PACS

Instrument Description Document

Part II

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<td>Prepared by</td>
<td>O. H. Bauer</td>
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<td>H. Feuchtgruber</td>
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<td>O.H. Bauer</td>
<td>PM</td>
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<td>A. Poglitsch</td>
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# DOCUMENT CHANGE RECORD

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1. FPU

1.1 Summary

1.1.1 Scope

Note: This document contains a description of the preliminary mechanical, thermal and optical design of the PACS FPU, dedicated to the activities of KT, only.

All dedicated documents and drawings specifying the related design, performances and budgets are referenced.

1.1.2 Conclusions

The current status of the design is subject to the Instrument Baseline Design Review (IBDR). The FPU has been designed to meet the requirements defined in the applicable documents according to section 1.3. The preliminary design, interfaces, performances and budgets are summarized in this document. The related documentation is summarized in Figure 1.1-1.

1.1.3 Abbreviations

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<td>AD</td>
<td>APPLICABLE DOCUMENT</td>
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<tr>
<td>BB</td>
<td>BREAD BOARD</td>
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<tr>
<td>CQM</td>
<td>CRYOGENIC QUALIFICATION MODEL</td>
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<tr>
<td>FPFPU</td>
<td>FIRST PACS FOCAL PLANE UNIT</td>
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<tr>
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<td>INTERFACE</td>
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<tr>
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<td>THERMAL MASS DUMMY</td>
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1.2 Instrument Overview

1.2.1 Architecture and Responsibilities

PACS is one of the 3 focal plane instruments of the FIRST/Herschel telescope. It is located within the cryostat and attached on an optical bench. The FPU comprises the subsystems depicted in Figure 1.2-1. The structure, optics, etc. as well as the flip mirror mechanisms have been designed by KT. The detectors and other mechanisms have been designed under the responsibility of the PACS consortium.

The mechanical configuration of the FPU is depicted in Figure 1.1-1. A detailed definition of the design is given in the drawings and specifications identified in RD2 and RD8.
Figure 1.2-1: Architecture and Design Responsibilities
### 1.3 Mirror Technology

#### 1.3.1 Material and Fabrication

As the result of a trade-off with environmental and performance requirements, the mirrors are made from forged aluminium alloy AA-6061 T6, matched to the thermo-mechanical properties FPU. Their bodies are light weighted, their surfaces single-point diamond-turned/milled. The mirrors are coated with an environmentally stable infrared-reflective coating.

#### 1.3.2 Coating

The coating method chosen was a HF-sputtered gold coating of sufficient thickness to ensure bulk reflection properties, over a thin chromium diffusion barrier to prevent migration of the gold into the base alloy. The composition is: Cr \( t \approx 20 \text{ nm} \) + Au \( t > 200 \text{ nm} \).

#### 1.3.3 Tolerances

**Large-Scale Surface Error**

Large-scale deviations are defined for spatial frequencies lower than 0.5 mm\(^{-1}\). Mirrors were specified to have a surface error of < 0.5 \( \mu \text{m} \) RMS compared to their design shape, over their clear aperture.

**Small-Scale Error**

Small-scale deviations (surface roughness) negatively affect the scattering properties of the mirror surfaces in the FIR, as well as their suitability for visible alignment. All mirrors have less than 50 nm RMS surface roughness.

#### 1.3.4 Surface Definitions

The surface definitions of the optical components are listed in annex A.

#### 1.3.5 Oversizing

All optical components of FPU have been oversized with at least 5% of the beam footprint, or 2 mm, for alignment margin. Additionally, some of the mirrors in the image slicer and spectrometer section received extra oversizing to allow as many diffraction side lobes as possible to propagate to the detectors (diffraction throughput).
1.3.6 Optical Quality

1.3.6.1 Spectral Region

The working spectral region is 60 - 210 µm.

1.3.6.2 Wavefront Specification

The contribution of each mirror to the overall wavefront distortion (WFE) budget, for each pixel in the FOV, is specified to < 0.5 µm RMS. This is related, but not identical, to the surface specification made in 1.3.4 above.

1.3.6.3 Spectral Transmittance

The spectral reflectance of the selected mirror coating was calorimetrically measured at 4.2K with a FIR laser (bold values)

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<th>Reflectivity [%]</th>
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<td>60</td>
<td>(99.5)</td>
</tr>
<tr>
<td>118</td>
<td>99.6 (99.55)</td>
</tr>
<tr>
<td>184</td>
<td>99.7 (99.65)</td>
</tr>
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</table>

The values are consistent with the bulk reflectivity of pure gold (in parentheses).
1.4  Filter Wheel

1.4.1  Overview

In the FPU one filter wheel each is integrated in the blue train of the Bolometer and spectrometer. The filter wheel assembly (see Figure 1.4-1 and 1.4-2) comprises a flat disc with 2 filter wheel positions, the magnetic motor drive, Hall effect sensors for position detection and 12 magnets for filter wheel rotor positioning. The complete filter wheels is assembled on a single adapter plate. The filter wheel is designed to sustain the launch environment without any support or launch locking device.
The requirements given in AD4 are covered by the following design:

- **Stop positions**: 2
- **Flip angle**: $0^\circ > 180^\circ > 360^\circ$
- **Precision of end stop**: $30 \text{ arcmin}$
- **Power dissipation per position change**: $< 50 \text{ mWs}$
- **Transition time**: $\leq 5 \text{ sec (average)}$
- **Operating temperature**: 3-300 K
- **Warming of parts within view of detector**: $< 0.1 \text{ K (filter wheel assembly requirement, only)}$
- **Duty cycle**: 1 per 30 min.
- **Operational life time**: $\geq 20000 \text{ cycles}$

The mechanism uses two ball bearings in order to rotate to one filter position. Dry gold coated ball bearings with a lifetime of 100000 cycles shall be used. The position accuracy for the two positions is achieved by means of a magnet supported fixation device at each position. An
accuracy of 10 arcmin will be achieved. In order to reduce the risk of rotating ball bearings always switching in reversed direction between two end stops, the mechanism is allowed to rotate a total of 360 deg. The ball bearings will be operated always in the same direction. This on the other hand reduces the risk of damage during launch, because no launch fixation is necessary. The motor to be integrated is a brushless motor with magnets positioned at the rotor. A position indicator on each end stop shall be realized by means of a hall sensor operable only during transition time. Therefore the motor and also the position indicator are in a powerless dormitory mode during measurement time of the instrument.

The filter wheel mechanism is mounted to the adapter plate. The filter wheel is driven by a magnetic motor, which is also mounted to the adapter plate. Details are given in RD7. The main preliminary features are given in Table 1.4–1:

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<tr>
<td>diameter, rotor</td>
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<tr>
<td>axial length</td>
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<td>Temperature range (non operational)</td>
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<td>Temperature change during cryostat cool downs / heat ups</td>
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<td>Magnet number</td>
</tr>
<tr>
<td>Phases (each redundant)</td>
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<tr>
<td>Torque constant</td>
</tr>
<tr>
<td>Operational current</td>
</tr>
<tr>
<td>Power per FW (average)</td>
</tr>
</tbody>
</table>

Table 1.4–1 Drive Specification

The design is given in Figure 1.4–3 below.
1.5 Calibration Sources

1.5.1 Design Parameter

Requirements according to PACS Calibration Source Performance Requirements, (AD5).
The design parameters of the integrating sphere are as follows:

- Inner diameter: 50 mm
- Circular aperture diameter: 12 mm

Some parameters are difficult to be evaluated without testing and are tbd for that reason only.
The parameters of the sphere shall be changed and measurements be performed to evaluate all
relevant parameter. The requested temperature range is defined at 50 K to 100 K.
The calibration source is designed to be manufactured from aluminum hemispheres coated
inside with nickel and gold as highly reflecting surface with 96% reflectivity. The standard
coating is sputtered gold. This shows a reflectivity of 98.3% (118µm) and 98.8% (184µm).
This fulfills the requirements of reflectivity. Due to the fact, that the calibration sources are
pretty small compared to emitting hole, the homogeneity shall be reached by means of a
surface creating a Lambertian straylight behaviour. Sputtered gold acts nearly as a mirror in
the long wavelength range. A different surface treatment with rougher surface and coating
with gold is under evaluation.
The reflectivity is measured to be:

- 99% (118µm)
- 99.2% (184µm)

which is quite a bit higher and allows more reflections.

The emitter itself is an assembly of 2 PT500 resistors (118 MF from Goodrich aerospace, glued to each other) directly measuring the temperature of the resistor itself.

The size of the source is 6.4 mm x 5.2 mm x 6.0 mm (weight approximately 0.55 g and heat-capacity 0.45 J/K) and is connected according to 4 wire measurement technique (for each of the two resistors). The layout is shown in Figure 1.5–4.

The four feet carrying the emitter itself will be made of glas-fibre board FR4 with a cross section of 0.2 x 0.3 mm² and a length of 24 mm in order to reduce the thermal heat loss due to thermal conductivity (see Figure 1.5–3).

2 x stiffening rings are foreseen to prevent buckling.

The wiring will be performed by means of 8 phosphorous wires in radial direction with a diameter of 10 µm.

A maximum power of $P_H = 10\, \text{mW}$ shall be used for total heating, a power of $P_M = 1\, \text{mW}$ for drive and temperature measurement (using the voltage measurement). To realize a temperature of 100 K the source current shall be stabilized with a 15 bit resolution. This achieves a temperature determination of 5 mK. Therefore, the absolute accuracy of the current measurement determines the stability of the emission. Short term variations may be reduced by means of slow electronics (integration time). The standard temperature shall be defined during the testing phase.

The internal surface of the calibration source is designed to be highly reflective in order to reduce the absorption losses. The design presented achieves a mean of about 20 reflections reducing the output to 70%. Due to the fact that the emitting cone is not completely limited to +/- 11.5 deg / see figure 1.5-1), the additional loss is estimated to about 60% providing a reflectivity of 30%. To achieve a high homogeneity over the pupil (aperture), the directly emitting surface is designed as a highly reflective surface. This scatter plate is positioned in the middle of the sphere in order to block direct emission of the source and increase the homogeneity. The source itself is positioned in the shadow of the scatter plate.

The final design parameter of the source, scatter mirror and source mirror shall be defined after a testing phase at MPE. These parameters to be evaluated are as follows:

- Scatter mirror shape: conical
- Scatter mirror roughness: 1 mm rms
- Scatter mirror position: figure 1.5-1 and 1.5-2
- Source position: figure 1.5-1 and 1.5-2

The final design shall be agreed with MPE according to the test results and software simulations.
Figure 1.5–1  Layout of the calibration source

Figure 1.5–2  Inside of the calibration source with scatter plate
Figure 1.5–3  Emitter with PCB feet

Figure 1.5–4  Electrical setup at working temperature

Figure 1.5–5 and Figure 1.5–6 show the BRDF and the specular reflexion of the gold coating.
Figure 1.5–5  GOLD Coating BRDF (Bidirectional Reflectance Distribution Function)

Figure 1.5–6  GOLD Coating at 96 µm and 184 µm
1.6  FPU Structure and Baffles

1.6.1  Overview

The FPFPU structure is depicted in Figure 1.6–1 to Figure 1.6–3. It is designed to provide smooth load paths and high stiffness (see RD2). The primary structure comprises four stand alone modules. The primary substructures are made from aluminum alloy. The suspension struts are mounted at the structure. The detectors are mounted to the structure. The 1.7 K items within the Ge:Ga detectors are directly linked with the He-tank via two thermal 2 K feed throughs at the FPU housing wall.
Figure 1.6–2  Primary Structure (continued)

Figure 1.6–3  Primary Structure (continued)
1.6.2 Substructures and Subunits

The following 6 substructures with the integrated detector assemblies within the FPFPU housing are the baseline design:

Top optics
- Entrance optics (9 mirrors)
- Aperture stop
- Chopper (1 mirror)
- Calibration Source optics (4 mirrors)
- 2 Calibration Sources
- Vent opening

Slicer
- Slicer optics (5 mirrors)
- Image Slicer (14 mirrors)

Bolometer
- Bolometer optics (7 mirrors)
- Filter Wheel No. 2 (blue channel)
- Dichroic beamsplitter
- Vent opening

Bolometer Assembly
- Red/Blue Bolometer Array
- Cryo cooler
- FPU suspension struts (x, y, z)
- Temperature sensor

Collimator
- Collimator mirrors (2 mirrors)
- Grating Assembly
- Thermal coupling 4 K (1)
- Vent opening
- Temperature sensor at 4 K coupling

Spectrometer
- Spectrometer optics (7 mirrors)
- Blue/Red photoconductor arrays
- Filter Wheel No. 1 (blue channel)
- Dichroic beam splitter
- Distribution boards (2)
- Thermal coupling 4 K (2)
- Vent opening
- FPU suspension struts (x), (x, y)
- Temperature sensors (2)

A self supporting subdivided mainframe (barrel solution) with stiffening ribs, forms the rigid core of each substructure to which the optics and baffles are attached. The optical items are attached by adjustable interfaces, as necessary. Usually lateral, rotational and axial (shimming) adjustment is foreseen.

To prevent differential thermal contractions within the instrument, the structure and the optical components are made from aluminum alloys with nearly identical thermal expansion coefficients. Therefore, no thermal stresses and differential contraction will change the optical performance of the instrument.

The following baseline material for the substructure housings and baffles was selected:
- AA 6061 T6

In order to avoid internal stresses due to manufacturing process a special in house thermal treatment (RD5) will be applied prior and during the manufacturing.

## 1.6.3 FPU Suspension

The FPU suspension is configured to establish the isostatic mounting of the FPU housing and additionally a thermal decoupling of the instrument from the optical bench. The conductivity via the suspensions provides some heat load to the temperature level 1. Therefore the length/cross section ratio of the struts is designed as a compromise between thermal and mechanical requirements. Considering the very limited envelope and the high mechanical loads CFRP is offering the best performance in terms of stiffness, strength and minimized thermal conductivity.

The fastening of the housing has to fix the translations in three coordinate axes as well as the rotations about axes. By separating the directions a strap solution was found, where every strap supports one degree of freedom and is flexible for the others. In this optimized rod solution only three joints to the Optical Bench remain (Figure 1.6–4).

From this figure it can be seen, that this configuration exactly fixes the 6 degrees of freedom of the housing: the x-translation as well as the rotation about the y/z-axis is suppressed by the tree x-rods and the y- and z-translations are suppressed by the y- and the z-rods respectively. To fulfill the requirements (AD3) the Straps were matched in length and cross section. Because the position of the joints at the housing is free, this positions were chosen such, that the required length of the rods (determined by frequency, thermal and strength requirements) is possible within the allowable envelope.
The selected strap length was determined by several constraints:

- Stiffness along the strap axis to ensure minimum eigenfrequencies
- Upper limit of cross section dependant on length of the rod to limit heat transfer
- Lower limit of cross section to ensure strength and buckling resistance.

For the configuration according to Figure 1.6–4 the joint with three connected Straps can be handled as a fixed bearing. No flexibility is necessary to for the Straps. This ensures a determined location of the entrance beam w.r.t. the optics.

