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|---|---|---|
| SRON HIFI | **SPECIFICATION** | **Hifi no.: SRON-G/HIFI/SP/1998-001**<br>**Inst.no.: HIFI Instrument**<br>**Issue: Issue 4.4**<br>**Date: October, 2004**<br>**Category: 2** |

# Title: HIFI Instrument Specification

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|---|---|---|---|
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**Remark**

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**All Sub-System managers are asked to check the requirements that are applicable to them. The applicable sign-off page is to be sent to HIFI project office by Facsimile or as a PDF file attached to an E-mail.**

***Distribution:***

- Steering Committee

- Project Team

**Document Change Record**

| Date | Issue/Revision | Section | Change |
|---|---|---|---|
| | | | |
| 99-11-16 | Draft 2.0, NDW | all | This is issue is a revision of earlier draft 1.4. Changes include revised LO s/s, add functional breakdown, separate description from requirements in old section 3, move requirements to new section 4, delete § 7, revise budgets, bands 6 & 7 changes, miscellaneous text changes. |
| 00-02-16 | Issue 1.0, NDW | | Major changes include: add Specification document tree; reference to Design Description; corrections re LO Source Unit changes; interface matrix; revise harness list and state source; revise description of observing timeline; added HRS mode list; define chopper positional accuracy, dead-time and speed; revise Allan variance specification; expand flux calibration budget.<br>Changes have been marked at the left side of each page. |
| 00-08-18 | Issue 2.0, PS | all | Major changes include: deletion of Specification document tree, add unique numbering of all requirements, all requirements related tables have been moved to a separate chapter (8),<br>Several Typos changed,<br>Several TBC and TBD issues have been made explicit.<br>References to section (numbers) IID-A and -B updated<br>Deletion of band 7 (CN-002)<br>Deletion of Cryo Cooler (CN-003)<br>4.1.6.2: fast mode for absorption line and extra galactic studies,<br>4.2.3.3: TBC deleted,<br>4.2.3.4: max throw, step size, period resolution<br>4.2.3.5: revised instrument stability requirement<br>4.3.1: revised instrument redundancy approach<br>4.3.3: grounding concept ref. added<br>4.3.4: Instrument Modes to be revisited<br>4.3.6: data handling moved to ICD<br>4.4.5: formulation of req. 4 altered<br>4.5.1: spectral resolution function defined<br>4.5.4: table updated<br>4.5.6: deleted<br>4.5.7: HRS and WBS ripple budgets added<br>4.5.8: HRS dynamic range budget added<br>7.1.5: Section on reliability added |
| 01-09-25 | Issue 3.0, WvL | 2.1<br>2.2<br>3.2.3<br>3.2.6<br>4.1.1<br>4.1.3<br>4.1.4<br>4.1.5<br>4.1.6.1<br>4.1.6.2<br>4.1.8<br>4.2.1.4<br>4.2.2.1 | OBS specifications added as applicable documents<br>TBD references made available<br>WBS description actualized<br>Harness description actualized<br>Observation timeline redefined<br>Signal frequency, side-band selection redefined<br>More appropriate paragraph title chosen<br>Spectrometer settings redefined<br>Explanary comments “on the fly mapping” changed<br>Editorial changes, redundant requirement deleted<br>Detailed requirements replaced by generic one<br>Editorial changes<br>Spectral resolution redefined |

| Date | Issue/Revision | Section | Change |
|---|---|---|---|
| | | 4.2.2.2 | WBS resolution from 1 MHz to 1.1 MHz |
| | | 4.2.2.3 | HRS lags per sub-band adapted |
| | | 4.2.2.6 | Frequency calibration accuracy reduced |
| | | 4.2.2.7 | Spectral purity defined for HRS, WBS and LO |
| | | 4.2.3.3 | Chopper requirements redefined |
| | | 4.2.3.5 | Power/spectroscopic Allan variance from 20 to 50% |
| | | 4.2.3.6 | Definition of internal calibrator requirements |
| | | 4.3.1 | Redundancy approach extended to all components |
| | | 4.3.3 | Editorial change: section added to AD-01 reference |
| | | 4.3.4 | Calibrator active in stand-by mode<br>Goal warm-up time from stand-by mode: 5 minutes |
| | | 4.3.5 | Detailing of automated tuning requirements |
| | | 4.3.6 | Dedicated applicable documents for data handling |
| | | 4.4.1 | Editorial changes |
| | | 4.4.2 | From circular to linear polarisation |
| | | 4.4.5 | ICU requirements redefined with reference to applicable documents |
| | | 4.5.2 | Accuracy LO master reference oscillator changed |
| | | 4.5.3 | Editorial change |
| | | 4.5.5 | Requirement on amplitude stability specified |
| | | 4.5.7.1 | Editorial change |
| | | 4.5.7.2 | WBS ripple applicable to 1 GHz subbands only |
| | | 4.5.9 | Maximum tuning time specified |
| | | 4.5.10 | Requirement on LO signal power loss specified |
| | | 4.5.11 | Update of LO power output per frequency range |
| | | 4.5.12 | Optical FPU Requirements refined or deleted |
| | | 6.1 | Radiation requirement defined |
| | | 6.2 | Editorial change: section added to AD-02 reference |
| | | 6.3 | Straylight requirement defined |
| | | 6.4 | Cleanliness levels refined |
| | | 6.4.1 | Bake-out requirements defined |
| | | 6.6 &6.7 | Reference for accoustic environment changed |
| | | 6.9 | Distinction between dP/dt inside and outside cryostat |
| | | 7.1.1 | Lifetime requirements confirmed |
| | | 7.2.4 | Editorial change |
| | | 7.2.7 | Requirement on venting defined |
| | | 7.3 | Electronic design requirements rewritten, with reference to applicable documents |
| | | 7.4 & 7.5 | For optical and software requirements reference is made to AD-01 and AD-02 |
| | | 8 Table 4.2.1.4-1 | Frequency bands 6L,6H defined |
| | | 8 Table 4.2.2.3-1 | HRS lags per subband adapated |
| | | 8 Table 4.5.1-1 | Update of frequency resolution budget |
| | | 8 Table 4.5.2-1 | Update of frequency accuracy budget |
| | | 8 Table 4.5.3-1&2 | Update sensitivity budget including LO injection |
| | | 8 Table 4.5.4-1&2 | TBD's in calibration budget specified |
| | | 8 Table 4.5.5-1&2 | Gain stability budget defined |
| | | 8 Table 4.5.10-1 | LO signal power loss budget defined |
| | | 8 Table 4.5.11-1 | Update and refinement of LO power output budget |
| | | 8 Table 6.4-1 | Update of contamination budget |
| **14-10-02** | **Issue 4, WvL** | | **Changes are marked (red/bold). Main changes are due to HRS descoping, the WBS 10 MHz i/f with the LSU and the rerouting of the IF signals. Furthermore the comments from WBS and HRS at the Management Meeting dd 8-10-02 have been incorporated.** |

| Date | Issue/Revision | Section | Change |
|---|---|---|---|
| 24-09-03 | Issue4.1, HA | 3<br>4.2.1.2<br><br>4.4.1<br><br>4.5<br><br>8 Table 4.2.1.4-1<br>8 Table 4.2.1.4-1<br><br>8 Table 4.5.2-1<br><br>8 Table 4.5.11-1 | CN/2002-002: Changed reference into IID-B.<br>CN/2002-005: Included bandwidth of 2.4 GHz for RF frequency range 1410 to 1910 GHz.<br>CN/2002-005: Added requirement (IS-04.04.01-14) for IF Up-Converter<br>CN/2002-005: Added section header.<br>Changed section headers to level 3.<br>CN/2003-003: Change of lower frequency for bands 2 and 5<br>CN/2002-005: For bands 6L and 6H changed Central Frequency into 3.6 GHz and IF bandwidth into 2.4 GHz.<br>CN/2002-005: Added line indicating IF up-converter frequency accuracy<br>CN/2003-003: Change of frequencies for bands 1b, 2a, 5a, 6Ha, 6Hb. |
| 13-11-03 | Issue 4.2, HA | 8 Table 4.5.10<br>8 Table 4.5.11-1<br>8 Table 4.5.1-1 | CN/2003-008: Band 1 LO power budget<br>CN/2003-008: Band 1 LO power budget<br>CN/2003-009: IFH/V frequency accuracy & lineidth budget |
| 28-01-04 | Issue 4.3, HA | 8 Table 4.5.11-1 | CN/2003-011: Reduce band 4 LO power requirement |
| 06-10-04 | Issue 4.4, HA | 4.2.2.1 IS-04.02.02.01-02<br>8 Table 4.5.11-1 | Error in frequencies corrected : 1410 Thz should be 480 MHz.<br>MPIfR/HIFI/CN/2004-006 Change of Band 3a and b edge frequencies |
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**Sub-System:** **ICU**

