrier” launch configuration.

9.5.4. Thermal Verification and Testing

9.5.4.1. General Test Requirements and Test Arrangement

When possible development tests will be performed with samples to demonstrate the adequacy of the selected materials and of the design. However, the qualification thermal tests will be performed with fully representative hardware. The details of the thermal tests to be performed and the logic how the thermal qualification of the units will be achieved will be presented in the DDVP.

As a general requirement each instrument unit must be tested with conductive and radiative interfaces as close as possible with the spacecraft interfaces in orbit. In particular:

- each instrument unit shall be connected to the test mounting panel using identical fixation interfaces as its fixation onto the PLM or SVM (insulation washers, interface filler,...),
- the test mounting panel temperature must be representative of the flight mounting panel temperature (margin to be added in test),
- its external thermo-emissive properties must be identical to the flight ones,
- the radiative environment must be as close as possible with the flight one (margin to be added in test).

Because qualification and acceptance temperature range encompass in orbit temperature range, the test interface temperature and/or power must be such to ensure the margin on temperature equipment is adequate

The thermal vacuum test arrangement must be designed to give the required qualification or acceptance temperatures on the equipment with approximately representative heat flows to and from the environment.

A possible test set-up is that the in flight mounting panel is replaced by a thermally controlled conductive support frame used as heat sink. The equipment is directly mounted to this heat sink.

A shroud surrounding the instrument unit simulates the radiative environment. The temperature of the instrument unit can be controlled both radiatively by adjusting the shroud temperature and conductively by adjusting the temperature of the fluid circulating in the mounting frame.

For all electronics units located into the SVM, the shroud temperature is maintained around the ambient temperature during the test. The conductive heat sink temperature is controlled to achieve the required temperature level on the instrument unit base-plate as specified TBD. Temperature range can be controlled using both the shroud and the heat sink temperatures.
9.5.4.2. General Test Condition and Instrumentation

The following minimum test requirements shall be satisfied:

- equipment shall be tested in a thermal vacuum environment having a pressure of 0.0013 Pa (10^{-5} Torr) or less. The test may begin when the pressure falls below 0.013 Pa (10^{-4} Torr), and a pressure of 0.0013 Pa or less shall be achieved prior to startup of the units not operating during first ascent,

- stabilisation is achieved when the equipment temperatures have been maintained within tolerance and have not changed by more than 1 °C during the previous one hour period.

The PI shall be responsible to define the adequate test instrumentation in order to demonstrate that temperature levels are achieved and to validate the instrument unit thermal mathematical model.

This test instrumentation shall include as a minimum:

- for the shroud temperature, the instrumentation necessary to allow accurate temperature control by using fluid loop or/and electrical resistance heaters,

- for the instrument unit at least one temperature sensor on each unit casing wall, and one temperature sensor on each unit foot,

- for the mounting plate, at least one temperature sensor close to each unit mounting foot, and four temperature sensors to derive the lateral gradients inside the mounting panel.

The general requirements for the design verification, qualification and proto-qualification tests are the following:

- During testing, the same item shall be tested in the normal post-lift-off sequence, to the thermal environments appropriate to non-operating, switch-on (start-up) and operating qualification temperature limits.

- If preferred the temperature cycle profile can be changed to give a hot phase first. The temperature gradient dT/dt must be < 2 °C/min for electronics boxes inside the SVM. For instrument units mounted externally of PLM and SVM, higher gradients can be defined in the equipment specification (tbc).

- Heat dissipations: the PI shall demonstrate the units dissipate not more than the maximum values defined in IID-B (AD 04,05,06,07,08) for each unit and instrument.

The general requirements for the acceptance tests are the following:

- In order to ensure the application of the maximum stress condition, the unit shall be operated continuously throughout the test which shall comprise tbd cycles, with full functional testing at the last 2 extremes, and adequate monitoring during the remainder of the test.
9.5.4.3. Thermal Vacuum and Balance Test

9.5.4.3.1. Thermal Vacuum Test:
The thermal vacuum test is required to evaluate and demonstrate the functional performance under vacuum of the instrument units. This is performed under the extreme and nominal modes of operation, with temperature conditions for the instrument more severe than the maximum and minimum temperatures predicted for the mission, namely within the acceptance or qualification temperature range.

9.5.4.3.2. Thermal Balance Test:
A thermal balance test at instrument level shall be conducted on instrument units whose thermal control is under PI responsibility. The results of the thermal balance test are used to correlate and update the instrument thermal mathematical models.

The thermal balance test simulates nominal conditions to verify the thermal control system. The number of energy balance conditions simulated during the tests shall be sufficient to verify the thermal design. The exposure shall be sufficient enough for the test item to reach stabilisation so that the temperature distribution in steady state condition may be verified.

The PI shall establish in the DDVP how and when the thermal vacuum and thermal balance will take place and shall demonstrate what is the logic to reach the qualification/acceptance of the instruments and its units.

9.5.4.4. Thermal Cycling Tests
Thermal cycling tests will be performed in order to demonstrate that the instruments and its units are able to withstand without degradation and under vacuum a number of thermal cycles representative of the lifetime of the instruments with margins starting from the minimal temperatures to the maximal temperatures defined in the IID-B (AD 04, 05, 06, 07, 08). Each thermal cycle shall include a soak time long enough to achieve thermal equilibrium of the instrument or the unit (T change 1°C/hour).

The PI shall define in the DDVP how the demonstration of the thermal cycling test adequacy will be conducted on the basis of results with representative samples or with flight units/instruments.

9.5.4.5. Thermal Shock Test
A thermal shock test will be conducted to verify that the instruments or the units can withstand a rapid cool-down under vacuum from room temperature to the minimal temperature defined in the IID-B. The PI shall establish what is the minimal duration of the cool-down still compatible with the unit/instrument. However, this duration shall be no greater than 5 hours.
9.5.4.6. Thermal Bake-out Test

A thermal bake-out will be conducted (at least) for the Herschel focal plane units inside the cryostat (about 80°C for 3 days). The capability of the FPU to withstand this bake out shall be demonstrated by test (tbc).

9.5.5. Mechanism Verification and Testing

9.5.5.1. General Test Conditions

In the DDVP, the PI shall present how he intends to demonstrate the functional performances of the mechanisms of the instruments and/or units on the basis of the results of tests at sample or of instrument/units tests and how the mechanisms will be qualified.

9.5.5.2. Performance Verification Testing

The performance validation of the mechanisms shall be established in agreement with the following requirements:

- the verification of the performances of the mechanisms shall be possible on ground at unit, assembly and system level,
- the operation of the mechanisms at system level shall not require special jigs or special attitudes of the units/instruments. (Note that it has been agreed to accept certain attitude of the HPLM for sorption cooler recycling and for SPIRE FTS),
- the testing shall demonstrate that all functional requirements are met with margins in representative environmental conditions.

9.5.5.3. Lifetime Verification Testing

Because mechanisms will operate during the whole lifetime of the mission, special attention shall be devoted to demonstrate the lifetime capabilities of the mechanisms. Therefore the following requirements shall be fulfilled:

- the lifetime of the mechanisms shall be demonstrated/qualified by test in a configuration representative of the realistic worst case conditions of the flight model,
- for test demonstration, the nominal number of cycles predicted for the flight items shall be multiplied by the following factors:

<table>
<thead>
<tr>
<th>Type/number of predicted cycles</th>
<th>Applicable factor for tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>ground operation before flight</td>
<td>4 (min. number is 10)</td>
</tr>
<tr>
<td>in orbit predicted cycles (when prediction is 1 - 10)</td>
<td>10</td>
</tr>
<tr>
<td>in orbit predicted cycles (when prediction is 11 - 1000)</td>
<td>4 (min. number is 100)</td>
</tr>
<tr>
<td>in orbit predicted cycles (when prediction is 1001 - 100000)</td>
<td>2 (min. number is 4000)</td>
</tr>
</tbody>
</table>
An actuation is a full output cycle or a full revolution of the mechanism to be applied. Lifetime of critical mechanism components shall be declared successful if the following conditions are satisfied:

- no metal to metal contact identified,
- no chemical degradation of dry lubricant,
- operational requirements met within specified tolerances for entire life tests,
- no rupture or loss of functionality of any part,
- stiffness requirement met for entire life test.

### 9.5.6. EMC Verification and Testing

The approach taken for the system EMC verification is by analysis and test. This is outlined below and defined in the EMC control plan (document Alcatel FP-ASPI-PL-1006). The analysis and the inputs to be provided by the instruments are tbd.

#### 9.5.6.1. EMC Verification Methods

The methods to be used in verifying the specified design requirements for both subsystem and equipment are defined in this section. The verification activities include:

**9.5.6.1.1. Analysis (A)**

Verification by analysis will be accomplished to satisfy specified requirements that do not necessitate test or demonstration to assure that these requirements have been met. Calculation replaces the test results.

**9.5.6.1.2. Review of Design (ROD)**

The verification of physical requirements will be performed by review of drawings, circuit diagrams etc.

**Commentary:** Example ⇒ Correct use of shielded wires, twisted wires, twisting rate, shield grounding, grounding diagrams.

**9.5.6.1.3. Inspection (INS)**

Verification by inspection will be accomplished to satisfy requirements such as:

- Conformance of drawings
- Workmanship
- Use of proper parts and materials

**Commentary:** Example ⇒ Use of correct wire and cable types, minimum distance between different wire classes for harness routing.

**9.5.6.1.4. Test (T), (DT), (QT), (AT)**

Several kind of testing will be used for verification of requirements during the different stages of the subsystem equipment project.
9.5.6.1.4.1. Development testing (DT)

Development testing is performed to substantiate analyses and to verify:

- Conformance characteristics
- Safety Margins
- Failure Modes.

The development tests will not be performed to formal test procedures. Breadboards and engineering models that must be of flight configuration in all the important electrical aspects will be used for these tests.

9.5.6.1.4.2. Qualification Testing (QT)

Formal qualification testing will be fully documented. Test data will be recorded on data sheets that are an integral part of the formal test procedures utilised for verification of the subsystem equipment.

The EMC qualification test sequence is outlined below:

- Bonding
- Isolation
- Grounding and conductivity test of space exposed surfaces
- Conducted emission
- Conducted susceptibility
- Radiated emission
- ESD.

Note: Electrostatic susceptibility tests can be waived if they are critical for the health of the units.

9.5.6.1.4.3. Acceptance testing (AT)

Acceptance testing are conducted to prove that the subsystem equipment design is like the design that was qualified, to demonstrate that the workmanship used meets the required standards and to demonstrate that the subsystem equipment meets the specification requirements. Formal acceptance testing will also be fully documented as required for qualification testing.

This test shall be accomplished on all FM hardware. Acceptance level testing shall comprise the verification of:

- Bonding
- Isolation
- Grounding and conductivity test of space exposed surfaces
- Conducted emission
- Conducted susceptibility
- ESD.

Note: Electrostatic susceptibility tests can be waived if they are critical for the health of the units.

9.5.6.1.5. Similarity Assessment (SIM)

Similarity verification will be accomplished for equipment/components where proof exists that it was previously qualified to the same, or more severe, environment.
Commentary: Example ⇒ A qualified pressure transducer used in an earlier mission and still manufactured can be verified by similarity.

9.5.6.1.6. Verification Matrix

<table>
<thead>
<tr>
<th>Verification Method</th>
<th>Verification Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similarity</td>
<td>A. Design</td>
</tr>
<tr>
<td>Analysis</td>
<td>B. Development</td>
</tr>
<tr>
<td>Inspection</td>
<td>C. Qualification</td>
</tr>
<tr>
<td>Review</td>
<td>D. Acceptance</td>
</tr>
<tr>
<td>Test</td>
<td></td>
</tr>
</tbody>
</table>

It is responsibility of the Prime Contractor and/or the relevant Subcontractor to complete the matrix in Table 9.5.6-1 in accordance with the requirements of the previous section and to submit it to ESA for approval.

The Prime Contractor is responsible to provide an overall verification matrix at subsystem level for approval by ESA.

<table>
<thead>
<tr>
<th>EMC Performance Requirement Reference</th>
<th>Verification Methods</th>
<th>Document Reference and Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N/A</td>
<td>A</td>
</tr>
</tbody>
</table>

Table 9.5.6-1: Example of Verification Matrix

9.5.6.2. Test Facility and Test Instrumentation Requirements

The test shall be performed following the applicable requirements contained in this section. Any condition, method not covered by these requirements or deviation to them shall be agreed with ESA. The actual test condition and methods selected for the test in question shall be described and documented in the relevant test documentation.

9.5.6.2.1. Ambient Electromagnetic Levels

Ambient conducted and radiated emission levels shall be measured prior to test and shall be at least 6 dB below the applicable limits. These measurements shall be performed with the test article turned off and with all the auxiliary equipment turned on. Ambient levels on power leads shall be measured with the leads disconnected from the test article and connected to a resistive load which draws the same current as the test article. The LISN shall be included in the test set-up.

9.5.6.2.2. Test Site Conditions

Testing shall be performed under the following atmospheric conditions where possible:

- Temperature 19° C ÷ 26° C
• Pressure \[ 813 \div 1040 \text{ hPa} \]
• Relative humidity \[ 20\% \div 80\% \]

Restriction as required by the ESA (e.g. Cleanliness class) might be added to those requirements.

### 9.5.6.2.3. Shielded Enclosures
Shielded enclosures shall be of sufficient size to adequately accept the test article without sacrificing test accuracy or requiring deviation from the methods specified herein.

### 9.5.6.2.4. RF Absorber Material
RF absorber material shall be used in shielded enclosures to reduce reflections from the surface of the enclosure to the measurement antennas.

### 9.5.6.2.5. Ground Plane
A solid plate ground plane shall be used. It shall have a minimum thickness of 0.25 mm for copper or 0.63 mm for brass and be 2.25 m\(^2\) or larger in area with the smaller side no less than 76 cm in length. When testing is performed in a shielded enclosure, the ground plane shall be bonded to the shielded room such that the DC bonding resistance shall not exceed 2.5 mΩ. In addition, the bonds shall be placed at distances no greater than 90 cm apart. For large test articles mounted on a metal test stand, the test stand shall be considered a part of the ground plane for testing purposes and shall be bonded accordingly.

### 9.5.6.3. Measuring Equipment/Instrumentation
This section describes the test equipment and instrumentation used in the test methods contained in this document.

Any other instruments that are capable of measuring the parameters of this specification may be used, after approval by ESA. In any case, the actual characteristics of the instrumentation used (factors, useful bandwidths, accuracy, sweep speeds etc) shall be listed in the test documentation.

#### 9.5.6.3.1. Measurement Receivers / Spectrum Analysers.
Any frequency selective receiver can be used to perform the testing described in this document. The receiver characteristics (i.e. sensitivity, selection of the bandwidths, detector functions dynamic range and frequency of operations) shall meet the requirements specified in this standard and shall be sufficient to demonstrate compliance with the applicable limits. Concerning the use of spectrum analysers, they can be used when overloading protection is provided by means of pre-selection input filters.

**Commentary:** In EMI testing, one of the most important considerations is preventing saturation of the spectrum analyser because spurious responses can be created within the instrument. A solution is to use a band-pass or tracking pre-selector that will greatly increase the analyser’s tolerance to broadband overload. These pre-selectors will virtually eliminate multiple and image responses. For these reasons, EMI receivers are preferred but spectrum analysers are allowed if input pre-selectors are used.
9.5.6.3.2. Computer Controlled Receivers

A detailed description of the operations that are directed by software for computer controlled receivers, shall be included in the test plan. Verification techniques used to demonstrate proper performance of the software shall also be included.