Mechanical Concept

- Struts length: 70 mm
- Cross section: 50 mm²
- I/F to external H/W: Aluminum fittings with 8 x M8 screw holes
- I/F fitting / strut: bolted

Material

The following materials were selected:

Baseline: CFRP with EN AW - 7075 fittings

- Matrix: Tenax HTA 5131
- Resin: Ciba Geigy (Araldite LY-3505)

Conclusions:

CFRP was pre-selected according to the sufficient and reliable mechanical properties, the minimum envelope and moderate heat conductivity at cryogenic temperatures compared with the other candidate materials.
1.6.4 Detector Suspension

6 struts / straps are configured to establish the suspension and additionally a thermal decoupling of the detectors from the FPU housing. The conductivity is a major source for the heat load of 1.7 K level, but the length/cross section ratio of the struts is designed as a compromise between thermal and mechanical requirements. CFRP, the selected material is offering very good performance in terms of stiffness, strength and minimized thermal conductivity.

1.6.4.1 Mechanical Concept

- Struts length/width: 70 mm/ 13 mm (see Figure 1.6–5)
- Wall thickness: 2-4mm (waisted)
- I/F to external H/W: EN AW-7075 fittings with 2 x M5 screw holes
- I/F fitting/strut: dia. 5 bolt

![Detector Struts Side/Iso View](image)

1.6.4.2 Material

The following materials were selected:
Baseline: CFRP with EN AW -7075 fittings
Matrix: TENAX HTA5131

Resin: iba Geigy (Araldite LY-3505)

1.6.5 Thermal Straps Feed Through

The following Figure 1.6–6 shows the feed through design of the 2 K thermal straps for the red and blue detector housing. The two 2 K thermal straps to the cryo-cooler is not described here.

![Feed through design](image)

Figure 1.6–6 Feed through design
A = Outside Sleeve, B = Inside Sleeve, C = Cold Finger, D = Retainer Ring 1, E = Retainer Ring 2, F = Muff, G = Ring

1.6.6 Baffles

An effective suppression of straylight and cross talk between the folded beams will be achieved by a large number of hierarchical baffles.
A field stop and Lyot stop at the temperature level 1 at the entrance optics and dedicated filters will significantly reduce straylight impacts induced by external sources. Details are given in RD20. The relevant baffles are given in Figure 1.6–7 to Figure 1.6–16.
Figure 1.6–9  Photometer housing seen from top optics

Figure 1.6–10  Bottom view of photometer housing (interface to bolometer)

Note: The 4th aperture stop at conic baffle to the detector arrays is not shown.
Figure 1.6–11  Collimator housing

Figure 1.6–12  Slicer seen from photometer
Figure 1.6–13  Slicer seen from collimator

Figure 1.6–14  Slicer internal view
Figure 1.6–15  Spectrometer seen from bottom (I)

Figure 1.6–16  Spectrometer seen from bottom (II)
1.6.7 IR Coating

The selected coating is specific Kayser-Threde inhouse coating at affected areas only, which will provide a 97% - 90% emissivity for 10° until 80° incidence. The effective paint thickness shall be 0.6 mm. Performance details are given in RD19.

1.6.8 Internal Interface

The internal interfaces are given in the following documents:
- RD9 Grating Assembly
- RD10 Detectors
- RD11 Chopper Assembly
- RD12 Distribution Boards
- RD13 Bolometer Assembly
- RD14 Filter Wheel
- RD15 Calibration Source
- RD16 Filter

1.6.9 Materials and Processes

Materials and manufacturing complies with space industry requirements (AD1). Established materials and manufacturing processes are selected. The materials and parts are compatible with the space environment. The structural materials are not be susceptible to stress corrosion. Where required, the parts are adequately protected against corrosion and moisture. As a general rule, no surface treatment is provided for stainless steel, beryllium, fiber-glass or carbon fiber, except for the needs of thermal control. Any other materials are surface treated with an approved method. Direct coupling of metal is avoided for an electrochemical potential difference more than 0.25 V. Electrically dissimilar materials are avoided for electrical bonds. The only permitted surface finishes for joint faces are (tbc):
- Clean metal, except magnesium
- Gold plate on the base metal
- Yellow chromatising (e.g Alodine 1200)

The spacecraft will be subjected to high radiation doses (tbd), which may be critical for material, such as, thermal paints and transparencies. The degradation of the properties of the chosen materials during the entire lifetime will be within acceptable limits.

Note: This requirement is assumed as N/A for FPFPU protected by cryostat vacuum vessel

In order to meet the stringent cleanliness requirements, all materials will satisfy the following outgassing criteria:
In general

- TML ≤ 1%
- CVCM ≤ 0.1%

Acceptance of standard parts and materials are based on guaranteed properties. Where these properties are not known, tests will be performed.

The selection of materials was based on the following criteria:

- Cleanliness
- Thermal coupling/de-coupling requirements
- Stiffness and strength
- Low mass

The main materials, coatings, adhesives and lubricants used are tabulated in Table 1.6–1, Table 1.6–2, Table 1.6-3. Details are given in the PMP list (RD18).

Most of the structural parts, such as the Top Optics, Slicer, Collimator, Spectrometer, Bolometer, Calibration Source, the mirrors and the filter wheel are made from aluminum alloy. Thermal decoupling of the photoconductor detector units from the FPU structure and the suspension of the total FPU structure is achieved by CRFP struts. The material coatings have been selected to satisfy the thermal radiation requirements.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Alloy</td>
<td>AA 6061 T6</td>
<td>Sub-Structures</td>
</tr>
<tr>
<td></td>
<td>EN AW-7075</td>
<td>Filter wheel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mirrors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strut fittings</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>X65Cr13 1.4037</td>
<td>Ball bearings</td>
</tr>
<tr>
<td></td>
<td>AISI 301 (1.4310)</td>
<td>Springs</td>
</tr>
<tr>
<td></td>
<td>A 4-70</td>
<td>Fasteners</td>
</tr>
<tr>
<td>Copper</td>
<td>Copper</td>
<td>2 K feed through</td>
</tr>
<tr>
<td>Carbon fibre epoxy</td>
<td>CFRP T300</td>
<td>TENAX HTA5131</td>
</tr>
<tr>
<td>Polyamide</td>
<td>Kapton</td>
<td>Tape, foil, wire insulation</td>
</tr>
<tr>
<td></td>
<td>Vespel Sp-3</td>
<td></td>
</tr>
<tr>
<td>Thermoplastics</td>
<td>PTFE</td>
<td>Wire insulation</td>
</tr>
<tr>
<td></td>
<td>Mylar (PETP)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.6–1 Materials**

<table>
<thead>
<tr>
<th>Coating</th>
<th>Specification/Supplier</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromating- ALODINE</td>
<td>LN 9368-1101</td>
<td>Aluminium parts</td>
</tr>
<tr>
<td>1200</td>
<td></td>
<td>(electrically conductive interfaces)</td>
</tr>
<tr>
<td>Gold sputtering</td>
<td>KT</td>
<td>Mirrors</td>
</tr>
</tbody>
</table>
### Table 1.6-2 Coatings

<table>
<thead>
<tr>
<th>Adhesive/Lubricants</th>
<th>Specification/Supplier</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Paint</td>
<td>KT 72</td>
<td>Calibration Source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Housing, baffles</td>
</tr>
</tbody>
</table>

### Table 1.6-3 Adhesives

<table>
<thead>
<tr>
<th>Adhesive/Lubricants</th>
<th>Specification/Supplier</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stycast Epoxy 2850-FT, Catalyst 9</td>
<td>Emerson &amp; Cuming</td>
<td>Structural parts</td>
</tr>
<tr>
<td>Epoxy compound</td>
<td>3 M</td>
<td>Gluing of Hall Sensors</td>
</tr>
<tr>
<td>Scotchweld EC 2216 B/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.7 FPU Performance

1.7.1 Alignment Stability

The alignment stability of the FPU is mainly determined by temperature changes. The axial and lateral changes of the detector position relative to the spacecraft/cryostat mounting interface (Optical Bench) are within the given tolerance:

1.7.2 Structural Analysis

1.7.2.1 Eigenfrequencies

The eigenfrequencies of the FPFPU are tabulated in RD3, together with the effective masses (RD3, RD5). The results are in compliance with the requirements (> 100 Hz) for the FPU as given in AD1.

1.7.2.2 Strength

The structure is able to sustain the worst combination of mechanical and thermal loads considering the appropriate safety factors (see section 3.4). Limit load factors are the worst combination of static and dynamic loads, pressure and temperature applied during handling, transportation, test, launch and orbit. The results of the preliminary quasi-static strength computations show no critical stresses (RD3). Adequate strength is demonstrated in terms of positive margins of safety with regard to limit load factors. The considered axial and lateral quasistatic limit load factors for the 2 nominal load cases and the superimposed safety factors applied to the suspended items are according to the requirements in AD1.

1.7.2.3 Moment of Inertia

The mass moment of inertia of the FPU was determined (RD6) for all flight hardware as required in AD1.

1.7.2.4 Center of Gravity

The center of gravity position of the FPU was determined (RD6) according to AD1 considering all hardware intended for flight w/o interconnecting harness.

1.7.3 Thermal Control

The FPFPU is a parasitic heat source to the CVV. The thermal budget for the operational reference case is depicted in AD1. A detailed description of the thermal behavior of the FPFPU is given in RD4. The description of the interface thermal mathematical model is given.
in RD4. However, an update of the very preliminary cryostat model is required in order to simulate in a representative manner the operational conditions. The thermal control system provides the following temperatures:

- For the reference load cases, i.e. operational flight modes, the required FPFPUs temperature level 1 and the detector temperature of level 0 can be achieved. The maximum thermal dissipation impact on both temperature levels is compliant (tbc) with the given budget.

### 1.7.4 Budgets

#### 1.7.4.1 Mass Budget

The total mass of the FPU baseline design is given in RD6.

#### 1.7.4.2 Power Budget

The dissipated power (tbc) of the supplied items is tabulated below:

- Filter Wheel Mechanisms (2) : 0.2 mW
- Calibration Source (2) : 1.5 mW at 100 K (operat. temp.) per calibration source

The thermal impact to the 2 K level (level 0) via the 2 thermal FPU housing feed throughs of the cooling straps is tabulated below:

- Feed throughs (2) : 0.15 mW (each)

### 1.8 Interface to Spacecraft

#### 1.8.1 Design Envelope

The design envelope of PACS FPFPUs is mainly determined by the cryostat, OB and HIFI, SPIRE interfaces. All hardware of the FPFPUs is within the specified envelope (AD2) with the following tolerances:

- For dimensions smaller than 500 mm the admissible tolerance is +0.5 mm to -0.0 mm
- For dimensions greater than 500 mm the admissible tolerance is +1.0 mm to -0.0 mm.

The design envelope is defined in the following Figure 1.8–1 (RD2).
Figure 1.8–1  Design Envelope
1.8.2 Optical Bench Interface

The FPFPU shall be mounted to the optical bench of the CVV by means of 6 struts with 8 bolts as depicted in Figure 1.8–2. The tree axis mounting pad contains a dowel plug which is drilled to fix relative position to the optical bench. The two axis mounting pad has a slotted hole(+- 0,1mm in z direction) to fix the rotation of the optical alignment (RD2).

![Figure 1.8–2 Optical Bench Interface](image)

The CVV optical bench mounting interface is designed according to AD1 to provide easy access during FPFPU integration. It contributes to a defined thermal contact. The mounting interface is designed to allow alignment during integration. A range of adjustment of ±3 mm vertical to the mounting plane is foreseen.

The FPFPU has 3 (AD2, RD2) interface points to the optical bench.

The instrument is hard mounted to the Optical Bench. The FPFPU provides in the 2 mounting pads a hole for a dowel (shear) pin of diameter 12 H7 and shimming plates (3 axes).
Details see ICD Drawing (RD2). Alignment mirror and cube positions are given in RD2 wrt. the reference coordinate system

1.8.3 Thermal Interface

The following thermal interface requirements are given (AD1):

Thermal contact conductivity:
- The optical bench is thermally insulated (S/C provided!). Temperature of the optical bench is \( \leq 10 \) K (tbc). The differential thermal shrinkage of the optical bench and PACS FPU is compensated by the PACS structure/ suspension system (i.e. 6 CFRP struts).
- The temperature level 1 (i.e. approx. 4 K) interface is provided by the cryostat. The thermal link (3 copper straps, AD1) is S/C provided. The location of the interface is on the side walls of the FPFPU. The layout and interface is given in RD2. No thermal stabilization of I/F temperature is provided. The Helium mass flow is constant.
- The level 0 interface (i.e. approx. 1.7 K) is provided by the He II tank. The thermal link (AD1) is S/C provided. The location of the Ge:Ga detector interfaces is on the side walls of the FPFPU (RD2), see Figure 1.8–2. The layout of the Ge:Ga detector 2 K feed throughs is given in chapt. 8.5. The level 0 interface of the bolometer sorption cooler is given in RD2. The interface temperature variations are tbd K/h on a timescale of days.
- The level 1 thermal interface shall be similar to the standard ISO mounting concept as given in AD1.
- The thermal harness interface data is specified in RD4.

Thermal radiative interface:
- The FPFPU is surrounded by the CVV instrument shield (approx. 2 K above the OB temperature), optical bench and neighboring instruments.

Emissivity:
- SPIRE housing: 0.2
- HIFI housing: 0.2
- Optical bench: 0.2
- Outer FPU surface: 0.2
- Instrument shield: 0.2

- Additionally, the aperture (0.002m², \( \varepsilon = 0.1 \)) from the telescope to the instrument via the CVV aperture will provide some thermal impacts on the FPFPU.
- Required interface temperatures (AD2):

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Operating</th>
<th>Start-up</th>
<th>Switch-off</th>
<th>Non-operating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Level 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(approx. 4.0 K)</td>
<td>3</td>
<td>5</td>
<td>NA</td>
<td>40 (tbc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Level 0</td>
<td>1.6</td>
<td>2.5</td>
<td>NA</td>
<td>40 (tbc)</td>
</tr>
<tr>
<td>(approx. 1.7 K)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
* Continuous temperature limit
** Short-duration temperature limit for bake-out during a maximum of 72 hours

During cryostat warm-up or cool-down phases the rate of temperature change $\Delta T/t$ shall not exceed 5 K/hour above 30 K (AD2).

### 1.8.4 Electrical Interface

#### 1.8.4.1 Grounding and Insulation

Distributed single point grounding system shall be realised (AD1). Grounding is performed via the level 0 and level 1 thermal straps.

#### 1.8.4.2 Connector and Harness

The cryogenic connectors and harness used are in compliance with AD1 and AD3. The cold FPFPU harness (temperature level 0 & 1) provided by Alcatel connects the external FPU connectors of following electrical units with the feed trough connector panels located at the inner cryostat wall:

- Grating assembly
- Photoconductor Detector & CRE & distribution boards(2)
- Bolometer (2)
- Chopper
- Temperature sensors
- Filter Wheels (2)
- Calibration sources (2).

Power distribution, command lines, signal lines for house-keeping purposes are the functional objectives for this harness. RD31 comprises the preliminary cold harness list, block diagrams, pin functions, expected currents and duty cycles, illustrating in detail the harness lines. The electrical harness interface is given in RD17, AD7 and AD2. The external mechanical FPU connector interfaces (accommodation) are given in RD2.

#### 1.8.4.3 Bonding

Bonding rules shall be considered (AD1). The grounding/bonding interconnection of the FPU with the S/C is provided by the thermal straps.