**Sub-System manager:** **R. Orfei**

**Signature:**

**Sign off date:**

**Sub-System:** **FP**

**Sub-System manager:** **C.K. Wafelbakker**

**Signature:**

**Sign off date:**

**Sub-System:** **WBS**

**Sub-System manager:** **T. Kuhn**

**Signature:**

**Sign off date:**

**Sub-System:** LO

**Sub-System manager:** R. Güsten

**Signature:**

**Sign off date:**

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|---|---|---|
| SRON HIFI | **SPECIFICATION** | **Hifi no.: SRON-G/HIFI/SP/1998-001**<br>**Inst.no.: HIFI Instrument**<br>**Issue: Issue 4.4**<br>**Date: October, 2004**<br>**Category: 2** |

**Sub-System:** **HRS**

**Sub-System manager:** **A. Cros**

**Signature:**

**Sign off date:**

**Table of Contents**

# 1 Introduction

## 1.1 Purpose

The purpose of this document is to specify the functionality, the performance and the operation of the HIFI instrument and to define the interfaces between its subsystems and with the **Herschel** spacecraft.

## 1.2 Scope

The HIFI specifications are described in three levels of documents:

1 Instrument Specifications
2 Unit Specifications
3 Interface Definitions

The specification tree is given in RD-04

The requirement allocation to the various subsystems is defined in dedicated Traceability Matrices. The purpose is to ensure tractability between the instrument specification and the subsystem specifications.

This document, the Instrument Specification contains:

~~a. the instrument description and a break-down of the instrument in its subsystems,~~
b. the functional specification of the instrument and sub-system requirement allocation,
c. the performance specification of the instrument and unit performance allocation.

The requirements have been labelled with unique identification numbers and are specified in chapter 4 through 7. Explanatory notes have been printed in italics.
Referenced figures and tables can be found in chapter 8.

# 2 Document References

## 2.1 Applicable Documents

| | | |
|---|---|---|
| AD-01 | Instrument Interface Document, part B | PT-HIFI-02125 |
| AD-02 | Instrument Interface Document, part A | PT-IID-A-04624 |
| AD-03 | FIRST-L2 Radiation Environment | Esa/estec/wma/he/FIRST/3 |
| AD-04 | FIRST Pointing Modes | PT-SP-04673 |
| AD-05 | OBS User Requirements Document | IFSI/OBS/SP/2000-001 |
| AD-06 | HIFI Interface Control Document | SRON-G/HIFI/SP/1999-001 |
| AD-07 | Product Assurance Plan for the FIRST-HIFI Instrument | SRON-U/HIFI/PL/1999-008 |
| AD-08 | Science User Requirements Document | SRON-G/HIFI/SP/2000-001 |
| AD-09 | Packet Structure ICD | SCI-PT-ICD-7527 |
| AD-10 | HIFI command specification | SRON-U/HIFI-SP-2001-004 |
| AD-11 | HIFI TC packet ICD | SRON-U/HIFI-SP-2001-001 |
| AD-12 | HIFI TM packet ICD | SRON-U/HIFI-SP-2001-002 |
| AD-13 | HIFI HK packet ICD | SRON-U/HIFI-SP-2001-003 |
| AD-14 | Digital Time Division Command/Response Multiplex Data bus | MIL-STD-1553B, Notice 2, 8-9-1986 |
| **AD-15** | **EMC Control Plan** | **SRON-U/HIFI/PL/2000-002** |
| **AD-16** | **HIFI Environmental Test Requirements** | **SRON-U/HIFI/SP/2001-012** |

## 2.2 Referenced Documents

| | | |
|---|---|---|
| RD-01 | HIFI Design Description | SRON-G/HIFI/RP/2000-001 |
| RD-02 | Observation Planning System | TBD |
| RD-03 | Acronyms List | SRON-U/HIFI/LI/2001-001 |
| RD-04 | Specification Tree | SRON-U/HIFI/LI/2001-005 |
| RD-05 | HIFI Quasi-Optical Alignment Budget | SRON-G/HIFI/TN/2000-004 |

# 3 Instrument Description

**For the instrument description refer to the Instrument Interface Document part B, AD-01, chapter 4.**

# 4 Instrument Requirements

IS-04 -

## 4.1 Observing Modes

IS-04.01 -

*Observations are defined by:*
*1) a timeline involving:*
*2) the pointing of the telescope,*
*3) the signal frequency, side band selection,*
*4) the L.O. and mixer frequency bands,*
*5) the configuration of the spectrometers (resolution and frquency ranges),*
*6) the signal modulation mode (on the fly mapping, beam switching, frequency switching),*
*7) the integration time,*
*8) other parameters.*
*Within certain constraints the observer can select each of items 2-8 as a function of time.*

### 4.1.1 Observation timeline

IS-04.01.01-01 Deleted.

IS-04.01.01-02 All instrument operations shall be timed through time tags.

IS-04.01.01-03 Spacecraft and instrument operations shall be synchronised only through time tags.

### 4.1.2 The pointing of the telescope

IS-04.01.02-01 The telescope pointing shall be commanded independently from the instrument, according to the observation timeline.

IS-04.01.02-02 Applicable pointing modes are: raster pointing, line scanning, solarsystem object tracking, position switching, nodding.

IS-04.01.02-03 A peak-up mode shall involve the execution of a small raster scan on a point source

IS-04.01.02-04 A peak-up mode shall involve the evaluation of the spectrometer outputs to compute a relative pointing correction.

IS-04.01.02-05 The pointing correction shall be communicated to the spacecraft CDMS for inclusion in the AOCS pointing offset.

### 4.1.3 Signal frequency, side-band selection

IS-04.01.03-01 The observer shall specify the central signal frequency.

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|---|---|
| IS-04.01.03-02 | Except near the edges of the L.O. bands, the observer may choose to observe with the L.O. above or below the signal frequency. |
| IS-04.01.03-03 | Frequency corrections for satellite motion, Sun's motion, source motion shall be handled off-line in the analysis of the data. |
| IS-04.01.03-04 | For frequency-switched observations the frequency throw must be specified. |

### 4.1.4 LO and mixer band selection.

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|---|---|
| IS-04.01.04-01 | The selection of LO and mixer bands shall normally follow from the selected signal and LO frequencies. |

### 4.1.5 Spectrometer configuration

| | |
|---|---|
| IS-04.01.05-01 | The observer shall be able to select the frequency ranges and the resolution of the High-Resolution Spectrometer. |
| IS-04.01.05-02 | The observer shall be able to select a reduced number of channels from the spectrometers |
| IS-04.01.05-03 | Deleted. |

### 4.1.6 The signal modulation mode

| | |
|---|---|
| IS-04.01.06-01 | The time to be spent in each modulation phase shall be limited by the spectrometer configuration and on-board spectra subtraction schemes. |

#### 4.1.6.1 On the fly mapping

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|---|---|
| IS-04.01.06.01-01 | During On-the-fly mapping data shall be taken continuously while the telescope is scanning across the source.<br><br>*Here the instrument does not use internal modulation, but uses spacecraft pointing performing a raster scan to modulate the signal.*<br><br>*This mode may also be useful in combination with beam and frequency switching.*<br><br>*This mode will normally require data selection as indicated in 4.1.5.* |
| IS-04.01.06.01-02 | The correlation of signal variation with *telescope* pointing shall be carried out on the ground. |

#### 4.1.6.2 Beam switching

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|---|---|
| IS-04.01.06.02-01 | Beam switching shall use the internal focal plane chopper to switch the |

beam between two positions on the sky.