9.5.6.3.3. Detector Function

A peak detector shall be used for all emission and susceptibility measurements. This device shall detect the peak value of the modulation envelope in the receiver bandpass. The output of the measurement receiver shall be calibrated in terms of equivalent root mean square (RMS) value of a sine wave with the same peak value. When other measurement devices such as oscilloscopes, non-selective voltmeters etc are used for testing, correction factors shall be applied for modulated test signals to correct the reading to equivalent RMS values under the peak of the modulation envelope.

9.5.6.3.4. Current Probes

The current probe transfer impedance which is defined as the ratio between secondary voltage across a 50 Ω load to the primary current shall be determined using the following procedure:

Terminate the signal generator with a short length of wire (20 cm) and a 50 Ω non-inductive resistor. The primary current \( I_p \) can be calculated.
Clamp the current probe around the wire between the signal generator and the 50 Ω load.
Connect the current probe to a receiver (50 Ω input impedance) and measure the secondary voltage \( V_s \).
The transfer impedance is \( Z_t = V_s / I_p \)

The transfer impedance of the current probe shall be included in the Test Procedure and Test Report. Any current probe capable of measuring to the limits specified in this document may be used. The current probe shall be located not more than 5 cm apart from the test article.

9.5.6.3.5. Test Antennas

Antennas used in performing the radiated emission and susceptibility tests shall be listed in the EMI test procedure. The following antenna characteristics are recommended:

- 30 Hz – 50 kHz, (RE01): Sensors that measure only magnetic fields
  
  a) Electrically small loops, whose impedance shall not resonate over the frequency range of use.
  
  b) Active magnetic sensors, which sense amplitude as opposed to the time derivative of the amplitude.

- 14 kHz – 30 MHz, (RE02): Electrically short high impedance electric field probe, vertically polarised. Traditionally the 41” rod with active or passive matching network to 50 Ω has been used.
• 14 kHz – 30 MHz, (RS03): The parallel plate (and its numerous modifications), long wire, and E-Field generator are available and listed in order of preference. The E-Field generator should be reserved for the case in which the test article is too large for other methods.

• 30 MHz – 200 MHz, (RE02/RS03): Dipole-like antennas. Typical antenna used in this band has been the bi-conical. Care should be exercised in the antenna selection to ascertain that the balun does an adequate job of matching the low frequency high antenna impedance to $50\,\Omega$.

• 200 MHz – 1 GHz, (RE02, RS03): The traditional Log-Periodic and Log-Conical are available. The double ridge horn can also be used, although the gain increases dramatically with the frequency. In this case, accurate calibration of the double ridge horn shall be proven and included in the EMC Test procedure.

• 1 GHz – 10 GHz, (RE02/RS03): Broadband (ridged) or standard gain horn. Log-Conicals are also available.

• 10 GHz and above (RE02/RS03): 20 dB standard gain horns.

9.5.6.3.6. Test Antenna Counterpoise (Monopole):
The following requirements shall be used when rod antennas that require a counterpoise are used. The test antenna counterpoise shall be referenced to the same ground reference used for the Electromagnetic Interference (EMI) meters. In shielded enclosures, the counterpoise shall be bonded to the reference ground plane. The bonding strap shall be a solid metal sheet having the same width as the counterpoise, welded along the entire edge at the points of contact. Alternatively, the counterpoise shall be clamped and/or soldered to the ground plane in two places. If desired, the counterpoise may be configured so that one dimension is of adequate length to reach the test article ground plane.

9.5.6.3.7. Impulse generators
Impulse generators shall conform to the above requirements:

a) Calibrated in terms of output to a $50\,\Omega$ load.
b) Spectrum shall be flat over its frequency range with an amplitude accuracy of $\pm 1\,\text{dB}$ within the frequency band being displayed by the spectrum analyser.

9.5.6.3.8. Standard Laboratory Equipment (SLE)
All SLE shall be operated as prescribed by the applicable instruction manual unless otherwise specified therein. This requirements document shall take precedence in the event of conflict with instruction manuals or other documents issued by industry or other Agencies unless identified in an approved test plan. For test repeatability, all test parameters used to configure the test shall be recorded in the EMI test plan and the EMI test report. These parameters shall include measurement bandwidths, video bandwidths, sweep speeds etc.

9.5.6.3.9. Power Supply Characteristics
Power supplies for test articles requiring a power source for their operation, supplied or not as part of the test article Electrical Ground Support Equipment (EGSE), shall have characteristics and tolerances as specified in the test article detailed specification measured at the test article input.

9.5.6.3.10. **Signal Sources**

Any commercially available signal source, power amplifier and general purpose amplifier capable of supplying the power required to develop the susceptibility level specified herein, may be used provided the following requirements are met:

a) Frequency accuracy shall be within ±2%.
b) Amplitude accuracy shall be within ±2 dB.
c) Harmonic content and spurious outputs shall be no more that –30 dB as related to fundamental power level.

9.5.6.3.11. **Test Article Electrical Ground Support Equipment (EGSE)**

The EGSE shall simulate the actual loads of the test article using the actual interface required in flight. Grounding techniques different from those approved are forbidden. The EGSE shall not interfere or cause EMI to the normal test article operations and shall withstand without malfunctions the environment in which it shall operate. Whenever possible, during the EMC tests the EGSE shall be located outside the shielded test enclosure area in an adjacent, attached shielded enclosure.

9.5.6.4. **Measurement Requirements**

9.5.6.4.1. **Measuring Equipment Calibration**

Measuring instruments and accessories used in determining compliance with this document shall be calibrated under an approved program in accordance with MIL-STD-45662A.

9.5.6.4.2. **Measurement Accuracy**

All test equipment (SLE, EGSE etc) shall be capable of measuring to within the following accuracy:

- 2% for frequency
- 3 dB for amplitude

9.5.6.4.3. **Measurement Bandwidths**

Narrow-band ranges for each tuned frequency range are listed in Table 9.5.6-2 below:

<table>
<thead>
<tr>
<th>Tuned Frequency (Hz)</th>
<th>Bandwidth Range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 – 300</td>
<td>1 – 30</td>
</tr>
<tr>
<td>300 – 3 k</td>
<td>5 – 50</td>
</tr>
<tr>
<td>3k – 30 k</td>
<td>10 – 500</td>
</tr>
<tr>
<td>30k – 1M</td>
<td>300 – 5k</td>
</tr>
<tr>
<td>1M – 30 M</td>
<td>1k – 50 k</td>
</tr>
<tr>
<td>30M – 1G</td>
<td>1k – 100 k</td>
</tr>
</tbody>
</table>
Table 9.5.6-2: Narrow-band range for each tuned frequency range

N.B. For conducted emission 30 Hz to 15 kHz (CE01) range the limit shall be measured with an effective bandwidth not exceeding 100 Hz.

9.5.6.4.4. Measurement frequency range

A continuous scan and recording of the specified frequency range for each applicable test shall be performed.

9.5.6.4.5. Susceptibility Frequency Range

Whether the interference shall be applied as continuous swept or as discrete frequencies shall be determined on the basis of the susceptibility criteria. When acceptable, discrete frequencies and their number/decade shall be approved by ESA.

9.5.6.5. Test set-up arrangement.

9.5.6.5.1. Isolation

Test instruments shall use an isolation transformer on the AC power lines and a separate ground cable to the central ground point. The ground cable shall consist of a braided cable.

9.5.6.5.2. Test Article Arrangement

Interconnecting cable assemblies and supporting structures shall simulate actual installation and usage. Shielded leads shall not be used in the test set up unless they have been specified in approved installation drawings. Diagrams of all cables that interconnect the test article showing all conductors, shielded and unshielded, shall be included in both the EMC test plan and EMC test report. In the event that the as-run procedure is included as an appendix to the test report, the cable diagrams in the test procedure will satisfy the requirement. Cables and test article shall be so arranged that there is minimum shielding interposed between the test article cables and the measurement antennas. All leads and cables shall be located within 10 cm from the ground plane edge nearest the measurement antenna and shall be supported at least 5 cm above the ground plane on non-conductive spacers.

9.5.6.6. Test Harness

The test article shall be connected to the relevant EGSE and SLE via dedicated cabling, which consist of:

- Standard Cabling
- Additional Cabling
- Connector Savers

9.5.6.6.1. Standard Cabling
The standard cabling shall implement the connection between the test article and its interfaces, simulated by the EGSE and SLE. It shall be identical to the respective flight cabling for the following aspects:

- Number and type of wires.
- Shielding termination
- Over-shielding and termination

The adopted shielding termination technology shall be agreed with ESA. In particular, shield disconnection shall be possible.

9.5.6.6.2. Additional Cabling

The additional cabling shall be interposed between the test article and the standard cabling as required by test methods. This cabling shall be configured as necessary to accommodate test needs (probe insertion, LISN insertion, etc) while maintaining the standard cabling configuration for all the other cables that are not involved.

9.5.6.6.3. Connector Savers

The type of connector savers shall be agreed with ESA. They shall not impair the shielding effectiveness of the standard cabling.

9.5.6.6.4. Shock and Vibration Isolators

If the test article is mounted on a base with shock or vibration isolators in the operational installation, the test set up shall include such mounting provisions. Bonding hardware and application for the test article shall be identical to the approved installation drawing. If no provisions for bond strap are made on the installation drawings, then no bond straps shall be used during testing.

9.5.6.7. Test Article loading

The test article shall be loaded with the full mechanical and electrical load or equivalent for which it is designed. If worst case EMI condition exist at a reduced load, the test shall include the reduced level loads as well as the full load.

9.5.6.7.1. Representative loading

The loads used shall simulate the impedance of the actual load. Mechanical devices, if any, shall also be operated under load. The test article shall be actuated by the same means as in the installation. As an example, if a solenoid is actuated through a silicon-controlled rectifier (SCR), a toggle switch shall not be used to operate the solenoid for the test.

9.5.6.7.2. Signal Inputs

Actual or simulated signal inputs and software required to activate, utilise or operate a representative set of all circuits shall be used during emission and susceptibility testing.

9.5.6.7.3. Source/Loads for Communication-Electronics Test Articles

All RF outputs of communication electronics test article shall be terminated with shielded dummy loads as appropriate for the test article and the test being performed to produce maximum normal output. At the frequencies of concern, the Voltage Standing Wave Ratio (VSWR) of the resistive dummy loads, attenuators,
directional couplers, samplers, power dividers and the internal standard impedance of the signal generators shall not be greater than:

- Transmitter Loads ⇒ 1.5:1
- All other dummy loads and pads ⇒ 1.3:1
- Standard signal generators ⇒ 1.3:1

9.5.6.8. Measurement Antenna Position

9.5.6.8.1. Location
When performing radiated emission and susceptibility tests, no points of the antennas shall be less than 1 m from the walls, ceiling or floors of the shielded enclosure or obstruction.

9.5.6.8.2. Biconical Antenna
A minimum distance of 30 cm from the floor and ceiling and 1 m from the walls of the shielding enclosure or obstruction can be accepted when the biconical antenna is used in vertical polarisation.

9.5.6.8.3. Linearly polarised antennas
For radiated emission measurements above 30 MHz, linearly polarised antennas shall be positioned to measure the vertical and horizontal components of the emission. For radiated susceptibility measurements above 30 MHz, linearly polarised test antennas shall be positioned so as to generate vertical and horizontal fields.

9.5.6.9. Line Impedance Stabilisation Network (LISN)
In order to reproduce the system power bus impedance and to standardise the measurement conditions used in different test sites, emissions and susceptibility measurements on primary power lines shall be performed on inserting a Line Stabilisation Network (LISN) between the EGSE power supply and the unit under test. The LISN schematic and the relevant impedance versus frequency are chosen in accordance with the bus impedance mask. The design of the LISN is usually provided by the spacecraft contractor. In case it is not available in time the LISN schematic and the relevant impedance versus frequency given in Fig. 9.5.6.9-1 and Fig. 9.5.6.9-2 shall be used.

![LISN schematic](image)

Fig. 9.5.6.9-1 LISN schematic
Fig. 9.5.6.9-2 Output impedance of the LISN with shorted input terminals

9.5.6.10. Test Configuration and Operation Requirements

9.5.6.10.1. Test Article Operations
For a representative set of all modes of operation, controls on the EUT shall be operated and adjusted as prescribed in the instruction manuals or as required by the test article specification in order to obtain optimum design performance. For susceptibility testing, the expected most susceptible modes shall be selected. For emission noise, the noisier modes shall be selected.

9.5.6.10.2. Input Voltage Selection
Except when specified differently, the voltage at the test article input power leads shall be selected as the worst case value with respect to the test within the nominal voltage range.

9.5.6.10.3. Interface Signal Operation
Interface signal of the test article shall be active during testing as required by operations defined in paragraph 9.5.6.10.1.

9.5.6.10.4. Susceptibility Criteria
The threshold of susceptibility shall be determined for test articles unable to meet the susceptibility criteria.

9.5.6.10.5. Time Duration
Each susceptibility level shall be maintained for a minimum time in order to ensure that possible susceptibility conditions are achievable and detectable.

9.5.6.10.6. Test Equipment Warm-up time.
Prior to performing tests, the measuring equipment shall have been switched on for a period of time adequate to allow parameter stabilisation. If the operation manual
does not specify a specific warm up time, the minimum warm up period shall be 1 hour.

9.5.6.11. Bonding, Isolation and Grounding/Conductivity Tests
These tests are carried out to demonstrate compliance with the required instrument performance.

9.5.6.12. Conducted Emission Tests
The suggested test set-ups for CEDM and CECM are shown in figure 9.5.6.12-1. For test in time domain, any switch for ON/OFF test will be positioned between a 10mF capacitor and the unit under test. The transients are then measured on the power lines between the switch and the unit under test.

![Figure 9.5.6.12-1 Conducted Emission - Test set-up for DM and CM](image)

9.5.6.13. Conducted Susceptibility Tests
The test set-up for differential mode susceptibility on primary power lines is shown in Figure 9.5.6.13-1 for frequencies up to 50KHz. For the frequency range 50KHz-50MHz then the test set-ups shown in Fig 9.5.6.13-2a or Fig. 9.5.6.13-2b should be used. The injected voltage relevant to the susceptibility threshold shall be monitored and recorded. The injected current shall be limited to 3 Ar.m.s on the input power lines.
Fig. 9.5.6.13-1 Conducted susceptibility on primary power lines, differential mode. Frequency domain 30Hz-50kHz

Fig. 9.5.6.13-2a Conducted susceptibility on primary power lines, differential mode. Frequency domain 50kHz-50MHz
The text set-up for common mode susceptibility on primary power lines and on signal bundles is shown in Figure 9.5.6.13-3. The signal lines shall be loaded with electrical simulators of the interfacing circuits.

Fig. 9.5.6.13-3 Conducted susceptibility on primary power lines and signal bundles. Common mode, frequency domain 10kHz-50MHz

The test set-up for common mode conducted susceptibility between the subsystem equipment signal reference and the ground plane (transient and steady state) is shown in Figure 9.5.6.13-4 (externally accessible ground wire) and Figure 9.5.6.13-5 (no accessible ground wire).

The suggested test set-up is as shown in Figure 9.5.6.14-1. The emission at the antenna at one metre distance from the test object, which gives the highest reading, shall be the Radiated Electric Field Emission (REE). Above 25 MHz, the requirement shall be met for both horizontally and vertically polarised waves. The upper frequency range of the measurement shall be in accordance with the following Table 9.5.6. A minimum of 10 discharges shall be performed.

<table>
<thead>
<tr>
<th>Highest Frequency of Equipment</th>
<th>Required Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 GHz</td>
<td>To tenth Harmonic or 1 GHz whichever less</td>
</tr>
<tr>
<td>1 - 10 GHz</td>
<td>To fifth Harmonic or 10 GHz whichever less</td>
</tr>
</tbody>
</table>

Table 9.5.614-1 Radiated emission test
9.5.6.15. Electro Static discharge ESD Tests

Figure 9.5.6.15-1 contains a suggested arc source schematic capable of establishing the required discharge. The discharge circuit must be adjusted in order to get the energy and the voltage specified in paragraph 5.14.3.11. Any other equivalent type of circuitry (e.g. ESD simulator) can be used and shall be fully described in the relevant plan.