#### 1.8.5 Optical Interface

The entrance optics and field of view with reference to the instrument mounting interface is depicted in Figure 1.8–3. For optical alignment of the instrument on the Optical Bench one mirror cube on the FPFPU shall be mounted (AD2, RD2)
The normal to each of the reference surfaces shall be parallel to the spacecraft x-axis (tbc). The minimum size of the faces is 15 mm x 15 mm (tbc). The quality of the surfaces is compatible with auto-collimation requirements (planarity better than $\lambda/4$) (tbc). The reference surfaces are marked with a cross. The position of the reference surface with regard to the detector is known to a tolerance of less than 0.1 mm (tbc). Auxiliary reference mirrors for direct alignment check after the integration in PLM at cold conditions shall be provided: N/A.

The HERSCHEL telescope is described in AD1. The co-alignment requirements (budgets) between telescope, optical bench and the FPFPU are specified in AD2. The optical interface to the telescope is given in Figure 1.8–3. The alignment will be provided by the S/C Prime Contractor.

![Optical Beam Stay Out Envelope](image)
1.8.6 Handling Interface

The FPFPU shall be equipped with handling points. For ground handling the FPFPU feed-throughs and aperture shall be protected by covers. Handling equipment and covers mounted to the instrument being non-flight items shall be painted red or red anodized and shall be equipped with a red flag carrying the notation "NOT FOR FLIGHT".

The handling points shall be selected such that sufficient accessibility for mounting and positioning of the FPFPU will be provided. The handling equipment shall be designed for application of standard tools, if special tools are required, these shall be delivered together with the FPFPU.

The FPFPU shall be accessible and mountable from the + X side (tbc).

The FPFPU shall be mountable/dismountable without removing another experiment (tbc).

1.8.7 Interface Drawing

The following data are comprised according to AD1 in the external FPFPU interface drawing (RD2).

- Dimensions and tolerances (ambient and operational temperatures)
- Identifications of the reference hole
- Mounting hole pattern dimensions and hole pattern
- Footprint (contact area)
- Spot-faced area for seating of the mounting screw washers, if any
- Dimensions and location of dowel pins, if any
- Mass and tolerances
- Location, type, function of all connectors
- Identification of non-flight items
- Location of unit and connector identification labels
- Details of instrument provided mounting hardware, thermal/electrical isolating provisions
- Location and routing of any harness, interconnecting modules of a "stacked" box configuration
- Location of cold strap interfaces to Helium tank (level 0) and temperature level 1
- Calculated Center of Gravity location in instrument unit coordinate system and Moments of Inertia and its coordinate co-ordinate system if different from instrument unit coordinate system
- Location of transport/storage purging connections (if applicable)
- Material of housing and surface finish
- Roughness of contact area
- Base plate material
- Surface properties (IR-emissivity)
- Specific heat (J/Kg/K) (calculated or measured)
- Heat flow
1.9 Cold Harness

1.9.1 Architecture

Taking in account the requirements for the cold harness (1.7 - 15 K) the most demanding one concerns the heat flux via the harness. Thus, this has been the leading factor for the detailed design and the material selection based on the flight proven IBSS design. The cold harness is specified in AD7 and RD17 and connects the following units:

- 2 Photoconductor Detector (red and blue) and dedicated distribution boards
- 2 Filter wheels
- 4 Temperature Sensors
- 2 Calibration Sources
- Chopper (cable procured by C. Zeiss)
- Bolometer Array (cable procured by CEA)
- Grating Assembly (cable procured by CSL)
- Heater (cable procured by MPE)

Additionally dedicated grounding lines are applied where applicable.

The functional tasks are:

- Power distribution
- Command lines
- Signal lines (housekeeping)

1.9.2 Harness Design

The detailed design has followed the following principles:

General rules:

- Cross sections of harness wires and shields, if necessary, are minimized
- Connectors are mechanically locked to prevent inadvertent disconnection
- Connectors are pin coded and labeled to avoid wrong mating
- Harness is attached by tyraps and glued/bolted tyrap bases
- Twisted wires are routed through a connector on adjacent pins.
- The housing of the connectors shall be electrically connected to the unit structure
- Connectors according to ESA-SCC-3401
- Cables according to ESA-SCC-3901/021
- Crimping technology according to ESA-PSS-01-726 (soldering: ESA-PSS-01-708).
- All signal lines are shielded 4 wires cables (AWG 28-32; exception MPE cables with AWG 38 – tbc)
- Space proven Kapton/Teflon harness shows excellent cryogenic performance properties.
- Cannon ITT microminiature connectors, MDM 340102901B are used
- Only connectors having two pin planes, limiting the number of pins to 37, are used
1.10 Distribution Board

1.10.1 General description:

The distribution boards are directly linked to the Ge-Ga Detectors and provide a capacitor circuitry for detector control (e.g. bias voltage). The following figure 1.10-1 shows the overall layout.

---

**Figure 1.10-1 Distribution Board IF layout**

The distribution board contains 120 WIMA MKS2 6.8 MicroF 50V capacitors and resistors which are mounted on PCB boards. On one side of the distribution board is connected to the detector, the other side is connected to the OB connector board. The connector types and numbers are specified in annex A and B. The distribution board consists out of two electronic boards which are connected together with a flexible cable. The length of the flexible cable is 60 mm.

The harness from the detector to the distribution board will be delivered by the MPE, the harness from distribution board to the cryo vacuum vessel connector board will be delivered by the S/C contractor.
1.10.2 Electrical Specification for the Electrical Parts:

- Resistors: RNC 55. Specification ESA SCC 4001 001
- Capacitors: WIMA Capacitors MKS2 6,8μF, 50 VDC, 30 VAC,
- All parts will be qualified by ESA.
- \( R \) - connection at 4 K: tbd
- \( C \) stray \( \leq 20 \) pF to FPU housing and closed route
- All PCB lines are EMC Class 3

1.10.3 Configuration:

Both the PCBs for the Blue Detector and the Red Detector are rigid-flex boards.
- Envelope Blue Detector Distribution Board: 278,5 mm x 150,0mm x 28,0 mm
  - Integration with an angle of 94,5 degrees.
- Envelope Red Detector Distribution Board: 278,5 mm x 150,0 mm x 29,0mm
  - Integration with an angle of 180 degrees like a sandwich construction.

1.10.4 Materials:

The following materials are used for the Distribution Board:

- Distribution Board Housing: Al6061 – T6
- Distribution Board: FR4
- Flexible Harness: Polyimide

All Aluminum parts shall be yellow chromatised with Alodine 1200 according to LN9368 1101. The PCBs shall be not coated.

1.10.5 Shielding

Concerning the shielding the printed wire above, below, and beside a signal line shall be connected to the adjacent cryo harness cable shield to establish a cable shield. The detailed PCB Board lay-out and the internal harness is given in the acceptance data package (EIDP).

(further IF details see RD 17)
2. CHOPPER

2.1 Chopper

Due to the high IR-background flux emitted by the 80 K telescope it is necessary to apply differential measurements. This makes the focal plane chopper an essential part of the PACS instrument.

The chopper will also be used as an optical switch for illumination of the detectors by one of the two internal calibration sources (black bodies).

The science goals put stringent requirements on the PACS chopper:

- large elongation angle ($\pm 4.1^\circ$ nominal corresponding to $\pm$ arc min on the sky, $\pm 9^\circ$ in calibration mode)
- high precision of the chopper end position ($< 1$ arcmin)
- high chopping frequency (up to 10Hz)
- high duty cycle in square wave modulation scheme, fast transitions (80% nominal @ 10 Hz, 70% for calibration @ 5 Hz), higher values for lower frequencies keeping the transition times constant
- low power dissipation ($< 4$ mW)
- low microphonic noise
- very long lifetime under cryogenic conditions (around 630 Mio cycles)

The detailed specifications can be found in Table 2.1-1, a design overview in Figure 2.1-1.

To reduce development risks and costs the PACS chopper design is based on the ISOPHOT type, which worked flawless and precisely under similar environmental conditions during 29 month of the ISO mission. However the demanding requirements of PACS (larger mirror, larger throw, longer lifetime, etc.) made a new development necessary. The basic principle is that of a linear motor with extremely strong magnets moving in alternating (electromagnetic) fields produced by coils made of highly conducting Al-wires. The chopper rotation axis is defined by mounting the rotor arm carrying the chopper mirror onto two flexural pivots.

To fulfill the requirements, special attention had to be paid to

- long lifetime and reliability of the flexural pivots at cryogenic temperatures
- low mass of moving parts and low momentum of inertia

The feasibility has been demonstrated by a prototype at MPIA. This knowledge has been nearly fully adopted by the industrial contractor (Carl ZEISS, Oberkochen) in the development and
building of the flight hardware. The design description of the chopper is given in PACS-MA-TN-405. The achieved performance data for the flight hardware are compiled in Table 1.1-2 comparing the models FM1 and FS, the latter has been selected as the flight model (taken from similarity report PACS-MA-LI-754). Both models were delivered from MPIA/ZEISS to MPE: FM1 in June 2005 and FS in April 2006.

The lifetime requirements of Table 0-1 have been verified with a representative lifetime model (LM) at LHe (liquid Helium) temperatures. This LM model has also undergone LHe cryovibration experiencing the load levels as specified (see test report PACS-ME-TR-054 for details).

<table>
<thead>
<tr>
<th>Dimensions envelope</th>
<th>125 mm X 80 mm X 40 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>≈ 300 g</td>
</tr>
</tbody>
</table>
| Mirror optical performance | < 150 nm  
roughness | < 50 nm  
reflectivity | ≥ 98% |
| Mirror Size         | elliptical 26 mm x 32 mm  
moving axis ± 0.1 mm  
sharp edges 10° wedge shaped |
| Chopper inclination | 0° ± 4.1° accuracy ± 1 arcmin  
± 9° accuracy ± 2 arcmin |
| Modulation function | arbitrary waveform  
square wave |
| Frequency ranges    | 0 Hz ... 10 Hz, adjustable |
| final position time (duty cycle) | ≥ 80%  
≥ 70% |
| power consume. 10 Hz square wave | ≤ 4 mW at 4 K |
| 10% calibration 9°; 90% observation 4.1° | |
| Peak current (≤ 8,9°) | 100 mA |
| resistance (complete) for drive current | appr. 20 Ω |
| fail save position | zero position ± 1 arcmin |
| environmental condition for operation | vacuum, 4 K (operation at RT possible) |
| Cool down-/Warm up-cycles | ≥ 15 |
| vibration loads (4 K) | < 26 g  
< 8 g RMS |
| Lifetime | ≥ 6 years, operation 33 % of time  
570 Mio. cycles  
63 Mio. cycles |

Table 2.1-1: Chopper Specifications
<table>
<thead>
<tr>
<th>Model:</th>
<th>FM 1</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror surface (WFE):</td>
<td>300 nm rms</td>
<td>140 nm rms</td>
</tr>
<tr>
<td>Dynamic performance:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dwell</td>
<td>38/38 ms at ± 4.1° &gt; 70 ms at ± 9°</td>
<td>39/&gt;40 ms at ± 4.1° &gt; 70 ms at ± 9°</td>
</tr>
<tr>
<td>accuracy</td>
<td>&lt; -1° 0.5' at ± 4.1°</td>
<td>&lt; 0.5°' at ± 4.1°</td>
</tr>
<tr>
<td></td>
<td>&lt; 1.5°/1° at ± 9°</td>
<td>&lt; 0.5°/1° at ± 9°</td>
</tr>
<tr>
<td>overshoot</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; ± 1° at ± 4.1°</td>
<td>&lt; ± 1° at ± 4.1°</td>
</tr>
<tr>
<td></td>
<td>&lt; ± 3°/1° at ± 4.1°</td>
<td>&lt; ± 0.5° at ± 9°</td>
</tr>
<tr>
<td>Power requirements:</td>
<td>1.203 mW at ± 4.1°</td>
<td>0.724 mW at ± 4.1°</td>
</tr>
<tr>
<td></td>
<td>1.376 mW at ± 9°</td>
<td>0.366 mW at ± 9°</td>
</tr>
</tbody>
</table>

Table 2.1-2: Measured Performance Data

For redundancy the chopper has two field plates (FP 420 L90B) as position sensors. For each of them an angular calibration relation has been established. These are documented in the Chopper User Manual, PACS-MA-HM-755 for the FS model of the chopper now installed in the PACS-FM.

The offset of the mechanical zero point (no drive current) from the optical zero point (normal to the interface plate surface, determining the mounting orientation of the chopper in the FPU) was measured by Zeiss with an alignment telescope with regard to a reflecting "mirror" on the interface plate as normal reference. Special shims were then produced to trim the offset to better than 1°. This measurement was done with the chopper axis mounted in vertical position in the test cryostat. It should be noted that, after mounting the chopper device in the FPU and due to different orientations of the axis during ILT and IMT, some hysteresis in the flex pivots torque in combination with gravitational forces (during ground tests) may cause a slightly different mechanical zero position. Therefore, for each ground test and also in orbit one of the first actions with regard to the chopper operation should be the determination of the offset position on the angular calibration curve. Once this is done, the position read-out is corrected for this offset, so that the mechanical zero position is then also the electrical zero position.

In order to achieve the fast transition times and high plateau position accuracy with only small overshoots an active control of the drive had to be developed. The implementation comprises a PID loop, a velocity loop, a current feedback loop and a notch filter for suppression of axial resonances. The parameters of these loops must be tuned for an optimal performance of the chopper. Detailed descriptions of the control loop design and simulations are in the Chopper Electrical Interface Control Document (EICD) PACS-MA-TN-778 (FS model) for the Zeiss breadboard electronic, and PACS-CL-TN-036 (Chopper Control Description) and PACS-CL-SR-002 (DEC/MEC User Manual) for the DECMEC electronic, respectively. Caused by the different development schedules at MPIA/ZEISS and CSL, there are some differences in the
design of both electronics, so that care must be taken to translate the Zeiss EGSE control parameter set into the DECMEC control parameter set (see PACS Calibration Document PACS-MA-GS-001, req. 2.3.2).

For each chopper model Zeiss has established two parameter sets, one for the on-sky elongation regime and a second one for the calibration source regime, taking care of non-linearities of the chopper drive properties.

The chopper can also be operated in a degraded mode with a reduced number of drive coils (1 or 2 instead of 3 nominal ones). This can be controlled by switches by-passing a coil affected by e.g. a short-circuit. Several control parameters must then be adjusted.

![Chopper Design Diagram]

Figure 2.1-1: Chopper Design

A description of the chopper and the prototype development can be found in

3. GRATING DESCRIPTION

3.1 Overview

The Grating Assembly consists of a flat 320 x 80 mm² infrared diffraction grating; its positioning mechanism; and launch-lock. The Grating Assembly is part of the PACS Focal Plane Unit (FPU) and is operated at liquid helium temperature (4.2 K). The Grating Assembly is powered and remote-controlled from the Detector & Mechanism Controller Unit (DEC/MEC), which is located on the Herschel SVM.

The Grating Assembly is made of the following sub-elements, also shown in the following pictures:

- diffraction grating;
- bracket;
- bearings;
- actuator;
- angle position sensor;
- launch-lock device;
- temperature sensors;
- limit switches/mechanical stops;
- internal harness and connectors;

Figure 3.1-1 Grating View 1
3.2 Redundancy Concept

All electrical circuits of the Grating Assembly are fully redundant but operate in cold redundant mode. Nominal circuits are connected to the nominal DEC/MEC and redundant circuits are connected to redundant DEC/MEC respectively through separate harnesses. In case of failure in the nominal unit, the redundant DEC/MEC will be switched ON by the S/C.

Redundancy requirements are implemented as follows:

- one main actuator with two redundant coils and probes;
- two redundant position sensors;
- two redundant limit switches;
- two redundant temperature sensors;
- two redundant launch-lock actuators;
- two (x2) redundant launch-lock position sensors;
- redundant harnesses and connectors.