IS-04.01.06.02-02 Beam switching shall be allowed to be combined with nodding of the telescope, to move the source from one chopped beam to the other.

IS-04.01.06.02-03 For the observer, the chopper throw shall be a fixed system parameter.

IS-04.01.06.02-04 Deleted

IS-04.01.06.02-05 The chopper frequency shall be selectable by the observer to be "normal" or "fast".

*The fast mode may be required for absorption line and very broad-line extragalactic studies, depending on the measured gain stability of the instrument. (see Section 4.2.3.3).*

#### 4.1.6.3 Frequency switching

IS-04.01.06.03-01 Freq. switching shall be implemented by rapid alternation between two L.O. frequencies in the same frequency band.

IS-04.01.06.03-02 The frequency switching frequency shall be the same as the "normal" focal-plane chopper frequency.

IS-04.01.06.03-03 The frequency offset shall be selected by the observer within the range allowed by the hardware.

### 4.1.7 Integration time

IS-04.01.07-01 The integration time shall be a multiple of the modulation period.

### 4.1.8 Other parameters

IS-04.01.08-01 Deleted

IS-04.01.08-02 Deleted

IS-04.01.08-03 Deleted.

IS-04.01.08-04 In routine observations , internal calibrations and instrument optimisation prodecures shall be inserted automatically by the ground segment.

## 4.2 Instrument Performance requirements

### 4.2.1 Frequency ranges & intermediate frequencies

#### 4.2.1.1 RF range

IS-04.02.01.01-01 The bandwidth of the Intermediate Frequency system shall be 4 GHz for the RF frequency range 480 to 1250 GHz and 2.4 GHz for the RF frequency range 1410 to 1910 GHz.

IS-04.02.01.01-02 HIFI shall cover the freq. ranges between 480 MHz and 1910 GHz

#### 4.2.1.2 IF band width

IS-04.02.01.02-01 The bandwidth of the Intermediate Frequency system shall be 4 GHz.

#### 4.2.1.3 Polarisations

IS-04.02.01.03-01 Two polarisations shall be measured simultaneously.

#### 4.2.1.4 Frequency bands

IS-04.02.01.04-01 The frequency ranges shall be divided into bands that can be handled by a single mixer pair.

IS-04.02.01.04-02 Only one mixer pair will be used simultaneously.

IS-04.02.01.04-03 Both mixers of a pair shall cover the same frequency range.

IS-04.02.01.04-04 Each frequency band shall have its own L.O. sources.

IS-04.02.01.04-05 The signal & IF frequency bands shall be as listed in Table 4.2.1.4-1.

### 4.2.2 Spectral properties

#### 4.2.2.1 Spectral resolution

IS-04.02.02.01-01 HIFI shall have a spectral resolving power which exceeds 3.10E6 (see Table 4.5.1-1).

IS-04.02.02.01-02 HIFI shall have a maximum spectral resolution ranging from 160 kHz at 480 GHz to 350 kHz at 1.91 THz (See Table 4.5.1-1).

#### 4.2.2.2 Wide-band measurements

IS-04.02.02.02-01 A wide-band spectrometer shall be implemented to simultaneously cover the entire IF band with a resolution of <1.1 MHz.

#### 4.2.2.3 High Resolution Spectrometer Modes

IS-04.02.02.03-01 The HRS shall provide as a minimum the modes as listed in Table

4.2.2.3-1.

#### 4.2.2.4 Sidebands

IS-04.02.02.04-01 HIFI shall observe in double-sideband mode: simultaneously in two frequency ranges, offset from the L.O. frequency in either direction by the IF frequency.

#### 4.2.2.5 Frequency setting

IS-04.02.02.05-01 For bands 1 to 5 the central signal frequency shall be adjustable with a resolution of 10 MHz or less.

IS-04.02.02.05-02 For band 6 the central signal frequency shall be adjustable with a resolution of 20 MHz or less.

#### 4.2.2.6 Frequency calibration

IS-04.02.02.06-01 The frequency calibration accuracy shall be better than one part in $10^7$.

#### 4.2.2.7 Spectral purity

IS-04.02.02.07-01 All spurious responses of the instrument shall be suppressed by at least 25 dB relative to the wanted response, but excluding the image response of the first mixer and the normal spectrometer frequency response function as expressed by requirement IS-04.05.01-02

*This requirement applies to the HRS and WBS at sub-system level, and to HIFI at instrument level.*

IS-04.02.02.07-02 There shall be no spurious signals apparent in a **difference** spectrum obtained from a 1 hour integration using a 200 second switching period with no line signal input.

*This requirement applies to the HRS and WBS at sub-system level, and to HIFI at instrument level.*

IS-04.02.02.07-03 The spectrometers shall not emit spurious signals into the IF system within the 4-8 GHz band with a level exceeding -102 dBm.

*This requirement applies to the HRS and WBS at sub-system level.*

IS-04.02.02.07-04 The local oscillator subsystem shall comply with the signal purity requirement (spurious signal level) listed in Table 4.5.3-1. ~~**(TBC)**~~

### 4.2.3 Radiometric properties

#### 4.2.3.1 Coupling with the Telescope

IS-04.02.03.01-01 The aperture efficiency shall be greater than 60% for all frequencies.

#### 4.2.3.2 Radiometric Calibration Accuracy

IS-04.02.03.02-01 The instrument internal noise temperature calibration accuracy shall be better than 10% with a goal of 3%.

IS-04.02.03.02-02 The end-to-end flux calibration accuracy shall be better than 10% with a goal of 3%.

#### 4.2.3.3 Focal Plane Chopper Parameters

IS-04.02.03.03-01 The maximum throw for beam switching shall amount to at least 3.0 arcminutes on the sky.

IS-04.02.03.03-02 The chopper position reproducibility shall be better than 1 arcseconds on the sky.

*This specification mainly drives the requirement on the repeatability of the angular position of the chopper mechanism. It is required to ensure that the desired flux calibration accuracy can be achieved.*

IS-04.02.03.03-03 The direction of motion of the chopped beam on the sky will be aligned with the z-axis of the spacecraft within 0.5 degrees.

IS-04.02.03.03-04 The chopper throw shall be adjustable with a precision of better than 1 arcseconds on the sky.

IS-04.02.03.03-05 The chopper period shall be adjustable between 200 and 3000 ms with a resolution of less than 10 ms.

IS-04.02.03.03-06 The chopper waveform shall be nominally square with a total dead-time of less than 20% of the period, i.e. a switch time of <10% of the period.

*Dead-time is defined as the fraction of time when integration is not possible due to e.g. non-compliance of chopper with IS-04.02.03.03-02 and IS-04.05.12.01-01*

#### 4.2.3.4 Frequency-Switching Parameters

IS-04.02.03.04-01 The frequency-switching throw shall be adjustable between 0 and > 90 MHz in steps of less than 10 MHz for bands 1 - 5.

IS-04.02.03.04-02 The frequency-switching throw shall be adjustable in steps < 20 MHz for higher bands.

IS-04.02.03.04-03 The frequency-switching period shall be adjustable between 1000 and 3000 ms. ~~**(TBC)**~~

IS-04.02.03.04-04 The frequency-switching period shall be adjustable with a resolution of less than 10 ms. ~~**(TBC)**~~

IS-04.02.03.04-05 The frequency-switching dead-time shall be less than 100 msec.

#### 4.2.3.5 Amplitude Stability

IS-04.02.03.05-01 The instrument shall have a total power Allan variance of no more than 50% higher than the theoretical value for an integration time of 1 s (corresponding to a chopper period of 2 s) and for the spectral resolutions listed in Section 4.2.2.1.