The discharge shall be a direct discharge of current through the equipment chassis and shall be generated by putting the tip of the gun in contact with the chassis or/and by moving it closer to the chassis until the discharge occurs.
9.5.7. **Qualification to the Radiation Environment**

Although, it will not be possible to effectively demonstrate the compatibility of the design of the instruments and their units with the specified radiation environment, the design shall achieve the following requirements:

- the components and their shielding shall be compatible with the requirements of the radiation environment such that the radiation dose will not cause failures or produce unacceptable changes in performance,

- components shall be qualified (either based on existing or new test data) to withstand twice the expected level of radiation,

- in the design there shall be included the tools necessary to restore the original performance of the detector systems (curing). It is highly recommended that detectors and associated electronics are exposed to a simulated radiation environment with the objectives of establishing preliminary curing procedures and determining realistic performance predictions.
10. MANAGEMENT, PROGRAMME, SCHEDULE

10.1. General
A major constraint of ESA’s Herschel/Planck programme is to implement a mission, which meets its scientific objectives within the defined financial envelope. In order to meet these constraints, it is ESA’s policy to minimise the spacecraft development risks by using as far as possible off the shelf hardware and to minimise the risks by following a properly phased design, development and verification programme. However, the programme may also be extremely vulnerable to potential payload problems. It is therefore essential that the PI adheres to the requirements established in this chapter.

These requirements address:

- the management structure of the instrument team, to ensure that an efficient organisational structure is established which will perform the design, development and verification of the instrument within the constraints of the programme
- project control processes to ensure that the work to be performed is adequately scoped and scheduled, and that appropriate configuration management principles are implemented
- regular reviews and reporting to provide an assessment of the completion status of the instruments and early identification of potential risks which may impact the performance of the instruments, the satellite interfaces and resources, and the schedule of deliverables
- the definition of deliverables as a working basis for spacecraft development and implementation
- the Herschel/Planck programme baseline schedule to synchronise due dates of deliverables.

10.2. Management

10.2.1. ESA Responsibilities
The overall management of the implementation and execution of the Herschel/Planck programme will be under the responsibility of the ESA Project Manager (PM) located at ESTEC, Noordwijk, The Netherlands. He will have overall responsibility for the implementation and execution of all technical and programmatic aspects including:

- Spacecraft development, integration and test
- Launch
- Initial Orbit Phase
- Spacecraft/Instrument Commissioning Phase
The ESA PM will be directly supported in the execution of the programme by an ESA Project Office located at ESTEC. All scientific aspects of the programme will be co-ordinated by the ESA Herschel/Planck Project Scientists (PS's), who are the formal interface for scientific matters. The ESA Space Science Department will be responsible for the Herschel/Planck scientific operations after successful completion of the Spacecraft/Instrument Commissioning Phase.

10.2.2. ESA Organisation

Under the responsibility of the ESA PM, a formal ESA Project Office structure will be implemented, which will include the following disciplines:

- System Engineering
- Spacecraft Engineering
- Payload Engineering
- Overall Spacecraft Assembly, Integration and Verification
- Mission Operations
- Product Assurance

Within the Payload Engineering, a group of engineers will be the interface on the ESA side between the Project Office and the Principal Investigator (PI) team, and will:

- Co-ordinate with the PI and his/her team on all matters pertaining to their instrument
- Control the programmatic and technical interfaces as defined in the (to be) approved Instrument Interface Documents (AD 04,05,06,07,08)
- Ensure that the Project Office is fully cognisant of the PI's needs on the spacecraft and mission design
- Assist the PI's from the Project Office's side in resolution of technical or programmatic problems as appropriate, and pursue formal approval of possible changes
- Witness the pre-delivery acceptance tests of the instrument on behalf of the ESA using appropriate PI team expertise.

10.2.3. Prime contractor Responsibilities

The ESA intends to delegate to the Prime contractor the responsibility of the management of all technical interfaces of the payload with the spacecraft system including all margins and schedules.

In the frame of its responsibilities, the Prime contractor will:

- Design, produce and verify Herschel and Planck spacecraft in compliance with the ESA system requirements and;
- Deliver in time a flight-worthy Flight Model for both spacecraft including the respective scientific instruments.

As part of its tasks related to instrument interfaces, the Prime contractor and its industrial team will jointly:

- Maintain (update & issue) the Instrument Interface Document (IID) part B, describing each instrument interface data to be used for the spacecraft
design, manufacturing and verification, using inputs from each relevant instrument team and after agreement with the relevant PI,

- Design, develop and verify both spacecraft in compliance with instrument interfaces as specified in each Instrument Interface Document (IID) part B,
- Produce this Instrument Interface Document (IID) part A, describing each spacecraft interface data to be used for the instrument design, manufacturing and verification.

These activities will be conducted under the supervision of the ESA and according to the rules defined in the ESA prime Contract. In particular, the Prime contractor with participation of the Instrument Consortium shall directly manage, define, analyse, verify all technical interfaces (mechanical, thermal, electrical, optical, software, …) between the Instrument and the spacecraft in order to guarantee the compatibility of the instrument with the spacecraft and with the other instruments.

Monitoring of the interfaces will be done via a close follow up of the instrument activities, and synchronisation with the satellites developments: technical meetings, teleconferences, exchange of technical documents, analyses of monthly report, reviews, …

The agency will approve the IID-B / IID-A, ensure the compliance of these documents with the scientific objectives of the mission and manage the interfaces of the instruments with the ground segment.

10.2.4. Prime contractor Organisation related to instrument interfaces

![Diagram of Prime contractor organisation related to Instrument interfaces]

Figure 10.2.4-1 Prime contractor organisation related to Instrument interfaces
10.2.5. Principal Investigator Responsibilities  
The PI shall represent the single point formal interface for the instrument with the ESA Project Office. It is the overall responsibility of the PI to ensure that the complete instrument programme is implemented and executed in a manner such that the science objectives are achieved within the mission constraints of the approved project.
Specifically the responsibility of the PI will include:

10.2.5.1. Management  
- Taking full responsibility for the instrument at all times and retaining full authority within the instrument team over all aspects related to the procurement and execution of the instrument programme. In this context the PI shall be empowered to take commitments and make decisions on behalf of the other participants in the instrument team.
- Establishing an efficient and effective managerial scheme to be utilised in all aspects of the instrument project.
- Organising the efforts, assigning tasks and guiding other members of his/her team
- The establishment, implementation, analysis and reporting of schedule network planning as required
- Providing the formal managerial interface of the instrument to ESA Project Office and supporting ESA management requirements (e.g. Instrument progress reviews, Spacecraft and Mission Project reviews, Change procedures, Product Assurance etc.) as required.

10.2.5.2. Scientific  
- Attending meetings of the Science Teams and supporting groups as appropriate and taking a full and active part in their work
- Participation in Herschel/Planck workshops and scientific conferences
- Publishing scientific results
- Cooperation with other Herschel/Planck PIs, Guest Observers, Mission and Survey Scientists, or other science colleagues in order to maximise the scientific return of the Herschel/Planck mission.

10.2.5.3. Hardware  
- Defining functional requirements of his/her instrument and its ancillary equipment
- Ensuring the development, construction, testing and delivery of the hardware associated with the instrument. This shall be in accordance with the scientific performance, technical and programmatic requirements in the (to be) approved IIDs (AD04, 05, 06, 07, 08)
- Ensuring adequate scientific calibration of all parts of the instrument both on the ground and in orbit
- Ensuring that the design and construction of necessary hardware, and its development and test programmes are appropriate to the objectives of his/her instrument, and reflect properly the environmental and interface constraints to which the hardware will be subjected during the complete mission
- To ensure that all procured hardware is compliant with ESA requirements through participation in technical working groups and control boards as requested, to ensure system level compatibility to be maintained.
10.2.5.4. Software
- To ensure the development, testing and documenting of all software necessary for the control, monitoring, testing, operation and data retrieval of his/her instrument
- To ensure the delivery of such software and its documentation to ESA or elsewhere, as requested in due time, to support each project phase such as Assembly, Integration, Verification (AIV), Launch and Flight Operations
- To ensure that all instrument software that interfaces with the project is compliant with ESA requirements

10.2.5.5. Documentation
- Providing all required analysis and documentation as specified in the IIDs (AD 04,05,06,07,08).

10.2.5.6. Product Assurance
- Providing Product Assurance functions that are compliant with the requirements in AD 19.

10.2.5.7. Data Processing and Dissemination
- Ensuring that calibrated data of the instrument is made available in due time for payload operations and planning as agreed by the Herschel/Planck Science Teams.
- Generation of retrieval and processing software that will ensure accessibility of the data generated by the instrument to Guest Observers and/or users of data banks.
- Making data and scientific results available to ESA in a timely manner and in a form suitable for public relations purposes (also for general public) as and when required.
- Provision of due acknowledgement to ESA in all published material

10.2.6. Instrument Team Organisation
The PI shall establish a detailed organigramme for his/her team with defined named responsibilities clearly showing that all aspects of the instrument are efficiently covered by the appropriate expertise. Co-investigators shall be identified in the organigramme. Managerially team members shall have no FORMAL interface with ESA and shall communicate formally to ESA via the PI.
Key personnel, including technical Instrument Managers, should be identified within the management scheme together with a short description of their tasks and functions.

10.2.7. Formal Communication

10.2.7.1. Principal Investigators
All FORMAL communication and agreements concerning technical and programmatic aspects shall be agreed between the PI, the Prime contractor PM and are to be approved of ESA PM.
All formal communication and agreements concerning scientific aspects shall be made between the PI and the ESA PS.

10.2.7.2. Communication with ESA Contractors

All communication between PI’s and the Spacecraft Prime Contractor shall be conducted directly, with copy to the ESA Project Manager. (tbc)

10.2.7.3. Communication with ESA Departments

Contacts with ESA departments concerning all non-scientific aspects of the instrument controlled by the PI/ESA agreement including post-launch activities shall be via the ESA Project Office.
This does not apply for direct, separate contracts outside the PI/ESA agreement.

10.2.8. Financing

PI’s shall at all times be responsible for the funding arrangements of their instruments and the management thereof.
PI’s shall not assume any funding from ESA for any part of their instrument. Should, for programmatic or technical reasons, a PI requests to use an ESA facility, then the use will be charged to the PI.
This requirement shall apply up to the point of final acceptance of the instrument by ESA.

10.3. Project Control

10.3.1. Project Control Objectives

In order to manage the overall Herschel/Planck programme, the Principal Investigator (PI) will implement project control systems and procedures focusing on the definition, maintenance and reporting of schedule, costs, and configuration information.
The objective of this section is to clearly specify the management information required from each Instrument Team. Due to the importance of the instruments in the programme, it is critical that each PI supports this scheme with relevant schedule and configuration information. In case the Principal Investigator feels that the spirit of the requirement could be met by a more appropriate approach, he should propose alternatives which will be reviewed by ESA.

10.3.2. Project Breakdown Structures

In order to clearly identify the instrument, the scope of the work and the responsibilities involved, the following structures will be created by the Instrument Team:

- the Product Tree (PT) to break down the instrument into its components, both hardware and software
- the Work Breakdown Structure (WBS) to define the scope of the work and the responsibilities of the Co-I’s involved.

Product Tree:
A Product Tree shall be developed by the PI, depicting a product oriented breakdown of the instrument into successive levels of detail. The Product Tree shall be submitted to ESA.

Work Breakdown Structure:
A Work Breakdown Structure shall be developed by the PI, based on its agreed Product Tree and extending the applicable elements to include appropriate development models and support functions necessary to produce all the deliverables. For each Work Package, the PI shall complete a Work Package Description (WPD). The PI shall ensure all the responsibilities assigned to manage or to perform all the Work Packages are identified in the instrument team organisation chart (see section 10.1). The WBS shall be submitted to ESA.

10.4. Schedule Control

10.4.1. Baseline Master Schedule
The PI shall establish and submit to ESA, a Baseline Master Schedule covering all the instrument programme activities identified in the Work Breakdown Structure. All milestones specified by ESA, shall be included in the schedule and be agreed by the Instrument Team. The PI shall identify additional milestones as required and agree them with ESA. All interfaces, such as procurement items, hardware deliveries, reviews, etc. shall be clearly identified. The schedule shall reflect the result of detailed task analysis and critical review of all the activities associated with the instrument programme. It shall contain all activity interdependencies, durations and constraints. Directly from the Baseline Master Schedule, a set of bar charts shall be created, covering:

- Overall instrument programme
- Individual instrument models
- Instrument model integration and testing
- Detailed bar chart of critical activities

Changes to the Baseline Master Schedule shall only be made with the approval of ESA.

10.4.2. Schedule Monitoring
The PI shall continuously record progress achieved and maintain forecasts. The PI shall consolidate the progress and forecasts of all groups contributing to the instrument and compare schedule performance with respect to the overall Baseline Master Schedule. Where deviations to the baseline have occurred or are predicted, the PI shall develop and implement corrective actions.

10.4.3. Schedule Reporting
In order to track the progress, the PI shall provide to the prime contractor and to ESA, the following schedule reports as part of the reporting procedure (see section 10.10):
- on a monthly basis:
  - Quick Look Report
- additionally, on a quarterly basis, progressed bar charts showing:
  - a summary of the whole instrument project
  - a summary of each constituent and each organisation
  - details of the next 6 months period.

During the manufacture and test phases the frequency of schedule reports may be increased should the ESA judge progress to be critical.

10.5. Configuration Management

10.5.1. Objectives
The objectives of Configuration Management are to establish:
- a configuration identification baseline system which defines through approved specifications, interface documents and associated data the requirements for the instrument
- a configuration control system which controls all the changes to the identified configuration of the instrument
- a configuration accounting system which documents all changes to the baseline configurations, maintains an accurate record of configuration change incorporation, and ensures conformity between the end item As Built Configuration (ABCL) and its appropriate design and qualification identification (CIDL including waivers).

10.5.2. Responsibilities
The PI shall be responsible for managing the configuration of his/her instrument and the lower level products of which it consists. For this purpose, he shall set up the necessary organisation and means for satisfying the objectives and requirements of configuration management.

The PI shall also impose configuration management requirements on contractors and suppliers as appropriate for the items being provided to the instrument. For this purpose, the PI shall ensure compatibility between his/her own configuration management and the one implemented by all other participants to his/her instrument programme.

The PI shall be responsible for the implementation and operation of a Configuration Control Board (CCB) at his/her level.

10.5.3. Configuration Identification
The configuration baseline shall be established with respect to requirements, design and verification. The baseline shall include:

- Instrument System Specification
- Instrument System Support Specification
- Interface Control Documents
- Design Analysis documents
- Design Specification
The configuration baseline shall be established and reviewed at each Instrument Review. It may also be established and reviewed as required at selected intermediate stages.

The "as designed" baseline shall be finalised at the Instrument Hardware Design Review. Verification documents including design analyses and test reports shall make reference to the configuration status of the design or the hardware or software being evaluated.

10.6. Configuration Control

10.6.1. Instrument Internal Configuration Control
As a Herschel/Planck part of the management structure, the PI shall set up a configuration control procedure for his/her instrument in such a manner that the status of all aspects of the instrument such as the design and manufacturing of hardware and development of software can be unambiguously defined at any time. The control procedure shall allow ESA, to conduct a configuration audit at any point in the programme in order to obtain the up-to-date status of the instrument.