3.3 Diffraction Grating

3.3.1 Optical Design

Optical characteristics of the PACS Grating are summarised in the following table.
Table 3.3-1: Grating specifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>useful area</td>
<td>80 x 320 mm², sharp edges</td>
</tr>
<tr>
<td>wavelength range</td>
<td>56 - 210 µm (1st and 2nd orders)</td>
</tr>
<tr>
<td>operating temperature</td>
<td>4.2K</td>
</tr>
<tr>
<td>blank material</td>
<td>aluminum alloy 6061 T6</td>
</tr>
<tr>
<td>grating constant</td>
<td>$g = 8.5 \pm 0.05$ grooves / mm</td>
</tr>
<tr>
<td>position tolerances</td>
<td>for each groove $\pm 0.3$ µm from its theoretical absolute position in the dispersion direction: $x_n = (x_1 + (n-1)g) \pm 0.3$ µm</td>
</tr>
<tr>
<td>groove parallelism</td>
<td>$\pm 10$ arcsec from any groove to any other groove</td>
</tr>
<tr>
<td></td>
<td>$\pm 10$ arcsec from grooves to rotation axis</td>
</tr>
<tr>
<td>groove profile</td>
<td>depth $56 \pm 2$ µm</td>
</tr>
<tr>
<td>front surface accuracy</td>
<td>better than $\pm 3$ µm, r.m.s.</td>
</tr>
<tr>
<td>reflective coating</td>
<td>Au (with Ni sub-layer)</td>
</tr>
<tr>
<td>alignment provision</td>
<td>physical materialisation of groove axis by reference mirror surface</td>
</tr>
</tbody>
</table>

Figure 3.3-1: Grating Profile

3.3.2 Mechanical Design

The 6061-T6 aluminium alloy - which is also selected as the structural material - is widely used as blank material for metal optics applications because of its long-term stability. Moreover this alloy features a flat coefficient of thermal expansion (CTE) and a high thermal conductivity in the range 4 - 15 K that make it quite tolerant to temperature gradients. Typical manufacturing processes start with a forged blank tempered to T6 condition and machined by normal methods to within 1 mm of the nominal dimensions. Manufacture then proceeds through various cycles of machining, heat-treating, plating, and optical finishing.

The ruling requires a minimum thickness of about 5 mm to 7 mm of aluminium. Structural analysis will be performed to ensure sufficient stiffness and to decrease mass.

Connection between grating and mechanism shaft will be performed through athermal mounting in order to keep alignment during cool-down.
# 3.4 Bracket

Bracket will be machined out a single blank of aluminum alloy 6061T6. It will be the base of the grating on which will be mounted all sub-elements (motor stator, position sensor stator, bearings, launch-lock). This is also the element that will interface with the FPU.

Bracket will be lightweighted to decrease the total mass of the grating assembly. Optimisation of lightweighting will be done taking into account the mechanical requirements. The bracket is shown in the figure hereunder.

![3-D drawing of bracket](image)

**Figure 3.4-1 : 3-D drawing of bracket**

# 3.5 Bearings

The mechanical loads on the bearings are important due to the high mass of the grating and the rotor of the actuator. Also, the grating must be positioned at any stable position within its range with minimal energy consumption. For these reasons, ball bearings appear to be the best choice. Among the various available configurations, the oblique-contact ball bearings are preferred for mounting accuracy and their ability to withstand simultaneous radial and axial loads.

AISI440C stainless steel bearings with Vespel ball separators were chosen for this application. The rings are not coated in order to allow an accurate angular positioning with low torque. Indeed, experience showed that dry lubricating coating was creating high perturbations while useless due to the very low speed of rotation. However, the balls are coated with TiC mainly to avoid cold welding of the balls to the rings when cooling down to cryogenic temperature.

The inner diameter is 35 mm and the outer diameter is 55 mm. A preloaded double rows ball bearing is used on motor side and handles the largest part of the mechanical loads, avoiding ball separation and shocks in the bearing during launch. A slightly preloaded single row ball bearing is used on the other side to handles the radial loads coming from flexure of the grating shaft but
mainly to allow better axial alignment and angular guidance of the grating. The applied preload is such that the total friction torque of the two ball bearings will not exceed 0.01 Nm.

The preload and axial positioning of the bearings are done using spring washers in order to be independent from the temperature conditions. Axial mounting include spring washer in order to compensate differential expansion between bearing and housing.

The shaft inside the bearings will be made of equivalent stainless steel to avoid differential expansion. Coupling to the aluminium grating shaft is done using conical connections with spring washers compensating the differential contraction between aluminium and stainless steel.

![Figure 3.5-1: Configuration of ball bearing](image)

### 3.6 Actuator

The selected actuator is an axial brushless DC torquer (pancake type) of a type that was developed by the Tiefieneraturlabor (TTL) of the Freie Universität Berlin for the German InfraRed Laboratory (GIRL). The design has been specially adapted to match the torque and power dissipation requirements of the grating. The stator is ironless and comprises two phase windings and Hall probes for generation of signals for electronic commutation. The rotor carries SmCo magnets and is made of magnetic stainless steel to form a magnetic loop. The winding of each phase is split into two separate coils to allow redundant operation. The Hall probes are redundant as well. This type of motor was flown on CRISTA-SPAS two times as well as on IBSS IR instrument. It is also used for the PACS filter wheels.

In the present application an average dissipation of 3mW is tolerated to the 4.2K level.
Figure 3.6-1: Cryomotor configuration scheme (TTL/F.U. Berlin)

Table 3.6-1: Specifications of the cryomotor KRYO 115 (TTL/F.U. Berlin).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>external diameter</td>
<td>116 mm</td>
</tr>
<tr>
<td>axial length</td>
<td>30 mm</td>
</tr>
<tr>
<td>total mass</td>
<td>≤ 1.300 kg</td>
</tr>
<tr>
<td>rotor mass</td>
<td>≤ 1.020 kg</td>
</tr>
<tr>
<td>rotor inertia</td>
<td>1.3 \times 10^{-3} \text{ kg m}^2</td>
</tr>
<tr>
<td>motor constant at RT</td>
<td>0.08 Nm/√W</td>
</tr>
<tr>
<td></td>
<td>0.9 Nm/√W</td>
</tr>
<tr>
<td>maximum current (per phase)</td>
<td>400 mA</td>
</tr>
<tr>
<td>Impedance at RT (per coil set)</td>
<td>75 Ω</td>
</tr>
<tr>
<td></td>
<td>0.6 Ω</td>
</tr>
<tr>
<td>torque constant</td>
<td>≥ 0.7 Nm/A</td>
</tr>
<tr>
<td>Number of poles</td>
<td>12</td>
</tr>
</tbody>
</table>

The stator will be directly bolted to the bracket while the rotor will be interfaced with the stainless steel shaft of the double rows ball bearing.

### 3.7 Angle Position Sensor

Inductive sensor was chosen for this application. Inductive sensors measure the variation of the magnetic flux, as generated by a rotor, through two coils.

The position sensor is an inductive rotary transducer consisting of two non-contacting elements (stator and rotor). The rotor disk bears a periodic "printed circuit" pattern, with accurately known pitch interval (256/360°, i.e. 128 period/360°). The stator disk carries two periodic patterns of same pitch. The second winding pattern is displaced a quarter of period from the first winding pattern. An AC excitation signal applied to the rotor results in two output signals from the stator, for which the amplitude will vary as sine and cosine functions based on the relative position in the pitch cycle. There is a unique pair of sine and cosine output amplitudes for every position within one cycle of the pitch. The accurately known pitch interval may be subdivided with high
precision by measuring and processing the sine and cosine amplitudes in the DEC/MEC electronics.

In order to reduce ohmic losses in the instrument cryo-harness the rotors (excitation) will be equipped with 10:1 transformers. The transformer has been especially designed for this application by TTL/FUB. The DEC/MEC reads the sine and cosine signals through high impedance lines of the cryo-harness. To be independent from the harness impedance, amplification of the signals is done through two transformers placed on the grating. These transformers are PICOY440 specially qualified for this application.

For redundancy purpose, two units will be mounted. The stators will be mounted on the brackets. The rotors will be connected to the stainless steel shaft between the motor and the grating. Wiring of the rotor will be routed adequately to reduce the parasitic torque.

![Inductosyn principle](image)

**Figure 3.7-1 : Inductosyn principle**

![Inductosyn stator](image)

Inductosyn stator

![Inductosyn rotor](image)

Inductosyn rotor

![Readout transformer](image)

Readout transformer

![Excitation transformer](image)

Excitation transformer

**Figure 3.7-2 : Inductosyn encoder and transformers**
3.8 Launch-lock mechanism

The launch lock will be activated by an independent motor. The rotation of a latch will catch a pin on the bottom of the grating and block its rotation. Two hall sensors are used as position indicators. A magnet mounted on the rotating latch induces the response of the locked or unlocked hall sensor depending on the position of the latch. A redundant motor is implemented in the design as well as a pair of redundant position indicators. The two motors are aligned on the same axis and located on each side of the latch.

The grating will be locked in a position inside the useful angular range (parallel to mounting plane by default). The system allows remote locking/unlocking. The mechanism is designed to lock the grating when it is in a position close to the horizontal.

![Figure 3.8-1: Grating launch-lock](image)

3.9 Temperature Sensors

Grating will be provided with two thermal sensors (nominal and redundant). Selected sensors are Lake Shore CERNOX-CX-1050.

These sensors are screwed on the back face of the grating in two symmetrical positions.

3.10 Limit Switches

Limit switches Baumer My-Com A were selected. They are mechanical switches with a reproducibility of 1 μm. The positioning will be performed with respect to a mechanical hard stop. Limit switches will only confirm that we are really in contact with a hard stop.
3.11 Instrument Mounting

The base plate of the grating assembly has a thickness of 11 mm. The mounting onto the instrument structure will make use of 3 bolts (M8). Invar washers will be used to compensate for the differential thermal expansion between the stainless steel screws and the aluminium. The lateral stability of the assembly shall be ensured by the friction between the baseplate and the mounting surface.

One dowel pin hole will be provided to allow on axis of rotation and shimming of the interface will define a second axis of rotation for alignment. A second hole is provided to allow the mounting of a second dowel pin to block the grating in aligned position.

3.12 Grating General Properties

3.12.1 External Configuration Drawing and Pictures

Figure 3.12-1: 3D view of the grating assembly
3.12.2 Mass Properties

The estimated masses of the grating parts are given in Fehler! Verweisquelle konnte nicht gefunden werden. The total mass measured for the PFM grating assembly (as shown in Figure 3.12-2) is 3.962 kg.

3.12.3 Internal Harness and Connectors

Most of the sub-elements are provided with pigtail connections. All harnesses will be routed to a connector panel located on the FPU wall. The panel will be designed by KT but manufactured by CSL. The connector mounting will be light tight using an Indium joint.

The electrical interface of the grating assembly will consist of 4 connectors ITT- Glenair® Micro-D type M83513-02/CN (2 nominal and 2 redundant) mounted on this panel.
Figure 3.12-3 : Grating connector pannel

The wiring diagram is shown in the picture hereunder.

Figure 3.12-4 : Grating electrical diagram
3.13 Grating Control

3.13.1 Connection to control electronics

The Grating is controlled through the "Detector & Mechanism Controller" (DEC/MEC), which is located on the Herschel SVM. The Grating is connected to the DEC/MEC as sketched below.

![Diagram of route to control electronics](image)

Figure 3.13-1: Route to control electronics

3.13.2 Positioning characteristics

The useful angular throw of the grating is of 43.52° (for PFM grating) centred on horizontal position. The resolution of the inductosyn position sensor is 0.155 arcsec with an absolute accuracy lower than 4 arcsec.

The position sensor must be homed at switch on to an absolute reference position which is the mechanical hard stop. The repeatability of the homing is better than 0.5 arcsec.

Typical movements of the grating are long displacements at constant speed (up to 4 °/sec.), stepping (smaller steps are 18 arc sec with transition < 32 ms) and switching between two positions (up to 3 arcmin at 3 Hz with a duty cycle of 80%).

The figure below shows typical movements of the grating (25 digits ~ 4 arcsec).
3.13.3 Control Concept

The grating position is controlled in closed loop between the position sensor signal and the actuator command. The resulting torque of the actuator is proportional to the current command, which is determined by comparison between the current position signal and the position set point.

The controller is based on a PID regulation and is implemented in the DEC/MEC CPU. The output command is therefore a digital signal which must be converted to an analog current command through a Digital/Analog converter. The electronics of the Inductosyn position provides an digital position signal to the CPU. A schematic of the control loop is given in the figure below.

![Control Loop Diagram](image)

The controller will be designed to obtain the better position accuracy and stability compared to the position set point, together with a minimum power dissipation in the actuator.

For long displacements, the grating is controlled at constant speed through a ramp evolution of the set point between its initial value and the new desired position. This will protect the system against excessive reaction of the controller when the difference between the current position and the set point is important.
4. **GE:GA DETECTOR**

4.1 **Introduction**

4.1.1 **Applicable documents**

- PACS-NV-DS-001 Process Identification Document
- PACS-NV-DS-002 Calculations for the design specification of the PACS detector arrays
- PACS-NV-DS-003 Low stress module spring design aspects
- PACS-ME-PL-002 Design, Development and Verification Plan
- PACS-ME-RS-002 Specifications for PACS-CRE
- PACS-ME-RS-004 PACS science requirements document
- PACS-ME-RS-005 PACS instrument requirements document
- SCI-PT/IFI/07222 Load limits
- PACS-ME-TN-011 Estimate of transient times for PACS Ge:Ga Photoconductors

See also PACS-NV-LI-001 (Configuration Status List)

- PACS-KT-ID-002 FPU Detectors Interface Control Document
- PACS-MA-ID-002 Ge:Ga Detector Electrical Interface Control
- PACS-NV-LI-001 Configuration Item Documentation List
- PACS-NV-ID-100 Interface Specification MPE housing – Ge:Ga Detector Array
- PACS-IM-ID-001 Interface Specification for the PACS-CREs
- PACS-KT-ID-002 FPFP Detectors Interface Control Document
- PACS-ME-ECR-012 Power supplies for additional Heater and Flasher in the FM/FS-FPU

4.1.2 **General description**

The two 25 x 16 element Ge:Ga photo-conductor arrays for PACS with highly and low stressed detectors proposed as baseline are extensions of the Ge:Ga array configuration demonstrated by the FIRSA Upgrading engineering study; they involve design improvements successfully applied in the detector arrays for FIFI-LS aboard SOFIA. The detector material and amount of stress defines the wavelength range of the instrument. Light cones in front of the actual detector block provide area-filling light collection in the focal plane feeding the light into the individual integrating cavities around each separate pixel. The detector crystals are connected to the input of the CRE and routed out of the array by a harness substrate and out of the box by a pigtail harness. One detector module consists of a linear 1 x 16 element configuration. Detector related optical parameters of the PACS focal plane unit are defined by the scientific requirements. Present description is based on design, results and performance of the engineering and the qualification model arrays.
4.2 Photoconductor Array Design

4.2.1 16 x 25 Pixel Array

The 16 x 25 pixel Ge:Ga arrays consist of an array housing with a 4.2 K base plate, a 1.7 K (2.5 K for the low stressed array. Hereafter, values for the low stressed array are put in brackets) module body and thermal insulators between the 4.2 K and 1.7 K (2.5 K) parts. The EM housing is taken as a baseline to explain the general design of the array camera. The 25 stressing modules are made up by a module body with stressing mechanism, 16 linear arranged detector pixels with joints and insulators, the thermally insulated front end electronic (FEE), a FEE connector, and fore optics with linear cones. The 25 high (low) stressed modules are integrated into the 1.7 K (2.5 K) array housing which is coupled to the 1.7 K cooling system via a cooling strap and mounted to the 4.2 K base plate via thermal insulators. To achieve a temperature of 2.5 K for the housing of the low stressed detector array a heater is attached to the housing. This heater can also be used to heat up the low stressed detectors to a temperature of 8 K, sufficiently high for the thermal curing of the nominal detector response after cosmic high energy irradiation. Also the high stressed array is equipped with such a heater. The necessary curing temperature is supposed to be 6 K (TBC). The centre distance of the pixels under warm conditions is 3.6 mm at the entrance of the fore optics. Due to the radial orientation of the optical axes to a pupil at 240 mm distance, the centre distance at the position of the detectors is 3.9 mm at room temperature. Detector pixel offset is 0.2 mm at maximum (goal <0.1 mm). The design of the modules and the housing for the engineering modules is shown in Figure 4.2-1.
All main metal components are made from a light metal alloy. For the spring and the fore optics a hard Al alloy (AlZn5.5MgCu) is used. Since Al material is used for all main components, mechanical stress caused by different thermal expansion is avoided between the housing parts. The design and arrangement of the 25 linear arrays implies that only one design of the module is necessary for the whole array. Each stressing module of one type (highly or low stressed) can be exchanged together with the module connector and fore optics from the top of the housing after removing the upper plate.