IS-04.02.03.05-02 The instrument shall have a spectroscopic Allan variance no more than 50% higher than the theoretical value for an integration time of 100 s (corresponding to a chopper period of 200 s) and for the spectral resolutions listed in Section 4.2.2.1, and with spectral channels separated by 2 GHz *(i.e. in different sub-bands of the spectrometers)*

#### 4.2.3.6 Internal Calibrator Requirements

IS-04.02.03.06-01 The internal calibrator shall allow to couple the RF input of the instrument to a thermal source.

IS-04.02.03.06-02 The internal calibrator temperature shall provide an effective brightness temperature over the frequency range of HIFI which can be varied between the FPU ambient temperature and >50 K.

IS-04.02.03.06-03 The internal calibrator shall comply with the relevant requirements listed in Table 4.5.4-1.

## 4.3 System concepts

### 4.3.1 Redundancy approach

IS-04.03.01-01 In the event of a single failure of a component, the instrument shall lose at most:
- one L.O. (sub-)band, or
- one polarisation.

*In case of deviations from this requirement, a RFW shall be issued , specifying the failure and the measures taken to increase the reliability.*

### 4.3.2 Power distribution

IS-04.03.02-01 The power distribution shall comply with figure 5.9.1-1 of IID-B [AD-01]

### 4.3.3 Grounding concept

IS-04.03.03-01 The grounding concept of the instrument is defined in the IID-B, Section 5.10.4 (AD-01).

### 4.3.4 Instrument modes

IS-04.03.04-01 The HIFI instrument shall have an Off mode.

In this mode all power is removed from the instrument.

*This mode will be used during emergencies and other critical phases in the FIRST mission (e.g. during launch and orbit insertion).*

IS-04.03.04-02 The HIFI instrument shall have a stand-by mode.

In this mode:
- All units in the SVM are active,
- Only thermal control of the LOU is active,
- Only the calibrator of the FPU is active,
- Housekeeping data will be available,
- No science data are produced.

*In this mode other instruments may be active,*
*This mode will be used when HIFI is not primary during normal science operations.*

IS-04.03.04-03 The HIFI instrument shall have a Primary mode.

In this mode:
- The instrument is operating,
- One mixer band and one LO sub-band are active,
- Scientific data are generated,
- Housekeeping data are generated,
- Pointing corrections may be generated as a result of peak-up rocedures,
-The instrument warm-up and stabilisation time, from standby mode, shall be less than 1 hour, with a goal of 5 minutes.

*The warm up time for the LOU, WBS, HRS and calibrator in the FPU from cold (I.e. from OFF mode) will be much more than 1 hour.*
*The stabilization time is defined as the time until the instrument meets its full performance specifications after some event.*

### 4.3.5 Instrument operations

IS-04.03.05-01 All sequencing of instrument operation shall be by the execution of commands in the Instrument Control Unit.

IS-04.03.05-02 The instrument shall have a single serial command bus visible to all subsystems.

IS-04.03.05-03 Synchronisation of the subsystems shall be through commands on this bus

IS-04.03.05-04 During routine operations, time-tagged command lists shall be prepared off-line, well in advance. This applies both to scientific observations and to calibration measurements.

| | |
|---|---|
| IS-04.03.05-05 | The instrument shall need automated tuning algorithms to optimise the magnetic field of the mixers of bands 1 through 5. |
| IS-04.03.05-06 | The instrument shall need automated tuning algorithms to optimise the LO power level setting. |
| IS-04.03.05-07 | The instrument shall need automated tuning algorithms to optimise IF gains in the spectrometers. |
| IS-04.03.05-08 | The algorithms shall be designed to complete their task within well-defined time limits, so that tuning requirements can not upset subsequent observing timelines. |
| IS-04.03.05-09 | To control the instrument with the limited uplink data volume, macro expansion or table look-ups shall be used. |

#### 4.3.6 Data handling

| | |
|---|---|
| IS-04.03.06-01 | The division of datahandling tasks between the spectrometers and the Instrument Control Unit shall be according to the HIFI Command Specification (AD-10), HIFI TM packet ICD (AD-11) and HIFI HK packet ICD (AD-12). |

### 4.4 Sub-system Functional Requirements

#### 4.4.1 FP Subsystem

| | |
|---|---|
| IS-04.04.01-01 | The Focal Plane Sub-system shall couple to the astromical (RF) signals from the telescope. |
| IS-04.04.01-02 | The Focal Plane Sub-system shall couple to the local oscillator signals from the Local Oscillator unit. |
| IS-04.04.01-03 | The Focal Plane Sub-system shall combine the RF and LO signals with a minimum loss to the RF signal. |
| IS-04.04.01-04 | The Focal Plane sub-system shall provide for division of the freq. coverage into 7 bands through spatial separation, only one band can be active at any time. |
| IS-04.04.01-05 | The Focal Plane Sub-system shall separate the two polarisations and couple them to separate mixers |
| IS-04.04.01-06 | The Focal Plane Sub-system shall allow for a single ~~circularly polarised~~ LO signal to pump two mixers. |
| IS-04.04.01-07 | The Focal Plane Sub-system shall mix the astronomical and LO signals to generate the Intermediate Frequency signals. |
| IS-04.04.01-08 | The Focal Plane Sub-system shall amplify, filter and condition the two |

IF signals from the single active band.

IS-04.04.01-09 The Focal Plane Sub-system shall distribute the two IF signals to each of the two spectrometer sub-systems via the spacecraft's cryoharness.

IS-04.04.01-10 The Focal Plane Sub-system shall provide a focal plane chopper for displacing the telescope beam on the sky or selecting an internal calibration source.

IS-04.04.01-11 The Focal Plane Sub-system provides an adjustable internal source for calibration purposes.

IS-04.04.01-12 The Focal Plane Sub-system shall allow optical verification of the alignment of the Focal Plane Unit with the LOU and telescope.

IS-04.04.01-13 The Focal Plane Sub-system shall generate housekeeping data as required.

IS-04.04.01-14 The Focal Plain Sub-system shall up-convert the 2.4 – 4.8 GHz Intermediate Frequency signals from the Band 6 mixers up to 4 – 8 GHz IF band accepted by the spectrometers.

### 4.4.2 LO Subsystem

IS-04.04.02-01 The Local Oscillator Sub-system shall generate a highly stable reference frequency signal in a Master Oscillator.

IS-04.04.02-02 The Local Oscillator Sub-system shall synthesise tuneable microwave signal phase locked to the MO reference signal

IS-04.04.02-03 The Local Oscillator Sub-system shall amplify and frequency multiply the microwave signal to generate the sub-mm LO signal in one of 14 sub-bands (a maximum of one LO sub-band is active at any time).

IS-04.04.02-04 The Local Oscillator Sub-system shall provide a means of coupling the output from pairs of the 14 LO sub-bands to the 7 mixer bands.

IS-04.04.02-05 The Local Oscillator Sub-system shall produce linear polarised output beams.

IS-04.04.02-06 The Local Oscillator Sub-system shall provide a means of adjusting the LO signal level to optimise the level at the mixers.

IS-04.04.02-07 The Local Oscillator Sub-system shall distribute the MO reference signal to the High Resolution Spectrometer sub-system **and the Wide Band Spectrometer Subsystem**.

IS-04.04.02-08 The Local Oscillator Sub-system shall generate housekeeping data as

required.