10.6.2. IID Configuration Control
The requirements defined in the IID Part A and Bs (AD 04,05,06,07,08) will be subject to configuration control and shall reflect the up to date agreed configuration baseline between ESA, prime contractor and the PI. Changes to these documents shall be handled using the Engineering Change Request (ECR) form. Deviations from the requirements defined in IID A and B will be handled using the Request for Waiver (RFW) form.

10.7. Configuration Status Accounting
The current status of all configured documents shall be sent to ESA, as part of the reporting procedure required in section 10.10. Configuration Item Data Lists (CIDL) listing all the documents and their applicable issues and revisions which define the configuration baseline shall be prepared and submitted for each Instrument Review.

The PI shall establish and maintain As Built Configuration Lists (ABCL) listing all the documents and their issues and revisions defining the as built configuration. Differences between the as designed baseline and the as built configuration list shall be identified for all qualification and flight hardware and software. The validity of all design verifications, including analyses and tests, shall be assessed for all the differences and modifications from the as designed baseline.

10.8. Reviews and reporting

10.8.1. General
The technical and programmatic aspects of each instrument programme shall be assessed between ESA, and each Instrument Team through:
- a cycle of formal Instrument Reviews
- instrument progress meetings
- regular progress reporting.

The overall scientific performance shall be monitored by ESA, during the review cycle and through the regular progress reporting supplied by the PI. Detailed scientific aspects shall be reviewed within the context of the Herschel/Planck Science Teams, as defined in the Herschel/Planck Science Management Plans.

Operations and data processing aspects shall be reviewed according to the Herschel and Planck SIRD’s.

10.8.2. Instrument Reviews

10.8.2.1. General

There shall be six major reviews for each instrument selected for the Herschel/Planck mission. The reviews form part of the overall Herschel/Planck review programme.

For each of the reviews, a review board will be set-up. The board will consist of ESA Personnel and will be chaired by the Herschel/Planck Payload Manager together with the Project Scientist or their designated representatives.

The reviews shall be conducted by ESA, nominally at ESA premises. The objectives will be to ensure that:

- The instrument design will be compatible for achieving the instrument performance.
- The instrument design complies with the interface requirements of the Instrument Interface Documents (IID’s)
- The scheduled delivery dates are compliant with the system level programme.

The data package to be reviewed shall cover both the instrument hardware and software together with details of any other deliverables such as MGSE, EGSE, OGSE and documentation and shall be delivered to the ESA Project Team as a minimum twenty working days prior to the scheduled review date.

The output of the review shall provide recommendations for consideration by the ESA Project Manager of the Principal Investigator in technical or programmatic areas. Either party shall provide a formal response to such recommendations within one month of review completion.

Non-compliance with other system elements will be brought forward to the following system level review for resolution.
results of the review.

It is realised that, aside the formal ESA reviews defined in this paper, instruments might want to conduct further instrument reviews, e.g. for internal monitoring of progress, request from funding agencies. In order to avoid duplication of effort combination of instrument internal and formal ESA reviews can be envisaged, as long as the objectives of both reviews match. For that reason it is planned to handle the below given dates for reviews in a flexible way, i.e. allowing a bandwidth of several months.

The following Instrument Reviews shall be held:

- the Instrument Baseline Design Review (IBDR, mid/end 2001)
- the Instrument Hardware Design Review (IHDR, mid/end 2002)
- the Instrument Flight Acceptance Review (IFAR, date 3rd quarter 2006)

In addition, Instrument Acceptance Reviews (IAR's) will be held at delivery of each of the instrument models.

10.8.2.2. Instrument Science Verification Review (ISVR)
It shall be conducted after instrument selection, in preparation for the release of the ITT for S/C development.
The objectives of the review shall be to demonstrate that:

- the instrument conceptual design has been finalised/ i.e. is compatible for achieving the instrument performance
- the instrument design will achieve the anticipated science objectives
- the overall interface requirements definition has been finalised
- the conceptual design for on-board software has been finalised
- the conceptual design for the necessary MGSE, EGSE and OGSE has been finalised.

10.8.2.3. Instrument Intermediate Design Review (IIDR)
It shall be conducted at the time of Prime Contractor selection.
The objectives of the review shall be to demonstrate that:

- the instrument detailed system design has been finalised
- the instrument subsystem design has been finalised
- the detailed interface requirements have been finalised
- the design for the on-board software has been finalised (User Requirements Document)
- the design of the necessary MGSE, EGSE and OGSE has been finalised.

10.8.2.4. Instrument Baseline Design Review (IBDR)

It shall be conducted in preparation for the S/C SRR.
The objectives of the review shall be:

- the freeze of instrument system and subsystem requirements
- the freeze of the on-board software requirements (Software Requirements Documents)
- the release for manufacture of instrument Avionics Model (AVM) and Cold Qualification Model (CQM)
- the freeze of the MGSE, EGSE and OGSE design
- the release for manufacture of the MGSE, EGSE and OGSE.

10.8.2.5. Instrument Hardware Design Review (IHDR)

It shall be conducted in preparation for the S/C AVM/CQM phase.
The objectives of the review shall be:

- the assessment of the instrument AVM/CQM programme
- acceptance of the AVM/CQM models for spacecraft system level
- the acceptance and freeze of the on-board software (Architectural Design Document)

10.8.2.6. Instrument Critical Design Review (ICDR)

It shall be conducted towards the end of the industrial phase C, in preparation for the S/C CDR, after release of the AVM/CQM test reports.
The objectives of the review shall be:

- the assessment of the results of the instrument level tests of the AVM/CQM
- the assessment of the results of qualification on instrument unit and subsystem level

10.8.2.7. Instrument Flight Acceptance Review (IFAR)
This review shall be conducted after completion of the spacecraft system level FM electrical verification including on-line compatibility tests with the respective flight operations centres and shall precede the programme level Flight Acceptance Review.

The objectives of the review shall be:

- the assessment of the results of the system level FM testing with respect to the instrument
- the assessment of the completion of qualification of instrument units and subsystems
- the update of the Instrument Users' Manual as required
- the close out any outstanding issue.

10.9. Instrument Progress Meetings

Regular Instrument Progress Meetings shall be held nominally on the premises of the PI’s during the design, development and verification programme of the instrument. These meetings will be conducted between ESA, the Prime Contractor and each Instrument Team with the objective of ensuring that the interface technical design integrity of the instrument, its compatibility with the spacecraft system, and instrument programmatics are proceeding in a manner which will not jeopardise the overall programme. The Instrument Team shall be represented by the necessary team to provide the required information, i.e. by the PI, the CO-Is, the Instrument Manager and the Local Project Managers as necessary.

The meetings shall be held on a quarterly basis. The frequency may be changed on request of ESA. Detailed technical problems occurring on either side of the interface shall be flagged during these meetings and corrective actions, including their schedule impact, agreed and implemented.

10.10. Reporting

The Principal Investigator shall submit to the Prime contractor and to ESA, 5 days after the end of the month, a Monthly Progress Report in which the current status of each activity is described and problem areas or potential problem areas are highlighted together with identification of proposed remedial action. The Monthly Progress Report shall include the following topics:

- Overall summary
- Design Development and Verification status
- PA status
- Programmatic status, including schedule reports
- Science Performance status
- Problem areas and corrective actions.

The Monthly Progress Reports submitted will be analysed in conjunction with the overall spacecraft programme by the prime contractor and ESA, and will serve as input to the regular Instrument Progress Meetings. By this monitoring action early
alerting to potential conflicts will be communicated back to the PI. In the case of major conflicts ESA and the prime contractor, may call for special schedule meetings to resolve the issue.

10.11. Deliverable Items

10.11.1. Mathematical Models
The PI shall deliver a Structural Mathematical Model (SMM) and a Thermal Mathematical Model (TMM) of his/her instrument units. These instrument mathematical models shall be updated as the design progresses. They will serve as input to the spacecraft mathematical models.

10.11.2. Instrument Models

10.11.2.1. General
The PI shall deliver the instrument models as defined in section 9.2:

Warm Electronic Units:
After the delivery of the PFM and for the duration of its testing, the AVM shall stay with the PFM for immediate replacement in the case of a failure in a PFM unit for which only spare subassemblies are available. The failed PFM shall be repairable within a period of 30 calendar days.

FPU/LOU/BOLA/Coolers:
For all units where CQM units will be refurbished as flight spares (see para 9.2.1.2), the CQM/FS units will be returned after test to the instrument team and shall be delivered at the defined date.

Each delivery shall include, as appropriate, instrument hardware, on-board software and ground support equipment. Each item delivered shall be accompanied by an End Item Data Package.

Prior to delivery, each item shall undergo formal acceptance on the basis of mutually agreed acceptance programme witnessed by engineers from ESA, and the spacecraft Prime Contractor.

This acceptance shall include as a minimum the formal verification of all interfaces between the instrument and spacecraft together with review of all applicable test reports and supporting analyses and documentation.

Shipment of the instrument models and any other equipment required by either ESA or the PI, shall be the financial responsibility of the PI. This responsibility shall extend to return for repair and return of all equipment following launch.

The points of delivery of all items will be determined later in the programme and be included in this document.

Any insurance deemed necessary by the Principal Investigator for his/her equipment during shipment or whilst on the premises of ESA, its Contractors or on the launch site, shall be the financial responsibility of the Principal Investigator.
10.11.2.2. Instrument Hardware
The build standard of each model shall be defined in IID-B and agreed with ESA. The PFM and the FS shall be fully calibrated before delivery. The PI shall support the system level integration and test activities as well as the launch preparation by supplying the GSE and the appropriate manpower and expertise.

10.11.2.3. On-board Software
The instrument on-board software shall be delivered together with the corresponding instrument model. The on-board software shall either reside in the instrument in a non volatile memory or be delivered in a format such that it can be loaded through the spacecraft telecommand up-link. In addition to the flight software, special test software for instrument diagnostics and failure investigation may be required. The on-board software to be delivered shall comply with the ESA software standard AD 14 and its guide to implementation. The PI remains responsible for the maintenance of the instrument software after delivery up to the end of mission. He shall support the verification of updated instrument software at system level.

10.11.2.4. Ground Support Equipment
The PI shall deliver the following ground support equipment together with each instrument model:

- Mechanical Ground Support Equipment (MGSE) necessary to transport, handle and integrate instrument hardware together with appropriate documentation and proof load and calibration certificates,
- Electrical Ground Support Equipment (EGSE) necessary to stimulate the instrument and to perform quick look analysis of instrument TM during system tests. It shall be designed such that it can be integrated into the system EGSE set-up. The instrument EGSE software to be delivered with the EGSE equipment shall comply with the ESA software standard AD14.

The instrument ground support equipment shall remain at the spacecraft integration site until launch. However, the PI remains responsible for the maintenance of this equipment. The PI shall also provide the necessary manpower and expertise support to integrate the instrument EGSE into the system EGSE.

10.12. Review Data Packages
A data package shall be provided for each of the scheduled Instrument reviews, detailed above. The package shall be delivered to the ESA Project Team in electronic form (PDF-file).

The packages shall contain the following information to the appropriate level (system, subsystem, unit) as required by the objective of the review and shall be adapted to each specific review. In order to avoid duplication of effort, the project is prepared to discuss and accept on a case by case basis different ways to provide the required information, i.e. either in a self-standing document package (preferred
way) or distributed among instrument generated documents and technical notes with a guide identifying the location of the information.

**Instrument Description Document:**
- A description of the current instrument design, its expected performance and interfaces

**Instrument Interface Document(s):**
- The IID-B updated to the current status

**Development Plan/AIV:**
- A New/critical technologies demonstration plan
- The Instrument Development and Verification plan
- Integration Plan and Procedures

**Test reports:**
- Test reports of environmental and functional tests, which demonstrate that the objectives of the instrument development, scheduled for the time of the review, have been met

**User Manual:**
- The User Manual

**Product Assurance:**
- Product Assurance documentation as required in the Product Assurance Requirements for the Herschel/Planck instruments

**Schedule:**
- Schedule network and bar-chart together with an assessment of progress and problem areas covering all aspects of the instrument and associated equipment

**Management:**
- Management Plan

**Ground Support Equipment:**
- Electrical ground support equipment, design, development and verification status including both hardware and software
- Mechanical ground support equipment, design, development and verification status
- Optical ground support equipment, design, development and verification status

**Software:**
- Onboard software (OBSW) – URD, SRD, ADD, DDD
- GSE’s, e.g. s/c simulator

Notes:
- Technical notes, covering any topic or analysis which is either required by the IID or has been requested by the ESA Project Team

10.13. Baseline schedule

10.13.1. Overall Herschel/Planck Baseline Schedule
The overall baseline schedule for Herschel/Planck is given in Figure 10.13.2-1 next page.

10.13.2. Baseline Schedule of Deliverables
The baseline schedule for all deliverables is given in Table 10.13.2-1

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Need/Delivery Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herschel AVM</td>
<td>April 2003</td>
</tr>
<tr>
<td>Herschel CQM</td>
<td>April 2003</td>
</tr>
<tr>
<td>Return Herschel CQM to PI</td>
<td>April 2004</td>
</tr>
<tr>
<td>Herschel PFM</td>
<td>July 2004</td>
</tr>
<tr>
<td>Herschel FS</td>
<td>July 2005</td>
</tr>
<tr>
<td>Planck AVM</td>
<td>April 2003</td>
</tr>
<tr>
<td>Planck CQM</td>
<td>April 2003</td>
</tr>
<tr>
<td>Return Planck CQM to PI</td>
<td>April 2004</td>
</tr>
<tr>
<td>Planck PFM</td>
<td>July 2004</td>
</tr>
<tr>
<td>Planck FS</td>
<td>July 2005</td>
</tr>
</tbody>
</table>

Table 10.13.2-1: Baseline Schedule of Instrument Deliverables
Figure 10.13.2-1: Herschel/Planck Baseline Schedule
NOTE

Please note that this document has been established on the basis of a previous Herschel telescope design and an earlier definition of the scientific instruments, i.e. is not compatible with the baseline configuration.

However, it can be expected that the main elements of this alignment plan w.r.t. alignment concept for the telescope and the FPU’s and the tolerances defined will not change significantly.

The document will be updated in due course.
FIRST

ALIGNMENT PLAN

SCI-PT-PL-02220 (ISSUE #1)
9 May 1996

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepared by</td>
<td>FIRST Alignment Working Group</td>
</tr>
<tr>
<td>Approved by</td>
<td>M. Anderegg</td>
</tr>
<tr>
<td></td>
<td>ESA/ESTEC</td>
</tr>
<tr>
<td>Approved by</td>
<td>F. Felici</td>
</tr>
<tr>
<td></td>
<td>Project Manager (Acting)</td>
</tr>
<tr>
<td></td>
<td>ESA/ESTEC</td>
</tr>
</tbody>
</table>
Table of Contents

1 INTRODUCTION
2 SPECIFICATIONS
   2.1 Configuration and Interfaces
   2.2 DEFINITIONS
   2.3 REQUIREMENTS
   2.4 ANALYSIS
3 AIT PHILOSOPHY
4 ALIGNMENT CONCEPT
   4.1 Telescope
   4.2 PLM
   4.3 Satellite level
5 ALIGNMENT MEASUREMENT METHODS
   5.1 Adjustment control
      5.1.1 Instruments - Optical bench
      5.1.2 Telescope/PLM
   5.2 END TO END TEST
      5.2.1 Objective
      5.2.2 Measurement method
6 REQUIREMENTS
   6.1 Telescope
   6.2 PLM
   6.3 Experiments
      6.3.1 Mechanical interface
      6.3.2 Optical interface
7 APPENDIX 1 - PUPIL OVERSIZING
8 APPENDIX 2 - ISO ALIGNMENT METHOD
9 APPENDIX 3 - OGSE DEFINITION
1 INTRODUCTION

This document provides the alignment plan for FIRST (Far InfraRed and Submillimetre Telescope) which has been defined through an Alignment Working Group managed by ESA.