4.2.2 Stressing module

The stressing module is a single operational linear array with 16 detector pixels. The main components of the stressing module are the 1x16 pixel detector array arranged in a detector cavity, a stress mechanism consisting of spring and screw, a front end electronics (FEE) at ~4 K, a harness substrate at ~4 K, and the fore optics (schematic view in Figure 4.2-2).

4.2.2.1 Module body

The module body consists of a plate with a thickness between 3.9 mm and 4.1 mm, which is divided into three functional sections, the spring, the FEE carrier and the detector channel with a diameter of (3.000±0.005) mm. The detector channel and the FEE frame are a mechanically stable unit. The fore optics is mounted with 2 screws and compensation washers in front of the array channel. The module itself is fixed at the fore optics by 2 screws on the array housing. At the back area, where each module is attached to the housing by an appropriated slit, are 2 wedges with headless screws between two modules. The U-shaped stressing spring surrounds the array stack via the U starting with one spring end at the top and ending with the other at the lower end of the array. Although it is part of the housing, via thin spring elements the stack is mostly mechanically de-coupled from the housing. The design ensures that the array channel and the FEE frame remain unstressed. An unbent detector channel is required for a homogeneous stress / cut-off wavelengths of the array and a stress free mounting of the module in the array housing. To improve the reflectivity in the detector channel or respective cavities, the housing is coated with a 10 µm multi Ni-Au layer (8 µm Ni and 2 µm Au). The trade name for this coating is Auruna 556 performed by Degussa, Germany.

4.2.2.2 Stressing Mechanism

The stressing mechanism consists of a spring designed as a part of the module housing but as far as possible mechanically de-coupled from the housing via a thin spring element and two clamps. The spring is a 4.1 mm thick U-design, with the detector channel in-between. The dimensions have been chosen so that it can withstand a maximum force of 800 N (200 N) at RT as calculated by a FEM analysis of this design for the highly (low) stressed module. Bending the spring with the required force causes a travel of approx. 1.7 mm as has been measured for a manufactured spring as a function of the force for the range between zero and 800 N (200 N) at RT. The force is adjusted by stressing screws.
4.2.2.3 Linear stressed array

Sixteen single detector pixels are mounted in a stack made up of “detector – metal contact – insulator – ball joint – metal contact” blocks into the detector channel which are then stressed by one spring. The detectors are positioned between gold coated (except for the first 6 QM arrays) CuBe pedestals on the metal contacts. Gold coating is performed at Fa. Drollinger, Germany. The pedestals, which are of the same size as the detectors, reduce the pressure gradient at the pixel corners.

Figure 4.2-2: Drawing of the photoconductor array design including fore optic, detector stack and cryogenic read-out electronic inside the module body. For the new bias concept, the bridging substrates and the wire channels are omitted on one side.
In Figure 4.2-3 the result of an FEM analysis demonstrates this behaviour clearly. Between two cylindrical pistons, a detector pixel was modelled using FEM calculations. In this analysis, the impact of de-centred pixels and the addition of cushion pads between the detector and the pistons was investigated. The cushion pad reduces the range of stress values within the pixel significantly, which minimises the risk of detector breakage and results in an increased sensitivity at the desired wavelengths. To get a homogeneous stress within the detector and along the array, the detectors are positioned as accurate as possible in the centre of the cavity. Figure 4.2-3 shows an increasing gradient of stress across the detector if de-centred by 20 μm. A feasible position accuracy is however approx. ± 0.01 mm.

The linear detector array is located between the 2 shanks of the U-spring. The force of the spring is transmitted to the detectors via a bolt. The components accomplish the functions:

- force transmittance from detector to detector
- optical shielding between the cavities in the detector channel via the metal contacts
- electrical insulation of the detector contacts from the housing and each other
- equalisation of non-parallel surfaces by the ball joints
- stress uniformity along the complete stack of 16 detectors

![Figure 4.2-3: FEM analysis of a detector (Ge – green) between two cylindrical pistons (steel – red). A perfectly centred pixel (left) and a 20 μm de-centred pixel (right) were studied. As shown for the centred case, the addition of cushion pads (dark green – Ag) between detector and pistons reduces the range of stress values considerably.](image)
4.2.2.3.1 Detector cavity

The small absorption efficiency of the Ge:Ga detector material requires the detector pixels to be integrated in optical cavities with apertures as small as possible. The detector blocks are mounted in the cylindrical detector channel of (3.000±0.005) mm diameter. The closed detector cavity is a cylinder of 3 mm diameter and a height of (2.1±0.05) mm. The cylindrical surface is prepared by electric discharge machining followed by diamond stone polishing with a surface roughness of typically 0.2 µm. Afterwards a (10±2) µm thick galvanic multi-layer gold coating is performed. The entrance aperture of 0.72 mm is located concentric to the detector pixel.

The efficiency of the cavity depends on reflections on the cavity surfaces, the absorbing detector surfaces, the loss areas such as gaps, the aperture and on the beam properties. A simple estimation can be made for a diffuse illumination. The absorbing detector surface is 6 mm² (absorption efficiency approx. 20%) and the loss areas are the entrance aperture (0.39 mm²), gaps between contact blocks and the channel wall (approx. 0.05 mm²) and the wire feed-through. Because of all these conditions the best achievable collection efficiency of the optics/detector geometry can be estimated roughly to 56%.

4.2.2.3.2 Detector Pixels

The detector pixels are special optimised Gallium doped Germanium detectors, manufactured by Haller/LBL/Berkely. The dimensions are 1 mm x 1 mm x 1.5 mm (height). For an exact positioning, the shape must fulfil very tight tolerances. The right-angles are within ±0.1°, the flatness of the surfaces are within 10 µm. The electrical metal-coated contacts are on the 1mm x 1mm surfaces. Ge:Ga detectors with a band gap of 11 mV show a peak response at \( \lambda_p \approx 90 \) µm and have a cut-off wavelength of \( \lambda_c \approx 112 \) µm. This 50% cutoff wavelength is shifted to \( \lambda_c \approx 127,5 \) µm for the low stressed array and shifted to 200 µm for the highly stressed array by application of uni-axial stress in <100> direction perpendicular to the contact surface. Defects such as under-etching should be smaller than 30 µm in diameter. The Gallium doping concentration varies from about 1⋅10^{14} cm^{-3} for the highly stressed detectors to 2⋅10^{14} cm^{-3} for the low stressed detectors. The dimensions of 1 mm x 1 mm x 1.5 mm (height) have been chosen as a compromise between sensitivity, cosmic ray vulnerability and the required external force.
4.2.2.3.3 Responsivity

The following plots represent typically measured relative responsivities of pixels 1-3 and 14-16 of the highly and low stressed photoconductor arrays. The cutoff wavelengths and the total variation are indicated. Accuracy of the cutoff wavelength determination is typically ±0.5% and of the shape of the relative responsivity ±10%. It is expected to keep the variations in the measured cutoff wavelengths below ±2.5 µm and to obtain a mean cutoff wavelength of 127.5 µm for the low and larger than 200 µm at 40 mV bias for the highly stressed arrays. An error bar of ~1 µm may be included in this specification limit.

Figure 4.2-4: Responsivity as measured by tests made during QM manufacturing of the linear detector arrays of type highly (left) and low (right) stressed.

Figure 4.2-5: Left: The mean value of the 50% level cutoff wavelengths $\lambda_{cw}$ obtained by measurement of each 6 pixels of the qualification model arrays 1 to 10 at 30 mV bias voltage. For the arrays QM 11 and 12 the bias voltage has been set to 40 mV and the pressure to 745 N/mm$^2$. Right: The maximum variation of $\lambda_{cw}$ of all measured pixels in the same qualification models as for the left graph.
4.2.2.3.4 Electrical connections and thermal design

The detectors with Au/Pd surfaces are clamped between the CuBe contacts. Au-wires of 0.025 mm diameter are glued to the contacts. For the signal wire side from the cavity PTFE insulated Ag coated Cu wires of 0.07 mm (0.21 mm with insulation) are fed within groves to the front area of the FEE. The interconnections from the Cu wire ends to the FEE input pads are made via Alumina bridging substrates where stainless steel wires of 0.025 mm diameter are used to make a connection to the CRE. The bias connections are made directly to the housing. Since the design change was made after manufacture of the QM array, for these the bias connection is made via the cross connection of the AWG 40 wires at the bridging substrates. Thermally insulating steel wires are necessary to keep the thermal load between the ~4 K and the 1.7 K level below the specified value. The allowed thermal load to the 1.7 K level is ~600 µW for two 16 x 25 pixel array. The FEEs are thermally insulated from the 1.7 K level and are cooled by the ~4 K level to avoid a heating of the FEE by the electrical power consumption, which would produce thermal radiation visible for the IR detectors. In this way the FEE power dissipation of 100 µW is kept away from the 1.7 K cooling stage.

4.2.2.3.5 Mass and mechanical interface

The interfaces are the type and sizes of substrate and the areas for mechanical fixation. The FEE is a hybrid set up on a thin film-Al2O3 substrate of 26 mm width, 36 mm length and 0.5 mm thickness (without SMDs). The total height limited by the module thickness of 4.1 mm must not exceed 2.7 mm. The mass is approximately 2 g. The areas for mechanical fixation are defined in the corresponding drawing (i.e. PACS-NT-AS-0002). The max. bending of the FEE substrate during vibration phases is ~1 µm at 20 g. The FEEs is mounted thermally insulated into the 1.7 K housing by 4 Kapton tubes. The tubes are the critical parts w.r.t. thermal conduction and the mechanical stability. The mass to be hold by this very thin construction must be as low as possible. The smallest mass is a free hanging FEE without any additional metal carrier. The thermal load to the 1.7 K level for 2 x 25 modules with each 4 posts is ~600 µW. For details see document PACS-NT-DS-002.

4.2.2.3.6 Electrical interface at the supply side

The FEE supply lines are connected by glued (H20E adhesive) 50 µm diameter gold-wire loops from the bonding pads on the FEE substrate to the bonding pads of the harness substrate. The centre distance of the gluing pads is adapted to the screen of the pin strip of the Nano connector. For the electrical connections from the FEE to the detectors thermally insulating steel wires will be used. At one side they are glued with H20E on the bond pads of the FEE and at the other end to the wires coming from the detectors and fixed on the Alumina bridging substrates. The input pads are located at or along the front edge of the FEE substrate. Distance and size are adapted to the dimensions of the glued steel wires. For details of the harness and FEE substrates see in the actual drawings in PACS-NT-ID-0002, PACS-NT-ID-0003 and PACS-NT-ID-0006.

4.2.2.3.7 FEE pigtail harness and cooling strap

The FEE supply and signal voltages are fed via a pigtail harness from the experiment harness to the FEE. The pigtail harness consists of a Nano or Micro connector with wires at the experiment side and a special connector glued to harness substrate (thermally insulated from the stressing spring). Due to thermal shrinking differences, it is required to make Au wire bridges from the
Nano connector to the harness substrate pads. The connector has therefore no real connection function. The FEE temperature is a result of the equilibrium of the FEE power consumption with the heat transfer to the HK level via cooling straps and the 1.7 K (2.5 K) housing via the FEE supports. The FEE substrate is thermally connected with the ~4 K heat sink via the Au wires from the FEE substrate to the harness substrate. The harness substrate itself is connected to the heat sink by two $\varnothing 0.25$ mm silver wires glued with Styca 2850 to the harness substrate. A FEE power consumption of 60 µW will increases its temperature by ~20 mK or somewhat more because of the limited effectiveness of the wire anchoring. For details see the Interface Control Documents PACS-NT-ID-100 and PACS-KT-ID-002.

4.2.2.4 Fore optics

As already mentioned, the small absorption efficiency of the Ge:Ga detectors requires that the detector pixels are integrated into the optical cavities with apertures as small as possible. To keep the optical filling factor close to 1, the light beam is guided by linear light cones to the apertures. The light cones are arranged as a linear 16 channel light-cone-fore-optics in front of the detector array channel with a radial orientation to a pupil at a distance of 240 mm. Figure 4.2-6 shows a measurement of the beam profile of the FIFI instrument (Poglitsch et al 1991) aboard KAO at 63 µm using the planet Mars (Nikola et al. 1993).

![Beam profile of three adjacent detectors of the FIFI instrument at 63 µm. The telescope was scanned across the source (Mars, ~8.7'' diameter) in a 10'' raster from the first detector (top), to the second (middle), and third (bottom) detector.](image-url)
The telescope was scanned in 10 arcsec steps across the sky such that the source moves through three adjacent detectors; the summed intensity of the three detectors varies only slightly with the position, demonstrating that the used light cones are area filling. The pixel centre distance at the front level is 3.6 mm and at the detector level 3.9 mm. A calculation for optimisation of the cone geometry has been carried out by MPE. The roughness quality of the surfaces of the light cones and the front area must be well adjusted to the pointed reflection of the IR beam and the possible manufacturing procedure. The surfaces are prepared by electrical discharge machining granting a surface roughness of about 0.2 μm. Coating the surface with a 10 μm thick Ni-Au layer afterwards ensures an optimum reflectivity close to 1 as proven by reflectivity measurements on flat samples. Within ±1° FOV 97% of the incoming radiation is guided into the cavity. The collection efficiency varies almost linearly to 0% at an opening angle of 14.5° with 50% transmittance at a half angle of 8°. For improvement of the light tightness of the fore optic-cavity system, a sealing made of 0.25 mm Ag wire is integrated between fore optics and front side of the module housing and between adjacent fore optics when integrated into the array housing.