### 4.4.3 HRS Subsystem

| | |
|---|---|
| IS-04.04.03-01 | The High Resolution Spectrometer Sub-system shall amplify and condition the two IF signals from the **Focal Plane Subsystem**. |
| IS-04.04.03-02 | The High Resolution Spectrometer Sub-system shall divide the IF band into a number of narrow sub-bands for each of the two IF signals. See Table 4.2.2.3-1 |
| IS-04.04.03-03 | The High Resolution Spectrometer Sub-system shall provide adjustable attenuators for setting the correct signal level in each of the sub-bands. |
| IS-04.04.03-04 | The High Resolution Spectrometer Sub-system shall down-convert the IF signal to video frequency. |
| IS-04.04.03-05 | The High Resolution Spectrometer Sub-system shall sample and convert the analogue video signals into digital signals. |
| IS-04.04.03-06 | The High Resolution Spectrometer Sub-system shall generate the autocorrelation function of the digital signals. |
| IS-04.04.03-07 | The High Resolution Spectrometer Sub-system shall provide at least Bandwidth/resolution combinations, as listed in Table 4.2.2.3-1, through reconfiguring of the digital correlator. |
| IS-04.04.03-08 | The High Resolution Spectrometer Sub-system shall integrate the autocorrelation function into separate buffers for each phase of chopping cycle. |
| IS-04.04.03-09 | The High Resolution Spectrometer Sub-system shall send the autocorrelation coefficients to the Instrument Control Unit. |
| IS-04.04.03-10 | The High Resolution Spectrometer Sub-system shall use the MO reference frequency signal to phase lock the internal oscillators used in the frequency conversion steps and the digital sample clocks. |
| IS-04.04.03-11 | The High Resolution Spectrometer Sub-system shall generate housekeeping data as required. |

### 4.4.4 WBS Subsystem

| | |
|---|---|
| **IS-04.04.04-01** | **deleted** |
| IS-04.04.04-02 | The Wide Band Spectrometer Sub-system shall amplify and condition the two IF signals from the **Focal Plane Subsystem**. |
| IS-04.04.04-03 | The Wide Band Spectrometer Sub-system shall divide the IF band into four sub-bands for each of the two IF signals. |

| | |
|---|---|
| IS-04.04.04-04 | The Wide Band Spectrometer Sub-system shall provide adjustable attenuators for setting the correct signal levels. |
| IS-04.04.04-05 | The Wide Band Spectrometer Sub-system shall provide a commandable comb generator for internal frequency calibration. |
| IS-04.04.04-06 | The Wide Band Spectrometer Sub-system shall down-convert the IF signal to a lower frequency suitable for injection into a Bragg cell. |
| IS-04.04.04-07 | The Wide Band Spectrometer Sub-system shall spectrally analyse the IF signals in a pair of 4-channel array Acousto Optic Spectrometers. |
| IS-04.04.04-08 | The Wide Band Spectrometer Sub-system shall integrate the sub-spectra into separate buffers for each phase of the chopping cycle. |
| IS-04.04.04-09 | The Wide Band Spectrometer Sub-system shall send the sub-spectra to the Instrument Control Unit. |
| IS-04.04.04-10 | The Wide Band Spectrometer Sub-system shall generate housekeeping data as required. |
| **IS-04.04.04-11** | **The Wide Band Spectrometer Subsystem shall use the MO reference frequency signal to phase lock the comb generator used in the frequency calibration steps.** |

### 4.4.5 ICU Subsystem

| | |
|---|---|
| IS-04.04.05-01 | The Instrument Control Unit shall interface with the CDMS via a 1553B bus interface as specified in Appendix 9 of the Packet Structure ICD (AD-9) and as specified in the applicable documents therein. |
| IS-04.04.05-02 | The Instrument Control Unit shall receive tele-command packets from the spacecraft CDMS, check and acknowledge them as specified in the Packet Structure ICD (AD-9). |
| IS-04.04.05-03 | The Instrument Control Unit shall execute the tele-commands, as specified in the HIFI Command Specification (AD-10). |
| IS-04.04.05-04 | The Instrument Control Unit shall, as a result of the tele-command execution, send commands or sequences of commands to the other sub-systems, as specified in the HIFI Command Specification (AD-10). |
| IS-04.04.05-05 | The Instrument Control Unit shall collect housekeeping data from itself and the other sub-systems, as specified in the HK packet ICD (AD-13) and send it as telemetry packets to the CDMS, as specified in the Packet Structure ICD (AD-9). |
| IS-04.04.05-06 | The Instrument Control Unit shall collect science data from the spectrometer sub sub-systems, as specified in the HIFI Command Specification (AD-10), packetize the science data, as specified in the TM packet ICD (AD-12), and send it as telemetry packets to the CDMS, as |

specified in the Packet Structure ICD (AD-9).

IS-04.04.05-07 The Instrument Control Unit shall execute algorithms to tune the instrument for an observation at a specific frequency, as specified in the HIFI Command Specification (AD-10).

IS-04.04.05-08 The Instrument Control Unit shall execute on-board calibration procedures, as specified in the HIFI Command Specification (AD-10).

IS-04.04.05-09 The Instrument Control Unit shall execute spectroscopy measurements, as specified in the HIFI Command Specification (AD-10).

IS-04.04.05-10 The Instrument Control Unit shall execute peak-up procedures, as specified in the HIFI Command Specification (AD-10) and send peak-up information as event packets to the CDMS, as specified in the Packet Structure ICD (AD-9).

IS-04.04.05-11 The Instrument Control Unit shall perform health checking by monitoring housekeeping data, as specified in the HIFI Command Specification (AD-10) and send (in the event of anomalies) event packets to the CDMS, as specified in the Packet Structure ICD (AD-9).

IS-04.04.05-12 Deleted

IS-04.04.05-13 Deleted

IS-04.04.05-14 Deleted

IS-04.04.05-15 Deleted

IS-04.04.05-16 Deleted

IS-04.04.05-17 Deleted

## 4.5 Budgets

### 4.5.1 Frequency Resolution Budget

IS-04.05.01-01 The instrument spectral resolution as a function of frequency for the WBS, and HRS in both normal and high resolution mode shall comply with Table 4.5.1-1

IS-04.05.01-02 The instrumental spectral resolution function shall be such that:
- >=95% of energy to be contained within 2 times the FWHM,
- >=99% of energy to be contained within 5 times the FWHM.
The centroid of the spectral response function shall lie within 0,1 FWHM of the peak response.

### 4.5.2 Frequency Accuracy Budget

IS-04.05.02-01 The instrument frequency accuracy budget for each of the two spectrometers shall comply with Table 4.5.2-1.

IS-04.05.02-02 The LO master reference oscillator shall have an accuracy of better than 1part in $10^7$.

*The frequency accuracy **of the HRS, ~~WBS~~ and LO subsystem** are determined by the stability of the LO master reference oscillator.*

### 4.5.3 Sensitivity budget

IS-04.05.03-01 The "as designed" instrument budget per sub-system is given in Table 4.5.3-1.

*This budget is based on achieving the baseline sensitivity described in the HIFI Proposal.*

### 4.5.4 Radiometric Calibration Budget

IS-04.05.04-01 The instrument temperature scale calibration accuracy shall comply with table 4.5.4-1.

IS-04.05.04-02 The system flux-to-temperature scale calibration accuracy shall comply with table 4.5.4-2.

### 4.5.5 Amplitude Stability Budget

IS-04.05.05-01 The total power Allan variance stability budget is given in Table 4.5.5-1.

IS-04.05.05-02 The spectroscopic Allan variance stability is given in Table 4.5.5-2.

### 4.5.6 Deleted

### 4.5.7 Ripple Budget

#### 4.5.7.1 HRS Ripple Buget

IS-04.05.07-01 The ripple budget for the HRS shall comply with Table 4.5.7-1

*Only ripple in [any] 250 MHz sub-band is relevant since the HRS shall have adjustable attenuators for each sub-band.*

#### 4.5.7.2 WBS Ripple and Dynamic Range Budget

IS-04.05.07.02-01 The combined ripple and dynamic range budget for the WBS shall comply with Table 4.5.7.2-1 .

*Only ripple in each of the 1 GHz sub-bands is relevant since the WBS*

*shall have adjustable attenuators for each sub-band.*

### 4.5.8 HRS Total Power Dynamic Range Budget

IS-04.05.08-01 The total power dynamic range budget for the HRS shall comply with Table 4.5.8-1.

*The dynamic range budget allows for up to 3 dB variation in the IF power level during the chop cycle for calibration or observation of strong continuum sources, e.g. planets. It is assumed that the attenuator setting in spectrometers is fixed during the chop cycle.*

### 4.5.9 Tuning Time

IS-04.05.09-01 The instrument tuning time shall not exceed 20 (TBC) seconds within one LO subband.

*This time includes calibrating the instrument*

### 4.5.10 LO Signal Power Budget

IS-04.05.10-01 The LO signal power loss budget is given in Table 4.5.10.