This plan starts from the Scientific Instruments / Telescope alignment needs derived from mission objective which have been shared to give allocations to telescope, instruments, payload module and satellite levels.

It describes the alignment concept covering adjustments and measurements methods for the integration of Scientific instruments and Telescope in the Payload Module (the internal alignment and associated control of the telescope and Scientific instruments are out of the scope of this document).

It defines the optical interfaces and associated OGSE necessary to implement this concept.
2 SPECIFICATIONS

2.1 Configuration and Interfaces

FIRST is composed with a telescope mounted on a Payload module (PLM) inside of which are located the scientific instruments.
2.2 DEFINITIONS

a. Telescope axis

Telescope optical axis (in "space image") is defined by the line passing through the centre of the secondary mirror and the telescope focus. The telescope focus is defined as the centre of the unvignetted field of view (this centre is referred to a reference mark on the telescope).

b. Instrument pupil and axis

The exit pupil of the instrument is defined as the image of the instrument internal pupil in telescope space. In the current design for PHOC and BOL instruments, the internal pupil is the mirror M4, while the instrument exit pupil is the image of M4 through M3, and is ideally located at M2 (exit pupil of the telescope) and centred with respect to M2, i.e. the centre of the instrument exit pupil is ideally also the centre of M2.

The instrument axis is here defined by the line passing through the instrument focus (instrument F.O.V. centre) and the exit pupil of the instrument.

c. Alignment parameters:

- the focus location error along the optical axis, "defocus", is the distance between the telescope focal plane and the instrument focal plane measured along X axis.

- the lateral alignment error is the distance between the Instrument focus (F.O.V. centre) and the theoretical centre of the field of view given by the telescope to the instrument, measured in a plane perpendicular to the optical axis.

- the tilt error refers to the lateral alignment error between the exit pupil of the instrument and the telescope pupil M2. Tilt error is the alignment between optical axis of the instrument and line between telescope secondary mirror (exit telescope pupil) and F.O.V centre of instrument.

- Roll error is the rotation of the whole focal plane around the optical axis.
2.3 REQUIREMENTS

The following figures are absolute requirements, which must be fulfilled in space.

a. Focus alignment:

The absolute focus alignment requirement between the telescope and each scientific instrument is equal to +/- 11 mm, with the following sharing:

- Telescope: +/- 9 mm (including +/- 5 mm variation during one orbit above 40000km altitude)
- PLM: +/- 5 mm.
- Instruments: +/- 3 mm.

The 11 mm defocus are within the WFE budget.

b. Lateral and tilt alignment:

It has been recognised by the Working Group that the main critical adjustment is the telescope and instrument pupils lateral alignment, or which is the same, the tilt error as defined in § 2.2.

The absolute tilt error must be below 12 arcmin which corresponds to 16 mm lateral misalignment between the telescope and instrument pupils.

This tilt error is shared by several contributors, among which are the knowledge of the instrument axis, the lateral alignment of the instruments on the optical bench, the knowledge of the M2 location with respect to the telescope reference frame, the lateral alignment of the telescope assembly on the PLM, etc.

The table hereafter considering "reasonable numbers" (and based on ISO experience), gives the present budget with the different individual requirements for lateral and axis alignments.

From this table, on can see in particular that:

- The instruments must be located within +/- 3 mm circle in YZ plane with respect to the PLM interface with telescope.
- The telescope focus must be located within a +/- 5 mm circle in YZ plane with respect to its interface with PLM.
- The telescope secondary mirror lateral location w.r.t. telescope/PLM I/F must be known (measured on ground) with an accuracy of +/- 1 mm and located within +/- 5mm.
- The telescope must be transversely aligned on the PLM with an accuracy of +/- 1 mm.
<table>
<thead>
<tr>
<th>AXIS</th>
<th>LATERAL</th>
<th>TILT (arcmin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruments adjustments in the focal plane w.r.t optical bench I/F</td>
<td>8 arcmin</td>
<td>3 mm</td>
</tr>
<tr>
<td>Optical bench / PLM</td>
<td>1 arcmin</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Telescope knowledge</td>
<td>NA</td>
<td>1 mm</td>
</tr>
<tr>
<td>PLM/Telescope adjustment</td>
<td>1 arcmin</td>
<td>1 mm</td>
</tr>
<tr>
<td>Telescope stability (equiv. WFE 2 μm)</td>
<td>NA</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>Instruments Stability</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>PLM Stability (ISO type)</td>
<td>0.4 arcmin</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>9.5</td>
</tr>
</tbody>
</table>

** included in "instrument adjustment"

c. Roll

The absolute requirement is roll less than 1 degree.
This requirement is not shared between the telescope, PLM and Instruments

2.4 ANALYSIS

a. Focus alignment

The rational for 11 mm telescope defocus has been already provided in ref. 2: this figure is consistent with the telescope image quality requirement.

Capability for PLM/Telescope interface adjustment along X axis must be kept to take into account the real location of the telescope focus.

b. Lateral and tilt alignment

In principle the instruments can be placed anywhere inside the telescope unvignetted field of view. Nevertheless, this requirement has an impact on the tilt performance (negligible on defocus: 5mm lateral gives only 0.7 mm defocus at the edge of the F.O.V due to the field curvature):

- with 2288 mm distance between secondary reflector and focal plane,
+/- 3 mm for instruments give 4.4 arcmin tilt
+/- 1 mm telescope secondary mirror lateral alignment gives 1.5 arcmin tilt.

These figures have to be taken into account inside the absolute 12 arcmin tilt specified.

The accuracy's for lateral location of secondary mirror (5mm), telescope focus (5mm) and instruments (3mm) mean that in the worst case, the centre of unvignetted field of view can be 13 mm misaligned w.r.t the instruments. That why a margin of 13 mm must be kept between the U.F.O.V provided by the telescope and the F.O.V used by the instruments.

The telescope I/F adjustment is consistent with the knowledge of secondary mirror lateral location: both are equal to 1mm inducing 1.5 arcmin tilt.

This knowledge of 1 mm secondary mirror lateral alignment must include the telescope mechanical interface tilt: with 1547.9 mm distance between secondary mirror and telescope interface, 2arcmin tilt at telescope I/F level induces 1 mm secondary mirror lateral shift.

The telescope/PLM interface adjustment on the secondary mirror lateral position knowledge criterion gives in the worst case (+ 5mm on secondary mirror and -5 mm on telescope focus) 10 mm lateral focus location w.r.t telescope/PLM I/F. This 10 mm leads to ~ 1mm defocus due to field curvature.

**Pupil oversizing**
In appendix 1, we have added a discussion on the pupil oversizing due to the tilt requirement

c. Roll

This requirement is not considered as a driving parameter.
3 AIT PHILOSOPHY

Telescope

The mirrors are integrated inside telescope structure and adjusted in order to 
achieve both the image quality and alignment requirements. Then these 
performances must be verified together with the environment test, at least:

- Image quality and alignment at ambient and cryo conditions
- Image quality and alignment before and after vibrations

The measurement of secondary mirror and focus lateral locations will be used for the 
adjustment of the whole three instruments w.r.t the PLM interface and for the lateral 
adjustment of the PLM telescope interface.

In addition, the knowledge of the telescope defocus can be also taken into account 
during PLM/Telescope interface adjustment.

Instruments

Prior to delivery to the PLM, each instrument is aligned with respect to its mechanical 
interface with the PLM. Here also the performances are verified with the environment 
tests.

PLM

The instruments are located inside the PLM. Before integrating the telescope, the 
instruments must be aligned w.r.t. the PLM/telescope interface and the alignment 
performances verified with the environment tests. 
After this level, it is not possible to re-adjust later the instruments independently 
inside the PLM.

Satellite

The telescope is finally mounted on the PLM with an adjustment of the 
PLM/Telescope mechanical interface to take into account (at least) the lateral shift of 
secondary mirror if this has not been done during the instruments adjustment.

During the environment tests, the alignment of telescope w.r.t. the instrument will be 
at least verified on optical reference located on PLM and telescope interface.
4 ALIGNMENT CONCEPT

The analysis of requirements made in the § 2.4, together with the conclusions of the Working Group show that the telescope and instruments pupils alignment (lateral and tilt requirements) is the driving element to define the alignment strategy.

To fulfil this requirement it is necessary to take into account the measured figures of telescope secondary mirror lateral position for the adjustment of the PLM/telescope interface.

4.1 Telescope

The alignment and the verification method for the internal alignment of the telescope are not covered by the present document.

The secondary mirror and focus lateral locations are within +/-5 mm with a knowledge better than +/-1 mm for secondary mirror. This defines the adjustment accuracy at PLM/Telescope interface (+/-1mm). The adjustment range must be larger than +/-5 mm lateral to take into account PLM accuracy’s. It is not yet decided if this interface adjustment is done on telescope or PLM side. This is not mandatory for this plan.

4.2 PLM

The sequence of adjustment and verification of the instruments inside the PLM follow the here below logic:

- The instruments are mounted on the optical bench inside the PLM without adjustment.

- The optical bench is adjusted w.r.t. PLM/Telescope I/F.

- The alignment stability is controlled during the PLM environment tests.

4.3 Satellite level

When the telescope is mounted on the PLM, this interface is adjusted to take into account telescope behaviour. We can not imagine that the PLM optical bench adjustment can take into account the telescope behaviour for two reasons:

- The adjustment of the PLM/Telescope interface is mandatory to avoid schedule links between the telescope and PLM activities.
- The optical bench adjustment capabilities will be limited.

The figure 4.3 summarises this alignment concept.
5 ALIGNMENT MEASUREMENT METHODS

5.1 Adjustment control

5.1.1 Instruments - Optical bench

The instruments are integrated without adjustment on the optical bench.

Instrument optical reference are used to check co-alignment of instruments on the optical bench and to adjust the optical bench with respect to the PLM/telescope mechanical interface:

An alignment cube and optical ball visualise the PLM mechanical I/F. Two linear tables are fixed at PLM I/F and aligned with respect to PLM cube with theodolites.

then the adjustment control of the optical bench can be performed:

- tilt measurement with theodolite and flat mirror (~10 mm diameter) mounted on top of the instruments.
- lateral measurements with same OGSE, the instruments flat mirror must have a reticule.
- Focus along X axis can be measured using Simon collimator.

These measurements can be performed at ambient or cryogenic temperatures (both are mandatory for PLM tests sequence)

5.1.2 Telescope/PLM

The telescope PLM I/F must be laterally adjusted and telescope tilt controlled. This is also achieved with theodolite and measurements on alignment cubes and optical balls mounted on PLM and telescope side.

5.2 END TO END TEST

5.2.1 Objective

A major recommendation of the Alignment Working Group is that an “end to end” test on the flight model is necessary to verify the lateral alignment between the instrument exit pupil and the telescope pupil M2. As a minimum, this measurement must be an alignment verification which can be done in warm conditions all along the development phase up to launch.
The objective for this test is to control the FM instrument optical alignment with respect to the FM telescope at satellite level at the end of the AIT sequence. The best is to be able to perform this test in warm and cold conditions which induce constraints on the facilities used. At least it must be done with telescope warm (launch configuration) to verify the integrity of alignments after satellite integration and environment tests, before launch.

From the alignment requirements, it has been assessed that the main critical parameter to be verified is the telescope and instruments pupils alignment.

### 5.2.2 Measurement method

The measurement of the telescope and instruments pupil co-alignment can be achieved through the primary mirror (ISO configuration, see appendix 2) or directly sighting the edge of the secondary mirror with a eye-piece located behind the secondary mirror.

This is illustrated on the two figures 5.1.2-a and 5.1.2-b.

To perform this alignment control, it is necessary to have, at least, marks at the edge of the M4 mirror inside the flight instrument (The telescope is integrated the last so the alignment control approach used on ISO with alignment dummies for instruments cannot be used for FIRST).

The table here below summarises the alignment control capabilities versus the alignment components available:

<table>
<thead>
<tr>
<th>INSTRUMENTS SELECTED</th>
<th>OPTICAL I/F</th>
<th>ALIGNMENT CONTROL AT SATELLITE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirrors on top of instruments</td>
<td>optical bench/ PLM stability</td>
<td></td>
</tr>
<tr>
<td>dedicated mirrors on the optical bench</td>
<td>telescope alignment w.r.t optical bench</td>
<td></td>
</tr>
<tr>
<td>dedicated mirrors (or marks on M4 mirror) inside one instrument</td>
<td>telescope alignment w.r.t one instruments axis</td>
<td></td>
</tr>
<tr>
<td>dedicated mirrors (or mark on M4 mirror) inside instruments</td>
<td>telescope alignment w.r.t instruments axis</td>
<td></td>
</tr>
</tbody>
</table>

ISO experience shows that it is not obvious to implement these components inside the FM instruments.

That is why it is today assumed that:

- marks on the M4 mirror will be available at least on the QM,
- dedicated mirrors simulating M3 and M4 will be placed directly on the optical bench,
- Instruments will have mirrors on the top

Figure 5.1.2-a Pupil co-alignment control - ISO configuration

Figure 5.1.2-b Pupil co-alignment control - Direct measurement
6 REQUIREMENTS

6.1 Telescope

The telescope must be delivered with an alignment cube and an optical ball.

With respect to this reference the following parameters must be measured prior to delivery:

- mechanical I/F tilt
- Secondary mirror location
- focus location

6.2 PLM

The PLM/Telescope interface must be also visualised with an alignment cube and optical ball mounted outside in the vicinity of this interface.

For instruments alignment control, an optical window (or FPA access) must be placed above the focal plane size of which must not limit the telescope unvignetted F.O.V.

A pupil simulator must be mounted on the optical bench in the telescope unvignetted F.O.V. This device must have two mirrors as defined in appendix.

6.3 Experiments

6.3.1 Mechanical interface

There is no adjustment on the optical bench.

6.3.2 Optical interface

a. outside on the top

Two flat mirrors with reticule are located at the top of the instruments. These mirrors visualise the mechanical reference of the instruments: One of the two mirrors is the origin of the coordinate system: Its cross is the origin and it simulate the X axis. The second one bears the cross which define only a line in Y/Z plane:
b. inside the instrument

Inside the development model it must be possible, as a minimum, to implement marks at the edge of the M4 mirror to materialise the edge of the pupil.
7 APPENDIX 1 - PUPIL OVERSIZING

The question as to whether the instrument exit pupil should oversize M2 or the contrary was not fully answered by the science team. J.M. Lamarre proposed that the instrument exit pupil should undersize M2 for avoiding unwanted modulations of the detected signal during sky shopping due to the sources located in the vicinity of M2. However, it was pointed out that such sources are not imaged through the telescope: the modulation during sky shopping would be due to direct radiation from these sources to the focal plane, which may lead to an acceptable modulation level.

Moreover, undersizing the instrument exit pupil w.r.t. M2 diameter by 16 mm for alignment purpose implies a reduction of the collecting area and therefore an energy loss of 13%.

Therefore the Working Group has considered, as a working assumption, that the instrument pupil oversizes M2. The reverse assumption has no impact on the present alignment plan.

Whatever will be the final choice of the science team, the following remarks should be made:

- The instrument exit pupil diameter cannot be made exactly equal to M2 diameter for alignment purpose. In any case, the exit pupil oversizing or undersizing will be of several millimetres.

- The tilt error value, that is 12 arcmin or equivalently 16 mm exit pupil oversizing, can be discussed, but it is doubtful that it will be significantly reduced without considerably increasing the alignment procedure complexity. One should keep in mind that all figures refer to cold condition. In addition, the major contributor is the internal alignment of instruments.