4.2.3 Dimensions of the array envelope

The assembly and integration of the 25 arrays into a housing requires a formation which allows a close packaging of all arrays next to each other, so that the centre optical line of each pixel goes through the focus, which is located 240 mm away from the cavity centre axis. Since the pixel separation is 3.9 mm vertically and horizontally in warm state, the arrays have to be manufactured slightly thinner than 3.9 mm, so that they fit next to each other taking the manufacturing tolerance into account. The radial arrangement requires a wedge-shaped module design. 20 mm bending radius of the harness wires have been taken into account. For details of the smallest envelope with non-radial outer edges for the single array see drawing PACS-NT-ID-0001 Issue 2.

4.2.4 Radiation Effects

The ionising radiation in space can seriously affect the calibration of the Ge:Ga detectors. Proton tests with a flux expected at L2 already showed glitches and a level of responsivity which is 5 times higher than the infrared response. The origin of the anomaly are excited electrons which are captured by ionized impurities in the Ge:Ga detector. These trapped carriers reduce the effective compensation. Self curing via IR background radiation is a method to reduce this effect, but in this special case it is not sufficient. Therefore, a combination of thermal heating and IR flasher is integrated to restore the changed detector response.
Figure 4.2.7: Left: Two flashers are placed within the baffling system of the blue detector. Right: Flasher with sapphire substrate, metallic film and other attached material.

Figure 4.2.7 shows the blue Detector. Two flashers are placed within the baffling system of each detector unit. Each flasher will be operated in parallel. The essential features of the flashers are illustrated in the right part of figure 4.2.7. The emitter substrate is sapphire metallized with an Al-film which is attached to the nylon suspensions, brass and gold wires (for more details, see *Applied Optics* Vol. 44, pp. 3208-3217). The flasher resistance is $150 \, \Omega$ at $4 \, \text{K}$.

Each detector is equipped with a heater which, in an additional operation mode, can also be used for the thermal curing. The applied mode of operation depends on the efficiency of the flashers which can not be verified prior being launched into orbit. The heater resistance (1 k$\Omega$) is almost independent from temperature.
4.3 Summary of the detector performance

A summary of the detector performance and design specifications together with the results obtained with the engineering and qualification modules is given in the tables below.

4.3.1 Table with detector performance

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Specified</th>
<th>Design / Achieved with EM/QM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mass</td>
<td>( \leq 5 \text{ kg} )</td>
<td>2.64 kg for both arrays without housing</td>
</tr>
<tr>
<td>2</td>
<td>Operating temperature</td>
<td>( 1.5 \text{ K} \leq T_{\text{det}} \leq 2.0 \text{ K} )</td>
<td>( T_{\text{nom.}} \approx 1.7 \text{ K} ) ( (T_{\text{nom.}} \approx 2.5 \text{ K}) )</td>
</tr>
<tr>
<td>3</td>
<td>Thermal budget</td>
<td>600 µW</td>
<td>(~(364 \text{ µW} + 262 \text{ µW})) contact resistances not included</td>
</tr>
<tr>
<td>4</td>
<td>Temperature increase of CRE substrate</td>
<td>(&lt; 50 \text{ mK} )</td>
<td>2 cooling straps ( \varnothing 0.25 \text{ mm} )</td>
</tr>
<tr>
<td>5</td>
<td>Temperature increase of CRE</td>
<td>(&lt; 10 \text{ mK} )</td>
<td>5 mK</td>
</tr>
<tr>
<td>6</td>
<td>Bias voltage</td>
<td>( 10 \text{ mV} \leq U_{\text{bias}} \leq 70 \text{ mV} ) ( (40 \text{ mV} \leq U_{\text{bias}} \leq 300 \text{ mV}) )</td>
<td>( U_{\text{nom.}} \geq 20 \text{ mV} )</td>
</tr>
<tr>
<td>7</td>
<td>Dark current</td>
<td>( \leq 5 \times 10^4 \text{ e/s} )</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Detector input capacitance to CRE</td>
<td>(&lt; 2 \text{ pF} )</td>
<td>1.4 pF</td>
</tr>
<tr>
<td>9</td>
<td>Vibration load</td>
<td>Input on optical bench: 15 g</td>
<td>100 g static tests @ RT: ~200 g</td>
</tr>
<tr>
<td>10</td>
<td>Wavelength range high stress with ( R &gt; 0.1 \cdot R_{\text{peak}} )</td>
<td>110 – 208 µm</td>
<td>50 – ~220 µm</td>
</tr>
<tr>
<td>11</td>
<td>Wavelength range low stress ( (R &gt; 0.1 \cdot R_{\text{peak}}) )</td>
<td>55 – 130 µm</td>
<td>40 – 150 µm</td>
</tr>
<tr>
<td>12</td>
<td>Current sensitivity high stress</td>
<td>( \geq 10 \text{ A/W} )</td>
<td>12 A/W @ 40 mV bias</td>
</tr>
<tr>
<td>13</td>
<td>Current sensitivity low stress</td>
<td>( \geq 3 \text{ A/W} )</td>
<td>3.5 A/W @ 100 mV bias</td>
</tr>
<tr>
<td>14</td>
<td>Uniformity cutoff wavelengths</td>
<td>195 µm &lt; ( \lambda_c ) &lt; 200 µm ( (125 \text{ µm} &lt; \lambda_c &lt; 130 \text{ µm}) )</td>
<td>( \lambda_c ): 50% of peak ( (\lambda_c) ) Goal:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>HERSCHEL PACS</strong></td>
<td>PACS Instrument Description Document Part II</td>
<td>Doc. ref. : PACS-ME-GR-002 Issue/Rev. : Issue 3 Date : 10-11-06 Page : 4-13</td>
<td></td>
</tr>
<tr>
<td><strong>200 ( \mu m &lt; \lambda_e &lt; 205 \mu m ) @ 40 mV bias</strong></td>
<td>Including error bars of ~1 ( \mu m )</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>15</strong> Uniformity of responsivity within one detector module</td>
<td>( \pm 30 % ) of mean (( R_{peak} ) of 16 pixels at CRE output)</td>
<td>Goal ( \pm 20% )</td>
<td></td>
</tr>
<tr>
<td><strong>16</strong> Mean quantum efficiency</td>
<td>( &gt; 30 % )</td>
<td>( &gt; 30 % ) Goal: 45 %</td>
<td></td>
</tr>
<tr>
<td><strong>17</strong> Uniformity of NEP within one detector module</td>
<td>( \pm 30 % ) of mean (at CRE output)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>18</strong> Cross talk</td>
<td>( &lt;1% )</td>
<td>( \sim 0.1% )</td>
<td></td>
</tr>
<tr>
<td><strong>19</strong> Applicable IR-flux range (each pixel)</td>
<td>( 1<em>10^{-15} ) (dark) ( \leq \Phi \leq 1</em>10^{-10} ) W nominal: ( 5<em>10^{-15} ) W/pixel ( \leq \Phi \leq 1</em>10^{-10} ) W ( \Phi \leq 1*10^{-7} ) W for curing purposes</td>
<td>Detectors are operated in spectrometry mode</td>
<td></td>
</tr>
<tr>
<td><strong>20</strong> Transient behavior</td>
<td>( \tau \leq 100 ) ms for any flux step within a.m. range (tbc)</td>
<td>( &lt;30 ) ms (by calculation)</td>
<td></td>
</tr>
<tr>
<td><strong>21</strong> Allowed number of cold cycles</td>
<td>( \geq 25 )</td>
<td>&gt;25</td>
<td></td>
</tr>
</tbody>
</table>
### 4.3.2 Table of array design and its manufacturing accuracy

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Specified</th>
<th>Design / Achieved with EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dimensions</td>
<td>1x1x1.5 mm³ (l x w x h), height tolerance: -30µm</td>
<td>30 µm irregularities possible</td>
</tr>
<tr>
<td>2</td>
<td>Stress variation interval at RT</td>
<td>68 N to 565 N at RT (17.7 N to 120 N)</td>
<td>745 N/mm² cold maximum force assumed maximum: 760 N/mm²</td>
</tr>
<tr>
<td>3</td>
<td>Mounting accuracy of centricity of detector stack (2σ)</td>
<td>&lt; ±20 µm</td>
<td>Goal &lt; ±10 µm</td>
</tr>
<tr>
<td>4</td>
<td>Slit size between detector contact and cavity (2σ)</td>
<td>30 to 70 µm</td>
<td>On one side improved to 0 µm to 50 µm with new bias concept</td>
</tr>
<tr>
<td>5</td>
<td>Accuracy of detector pixel location along cavity centre line</td>
<td>±0.2 mm</td>
<td>Goal ±0.1 mm</td>
</tr>
<tr>
<td>6</td>
<td>Rotational detector mounting accuracy</td>
<td>±5°</td>
<td>Goal &lt; ±1°</td>
</tr>
<tr>
<td>7</td>
<td>Surface roughness fore optics</td>
<td>&lt; 0.3 µm</td>
<td>Goal 0.2 µm</td>
</tr>
<tr>
<td>8</td>
<td>Surface roughness detector cavity</td>
<td>&lt; 0.3 µm Some grooves from diamond polishing or irregular EDM sparking will be accepted</td>
<td>Goal 0.1 µm (close to mirror quality)</td>
</tr>
</tbody>
</table>
5. PHOTOMETER

5.1 Detection Principle

The PACS Photometer detectors are bolometers. Bolometers are "quadratic" detectors: the absorbed radiant energy is transformed in heat. The electrical output of the detectors is the measurement of the temperature elevation produced by the power absorption. Common bolometers are not wavelength selective over a wide range, and careful filtering is generally needed. Common bolometers are also sensitive to many types of energy: radio frequencies, microphonics, or energetic particles... Special care must be taken to avoid these unwanted energy types to reach the detectors. They degrade the detector performances.

5.1.1 The sensitive Part of the Detector

The sensitive part of the detectors is the insulated structure whose temperature changes with incident flux.

5.1.1.1 Heat capacity

The detector response is dependent on the heat capacity of the sensitive part. If we consider only the thermal behaviour, the lower thermal capacity will produce the higher temperature response, for a given amount of energy. As heat capacity, at a given temperature (T), is proportional to the mass, the sensitive part is made of the minimal material contents. The goal is, in a first step, to achieve the smaller thickness compatible with material mechanical constraints, and in the second step, make this surface an openwork with holes compatibles with the desired absorbed wavelength.

The detector looks then like a mesh. The heat capacity will dramatically decrease if this mesh is cooled down to sub Kelvin temperature. At very low temperature the specific heat of most materials decreases. This is true especially for mono-crystals whose specific heat dependence is proportional to $T^3$. PACS bolometer detectors are made of mono-crystalline silicon, cooled to 300 mK. The geometrical characteristics are given in the table:

<table>
<thead>
<tr>
<th></th>
<th>Blue&amp; Red focal planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel pitch</td>
<td>750 µm</td>
</tr>
<tr>
<td>Active surface</td>
<td>640 x 640 µm²</td>
</tr>
<tr>
<td>Mesh thickness</td>
<td>5 µm</td>
</tr>
<tr>
<td>Mesh pitch</td>
<td>35 µm</td>
</tr>
<tr>
<td>Silicon mesh width</td>
<td>5 µm</td>
</tr>
</tbody>
</table>

Table 5.1-1: Pixel geometric parameters
5.1.1.2 Thermal conductance

The thermal conductance is the second important parameter of the bolometers. If null, the system is perfectly insulated. The readout time is infinite, and the accuracy of the energy measurement could be perfect. But it is also a one shot detector!

In a more realistic situation, we need to extract the energy from the active part of the detector. This is done by microscopic silicon rods between the active part of the pixels and the heat sink (inter pixel wall linked to the 300mK cooler cold tip). Heat transmission at very low temperature in silicon is made through ballistic phonon exchange. This exchange determines the ultimate theoretical sensitivity expected from the detector: the "thermal" noise is then governed by phonon fluctuations between the "hot source" (the sensitive Part of the Detector), and the substrate (inter pixel walls).

The bolometer performances are very dependent from the actual conductance: if too small the temperature of the suspended part will be too high: we will lose the low capacitance property, too large and the temperature increase will be too small to be efficiently measured.

Figure 5.1-2: The active detector unit: bolometer Pixel
These arguments show that a bolometer must be tailored for a peculiar application. In our case, the power from the Herschel telescope primary mirror is the driver. The calculated range of expected power in PACS operations is between 1 and 7 pW. The active part of the detector is suspended (mechanically) and insulated (thermally) by four silicon rods of 2 µm x 5 µm section, and 650 µm length.

Figure 5.1-3: Detail of the detector suspension area in the electron beam microscope

5.1.1.3 Operating Temperature

The operating temperature will give, as previously stated, through the thermal conductance value, the ultimate performances that can be achieved by the detectors. Simple thermodynamic calculations show that 300 mK is sufficient to ensure a thermal noise compatible with the desired sensitivity: NEP close to the background limited values \( \geq 1 \times 10^{-16} \text{ W/} \sqrt{\text{Hz}} \).

5.1.1.4 Thermometer

The sensitivity of the detectors, once the heat capacity and the thermal conductance set, is determined by the thermometer performances. The thermometer in our case is "simply" a resistance whose value is strongly dependent with T. The higher dR/dT, in the range of interest, gives the higher detector response.

At 300 mK in most doped semiconductors, charge carriers are frozen and cannot be used for thermal metrology. The only way to get significant semiconductor conduction, is to have a compensated implantation.
In the compensated mode, silicon is doped with both n and p impurities: Phosphorus and Boron atoms in different proportions allow the "hopping conduction" of charges. In our case a 50% Boron compensation was found to be optimal.

All the states introduced by the impurities levels, develop around the Fermi level, a very shallow pseudo gap behaviour: the "Coulomb gap". Electrons jump between states at a frequency activated by the temperature. An electric field application modifies slightly the probability to jump to a state located at lower potential electric energy. The net current is given by the Efros formula:

$$R(T) = R_0 \exp\left(\frac{T}{T_0}\right)^{1/2} \exp\left(-\frac{q(aT^2 + bT + c)E}{kT}\right)$$

Where E is the electric field, k the Boltzmann constant, q the electric charge. Other parameters (R0, T0, a, b, c) must be extracted from data. The polynomial expression (aT^2+bT+c) is the electrons hopping length L(T).

Thermometer physical parameters were measured for different implantation levels, shapes, lengths between 260 mK and 1 K. Measurements were done with small (40 µm x 40 µm), intermediate, or long (25 µm x 400 µm) thermometers. Some measurements were also done with folded, or straight thermometers.

Thermometer shapes tested in 98-99

The conclusion of these measurements is that all shapes, but straight ones, show important non-ohmic behaviour (i.e. field effect). The field effect influence, damps the thermometer characteristics. The electric field must be as small as possible for a given bias value: the longer thermometers give then the better results. Folded geometries are not as efficient as straight ones.
(again probably linked to electric field crosstalk). In the final design the thermometers (reference and pixel) are long strips of 40 µm x 600 µm.

At very low temperature, in the hopping regime, the thermometer uniformity is also a very important parameter: electrical conductance behaves as an exponential function of the density of impurities. Any non-uniformity in density, will produce a non-uniform current flowing through the thermometer, with maybe local unwanted self-heating, or 1/f noise generation.

In order to manufacture uniform thermometers two design processes were explored: multi-energy silicon bulk implantation and mesa thermal diffusion.

-1) deep implanted thermometers;

-2) MESA diffused thermometers.

![Comparison of the multi implanted and mesa schemes for thermometers](image)

In the multi energy bulk implantation Phosphorus and Boron were successively implanted at five energies with a moderate temperature elevation for a limited diffusion of doping species. The goal homogeneity was not reached by this method.