### 4.5.11 Frequency Ranges, Polarisations, Power

IS-04.05.11-01 The required frequency ranges, nominal, maximum and minimum power levels to be delivered by the LOU to the interface shall comply with the values as mentioned in Table 4.5.11-1. (TBC)

IS-04.05.11-02 The deviation of polarisation **at the LOU-FPU interface** from that specified in the ICD shall be such as to maintain less than 20% imbalance in the LO pump level for each mixer of the pair.

IS-04.05.11-03 It shall be possible to set the LO power level with a resolution or step size of less than 0.5 dB over the power range -10dB to + 3dB with respect to the nominal power. (TBC)

### 4.5.12 Optical beam

#### 4.5.12.1 Positional Stability

IS-04.05.12.01-01 Changes in the quasi-optical alignment of the FPU-defined beam in the focal plane of the telescope with time shall not exceed 50% of the tolerances given in Table 7.1 of RD-05 [SRON-G/HIFI/TN/2000-004, HIFI Quasi-Optical Alignment Budget].

*This specification mainly drives the requirement on the stability of the angular position of the chopper mechanism while integrating (i.e. outside of the chopper dead-time). It is required to ensure that the desired flux calibration accuracy can be achieved*

#### 4.5.12.2 Sidelobe Level and Beam PSF

IS-04.05.12.02-01 Deleted(satisfactory sidelobe level and beam psf ar guaranteed by other performance requirements).

#### 4.5.12.3 Main Beam Efficiency

IS-04.05.12.03-01 Deleted ( Satisfactory main beam efficiency is guaranteed by other optical performance requirements).

#### 4.5.12.4 Relative Pointing Offset Between Polarisations

IS-04.05.12.04-01 The optical alignment shall comply with the tolerances given in Table 7.1 of RD-05, the HIFI Quasi-Optical Alignment Budget.

# 5 Interface requirements

| | |
| --- | --- |
| IS-05-01 | Internal interfaces within the HIFI instrument shall comply with the ICD [AD-06]. |
| IS-05-02 | Interfaces with the spacecraft shall comply with the IID-B (AD-01) and sections 5.1 to 5.11 of IID-A (AD-02). |

# 6 Environmental Conditions

## 6.1 Radiation

IS-06.01-01 All hardware shall withstand the radiation environment as specified in AD-03 without failure or significant degradation in performance and in accordance with the guidelines given in Section 9.5.7 of AD-02.

## 6.2 Electro-Magnetic Compatibility

IS-06.02-01 The instrument shall comply with the EMC environment as defined in the IID-A, Section 5.14 (AD-02).

IS-06.02-02 EMC verification and testing shall be in accordance with IID-A, section 9.5.6 (AD-02) **and the EMC Control Plan (AD-15).**

## 6.3 Straylight

IS-06.03-01 The instrument shall comply with the straylight requirements as defined in the IID-A, section 5.8.1.2 (AD-02).

## 6.4 Cleanliness

IS-06.04-01 The cleanliness levels for particulate and molecular contamination shall comply with Table 6.4-1.

### 6.4.1 Bake-Out

IS-06.04.01-01 deleted

IS-06.04.01-02 deleted

IS-06.04.01-03 deleted

IS-06.04.01-04 The instrument shall comply with the bake-out requirements as defined in IID-A, section 9.5.4.6 (AD-02) and IID-B, section 5.7.4 (AD-01).

## 6.5 Vibration Levels

IS-06.05-01 The sine vibration environment incl. Acceptance and qualification shall comply with section 9.5.3.3. Of IID-A (AD-02).

IS-06.05-02 The random vibration incl. Acceptance and qualification shall comply with section 9.5.3.4 of IID-A (AD-02).

## 6.6 Acoustic

| | |
|---|---|
| IS-06.06-01 | The acoustic environment including acceptance and qualification shall comply with data given in section 9.5.3.5 of IID-A (AD-02). |

## 6.7 Shock

| | |
|---|---|
| IS-06.07-01 | The instrument shall comply with the shock environment as given in IID-A, section 9.5.3.6. (AD-02). |

## 6.8 Temperature

### 6.8.1 Inside the cryostat

| | |
|---|---|
| IS-06.08.01-01 | The instrument shall function nominally with the temperatures as given in AD-01 par 5.7.1. |
| IS-06.08.01-02 | The instrument shall function nominally with the rate of temperature change dT/dt given in AD-01 par 5.7.1. |
| IS-06.08.01-03 | The instrument shall survive the maximum rate of temperature change dT/dt during cryostat warm-up or cool-down phases as given in [AD-01] par 5.7.1. |

### 6.8.2 At the LOU

| | |
|---|---|
| IS-06.08.02-01 | The instrument shall function nominally with the temperatures as given in AD-01 par 5.7.2. |
| IS-06.08.02-02 | The instrument shall function nominally with the rate of temperature change dT/dt given in AD-01 par 5.7.2 and 5.7.3 . |

### 6.8.3 On the SVM

| | |
|---|---|
| IS-06.08.03-01 | The instrument shall function nominally with the temperatures as given in AD-01 par 5.7.3. |
| IS-06.08.03-02 | The instrument shall function nominally with the rate of temperature change dT/dt given in AD-01 par 5.7.3. |

## 6.9 Pressure

| | |
|---|---|
| IS-06.09-01 | The FPU shall survive with the rate of pressure change dP/dt inside the cryostat as given in AD-01 par. 5.7.1. |
| IS-06.09-02 | Hardware outside the cryostat shall survive the conditions as given in AD-02 par. **5.16.1**. |

# 7 Design Requirements

## 7.1 General

### 7.1.1 Life time

| | |
|---|---|
| IS-07.01.01-01 | The instrument shall be designed for a mission lifetime of 3,5 years.<br>***Refer to the HIFI Environmental Test Requirements [AD-16].*** |
| IS-07.01.01-02 | The instrument shall be designed for a ground operational lifetime of 2 years.<br>***Refer to the HIFI Environmental Test Requirements [AD-16].*** |
| IS-07.01.01-03 | The instrument shall be designed for a ground storage lifetime of 2 years. |

### 7.1.2 Maintainability

| | |
|---|---|
| IS-07.01.02-01 | **The hardware design shall be such that it is easy accessible for maintenance and repair.** |

### 7.1.3 Interchangeability

| | |
|---|---|
| IS-07.01.03-01 | **The hardware design shall be such that flight and flight-spare items are interchangeable.** |
| **IS-07.01.03-02** | **The hardware design shall allow a late exchange of critical components.** |

### 7.1.4 Safety

| | |
|---|---|
| IS-07.01.04-01 | HIFI safety requirements shall comply with section 7 in AD-07. |

### 7.1.5 Reliability

| | |
|---|---|
| IS-07.01.05-01 | The probability of survival corresponding the operational duration shall be at least 95 % (EOL) for the WBS, HRS, ICU, FCU, LCU and LSU. |
| IS-07.01.05-02 | All units shall be designed so that no sequence of commands can cause permanent damage to hardware. |

## 7.2 Mechanical

### 7.2.1 Safety and sizing factors

| | |
|---|---|
| IS-07.02.01-01 | The instrument shall comply with the safety and sizing factors given in par 9.4.1.2.3 in AD-02. |

### 7.2.2 Limit Loads

IS-07.02.02-01 The instrument shall comply with the limit loads given in par 9.4.1.2.4 in AD-02.

### 7.2.3 Stiffness

IS-07.02.03-01 The instrument shall comply with the stiffness requirements given in par 9.4.1.2.5 in AD-02.

### 7.2.4 Structural margins

IS-07.02.04-01 The instrument shall comply with the structural design margins given in par. 9.4.1.2.6 in AD-02.

### 7.2.5 Mechanism design requirements

IS-07.02.05-01 For the design of mechanisms, ECSS-E-30-00 part 2-3 shall be used as guideline.

*This as a replacement for Mechanism design requirements as given in AD-02, par. 9.4.3.1.2*

### 7.2.6 Materials and processes selection.

IS-07.02.06-01 The selection of materials and processes shall be in accordance with AD07 section 3.