- Should the problem of straylight due to the exit pupil oversizing be really critical, two solutions can be envisaged:
  1) undersizing the instrument exit pupil to the detriment of collected energy,
  2) use the end to end test not only to verify the pupils co-alignment but also to re-align the instrument exit pupil w.r.t. M2 by translating the telescope w.r.t. the PLM and/or the instruments on the optical bench. This last solution adds complexity at PLM level.
8 APPENDIX 2 - ISO ALIGNMENT METHOD

1. Simon Collimator

This collimator has been developed for the ISO telescope focus measurement along optical axis ("defocus"). Its principle is based on the idea to select an optical frequency where the contrast variation is high with defocus. This is illustrated on the figure here below:

So in the focal plane of the simon collimator, we have placed two grids frequency of which is half the cut-off frequency \( v_0 \), \( \epsilon_0/2 \) mm defocused as illustrated on the figure here after. The alignment is correct when the two grids are seen with the same contrast:

2. Axis measurement
the figure below gives the measurement configuration: a collimator placed in front of the telescope is focused, through the primary mirror on the edge of the secondary mirror where is also located the image of the instrument pupil given by the field mirror M3.

To measure the co-alignment of the telescope and instrument pupil, concentric circles are put on the M4 mirror:

Two observations are made at the edge of the pupil, 90 degrees apart which give the following results:
Edge of Secondary mirror

Main circle (pupil diameter)

**ALIGNED**

**MISALIGNMENT**
9 APPENDIX 3 - OGSE DEFINITION

1. Tilt Alignment measurement accuracy

The global specification is 12 arcmin.

The present budget (cf § 2.3) gives 9.5 arcmin tilt performance, so the measurement accuracy (including OGSE and Optical reference performances) must be below 7 arcmin ($\sqrt{12^2 - 9.5^2}$).

2. OGSE definition

This analysis is done in the case of ISO configuration (cf figure Appendix 2 §2) to define the parameters of the collimator, but the proposed definition of the alignment mirrors is valid for both configurations.

The telescope entrance pupil location is about 16 meters behind the primary mirror with a magnification factor w.r.t. M2 equal to $\gamma = 11.8$.

1 arcmin tilt of instrument axis w.r.t. telescope induces .7 mm pupil misalignment at M2 level and therefore ~ 8mm lateral misalignment on the entrance pupil.

The sighting collimator will be placed in front of the telescope at ~ 2 metres from the primary mirror.

So this lateral shift is seen under 1.5 arcmin angle. Which is seen without difficulty for an observer with x10 magnification factor on the collimator.

Taking into account the ISO alignment dummy design, as shown on the figure here after, the characteristics could be:

- M3 diameter: TBD versus collimator F.O.V (10 arcmin?) and vignetting analysis not performed up to now.
- M4 -M3 distance: 300 mm
- M4 diameter (mini): 31 mm

distance between two circles (equivalent to 3 arcmin): 270 $\mu$m
thickness of circles: 50 $\mu$m

The magnification between M4 and entrance pupil is about 90. So the circle thickness is 4.5 mm seen on the entrance pupil.

With 50 mm collimator pupil diameter, this thickness is less than 0.1 time the cut off frequency of the collimator. So the loss of contrast is negligible due to the collimator performance and will be only affected with the primary mirror image quality on a reduced surface of 50 mm diameter.

This collimator aperture gives a PSF radius in focal plane (diffraction only at 0.6 $\mu$m) = 0.4mm to be compared with telescope image quality = 1.65 mm. This collimator
can also be used as it is for telescope optical axis stability (accuracy in the range of 0.2 - 0.5 arcmin). A cross must be on the field mirror, and the PLM optical reference must be seen from the telescope side.
Annex 2 - HIFI LOU ALIGNMENT PLAN

Draft HIFI proposal for the alignment of the Local-Oscillator Unit with the Focal-Plane Unit

Note: This proposal will be updated in due course to reflect the current alignment concept as given in section 5.8 in the HIFI IID-B.

D.A. Beintema, 2 March 2000

1. Introduction

This memo describes the plans existing at SRON for the alignment of the HIFI LOU with the FPU.

To align the HIFI Focal Plane Unit with the local oscillator with the required precision will require at least two visible-light windows in the FIRST cryostat. Natural positions for these two windows would be adjacent to the first and last of the seven sub-millimeter windows, in positions 0 and 8 as it were. Indeed in their cryogenic interface study for FIRST (end ’99) DSS proposed two windows at these locations.

DSS proposed to use alignment cubes (with reflecting surfaces for orientation and crosses for position reference), mounted on the +Z and –Z faces of the LOU and of the FPU. The use of these cubes is obvious during the integration of the instrument. For the critical alignments (rotations around the X and Z axes and translations parallel to the X and Z axes) the +Y and/or –Y faces of the alignment cubes can be used. After having sighted the FPU cubes with theodolites through the visible-light windows in the cryostat wall, the LOU can be aligned with its alignment cubes. If the cubes on the LOU are partially transparent then the alignment can also be checked after integration by measurements along the Y axis through the cubes on the LOU and through the two alignment ports.

However, in cryogenic instrument-level tests, with the FPU at 15 K and with the LOU at 150 K or 180 K, it will be very difficult to check the alignment of the two units. For that reason HIFI proposes to use a special camera system to monitor the alignment of the two units. Originally the plan was to use special alignment devices instead of alignment cubes on the two units, but the latest plan is to make use of alignment cubes along the lines proposed by DSS.
The HIFI plan will allow to monitor the alignment of the LOU with the FPU at all stages of ground testing. The camera system will consist of two pieces of special ground support equipment mounted temporarily on the LOU. The same equipment will (have to) be used when mapping the LOU beams and the FPU LO ports at the interface plane between LOU and FPU.
2. HIFI proposal

HIFI proposes the following alignment measures for the LOU – FPU alignment:

1) Two alignment axes will be used, parallel to the telescope Y axis, running at \( Z = +200 \text{ mm (TBC)} \) and \( Z = -200 \text{ mm (TBC)} \), \( X = 63 \text{ mm above the optical bench surface} \).

2) A pair of alignment cubes permanently mounted on the FPU, one on each alignment axis. The cubes will be mounted as close as possible to the LO windows. Only the \(-Y\) surfaces will be used (plane reflectors and crosshairs). They shall be visible from the \(-Y\) side.

3) A pair of alignment cubes permanently mounted on the LOU, one on each alignment axis. The cubes will be mounted at least 50 mm behind the front surface of the LOU, to allow space alignment cameras alongside the LOU. Both the \(+Y\) and \(-Y\) surfaces of these cubes will be used (plane reflectors and crosshairs). The cubes shall be visible from the \(+Y\) side (for alignment monitoring) and from the \(-Y\) side (during integration).

4) A pair of alignment windows in the cryostat wall, providing a free diameter of at least 20 mm around each alignment axis.

5) Two pairs of alignment cameras, to be mounted temporarily on the LOU, allowing to monitor simultaneously tilt and offsets with respect to the X and Z axes. Required accuracy: \(<0.1 \text{ mm}, <0.005^\circ\). The cameras shall function at room temperature and at the operating temperature of the LOU.

6) A calibration setup to calibrate the alignment cameras.

Items 2, 3, 5 and 6 would be provided by the HIFI consortium.

Alignment monitoring will be applied:

1) when testing the FPU and the LOU against their I/F requirements
2) during AIV at instrument level
3) during instrument-level testing and calibration
4) to verify successful integration at system level
5) in system tests, including thermal-vacuum tests

Status

Prototyping of the optics of the alignment camera system should start very soon. That exercise will also serve to prove the concept. Assuming that the concept can be made to work, detailed design and fabrication will then follow, along with the development of the test cryostats.
Design principle

The dashed contour indicates the boundary of the alignment camera equipment. Crosshairs, illumination and imaging optics have been omitted in this sketch.
alignment axis the equipment is semi-transparent!
Annex 3

to the IID-A

Planck ALIGNMENT PLAN

HP-3-ASPI-PL-0078
### PLANCK ALIGNMENT PLAN

<table>
<thead>
<tr>
<th>Responsibility-Company</th>
<th>Date</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.MARTIN</td>
<td>30/07/01</td>
<td></td>
</tr>
<tr>
<td>Approved</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.B.RITI</td>
<td>30/07/01</td>
<td>30/07/01</td>
</tr>
<tr>
<td>C.SINGER</td>
<td>30/07/01</td>
<td></td>
</tr>
<tr>
<td>C.MASSE</td>
<td>01/08/01</td>
<td></td>
</tr>
<tr>
<td>P.RIDEAU</td>
<td>31/07/01</td>
<td></td>
</tr>
<tr>
<td>Released</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.J.JUILLET</td>
<td>31/07/01</td>
<td></td>
</tr>
</tbody>
</table>

PT Code: 20000

Emitting entity: DOS

(Original holding)
**CHANGE RECORDS**

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>DATE</th>
<th>§: CHANGE RECORD</th>
<th>AUTHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>27/07/2001</td>
<td>First issue</td>
<td>PH. MARTIN</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

1. INTRODUCTION .................................................................................................................. 5

2. DOCUMENTS ......................................................................................................................... 5

3. SPECIFICATIONS .................................................................................................................. 6
   3.1 CONFIGURATION AND INTERFACES ....................................................................................... 6
   3.2 DEFINITIONS ......................................................................................................................... 8
   3.3 REQUIREMENTS..................................................................................................................... 8
   3.4 ANALYSIS ............................................................................................................................ 9
       3.4.1 Wave front error ........................................................................................................... 9
       3.4.2 Line of Sight................................................................................................................ 15

4. AIT PHILOSOPHY AND ALIGNMENT CONCEPT .................................................................. 18
   4.1 TELESCOPE ...................................................................................................................... 18
   4.2 INSTRUMENTS .................................................................................................................. 18
   4.3 PLM AND SATELLITE ....................................................................................................... 19

5. ALIGNMENT MEASUREMENT METHODS .............................................................................. 22
   5.1 THEODOLITE MEASUREMENTS .......................................................................................... 22
   5.2 TELESCOPE WFE MEASUREMENT ....................................................................................... 23
   5.3 LOS SPIN AXIS ADJUSTMENT ............................................................................................ 23

6. ALIGNMENT BUDGET ............................................................................................................ 24
   WFE .................................................................................................................................. 24
   LOS .................................................................................................................................. 26

7. REQUIREMENTS ...................................................................................................................... 28
   7.1 AT REFLECTORS LEVEL ...................................................................................................... 28
   7.2 AT TELESCOPE LEVEL ...................................................................................................... 28
   7.3 AT FPU LEVEL .................................................................................................................. 28
   7.4 AT SATELLITE LEVEL ........................................................................................................ 29
1. INTRODUCTION

This document provides the alignment plan for PLANCK satellite.

It describes the alignment concept covering adjustments and measurement methods for the telescope integration, Focal Plane Unit (FPU) integration in the telescope focal plane and finally telescope integration in the Payload Module and final adjustments at Satellite level. The internal alignment of the FPU (horns adjustment for LFI and HFI, LFI/HFI I/F adjustment are out of the scope of this document and are under LFI/HFI responsibility).

This plan starts from the Scientific Instruments (LFI/HFI) needs which are shared to give allocations to telescope, Instruments and Satellite levels.

It defines the optical interfaces and associated OGSE necessary to implement this alignment concept.

2. DOCUMENTS

<table>
<thead>
<tr>
<th>RD#</th>
<th>Designation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD 1</td>
<td>Optical analysis</td>
<td>H-P-ASPI-LT-0072</td>
</tr>
<tr>
<td>RD 2</td>
<td>Primary reflector / secondary reflector specification</td>
<td>SCI-PT-RS-07422</td>
</tr>
<tr>
<td>RD 3</td>
<td>Cryo-structure Specification</td>
<td>HP-3-ASPI-SP-0021</td>
</tr>
<tr>
<td>RD 4</td>
<td>System Requirement Specification</td>
<td>SCI-PT-RS-05991</td>
</tr>
<tr>
<td>RD 5</td>
<td>Planck Telescope Specification</td>
<td>HP-3-ASPI-SP-0004</td>
</tr>
<tr>
<td>RD 6</td>
<td>Planck telescope design specification</td>
<td>SCI-PT-RS-07024</td>
</tr>
<tr>
<td>RD 7</td>
<td>STB of alignment tools Cube-tooling ball - target</td>
<td>ASPI/01/BO/IT/034</td>
</tr>
</tbody>
</table>
3. SPECIFICATIONS

3.1 Configuration and Interfaces

The three elements that make up the optical payload (Figure 3-1) are the primary reflector, the secondary reflector and the focal plane unit (FPU). The reflectors must be well manufactured and correctly aligned with respect to each other, with respect to the FPU, and with respect to spin axis, to get:

- the angular resolution on the sky
- the ellipticity of the far field radiation pattern
- the line of sight with respect to the spin axis (i.e. the Absolute Pointing Error). The Line of Sight knowledge and stability are necessary for each detector to observe precisely the same location in the sky, seen many times during the sky survey
- the spill-over for each horn of the focal plane unit in order to minimize the straylight coming from sources external to the spacecraft in the far-field of the telescope.
Figure 3-1: Optical configuration
3.2 Definitions

Detector Line of Sight
Each detector has its own Line of Sight, defined as the direction in the object space of the radiometric centre of its actual far field pattern as projected by the telescope.

Telescope Line of Sight
The telescope line of sight is defined as the actual direction of the projection, in the object space, of a theoretical point being placed at the centre of the focal plane axis system.

Telescope assembly
This refers to telescope being associated with FPU.

Telescope assembly Line of Sight
The telescope Line of Sight is defined as the actual Line of Sight of the 353-4 HFI horn. This horn is the closest to the centre of the field of view of the telescope.

3.3 Requirements

Pointing Error - Line of Sight

The Absolute Pointing Error APE is the only pointing error directly applicable to the alignment plan. It is defined in the system requirement specification RD4 (MOOF-045). Requirements and goals are presented in the following table:

<table>
<thead>
<tr>
<th>Angular Error</th>
<th>Requirement for LOS (arcmin)</th>
<th>Requirement around LOS (arcmin)</th>
<th>Goals for LOS (arcmin)</th>
<th>Goals around LOS (arcmin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APE</td>
<td>37</td>
<td>37</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

LO S requirement comes from the classical scientific need of knowing in which direction each horn is looking. Around LOS requirement is more specific, and seems to be more stringent. It is derived from the need for two horns aligned in the focal plane to look at the same direction during sky survey.

Image quality - Wave front Error

Telescope performances are specified in terms of RF performance (gain), Image Quality performance (WFE) and ellipticity (see RD 6). These performances are assumed to be applicable to the telescope assembly.

The Image Quality requirement has been used to assess the required alignment performance and stability of the reflectors and the FPU since it is easier to manage with optical software.
WFE requirements defined in RD 6 for different frequency (to which are associated specific position of the focal surface) are applicable to alignment plan:

WFE degradation must not exceed 42µm, 28µm WFE degradation being the design goal.

Gain and ellipticity are covered by WFE specification, and thus are not analysed here

### 3.4 Analysis

The underlying philosophy of the following analysis is that:
- Until the PLM level, main alignment and stability needs of optical elements are driven by imaging quality concerns, and thus WFE. Impact on LOS is mainly undergone.
- At PPLM and satellite level, alignment has no impact on WFE Error, and is thus driven by Absolute Pointing Error requirements.

#### 3.4.1 Wave front error

From the WFE requirement of the telescope assembly and the sensitivity analysis performed on the tilt and decenter of the PR, SR and FPU (see RD1), a Wave Front Error (WFE) budget has been built up to assess the allocations for the telescope, the FPU and the telescope/FPU integration which allows to reach the telescope assembly stage (Figure 3-2).