We explored then to the "mesa" configuration. As seen in Figure 5.1-6, the thermometer is in relief from the grid layer (about 0.5µm) and insulated from the grid by a ion non-permeable sub-micronic layer of oxide (SiO₂). Implantations of Boron and Phosphorus are done at one energy only, and the wafer is "baked" at around 1000 °C for many hours to make the density of doping species uniform. This time uniformity was confirmed by SIMS tests. The cost is a more complex pixel manufacture process (40 steps added).

5.1.1.5 Signal output

As shown in the microphotography (Figure 5.1-1), two thermometers are used for each pixel. The signal is the voltage variation at the middle point of a two resistor bridge. The high bias value VH is applied to the reference resistor, the low voltage VL at the bolometer resistor end. The bolometer resistance decreases with the pixel temperature elevation, then, the amount of Joule power delivered by the bias varies with pixel temperature (i.e. with Signal). Fortunately the current flowing through the detector is limited by a reference resistor located in the inter pixel wall and firmly linked to the bath temperature (i.e. 300 mK). It prevents any “burnout” phenomena. Due to the complex dependence of the resistance with electric field, the reference resistor is not really a “constant charge resistor”: its value depends dynamically on the applied bias.

In the diagram hereafter, we see that the bridge middle point is linked to a pMOS readout transistor, through a "gate" (small nMOS transistor-2 µm x 2 µm). “Readouts” and “gates” transistors geometries were controlled to:
a) to achieve the lower 1/f noise on the readout transistors (large);
b) to reduce the injected capacitive charge on the gate transistors (small).

pMOS and nMOS types were chosen to decrease as much as possible, the bias command values.

Figure 5.1-7: General scheme of the detector and its cold readout electronics

5.1.2 Detector Electromagnetic Absorption

A thin metallic layer in vacuum can absorb up to 50% of the normal incident radiation. The transformation of radiant energy to heat is classically described, in a first step, as the effect of the free electrons motion induced in the metal foil by the Lorenz force (under the influence of the electric component of the electro-magnetic field), and in the second step by the joule effect of these moving electrons in the resistive metal.

In classical bolometers, surrounding the absorber with an integrating cavity increases the absorption efficiency. The radiation, then, passes many times across the absorber, and is almost completely absorbed. In this case the absorber itself is made as small as possible (compatible with wavelength) to save heat capacity. A "non imaging" light concentrator (a Winston cone usually) is used to achieve large collecting surface without increasing the actual detector size. The drawback of this system is non-complete focal plane coverage. In this case, only 30% of the focal plane is covered simultaneously! The remaining light is backscattered.

The goal of the PACS detectors is to manufacture large arrays covering the complete focal plane. The Winston cone and integrating sphere are excluded: the detectors themselves must cover the whole collecting surface and must absorb most of the radiation in a one-pass process.

5.1.2.1 Resonant absorption

The problem of "one pass absorption" can be solved by use of resonant absorption. The technique was discovered during World War II and applied widely to stealth techniques.
In this scheme a reflective layer is placed after the absorber. The reflected waves combines with incident to form standing waves with an electric field node, and a magnetic field loop at the reflector surface. At quarter wave distance above the reflector the situation is completely different: we have there a node of magnetic field and a loop of electric field.

If the absorber is placed at this location and behaves as expected: the surface resistance matched to the vacuum impedance (377 Ω/sq), the system can absorb theoretically 100% of the incoming radiant energy. This process, a "loose" two waves interference, makes a wide absorption profile, with a poor dependence with angle of incidence.

![Electromagnetic fields scheme in the resonant absorption process](image)

**Figure 5.1-8: Electromagnetic fields scheme in the resonant absorption process**

Hereafter the figure shows calculated absorption for the blue and red PACS channels in the simple geometry described previously.

![Absorption diagram calculated for two PACS possible detector configurations](image)

**Figure 5.1-9: Absorption diagram calculated for two PACS possible detector configurations**
With a 20 µm cavity (blue curve) the right side of the diagram shows that the absorption curve is maximum for 80 µm wavelength and drops smoothly towards longer wavelength. For shorter wavelength the fall is sharper: a minimum (zero) is reached for waves of 40 µm.

We deduce from this diagram that the quarter wave cavity is well adapted for wide absorption, specially towards long wavelength. This shows that the configuration have some self-filtering properties that can be exploited. The red curve shows the expected scaling with a 25 µm wide cavity.

![Absorber configuration in the resonant scheme. The metallic layer deposited on a silicon grid faces the reflector, a gold layer. The EM standing wave develops, and an electric field loop is present at the absorber location.](image)

This absorption profile can still be tailored to increase or decrease some peculiar wavelength range by a horizontal resonance. This new resonance is performed by the absorber pattern, which can replace the homogeneous absorber layer. Most popular patterns are "inductive meshes" (short wavelength passes), "capacitive squares" (long wavelength passes) or some combination "crosses or negative crosses" (band-passes or notches).

Different absorber geometries were tested. The figure hereafter shows three possible different geometries. In grey the silicon mesh structure, in red the metallic absorber pattern.

![Examples of tested absorbers geometries](image)

Finally the PACS detector absorber is simply a mesh as shown in the next figure. Most of the physical parameters are reported on the side of the figure (volume, mass, thermal capacity).
### 5.1.2.2 Cavity

The quarter wave cavity is obtained by hybridisation of two silicon chips, one containing the active part of the bolometers (CD for "Composant de Détection"), the other displaying the reflector (CL for "Circuit de Lecture"). Indium bumps in-between ensure at the same time the electrical contacts from the thermometers, the cavity width and thermal coupling to the 300 mK heat sink. At the operating temperature, Indium is supposed to be superconductive and then a strong thermal insulation is expected. In reality, we measured the indium bump thermal conductance and found it sufficient to ensure a good link to the heat sink.

![Figure 5.1-11: PACS detector geometry](image)

**Indium bumps**

** silicon grid**

**interpixel wall**

![Figure 5.1-12: Microphotography of a mounted pixel](image)
5.1.2.3 Metal absorber

The absorber thermal properties are essential to achieve good performances of the detectors: it can be a non-negligible amount of the pixel heat capacity. Normal metals have a specific heat, which varies as $T$. Compared with the $T^3$ dependence for mono-crystal, the metallic "weight" can be as important, at very low Temperature, as silicon structure. Some metals show however an important drop of specific heat with temperature: the superconductors. These metals can then be used far away from the transition to benefit of this property. But, if metals are in the superconductive phase how can they be absorbers?

In fact the superconductive state is valid only for DC and "low" frequency currents. If the energy carried by the radiant energy is sufficient to break Cooper pairs, photons can be absorbed. For longer wavelength the metal is a perfect reflector.

One of our tasks, at the beginning of the project, was to find metallic species (pure or alloys), compatibles with wafer manufacture, superconductive at the effective operating temperature and still showing good absorber properties.

Three alloys were tested: WN, TiN and TaN deposited in thin layer, with the required HF resistivity. We measured the transition temperature and then deduced the cutoff wavelength.

<table>
<thead>
<tr>
<th>ALLOY</th>
<th>Transition temperature</th>
<th>Theoretical cut-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>WN</td>
<td>4.1 K</td>
<td>≥280GHz or ≤1.08µm</td>
</tr>
<tr>
<td>TiN</td>
<td>2.2 K</td>
<td>≥140GHz or ≤2.15µm</td>
</tr>
<tr>
<td>TaN</td>
<td>1.2 K</td>
<td>≥65GHz or ≤4.6µm</td>
</tr>
</tbody>
</table>

Table 5.1-2

We finally chose, for the PACS application, in both bands, TiN as metal absorber.

5.1.3 Acquisition Principle

As stated previously, bolometers are detectors sensitive to many energy manifestations (energetic particles, RF, microphonics…). The first measurements performed with the PACS detectors, showed moderate sensitivity to microphonics, but they showed also that they were easily perturbed by Radio Frequencies. The acquisition scheme adopted, had to preserve the detector sensitivity (signal and noise) at all steps of the electric chain, and should remove some types of perturbations as efficiently as possible.

On the detector itself:

We deliberately decided to make the PACS thermometers as high impedance as possible to increase the output signal above many possible readout and amplification sources of noise.

We adopted a differential scheme since most perturbations (microphonics, RF…) affect the whole array. Blind pixels on the side of the arrays were initially implanted for this purpose. The perturbation signal present on both active and blind pixels could then be easily removed. In fact we experienced a drawback to this scheme. The differentiation increased widely the dynamic range squeezing the noise sampling at an unwanted limit compared to the sources amplitude requirement. The differentiation increased also, as expected, by a factor $\sqrt{2}$ the incoherent noise
Finally, on PACS these two effects obliged to withdraw the analogue differential scheme at the pixel level.

On the readouts MOS transistors:

The differential scheme was maintained at the readout level because temperature variations affect the threshold of the MOS transistors used in the impedance adaptation circuit. The differentiation is made against a reference voltage at the 2K impedance adaptation level.

5.1.3.1 Impedance adaptation

In the PACS system, a cascade of impedance levels is mounted to decouple and limit the range of possible perturbations.

The detector resistance bridge itself is a very high impedance component (TΩ range). Such a large value is required to obtain large signals. We take advantage of this very high resistance value to filter the signals in the required operating bandwidth (~10 Hz), taking into account the complete electrical stray capacity of the line between detector and readout transistors.

In PACS our present goal is to achieve 10 Hz at the detector level, and 1.5 kHz at the first and second impedance adaptation levels. The later frequency limits are driven by the frame rate (40Hz), the multiplexing (16->1) and double correlated sampling mode (see §5.3 and 5.1.3.3).

The location of the different impedance adaptation circuits are chosen to get the necessary stray capacitance compatible with the different bandwidths and power dissipation budgets. The first adaptation stage (300 mK/ 5µW total) is at only few mm from the detectors (TΩ circuit range). The second stage (2K /3 mW total) is at 5 cm from the 1st stage (MΩ circuit range). And the last stage between the 2K readout and 300K warm electronics, is in the KΩ range. It was checked sufficient to discard the “BOLA BOX” containing J-FET circuits, and initially located on the CVV.

![Figure 5.1-13: Schematics of the cascaded impedance adaptation readout circuit](image-url)
5.1.3.2 Differential mode

The PACS bolometer arrays are not very susceptible to microphonics. This is probably due to the mechanical arrangement (no loose parts, metal on silicon connections…).

Our main goal, during design, was to remove the electromagnetic perturbations on the different stages of electronics. For this purpose, the detectors and the two impedance adaptation stages are confined in a metallic enclosure, the BFP box. We ensure then a continuous shielding between the warm electronics and the detection layer. The weak point, in this case, is the 7 meters long harness joining the warm service module to the 300 mK stage inside the cryostat. A reference voltage (VH_BLIND), filtered to few Hz is fed into the second impedance adaptation stage. Bolometer outputs and the reference voltage follow the same tracks (twisted pairs) to the differential input at the warm electronics input level.

5.1.3.3 Double correlated sampling

The readout pMOS and other stages of the electronics will introduce extra noise over the bolometer ultimate performances. The lack of optical modulation with a known source cannot prevent from electronic noise generated inside the detector.

The system includes nevertheless an electronic modulation just after the bolometer, and before the 300 mK pMOS readout. We successively read the bolometer bridge value, and a reference voltage (Vref_1 in Figure 5.2-2) and digitise the difference. The system is modulated at 1280 Hz, and the low frequency noise generated after the modulation point is removed from the recorded data.

The final output is then the product of a double differentiation process:

- synchronous using the VH_BLIND reference,
- time dependent with electronic Double Correlated sampling (DCS).

The DCS mode is the standard mode of operation. It can be used or not by simple tele-command. In the later case, the recorded signal is simply the pixel output.
5.2 Bolometer Array Description

5.2.1 Detector Layer

Detector arrays are produced, in a collective way, as 16 x 16 active pixels sub-arrays. 16 x 16 sub-arrays can be butted on three sides to be assembled in large focal planes. Inside a sub-array, inter-pixel is a transparent silicon wall of 400 µm x 70 µm. This geometry defines the Composant de Détention (CD).

![Figure 5.2-1: Schematics of the detection assembly: CD & CL Integrated Circuit](image)

5.2.2 300 mK Readout & Multiplexer (CL)

The cold "Circuit de Lecture" (CL) layer is an active relay between the detection layer and the cold Buffer (BU). The surface of this chip contains the reflectors for the quarter wave resonant cavity. Under each reflector various pMOS readout circuits are implemented.

CL outputs are high impedance lines to the BU level. The impedance adaptation between CL input and output is made through pMOS readout transistors. The transistors gain was measured to be close or above 95%. The multiplexing function is performed on the same circuit. 16 channels are connected to one output. The multiplexing function is obtained by nMOS gates. Hereafter the final electrical scheme of the CL circuit is reported.
In the electric scheme above, we show two successive pixels readouts out of 16. The bolometers bridges relative to the CD are also displayed here. The decoder presents successively each pixel to the BU input through the "bus line". VRL is the voltage reference input used for the double correlated sampling. Each pixel is linked to its own readout pMOS biased by the VDL input. VGL1 sets the current flowing in the pMOS bridge, the output impedance, and the power dissipated at 300 mK. At this level, the MOS readout geometry is selectable by the input SEL_1 amongst six possibilities (not selectable by command).

CL with hybridised CD circuits on top are placed on a Titanium plate by large indium bumps (800 µm).

A thin ribbon cable is the electrical link of this assembly to the Buffer Unit. Two CL are linked to a single buffer unit.

Buffer Unit function is again to adapt bolometers signals to the output line in the 2 K given thermal budget (< 3 mW total). The distance between BU and the next electronic stage: BOLC, is now few meters. The current running through the readout bridge is one order of magnitude
more important than the correspondent one in the CL circuit, and the output impedance is sufficiently reduced to cope with the line stray capacity to ensure the needed bandwidth.

The reference signal VH_BLOYD is distributed at this level to perform the real differential output.

Figure 5.2-4: Electric scheme of the Buffer Unit. The signals from active and reference voltage are matched as differential output.

Here again, the MOS transistor geometry is selectable amongst six types by the activation of S_BU# input (not selectable by command).

5.3 Bolometer Focal Plane (BFP)

Sub arrays are mounted in an optical-mechanical structure shielding detectors from outside conditions: temperature greater than 300 mK, unfiltered photonic load, RF electromagnetic perturbations. The bolometer focal plane parts can be seen as an assembly of five sub-units described hereafter from the coldest (inner part) to the external envelope.

- 300 mK focal plane,
- 300 mK strap to the cooler,
- 2 K mechanical support,
- 2 K buffer support and
- Envelope.

5.3.1 300 mK Focal Plane

Individual sub-array assemblies (see § 5.2.2) are butted to form the final focal planes.
Figure 5.3-1: 300 mK assembly

Each titanium plate correctly positioned by pins, is attached to the common carrier which defines the overall array geometry. 300 mK-2 K ribbons cables on two sides ensure the electrical link to the 2 K Buffer Unit. The common carrier is screwed to the suspension structure carrying the pulleys. The bottom end of the common carrier is a lug on which the cooler strap is attached. The suspension structure is insulated from 2 K level by a set Kevlar® wires.

Figure 5.3-2: The 300 mK stage suspended in the 2 K mechanical structure

The suspension system consists of two opposite wires winded around pulleys alternatively between the 2 K and 300 mK levels. Each end is also firmly winded (70 N) around a capstan and tightened up. The wire diameter is 280 µm. The measured resonant frequencies are:

a) in transverse direction : 200 Hz
b) in axial direction 500 Hz.