### 7.2.7 Venting

IS-07.02.07-01 Venting holes shall be provided to accommodate the depressurisation. The diameter of holes or the width of slits shall be less than 2 mm. Sources of virtual leakage such as blind holes shall be avoided in hardware constructions.

## 7.3 Electronic

### 7.3.1 Primary power

IS-07.03.01-01 The Primary power interface shall be in accordance with AD-02, Section 5.9.5 up to and including section 5.9.5.7.

### 7.3.2 CDMS interface

IS-07.03.02-01 The instrument shall interface with the S/C CDMS via a 1553B bus, as specified in the MIL-STD-1553B (AD-14) and the Satellite Data Bus Protocol Specification, which is Appendix 9 of the Packet Structure ICD (AD-9).

### 7.3.3 Electrical Interfaces

| | |
|---|---|
| IS-07.03.03-01 | Electrical Interfaces shall be in accordance with the AD-02, Section 5.14.1. |

### 7.3.4 Harness, Connectors and Shielding

| | |
|---|---|
| IS-07.03.04-01 | The warm and cryo harness shall be in accordance with IID-A, Section 5.10.2 plus 5.10.3 and section 5.14.2 (AD-02). |
| IS-07.03.04-02 | Connector types and use shall be in accordance with IID-A, Section 5.10.2 plus 5.10.3 and section 5.14.2 (AD-02). |
| IS-07.03.04-03 | Shielding of Harness, Connectors and Equipment shall be in accordance with IID-A, Section 5.14.2 (AD-02). |
| IS-07.03.04-04 | The electrical interfaces between s/c and HIFI are defined in IID-B, Section 5.10.2.1 (AD-01). |
| IS-07.03.04-05 | The internal electrical interfaces are defined in the HIFI-ICD, section 4 (AD-06). |

### 7.3.5 Grounding and Isolation

| | |
|---|---|
| IS-07.03.05-01 | Equipment Grounding and Isolation shall be in accordance with IID-A, Section 5.10.3 (AD-02). |

### 7.3.6 Bonding

| | |
|---|---|
| IS-07.03.06-01 | Bonding of equipment shall be in accordance with IID-A, Section 5.10.4 (AD-02). |

### 7.3.7 EEE components selection

| | |
|---|---|
| IS-07.03.07-01 | The selection of EEE components shall be in accordance with the PA plan, Section 4 (AD-07). |

### 7.3.8 EEE component derating

| | |
|---|---|
| IS-07.03.08-01 | Derating of EEE components shall be in accordance with the PA plan, Section 6.4 (AD-07). |

### 7.3.9 Radiation

| | |
|---|---|
| IS-07.03.09-01 | All hardware shall be designed in accordance with the guidelines given in section 9.5.7 of AD-02. |

## 7.4 Optics

| | |
| --- | --- |
| IS-07.04-01 | The optical design shall comply with the requirements in IID-B, section 5.8 (AD-01). |

## 7.5 Software

| | |
| --- | --- |
| IS-07.05-01 | On-board software shall comply with the requirements in IID-A, section 5.13.2 (AD-02). |

# 8 Tables and Figures

Table 4.2.1.4-1 HIFI Frequency bands

| Band | Frequency Range (GHz) | IF Central Frequency (GHz) | IF Frequency Bandwidth (GHz) | Polarisations |
|---|---|---|---|---|
| 1 | 480-640 | 6 | 4 | 2 |
| 2 | 636.2-800 | 6 | 4 | 2 |
| 3 | 800-960 | 6 | 4 | 2 |
| 4 | 960-1120 | 6 | 4 | 2 |
| 5 | 1110-1250 | 6 | 4 | 2 |
| 6L | 1410 – **1703** | 3.6 | 2.4 | 2 |
| 6H | **1703** –1910 | 3.6 | 2.4 | 2 |

Table 4.2.2.3-1. The High Resolution Spectrometer modes listing the required number of sub-bands, sub-band bandwidth and corresponding resolution per polarisation. The resolution is that obtained with Hanning weighting.

| **Mode** | **normal** | **high resolution** | **low resolution** | **wide band** |
|---|---|---|---|---|
| resolution, FWHM | 0.27 MHz | 0.14 MHz | **0.54** MHz | **1.1 MHz** |
| lags per sub-band (min.) | 2030 | 4060 | **1015** | **1015** |
| sub-band bandwidth (min.) | 250 MHz | 250 MHz | **250** MHz | **500 MHz** |
| number of sub-bands (min.) | **2** | **1** | 4 | **8** |

Table 4.5.1-1 The instrument spectral resolution budget showing the frequency resolution as a function of signal frequency and spectrometer.

| Frequency /GHz | 480 | 640 | 800 | 960 | 1120 | 1250 | 1410 | 1910 |
|---|---|---|---|---|---|---|---|---|
| Max. LO FWHM linewidth /MHz | 0.080 | 0.11 | 0.13 | 0.16 | 0.19 | 0.21 | 0.24 | 0.32 |
| **IF up-converter FWHM linewidth /MHz (20 mV rms ripple)** | | | | | | | **0.05** | **0.05** |
| **WBS** | | | | | | | | |
| WBS FWHM resolution /MHz | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Instrument FWHM spectral resolution /MHz | 1.00 | 1.01 | 1.01 | 1.01 | 1.02 | 1.02 | 1.03 | 1.05 |
| **HRS Normal** | | | | | | | | |
| HRS-normal FWHM resolution /MHz | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 |
| Instrument FWHM spectral resolution /MHz | 0.28 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 | 0.36 | 0.42 |
| **HRS High resolution** | | | | | | | | |
| HRS-high FWHM resolution /MHz | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Instrument FWHM spectral resolution /MHz | 0.16 | 0.18 | 0.19 | **0.21** | **0.23** | **0.25** | **0.28** | **0.35** |
| Instrument FWHM spectral resolution /(m/s) | 101 | 82 | 72 | **66** | **62** | **60** | **59** | **55** |

Table 4.5.2-1 The instrument frequency accuracy budget. The WBS frequency accuracy **is required to be better than** 100 kHz. The HRS frequency accuracy is required to be better than 5 kHz. **However, the accuracy of the HRS and the oscillators in the WBS will be determined** by the LO master reference oscillator and thus will be ~ 600 Hz. **The overall WBS frequency accuracy will be limited by other factors such as the accuracy of determining the centre frequency of certain channnels with the comb generator and the frequency non-linearity of the Bragg cell and WBS optics. The IF up-converters have a free-running local oscillator (band 6 only) which contributes to the budget.**

| Frequency /GHz | 480 | 640 | 800 | 960 | 1120 | 1250 | 1410 | 1910 |
|---|---|---|---|---|---|---|---|---|
| LO system frequency accuracy /MHz | 0.048 | 0.064 | 0.08 | 0.096 | 0.112 | 0.125 | 0.141 | 0.191 |
| IF Up-converter frequency accuracy /MHz | - | - | - | - | - | - | **0.050** | **0.050** |
| **WBS** | | | | | | | | |
| AOS frequency calibration accuracy /MHz | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Instrument frequency accuracy /MHz | 0.15 | 0.16 | 0.18 | 0.20 | 0.21 | 0.23 | 0.29 | 0.34 |
| **HRS** | | | | | | | | |
| HRS frequency accuracy /kHz | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Instrument frequency accuracy /kHz | 53 | 69 | 85 | 101 | 117 | 130 | **196** | **246** |
| Instrument frequency accuracy /(m/s) | 33 | 32 | 32 | 32 | 31 | 31 | **42** | **39** |

Table 4.5.3-1 The HIFI instrument sensitivity budget, summarising the requirements by sub-system versus frequency. This table is based on the baseline sensitivity described in the HIFI Proposal.