![Telescope assembly WFE budget breakdown](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope WFE degradation at a defined field position including apodization</td>
<td>31 µm rms</td>
<td>24 µm rms</td>
</tr>
<tr>
<td>FPU WFE degradation at 217 GHz including apodization</td>
<td>16.5 µm rms</td>
<td>8.5 µm rms</td>
</tr>
<tr>
<td>Telescope - FPU integration</td>
<td>16.5 µm rms</td>
<td>8.5 µm rms</td>
</tr>
<tr>
<td>Margin wrt the requirement</td>
<td>16.5 µm rms</td>
<td>wrt the goal: 8.5 µm rms</td>
</tr>
</tbody>
</table>

Figure 3-2 : Telescope assembly WFE budget breakdown

From these WFE allocations, PR, SR and FPU tilt and decenter requirements are derived. They shall be fulfilled taking into account at least the various contributors as defined in Figure 3-3, Figure 3-4 and Figure 3-5.

Alignment requirements derived from the WFE performance are described hereafter.
Alignment requirements at reflector level:

- Misalignment (including knowledge) of best fit ellipsoid (BFE) w.r.t. to the reflector mechanical interface must be lower than:
  PR: +/-0.1mm translation along each axis, and +/-0.1mrad rotation around each axis
  SR: +/-0.1mm along each axis, and +/-0.1mrad around each axis

- Stability of best fit ellipsoid w.r.t. to the reflector mechanical interface must be better than:
  PR: +/-0.1 mm along each axis, and +/-0.1 mrad around each axis
  SR: +/-0.1 mm along each axis, and +/- 0.1mrad around each axis

For the in-orbit reflectors deformations not to induce a WFE degradation higher than 6µm, the following stability of curvature radius R and conic constant K are required (this does not include cool-down effects, which are compensated on ground):

<table>
<thead>
<tr>
<th>Reflector</th>
<th>Parameter</th>
<th>Tolerance</th>
<th>Induced WFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR</td>
<td>Radius</td>
<td>+/-0.25mm</td>
<td>1µm</td>
</tr>
<tr>
<td></td>
<td>Conicity constant</td>
<td>+/-0.0003</td>
<td>2µm</td>
</tr>
<tr>
<td>SR</td>
<td>Radius</td>
<td>+/-0.2mm</td>
<td>5µm</td>
</tr>
<tr>
<td></td>
<td>Conicity constant</td>
<td>+/-0.0003</td>
<td>2µm</td>
</tr>
<tr>
<td></td>
<td>Quadratic sum</td>
<td></td>
<td>6µm</td>
</tr>
</tbody>
</table>

Alignment requirements at telescope level

- Misalignment of reflector mechanical interface w.r.t. to telescope mechanical reference frame must be lower than:
  PR: +/-0.05mm translation along each axis, and +/-0.1mrad rotation around each axis
  SR: +/-0.05mm along each axis, and +/-0.2mrad around each axis

- Minimum adjustment range of the SR - from which are derived from:
  - Maximum misalignment of BFE wrt. to the reflector mechanical interface
  - Maximum misalignment the reflector mechanical interface wrt. telescope mechanical reference frame
  is: +/-1 mm along each axis, and +/- 3mrad around each axis.

In order to fulfill WFE requirements, the accuracy of SR alignment must be better than:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx</td>
<td>0.07 mm</td>
</tr>
<tr>
<td>Ty</td>
<td>0.05 mm</td>
</tr>
<tr>
<td>Tz</td>
<td>0.07 mm</td>
</tr>
<tr>
<td>Rx</td>
<td>0.10 mrad</td>
</tr>
<tr>
<td>Ry</td>
<td>0.05 mrad</td>
</tr>
<tr>
<td>Rz</td>
<td>0.10 mrad</td>
</tr>
</tbody>
</table>

- Misalignment of the FPU/telescope mechanical interfaces wrt telescope mechanical reference frame must be lower than:
  +/-0.05mm translation along each axis, and +/-0.2mrad rotation around each axis
Taking into account the previous requirements, the following optical interfaces should be respected:

The best focus at operational conditions, i.e. image of a collimated beam directed in the theoretical nominal LOS direction shall be located within a cylinder of diameter of 1mm and length of 4mm around the theoretical nominal focus location Ordp (see P-TEL-PHY-045 in RD5).

This best focus shall be known to be within a cylinder of 0.5 mm diameter and 0.5 mm length, with the cylinder axis in the Z_{ftp} direction of the FPU co-ordinate system (see P-TEL-PHY-050 in RD5).

This knowledge will have an impact on the position of the FPU w.r.t. focus and consequently on the telescope WFE.

**Alignment requirements at FPU level**

Two contributors to WFE degradation by FPU manufacturing have bee identified:

- actual geometry and orientation of each horn. 11.5 microns rms WFE are allocated
- actual location of each horn wrt FPU/telescope interface: 11.5 microns rms WFE are allocated

The previous 11.5 µm WFE allocation induced by mislocation of the horns leads to the following alignment tolerances:

+/-0.4mm translation (position and stability) along each X and Y axis, and +/-0.5mrad rotation around each X Y axis

+/-0.5mm translation along Z axis of the average focal plane surface wrt its theoretical Z position (manufacturing + cool-down)

+/-0.1mm maximum deviation (position and stability) along Z axis wrt to average focal plane surface

+/-0.1mm knowledge accuracy of the average focal plane surface Z axis position wrt its theoretical Z position.

**Alignment requirements at telescope assembly level**

- manufacturing precision of focal shim thickness is +/-10µm.

- Maximum focal shim parallelism tolerance is 0.1 arcmin
Figure 3-3: Telescope WFE main contributor

Telescope WFE degradation at 857 GHz horn position including apodization
Requirement: 31 µm rms
Goal: 24 µm rms
Figure 3-4 : FPU requirement and main contributors

Maximum WFE degradation induced by FPU at 857 GHz horn position including apodization
Requirement : 16.5 µm rms
Goal : 8.5 µm rms

Horn geometry under operational environment
FPU tilts & decenter effects

Manufacturing
Launch effects
Gravity release
Cool-down effects
In orbit effects

knowledge accuracy of horn position along Z axis
manufacturing accuracy of horns along X and Y axis
knowledge accuracy of horn position along Z axis
position accuracy of horn position along X and Y axis
Thermoelastic effects
Moisture effects
Figure 3-5: Telescope/FPU integration requirement and main contributor

Maximum WFE degradation induced by FPU integration at 857 GHz horn position including apodization
Requirement: 16.5 µm rms (goal 8.5µm)

Best focus position

FPU integration accuracy

- Knowledge accuracy of telescope best focus
- Knowledge accuracy of FPU focal surface

- Position accuracy of the best focus along X & Y axis
- Integration accuracy / Z axis (adjustable shim manufacturing accuracy)

- Integration accuracy / X and Y axis

- Knowledge accuracy of the best focus along Z axis

Figure 3-5: Telescope/FPU integration requirement and main contributor
3.4.2 Line of Sight

The following contributors to APE have been identified:
- AOCS performances
- LOS theoretical position, actual position, knowledge, stability
- spin axis theoretical position, actual position, knowledge, stability

There are actually two ways to fulfil LOS requirements:

1) if LOS must be exactly aligned on its theoretical direction (85° wrt spin axis), then an adjustment of the satellite spin axis will be used. It uses an inertia measurement device, and the inertia axis are adjusted by adding mass.
2) if the LOS need is not its absolute position wrt to satellite spin axis, but its deviation wrt to known (measured) position, then a spin axis adjustment won’t be necessary for LOS.

However, a spin axis adjustment will certainly have to be done for around LOS purposes, and in any case to adapt actual mass repartition wrt anticipated one.

The underlying hypothesis of the actual LOS budgets is that, at satellite level, the spin axis is adjusted (by adding a little amount of mass) to match as best as possible its theoretical orientation (85°) wrt actual LOS of Planck telescope. This concerns LOS and around LOS alignment. Thus,
- LOS positioning budgets until telescope assembly level are needed to assess which amplitude will have to have spin axis adjustment
- data on spin axis adjustment accuracy, LOS stability budgets, and LOS knowledge budgets give final APE contribution, for both LOS and around LOS.

WFE is driving alignment requirement until telescope assembly level. Nevertheless, in order to have
-a reasonable adjustment range compatible with adjustment method,
-a good knowledge of LOS before spin axis adjustment,
the following alignment requirements at PPLM and satellite level have been derived:
Alignment requirements at FPU:

Each horn position (X and Y) will have to be known wrt telescope/FPU mechanical interface with an accuracy better than +/-0.1mm

Each detector line will have to be known to be aligned parallel to Y axis wrt to telescope/FPU mechanical interface with a 1 arcmin accuracy - this has a direct impact on around LOS knowledge.

Alignment requirements at telescope level:

FPU/telescope mechanical interfaces will have to be known wrt telescope reference frame, with the following accuracy:
+/-.05mm along X and Y axis,
+/-.5arcmin around O rdp

Telescope assembly/cryostructure alignment requirements:

Telescope assembly/cryostructure interface plane must be perpendicular to telescope Z axis with an accuracy better than 1.3 arcmin, this corresponds to 0.8mm of cryostructure parallelism on a ~2100mm interface diameter.

PLM/SVM alignment requirements:

PLM/SVM interface plane must be perpendicular to Z axis with an accuracy better than 1.6 arcmin, this corresponds to 1mm of SVM parallelism on a ~2100mm interface diameter.

At first, fig 3-6 is a global breakdown at satellite level. It represents the PLM contributors to the APE requirements.
Then fig. 3-7 represents the budgets of actual LOS position (along and around theoretical LOS), leading to the necessary amplitude of spin axis adjustment.
APE along LOS

PLM contribution to APE requirements
11.7 arcmin (LOS)
7.8 (around LOS)

Spin axis adjustment accuracy
LOS deviation
launch and in orbit effects
On ground LOS knowledge

telescope
FPU

Figure 3-6 LOS requirement and main contributors

maximum adjustment range
TBD arcmin

Wobble bias
TBD arcmin
on ground
LOS orientation / PLM
PLM/SVM orientation

telescope assembly
telescope assembly / cryostructure

Figure 3-7 LOS adjustment range – main contributors
4. AIT PHILOSOPHY AND ALIGNMENT CONCEPT

For cost and technical reasons the verification of the alignment performances of horns inside the telescope is not possible by end to end tests at operating temperature at satellite level so indirect verifications by alignment survey at each stage of the AIT is proposed following the sequence summarised in Figure 4-1.

4.1 Telescope

The telescope is aligned to meet both the image quality and LOS requirements for the theoretical location of the FPA at cryogenic temperature.

For this alignment, the two reflectors are equipped with corner cubes and optical balls (see RD4), and an optical quality measurement device (Wave Front Sensor) is used. Moreover, a test FPU with optical references will be used to control the alignment at cryogenic temperature. Thus, it will have to be representative in terms of thermal behaviour, and to be equipped with optical balls and cubes.

A coarse alignment based on theodolite measurement method using optical reference on the structure, the 2 reflectors and the FPU allow the adjustment of the primary mirror and a first adjustment of the secondary. This first alignment should be sufficient to meet the LOS requirement.

A fine adjustment of the secondary mirror is then performed by a wave front analysis method. The minimisation of the WFE will optimise the image quality.

The thermo-elastic behaviour of the telescope structure must be taken into account when adjusting the telescope at ambient to implement the necessary focus offset which will give the correct focus location at cryogenic temperature.

The telescope optical and alignment performances are verified under mechanical and cryogenic environments, particularly the FPU stability at cryogenic temperature because this measurement cannot be performed during cryogenic test at PLM level (baffle around the telescope limiting the sighting possibilities).

4.2 Instruments

Prior to delivery for integration in the telescope focal plane, HFI and LFI must be integrated together and the horns must be aligned (centring, focus and orientation) with respect to its mechanical interface with the telescope. Their locations are given w.r.t. an optical alignment reference (mirror and mark) at ambient and cryogenic temperature.

Here also the alignment performances must be checked with the environment tests at instrument level.
4.3 PLM and Satellite

The telescope is mounted on the cryo-structure of the PLM without any adjustment (however, a shim which is located at the telescope assembly/cryostructure interface could be used for an eventual adjustment at this level).

During the PLM integration, the FPU alignment is obtained by the mechanical mounting and by similarity with the test FPU used to align the telescope. Then the alignment w.r.t. the telescope reference frame is controlled using FPU alignments cubes.

Then the satellite must be balanced in order to adjust the spin axis direction w.r.t. the instrument line of sight (through the telescope reference frame).

At system level the telescope and FPU alignment is measured and reported in the spacecraft reference frame.

The verification of the alignment stability at satellite level will be performed:

1) through theodolite measurements on the optical targets (alignment cubes and optical balls) located on reflectors and FPA (TBC).
2) The LOS direction (w.r.t. the telescope reference frame) will be measured during the RF ambient test of the RFQM for the representatives LFI horns of FPA. (this will validate the alignment philosophy and accuracy)
3) End to End alignment verification should be possible on 306GHz LFI horns, (if LFI capability to operate at ambient is confirmed)

From all these measurements the LOS of each horn in the satellite reference frame is derived.
Telescope structure with optical reference

Primary mirror with optical reference

Secondary mirror with optical reference

FPU alignment model with optical reference

Telescope integration with optical reference

PM & SM coarse adjustment (theodolite method)

SM fine adjustment (WFE method)

Compensation of in orbit effects (hygro, thermal)

Cryogenic test (WFE, LOS)

Re-adjustment (if necessary)

Telescope mechanical environment tests align. & WFE control

RF ambient test LOS measurement RFQM only

FPU with optical reference

PLM integration adjustment of BEU I/F on PLM platform

PLM test

Satellite integration & tests

Satellite balancing Spin axis adjustment / satellite opt. ref

LFI RF ambient test LOS measurement in S/C ref. frame

LOS computation in the satellite ref. frame when cold

Figure 4-1 PLANCK Alignment sequence
TELESCOPE QM
TELESCOPE ALIGNMENT
- Ambient
- Cryogenic
- Vibration
- Thermal cycling

FPU INTERNAL ALIGNMENT
- horn s / optical references / mechanical interface

INSTRUMENTS QM

FPA / TELESCOPE ALIGNMENT
- LOS Direction (RF test)
- Ambient

PLM QM
- Control of HFI / LFI co-alignment (ambient)

ALIGNMENT CONTROLS:
- mirrors, FPA
- Ambient
- Vibration
- Cryogenic
- SPIN AXIS ALIGNMENT (balancing)

FPA / TELESCOPE ALIGNMENT
- Ambient

PLM RFQM

INSTRUMENTS FM

FPU INTERNAL ALIGNMENT
- horn s / optical references / mechanical interface

TELESCOPE FM
TELESCOPE ALIGNMENT
- Ambient
- Cryogenic
- Vibration

FPA / TELESCOPE ALIGNMENT
- Ambient

PLM FM
- Control of HFI / LFI co-alignment (ambient)

ALIGNMENT CONTROLS:
- mirrors, FPA
- Ambient
- Vibration
- Cryogenic
- SPIN AXIS ALIGNMENT (balancing)

LOS (LFI RF ambient test)

PLANCK QM

PLANCK FM

PLANCK STM

PLANCK PFM

Qualification

Acceptance

Figure 4-2 Planck Alignment verification on QM and FM
5. ALIGNMENT MEASUREMENT METHODS

5.1 Theodolite measurements

Most of the alignment of the different elements (reflectors in the telescope structure, FPU in the telescope focal plane, telescope LOS w.r.t the spin axis) are performed with theodolite measurements. This measurement method is well known and the measurement accuracy is in the range of:

- Angles: 10 arc sec; this is achieved between two corner cubes
- Position (lateral measurement): 0.1 mm. This is achieved between to balls being separated by 1m.

This method does not require an OGSE development: theodolite and optical cubes or alignment balls are available off the shelf.

At least, the following optical cubes and balls are necessary:

- FPU will be equipped with 1 ball (as a minimum) and 1 corner cube. both will have to be visible at satellite stage.