The detectors are finally protected from radiation and other possible contamination sources by a 300 mK filter. The hot pressed film (from Cardiff) is held by a ring and located only few
millimetres above the detector. An electrical grounding continuity is applied to the filter itself to prevent any electrostatic discharge development.

### 5.3.2 300 mK link to the Cryocooler

At sub Kelvin temperature, minimization of thermal interfaces is essential. This was one of our constant aims in achieving the mechanical design. The Oxygen free copper strap, in the BFP, is directly linked to the common carrier by a CHC M3 screw.

![Figure 5.3-3: Thermal link to the 300mK sink.](image)

We solved the problem of the stay light baffling at this level by implementation of a labyrinth formed by three embedded cones, one attached to the strap, the two others on the envelope structure. The clear aperture between the cones, needed to ensure the thermal insulation and air venting of the BFP envelope, is partly filled by absorbing paint to achieve a large stray light rejection.

### 5.3.3 2 K Mechanical Support & Thermal loads

The H shaped mechanical support is the skeleton of the BFP assembly (see picture). It supports the Kevlar wires, carry the envelope and ensure the BFP fixation.

We calculated the thermal load on 300 mK stage due to conduction. Kevlar wires and ribbon cables are the only possible links at the BFP level (radiative exchange was found to be negligible at such temperatures).

- **Kevlar wires**: \( \lambda(T)=21.5 \times 10^{-6} \times T^{1.58} \) W/K.cm. \( \Omega=0.28 \) mm, \( L=2 \) cm and \( \Delta T=1.7 \) K
  
  \[ P = 1.5 \times 10^{-2} \mu W \text{ for one wire} \]
  
  calculated \( P_{tot} = 0.3 \mu W \text{ for 20 wires.} \)

- **Ribbon cables**: We measured the thermal conductance of the ribbon cable between 0.3 and 1.8 K and found to be 0.033 \( \mu W \) for a 70 mm long, 25 \( \mu m \) thick and 1 cm large Kapton strip carrying 51 (100 \( \mu m \times 5 \mu m \)) constantan wires.

  With the current geometry we calculated:
  - \( P(\text{Red BFP}) = 0.13 \mu W \) and,
  - \( P(\text{Blue BFP}) = 0.53 \mu W \)

  **Total heat load from conductance on the 300 mK Cryocooler**: \( \Phi \approx 1 \mu W \)
Value to be compared with the Power budget delivered by the Cryocooler for a 48 h cycle to users: 12 µW.

Figure 5.3-4: Mechanical assembly seen from the BU side. Note the ribbon cables attachments.

5.3.4 2 K Buffer Support

The Buffer Units and the interconnection circuits (RI), are attached to the mechanical support by two common Titanium plates. The 2 K-4 K ribbon cables are also attached there. For obvious chiral reasons, there are two types of BU circuits (type I and II), allowing to have the same outputs interfaces as well as two 2 K – 4 K ribbon cables types (see §5.4.3).

Figure 5.3-5: Electric link between 300 mK stage and 2 K stage. Envelope

The external envelope achieves the detector shielding. The access to inner part of the BFP while mounting the thermal strap is made possible thanks to two half shells fixed to the H shaped support. A socket closes the box, and finally a conic stray light shield in front of the detectors protects them from unwanted stray light. Inside the cone, an air gap filter (Cardiff), combined with the second hot pressed located at the narrow end, reduces the optical bands.
5.4 Photometer Focal Plane

5.4.1 Optical Specifications

5.4.1.1 Global optics interface & Wavelength coverage

The interface between PACS optics design and Photometer Focal Plane Unit (PhFPU) is given here. The dichroic splits the wavelengths in two channels called the "Red" and "Blue" channels. The Blue detectors must be sensitive from 60 to 130 μm (8 sub arrays -2048 pixels) while Red detectors are devoted to the 130-210 μm band (2 sub arrays 512 pixels, see §5.1.2.1). A distinct magnification is introduced by the set of three mirrors to achieve the same field of view (FOV) for the two channels: (3.5' x 1.75')
Filters carried by a cold filter wheel in front of the Blue channel select again two optical bands:

- **Blue Band 1**: 60-85 µm
- **Blue Band 2**: 85-130 µm

### 5.4.1.2 Focal plane geometry

The PACS arrays fill the Herschel Telescope focal plane portion without significant holes. In the Blue focal plane 8 sub arrays are butted with an inter-array gap slightly greater than a 1 pixel row (~950 µm). The red focal plane is composed of only two sub arrays.

![Focal Plane Characteristics](image)

In this assembly each Blue pixel covers (3.2 arcsec)$^2$, while the Red pixel covers (6.5 arcsec)$^2$.

The positioning tolerance between sub-arrays at the operating temperature is ± 75 µm. Inside a sub array the position accuracy is better than 1 µm

### 5.4.1.3 Topologic Focal Plane identification

The following figures define the different sub-units with reference to the 300 mK strap feedthrough direction.

The blue focal plane is defined as follows:
Figure 5.4-3: Blue focal plane identification.

…and the (simpler!) red one:

Figure 5.4-4: Red focal plane identification

When reading the array, the addresses of the right hand and left hand sub arrays are inverted to be able to read 32 active pixels of the same row simultaneously.

Figure 5.4-5: Detector array readout sequence
5.4.2 2 K Stage

The Blue and Red BFPs are mounted on a thermally insulated structure. Insulation is obtained by a set of stainless steel tubes.

![Figure 5.4-6: The 2K stage: the BFP frame](image)

The 2 K strap is attached to the structure (green frame in the figure). Absolute positioning of the detectors can be obtained at the structure level only. Relative positioning of the two focal planes is frozen when mounting the complete 2 K stage (structure + BFPs).

5.4.3 4 K Stage

The 4 K stage is composed of the BFP enclosure (in blue in the figure), a stack of RF filter boxes (light blue), the connector panel (green), and the cryocooler structure with shields beneath.

![Figure 5.4-7: The complete PhFPU assembly](image)
The 300 mK strap between the cold tip and the BFPs is shown in pink. On the sides of the 4K enclosure, we can see the guiding pins (orange), used to assemble the photometer to the PACS assembly.

A black painted metallic "blanket", on the PhFPU, achieves to define the optical interface with respect to the main part of PACS. A wall ensures the complete separation of blue and red channels.

![Diagram of PACS instrument](image)

**Figure 5.4-8: Stray light interface with PhFPU**

### 5.4.4 Electrical Interface

The PACS photometer has its own interface with warm electronics. This interface must ensure an efficient stray light rejection and RF filtering.

#### 5.4.4.1 Mechanical description of the connector panel

The electrical interface with the cold harnesses is made at a connector panel with seven slots and an additional pair of connectors. On the PhFPU, all the connectors are cannon MDM 37.

The seven slots on the connector panel link the electric cables to the inner part of the PACS instrument. Special care was taken to avoid any stray light or RF perturbation to enter the instrument. On the side of the connector panel, two extra connectors, also MDM 37 type, are linked to the cryocooler (outside PACS enclosure).
Six of the seven slots are used to access to the six BU (four for the Blue and, two for the red channel). The remaining one connects to all the Housekeeping probes (essentially Temperature measurements), and the heaters dedicated to the fridge charcoal pump and thermal switches.

The PACS enclosure must act as a Faraday cup. For this purpose, all the FR filter Boxes and connectors are sealed with indium strips.

5.4.4.2 2K-4K ribbon cable and RF filters

The RF filter boxes have the double function to prevent any light and RF intrusion inside the PACS instrument. The light filtering is made by the MDM connector itself, whose putting was measured to be opaque to IR light.

The RF filtering is also provided by the cryogenic filter connectors loaded with 2500 pf capacitance for inputs, and 300 pf for outputs. At the other end of the box, the ribbon cable is sealed by an indium strip and pinched in the box aperture.

Outside the connector panel, the harnesses MDM connectors also wear metallic backshells.
Figure 5.4-10: Ribbon cable geometry

The 2 K – 4 K ribbon cable is a flex rigid assembly. On the rigid pieces, commercial passive RF filters chips are implemented. Unfortunately the need to reduce the line capacity (see §5.1.3) obliges to use filters of moderate efficiency at the multiplexing frequency.

Figure 5.4-11: View of the Buffer Unit with 2K – 4 K test ribbon cable: the RF filters are not implemented in this configuration.

5.4.4.3 Grounding policy

The effective system grounding has also a very important impact on the detector performances. The presence of two completely separate focal planes avoids having the "star point" at the BU
level as commonly suggested. We choose the RF filter boxes location for the grounding star point as shown in the next figure.

![PhFPU Grounding Scheme](image)

Figure 5.4-12: PhFPU Grounding Scheme

### 5.4.5 Cryocooler

The 300 mK cryocooler is a subsystem located below the photometer 4 K structure. Its mechanical interface to the photometer and then to the PACS instrument is simply a set of six CHC screws. The outer part of the cryocooler is a mechanical structure linked to the Level 1 (L1) instrument level. Inside this structure a thin Ti tube links two suspended Titanium spheres. Four Kevlar wires sets ensure the thermal insulation from the L1 stage. The larger sphere (the pump), filled with charcoal is thermally linked to the level 0 (L0) Herschel strap by a thermal heat switch. Heaters on this sphere allow to change charcoal temperature (with help of the heat switch) to control the charcoal pumping or outgassing speed.

![The Herschel cryocooler design (present also in SPIRE)](image)

Figure 5.4-13: The Herschel cryocooler design (present also in SPIRE)
At the other end, a smaller sphere (called evaporator) filled with foam is able to maintain liquid Helium in the cavity, even in the absence of gravity, thanks to the capillary forces. In between the “tube” seals the system and ensures the thermal insulation from the “hot” sphere containing charcoal to the “cold” evaporator. A cold ring, on the tube, attached to the L0 level acts as an active shield. The evaporator is also linked to a second 2 K strap by a second heat switch, to induce the He condensation during recycling process.

![Diagram of thermal interface between the cryocooler, the Herschel vessel and the PACS photometer 2 K level](image)

**Figure 5.4-14:** Thermal interface between the cryocooler, the Herschel vessel and the PACS photometer 2 K level

The “Fridge” is filled with $^{3}$He. The extraordinary pumping speed of charcoal around 2 K allows to reach 270 mK at the cold tip with a small heat load (few µW). The cryocooler will be electrically insulated from the cryostat, and a baffling system will prevent stray light to enter the PACS instrument.
6. CRYO HARNESS

6.1 Cryo Harness

The PACS cryo harness accomplishes the electrical connections between the warm drive/data acquisition electronics and the detector/mechanical units inside the FPU.

It consists of three main parts:

1. The wiring outside the cryostat vessel, between the warm electronics (~300 K) and the cryostat feedthroughs (~100 K).
2. The wiring inside the cryostat vessel, between the feedthroughs and the FPU connectors (~ 4 K).
3. The wiring inside the PACS FPU and the subunits.

Figure 6.1-1 gives an overview about the PACS cryo harness.

Due to the large temperature gradient along the harness, in particular inside the cryostat vessel, special cables with low heat conduction have to be used. Some actuators inside the FPU need drive currents > 10 mA and therefore require a trade off between heat conduction and heat dissipation due to the electrical resistance. Figure 6.1-3 shows the wiring of the cryo mechanics.

Supply lines for the detector units as well as the lines of position sensors are susceptible for electromagnetic interference (EMI) and are therefore shielded carefully. The connection of the shields must be in agreement with the overall grounding concept, which also includes the spacecraft structure. EMI aspects also have to be considered in the routing and bundling of lines because signal levels in the sub-mV range have to be measured. During design of the PACS cryo harness concept such aspects were regarded and have been applied as far as possible. A detailed description of the Cryo Harness can be found in PACS-MA-SP-001, PACS Cryo Harness Specification.

For the detector arrays some of the supply lines are used in common for several modules. This reduces considerably the total number of lines required. In order to reduce the risk for losing a complete Ge-detector array in case of a failure in a supply or a detector module, each of the two Ge-detector arrays is split into two separate supply groups. The wiring for this is done on two distribution boards inside the FPU. These boards also serve as carrier for the 50 connectors, where the pigtails of the detector modules are plugged to and for the decoupling capacitors required to reduce crosstalk and EMI (Figure 6.1-4).

For the output lines of the Ge-detector modules, which carry the multiplexed (~8 kHz) analog signals, triaxial cables are used. The inner shields are driven by amplifiers of gain = 1 in the warm electronics. By using this technique the effective line capacity is nearly zero and the power dissipation of the Cold Readout Electronics (CRE) into temperature level 1 (4 K) is reduced by about factor of 2. This is necessary to comply with the allowed power budget.
The Bolometer detectors are also split in separate supply groups, four in the “blue” channel and two in the “red” channel. The twisted pair output lines are driven by differential buffers. This is possible because of the lower sample rate (40 Hz). (Figure 6.1-2).

The nominal voltages on any line are ≤ 30 V.
HERSCHEL
PACS

PACS Instrument Description

Part II

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Short λ detector assembly

Long λ detector assembly

"Blue" bolometer assembly

"Red" bolometer assembly

Bol.-Cooler, temp.control

Distribution board 2

Distribution board 1

PACS FPU

Cryo mechanics
(Grating,
Filter wheels, Chopper)

Calibr. sources

Temperature sensors

Warm drive,
control and
data acquisition
electronics

DEC / MEC and BOLC

Inside cryostat vessel

Outside cryostat vessel

Inside Service Module

Figure 6.1-1: Overview PACS cryo harness

CVV internal harness 138 100 (SST/Brass, no overshields)

CVV external harness 138 200 (SST/Brass)

131 lines + 69 shields + 2 bundle overshields
(40 cables, 5 cable types)

123 lines + 69 shields + 2 bundle overshields
(40 cables, 5 cable types)

380 lines + 32 shields + 4 bundle overshields

94 lines + 12 shields + 2 bundle overshields

96 lines + 24 shields + 2 oversheilds
(24 cables, 1 cable type)

236 lines + 49 shields + 3 overshields

236 lines + 49 shields + 3 overshields

Total CVV internal:
1060 wires + 255 shields

Total CVV external:
1060 wires + 255 shields, 15 bundles/oversheilds

SVM-Connector bracket

SVM int. harness 138 300 (Cu)

Total CVV internal wires not counted

Inside Service Module

CVV- feedthroughs (100/128 pins)

SVM internal harness 138 300 (Cu)

94 lines + 12 shields + 2 bundle overshields

380 lines + 32 shields + 4 bundle overshields

96 lines + 24 shields + 2 oversheilds
(24 cables, 1 cable type)
Figure 6.1-2: Bolometer subsystem
Figure 6.1-3: Wiring of PACS cryo mechanics
One assembly is composed of 25 detector modules consisting of 16 detectors each.

For each assembly 25x16 detector wires + 25x3 temp sens wires.

Special connections (31 contacts):

- 1.7 K/2.5 K ~ 4.2 K
- 300 K

Integrating PreAmp’s, Multiplexer

Stressed Ge:Ga Detectors

Harness < 30 cm, Cu

Harness 138 100.. CVV int

Harness 138 200.. CVV ext

Harness 138 300.. SVM

Distribution Board #2

(2 supply-groups for detector-assembly 2)

Distribution Board #1

(2 supply-groups for detector-assembly 1)

Vessel feedthroughs

SVM-Connector bracket

~ 6 m, SST/Brass

~ 1.8 m, Cu

~ 100K

~ 300K

300 K

PACS Ge-Detector-Subsystem

PACS Instrument Description

Part II

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