- Each reflector will be equipped with 3 optical balls minimum( 4 would be better) and 1 corner cube. On each reflector, 1 ball and the cube will have to be visible at satellite stage (with baffle), this might be done by amovible mount, which would be taken off before launch in order to save space under cover.

- Telescope reference frame shall be equipped with 2 cubes and 4 optical balls.

- SVM reference frame shall be equipped with 2 cubes and 4 optical balls.

The criterion for location of the optical references is limited to the capability of sighting under the various test configurations.

The figure here after present the typical alignment test configurations with the location of OGSE (theodolite and optical references). Satellite has its X axis parallel to the ground, so that theodolite pointing is horizontal.
5.2 Telescope WFE measurement

The final adjustment of the secondary reflector w.r.t the primary reflector to achieve the required image quality. The minimisation of the WFE will optimise the image quality. The measurement of the WFE (typically an Hartmann method) will have to have a 8.1mm accuracy, and can be performed at 10µm wavelength.

5.3 LOS Spin axis adjustment

Due to LOS - and especially around LOS- on ground misalignment, and to actual mass repartition, a spin axis adjustment will have to be done at satellite level. By adding a little amount of mass at given locations, this spin axis - which is naturally the principal inertia axis - is adjusted. The accuracy of such an adjustment on the order of magnitude of 2arcmin.
6. ALIGNMENT BUDGET

6.1 WFE

![Figure 6-1 telescope assembly WFE budget](image)

- PR & SR WFE: 29.5 µm
- PR & SR WFE due to MSE at operational: 28.5 µm
- PR & SR WFE misalignment of BFE at operational: 5 µm
- PR & SR WFE curvature in orbit stability: 6 µm
- PR & SR WFE due to MSE at operational: 28.5 µm
- PR & SR WFE misalignment of BFE at operational: 5 µm
- PR & SR WFE curvature in orbit stability: 6 µm
- PR WFE at operational: 20.4 µm
- SR WFE at operational: 20.4 µm
- Telescope assembly: 0.1 µm
- WFE Measurement accuracy: 8 µm
- Telescope WFE degradation at 857 GHz horn position including apodization: 11.3 µm
- Requirement: 31 µm rms
- Preliminary budget: 32 µm
- WFE induced by PR & SR tilts & decenters: 11.3 µm
- Gravity release: 2.1 µm
- Cool-down effects: 2.8 µm
- In orbit effects: 6 µm
- AIT: 8.1 µm
- Launch effects: 2 µm
- Gravity release: 2.1 µm
- Cool-down effects: 2.8 µm
- In orbit effects: 6 µm
- thermoelastic effects: 5 µm
- Moisture effects: 4.3 µm
Maximum WFE degradation induced by FPU integration at 857 GHz horn position including apodization
Requirement : 16.5 µm rms (goal 8.5µm)
preliminary budget : 3.7 µm rms

Best focus position
3.6 µm

Knowledge accuracy of telescope best focus along Z axis
3.2 µm

Knowledge accuracy of telescope best focus along X & Y axis
1.6 µm

Knowledge accuracy of telescope best focus along FPU focal surface
1.2 µm

Position accuracy of the best focus along X & Y axis
1.6µm

Integration accuracy of FPU focal surface
neg

Integration accuracy / Z axis (adjustable shim manufacturing accuracy)
0.7µm

Integration accuracy / X and Y axis
0.7µm

Figure 6-2 FPU/telescope integration WFE budget
6.2 LOS

Figure 6-3 alignment contribution to APE requirements
Figure 6-4 on ground offset: LOS and around LOS
7. REQUIREMENTS

7.1 At Reflectors level

Each reflector will be equipped with 3 optical balls minimum (4 would be better) and 1 corner cube. On each reflector, 1 ball and the cube will have to be visible at satellite stage(with baffle).

The optical surface of the reflectors (Best Fit Ellipsoid) must be measured with respect to these optical references.

- Misalignment (including knowledge) of best fit ellipsoid (BFE) w.r.t to the reflector mechanical interface must be lower than:
  PR: +/-0.1 mm translation along each axis, and +/-0.1 mrad rotation around each axis
  SR: +/-0.1 mm along each axis, and +/-0.1 mrad around each axis

- Stability of best fit ellipsoid w.r.t to the reflector mechanical interface must be better than:
  PR: +/-0.1 mm along each axis, and +/-0.1 mrad around each axis
  SR: +/-0.1 mm along each axis, and +/- 0.1 mrad around each axis

7.2 At Telescope level

- The reflectors must be adjusted to achieve the following accuracy in the LOS location wrt telescope reference frame:

  +/-2 arcmin LOS at operational
  +/-0.7 arcmin around LOS at operational

Which leads to the following accuracy in the telescope focal plane:

  +/-0.5 mm position accuracy along X and Y wrt theoretical position (Ordp)
  +/-0.7 arcmin around Ordp

FPU/telescope mechanical interfaces will have to be known wrt telescope reference frame, with the following accuracy:

  +/-0.05 mm along X and Y axis,
  +/-0.5 arcmin around Ordp

- Telescope reference frame shall be equipped with 2 cubes and 4 optical balls, being placed at TBD position.

7.3 At FPU level

The horns must be located with the following accuracy w.r.t the mounting interface to the telescope FPU:

  +/-0.4 mm translation (position and stability) along each X and Y axis, and +/-0.5 mrad rotation around each X Y axis

  +/-0.5 mm translation along Z axis of the average focal plane surface wrt its theoretical Z position (manufacturing + cool-down)
+/-0.1mm maximum deviation (position and stability) along Z axis wrt to average focal plane surface

+/-0.1mm knowledge accuracy of the average focal plane surface Z axis position wrt its theoretical Z position.

Each horn position (X and Y) will have to be known wrt telescope/FPU mechanical interface with an accuracy better than +/-0.1mm.

Each detector line will have to be known to be aligned parallel to Y axis wrt to telescope/FPU mechanical interface with a 0.1 arcmin accuracy – this has a direct impact on around LOS knowledge.

The instruments (HFI inside LFI) FPU must be delivered with an alignment cube and optical ball mounted at the rear side.

The location of this optical reference w.r.t the mechanical interface must be known with the following accuracy:

<table>
<thead>
<tr>
<th>Lateral</th>
<th>0.05mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>0.05mm</td>
</tr>
<tr>
<td>Tilt</td>
<td>20arcsec</td>
</tr>
</tbody>
</table>

### 7.4 At Satellite level

SVM reference frame shall be equipped with 2 cubes and 4 optical balls.

The spin axis of the satellite must be adjusted with an accuracy of 2 arcmin with respect to the telescope LOS.

The spin axis adjustment range must be at least 7.1 arcmin for LOS and 3.6 arcmin around LOS. These offsets should be much lower to the one due directly to actual mass repartition.
Annex 4

to the IID-A

Herschel Pointing Modes

SCI-PT-RS-07725
HERSCHEL / Planck Project

Herschel Pointing Modes

( Annex I to SRS )
TABLE OF CONTENTS

1 INTRODUCTION .............................................................................................3
2 RASTER POINTING........................................................................................3
   2.1 Normal raster pointing ............................................................................3
   2.2 Raster pointing with OFF-position..........................................................4
3 LINE SCANNING.............................................................................................6
   3.1 Normal line scanning ..............................................................................6
   3.2 Line scanning with OFF-position ..............................................................6
4 TRACKING OF SOLAR SYSTEM OBJECTS...............................................10
5 POSITION SWITCHING .............................................................................11
6 NODDING......................................................................................................12
1 INTRODUCTION

Herschel / Planck is an ESA mission that combines the Herschel (previously called FIRST) and the Planck missions within one single programme.

The Herschel telescope (previously FIRST: Far Infrared and Sub-millimetre Telescope) is dedicated to perform astronomical observations in the far-infrared and sub-millimetre wavelength range. Herschel, the fourth European Space Agency (ESA) cornerstone mission is a multi-user observatory type mission. The detectors of the Herschel instruments have to be cooled to cryogenic temperatures in the range of 0.3 to 2K in order to reach the necessary sensitivity for the observation of a variety of weak radiation sources.

This document defines requirements for Herschel pointing modes to support Scientific Observations, in particular to make maps of extended objects, or to make high sensitivity measurements. This document is annex to the Herschel / Planck Satellite System Requirements Specification (SRS) SCI-PT-RS-05991.

2 RASTER POINTING

2.1 Normal raster pointing

Raster pointing is a series of fine pointing observations of equal duration (t), separated by slews, in order that the pointing of the telescope axis moves in a raster pattern as defined in Fig. 1. In this figure the following notations are used:

- M is the number of pointings per line.
- N is the number of lines.
- $d_1$ is the spherical angular distance between successive steps.
- $d_2$ is the spherical angular distance between successive lines.

In addition the inertial attitude of the pattern is defined by the quaternion $Q_{rast}$ of the 1st raster point and an angle $\phi$ defining the rotation of the pattern axes with respect to local instrument axes.

The raster parameters, $\phi$, M, N, $d_1$ and $d_2$ are within the following range and resolution:

$\phi$: 0 – 90 degrees  
resolution: 0.1 degrees
M: 2 - 32
N: 1 - 32

d_1: 2 arcsec - 8 arcmin; resolution: 0.5 arcsec

d_2: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

Note that d_2 being zero, means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, t, will be between 10 seconds and 30 minutes.

2.2 Raster pointing with OFF-position

Raster pointing with OFF-position is a special form of raster pointing where, after a specified number of raster points (ON positions), the spacecraft slews to a predefined point (the OFF position), after which it resumes its raster pointing where it left the raster before going to the OFF position. The number of raster pointings (K) before going to the OFF position is determined by the timing characteristics of the raster pointing such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of raster pointing is shown in Fig. 2.

For the ON positions, the raster is defined by the parameters Q_{rast}, \varphi, M, N, d_1 and d_2, with for each position an equal observation time t. The definition of these parameters is given above for normal raster pointing and its range and resolution are specified below.

The OFF position is defined by the parameter Q_{off}, specifying the quaternions of the OFF position in inertial coordinates.

K is the number of consecutive ON positions before going to the OFF position, and t_{off} is the time of stable pointing in the OFF position.

The pattern is followed line by line and where after each K ON positions the spacecraft moves to the OFF position. After each OFF position, the raster pointing shall be resumed for the next K ON positions, etc. (Fig. 2).

The raster parameters, \varphi, M, N, K, d_1 and d_2 are within the following range and resolution:

- \varphi: 0 – 90 degrees resolution: 0.1 degrees
- M: 2 - 32
N: 1 - 32

K: 2 - M x N

d₁: 2 arcsec - 8 arcmin; resolution: 0.5 arcsec

d₂: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

The maximum value of K being equal to the total number of ON positions implies normal raster pointing with only a single OFF position pointing at completion of the raster.

Like for normal raster pointing, d₂ being zero means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, t, will be between 10s and 30 minutes.

The spherical coordinates of the OFF position with respect to the centre of the map shall be within the following range:

d₁₀ff: ±(0 arcmin - 2 degrees); d₂₀ff: ±(0 arcmin - 2 degrees)

The duration t₀ff, of stable pointing in the OFF position is within the range TBD s to TBD min.
3 LINE SCANNING

3.1 Normal line scanning

This is a scanning mode along short parallel lines, such that the telescope axis moves as shown in Fig.3 with parameters as defined below:

N is the number of lines.
D₁ is the angular extent of the lines.
d₂ is the angular distance between successive lines.

The inertial attitude of the pattern is defined by the quaternions Q_{scan} of the beginning of the 1ˢᵗ scan line and an angle \( \phi \) defining the rotation of the scan lines with respect to local instrument axes.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 3.

The scan parameters, \( \phi \), N, D₁ and d₂ are within the following range and resolution:

\( \phi \): 0 – 90 degrees  resolution: 0.1 degrees
N: 1 - 32
D₁: 1 arcmin - 20 deg; resolution: 1 arcmin
d₂: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

Note that the minimum of d₂ being zero, means that it shall be possible to scan N times the same line.

The scan rate, r, shall be changeable by ground command and will be between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

3.2 Line scanning with OFF-position

Line scanning with OFF-position is a special form of line scanning where, after a specified number of lines, the spacecraft slews to a predefined point (the OFF position), after which it resumes its line scanning where it left the pattern before going to the OFF position. The number of lines (K) before going to the OFF position is determined by the timing characteristics of the operation such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of line scanning is shown in Fig. 4.

The line scan pattern is defined by the parameters Q_{scan}, \( \phi \), N, D₁ and d₂ as given above.
The OFF position is defined by the parameter $Q_{off}$, specifying the quaternions of the OFF position in inertial coordinates.

$K$ is the number of consecutive lines before going to the OFF position, and $t_{off}$ is the time of stable pointing in the OFF position.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 4 and where after each $K$ lines the spacecraft moves to the OFF position. After each OFF position, the line scanning shall be resumed for the next $K$ lines, etc.

The scan parameters, $\varphi$, $N$, $D_1$ and $d_2$ are command within the following range and resolution:

- $\varphi$: 0 – 90 degrees resolution: 0.1 degrees
- $N$: 1 - 32
- $K$: 1 - $N$
- $D_1$: 1 arcmin - 2 degree; resolution: 1 arcmin
- $d_2$: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

The maximum value of $K$ being equal to the total number of lines implies normal line scanning with only a single OFF position pointing at completion of the line pattern.

The scan rate, $r$, is between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

The spherical coordinates of the OFF position with respect to the centre of the map shall be within the following range:

- $d_{1off}$: $\pm(0$ arcmin - 2 degree); 
- $d_{2off}$: $\pm(0$ arcmin - 2 degree)

The duration $t_{off}$ of stable pointing in the OFF position is within the range TBD s to TBD min.
Figure 1  NORMAL RASTER POINTING

Figure 2  RASTER POINTING WITH OFF-POSITION
Figure 3  NORMAL LINE SCANNING

FIGURE 4  LINE SCANNING WITH OFF-POSITION
4 TRACKING OF SOLAR SYSTEM OBJECTS

The satellite shall be able to follow, by ground commanded tables of coefficients of Chebyshev polynomials, objects such as planets, comets, etc. having a maximum speed relative to the tracking star of 10 arcsec/min.

The trajectory of such solar system object will be described by Chebyshev polynomials (TBC).

The attitude defining the raster ($Q_{\text{rast}}$) (for raster, position switching or nodding) and line scan patterns ($Q_{\text{scan}}$) shall also be possible reference to a solar system object, i.e. the whole pattern moves with the solar system object.
5 POSITION SWITCHING

Position switching is an observing mode in which the instrument line of sight is periodically changed between a target source and a position off the source.

Periodically the telescope pointing direction is changed between a target source and some position off the source.

This is a special case of normal raster pointing with the following raster parameters:

- $\varphi$: 0 – 90 degrees  resolution: 0.1 degrees
- $M$: 2
- $N$: 1 - $n$
- $d_1$: 2 arcsec – 2 deg;  resolution: 0.5 arcsec
- $d_2$: 0

The integration times in the "on" and "off" positions are equal and are within the range of 10 s (TBC) to 20 min (depending on the throw).
6 NODDING

Nodding is an observing mode in which the target source is moved from one instrument chop position to the other chop position. In this case the pointing direction will change in the direction of the instrument chopper throw.

Periodically the telescope pointing direction is changed such that the source is moved from one instrument chop position to the other position.

This is a special case of normal raster pointing with the following raster parameters:

\[ \varphi = 0 \]

\[ M = 2 \]

\[ N = 1 - n \]

\[ d_1 = 2 \text{ arcsec} - 16 \text{ arcmin}; \quad \text{resolution:} \quad 0.5 \text{ arcsec} \]

\[ d_2 = 0 \]

The integration times in both positions are equal and are within the range of 10 s (TBC) to 20 min (depending on the throw).