| Frequency /GHz | 480 | 640 | 800 | 800 | 960 | 1120 | 1250 | 1410 | 1910 |
|---|---|---|---|---|---|---|---|---|---|
| Band | 1 | 1, 2 | 2 | 3 | 3, 4 | 4, 5 | 5 | 6L | 6H |
| LO injection (b/s=beamsplitter, dip.=diplexer) | b/s | b/s | b/s | dip. | dip. | dip. | dip. | dip. | dip. |
| Max. Instrument DSB noise temp. /K | 82 | 127 | 175 | 178 | 227 | 275 | 583 | 748 | 771 |
| Max. FPU noise temperature /K | 81 | 125 | 172 | 175 | 223 | 270 | 573 | 735 | 758 |
| Min. FPU gain /dB | 34.5 | 32.5 | 31.2 | 31.1 | 30.0 | 29.2 | 25.9 | 24.9 | 24.7 |
| Max. LO - mixer signal leakage /dB | -14.9 | -14.9 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.1 | -15.1 |
| Max. LOU sideband noise at IF offset /K | 215 | 288 | 360 | 365 | 440 | 514 | 575 | 650 | 886 |
| Max. LOU sideband noise at IF offset /(dBc(/Hz)) | -152.5 | -152.9 | -153.5 | -144.9 | -148.3 | -147.7 | -139.1 | -138.5 | -137.2 |
| Max. LOU spurious level /dBc | -101.2 | -101.6 | -102.3 | -93.6 | -97.0 | -96.4 | -87.8 | -87.2 | -85.9 |
| Max. Cryoharness IF cable loss /-dB | -10.0 | -10.0 | -10.0 | -10.0 | -10.0 | -10.0 | -10.0 | -10.0 | -10.0 |
| Max. Spectrometer noise temp. /K (NF = 3dB) | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |

Table 4.5.3-2 HIFI Instrument Sensitivity Budget being a breakdown of the contributions of various items to the instrument noise temperature versus frequency.

| Frequency /GHz | 480 | 640 | 800 | 800 | 960 | 1120 | 1250 | 1410 | 1910 |
|---|---|---|---|---|---|---|---|---|---|
| DSB instrument noise temp. /K | 82 | 127 | 175 | 178 | 227 | 275 | 583 | 748 | 771 |
| DSB receiver noise temp. at mixer /K | 70 | 110 | 150 | 150 | 190 | 230 | 510 | 650 | 650 |
| FPU optics /K | 0.6 | 0.8 | 1.2 | 1.2 | 1.4 | 1.8 | 2.0 | 2.4 | 3.8 |
| LO beamsplitter or diplexer /K | 0.2 | 0.3 | 0.3 | 0.7 | 0.9 | 1.1 | 1.2 | 1.5 | 2.3 |
| LO sideband noise /K | 10 | 12 | 15 | 15 | 17 | 20 | 22 | 24 | 32 |
| Mixer /K | 47 | 83 | 126 | 128 | 173 | 209 | 424 | 583 | 593 |
| Mixer-IF cable /K | 7 | 9 | 9 | 9 | 9 | 11 | 36 | 36 | 37 |
| FPU IF amplifier /K | 17 | 21 | 21 | 22 | 22 | 28 | 88 | 88 | 90 |
| Cryoharness IF cable /K | 0.3 | 0.5 | 0.7 | 0.7 | 0.9 | 1.1 | 2.3 | 2.9 | 3.0 |
| Warm IF system /K | 1.1 | 1.7 | 2.3 | 2.3 | 3.0 | 3.6 | 7.6 | 9.8 | 10.1 |

*Table 4.5.3-2 is a breakdown of the contributions to the overall instrument noise temperature at component level.*
*Notes:*
*1. The FPU subsystem noise temperature is defined at the input to the instrument, i.e. just in front of M3, and excludes telescope coupling efficiency.*
*2. The FPU subsystem gain is defined from the optical input to the FPU to the IF output and includes internal optics losses, LO diplexer signal transmission loss, mixer conversion loss, IF coupling losses, IF amplifier gain, band equaliser loss, and IF power combiner loss.*
*3. The LOU-mixer coupling loss refers to the LOU-to-mixer coupling loss at the signal frequency and includes the CVV window loss, heat filter loss, LO diplexer injection loss (leakage at the signal frequency), power splitting between the mixer pair, and LO-mixer beam coupling loss.*
*4. The LOU sideband noise is the level of the internally generated noise at the output of the LOU and at a frequency offset from the carrier equal to the IF frequency.*

Table 4.5.4-1 Instrument temperature scale calibration accuracy budget

| | |
|---|---|
| Calibration load radiometric temperature accuracy | < 0.5K |
| Calibration load coupling accuracy | < 1% |
| Spectrometer linearity | < 1% |
| Sideband ratio calibration error | < 3% |
| Gain instability | < 3% |
| Instrument temperature calibration accuracy | < 10% |

Table 4.5.4-2 System flux scale calibration accuracy budget

| | |
|---|---|
| Instrument temperature calibration accuracy)[1] | < 10% |
| Gain error due to mis-pointing | < 3% |
| Spectrometer linearity | < 1% |
| Sideband ratio calibration error | < 3% |
| Gain instability | < 3% |
| Astronomical flux calibrator error | < 3% |
| Beam dilution effects | < 3% |
| Instrument flux calibration accuracy | < 10% |

)[1] This does not impact the flux calibration directly, since astronomical sources will be used as primary calibrators.

Table 4.5.5-1 The total power Allan variance stability budget for HIFI in a 2 second chop cycle (i.e. for a 1 second integration time). Hanning weighting of the HRS autocorrelation data is assumed and the correlator efficiency of 81% has been allowed for in the listed noise equivalent bandwidths.

| Spectrometer | WBS | HRS | HRS | HRS |
|---|---|---|---|---|
| Resolution Bandwidth /MHz | 1.1 | 0.54 | 0.27 | 0.14 |
| Noise Equivalent Bandwidth /MHz | 1.6 | 0.47 | 0.24 | 0.12 |
| | | | | |
| Total power Allan variance of FPU gain | 1.56E-07 | 1.56E-07 | 1.56E-07 | 1.56E-07 |
| Total power Allan variance of spectrometer | 1.56E-07 | 5.30E-07 | 1.06E-06 | 2.04E-06 |
| | | | | |
| Excess system Allan variance | 3.13E-07 | 6.86E-07 | 1.22E-06 | 2.20E-06 |
| Ideal Allan variance | 6.25E-07 | 2.12E-06 | 4.24E-06 | 8.18E-06 |
| Total power Allan variance of System | 9.38E-07 | 2.81E-06 | 5.46E-06 | 1.04E-05 |
| | | | | |
| Excess variance | 50% | 32% | 29% | 27% |
| Excess noise | 22% | 15% | 13% | 13% |

Table 4.5.5-2 The spectroscopic Allan variance stability budget for HIFI in a 200 second chop cycle (i.e. for a 100 second integration time). Hanning weighting of the HRS autocorrelation data is assumed and the correlator efficiency of 81% has been allowed for in the listed noise equivalent bandwidths.

| Spectrometer | WBS | HRS | HRS | HRS |
|---|---|---|---|---|
| Resolution Bandwidth /MHz | 1.1 | 0.54 | 0.27 | 0.14 |
| Noise Equivalent Bandwidth /MHz | 1.6 | 0.47 | 0.24 | 0.12 |
| | | | | |
| Spectroscopic Allan variance of FPU gain* | 1.56E-09 | 1.56E-09 | 1.56E-09 | 1.56E-09 |
| Spectroscopic Allan variance of spectrometer | 1.56E-09 | 5.30E-09 | 1.06E-08 | 2.04E-08 |
| | | | | |
| Excess system Allan variance | 3.13E-09 | 6.86E-09 | 1.22E-08 | 2.20E-08 |
| Ideal Allan variance | 6.25E-09 | 2.12E-08 | 4.24E-08 | 8.18E-08 |
| Spectroscopic Allan variance of System | 9.38E-09 | 2.81E-08 | 5.46E-08 | 1.04E-07 |
| | | | | |
| Excess variance | 50% | 32% | 29% | 27% |
| Excess noise | 22% | 15% | 13% | 13% |

* Differential gain fluctuations across the IF passband.

Table 4.5.7.1-1 HRS passband ripple budget.

| Applicable bandwidth | 4 GHz |
|---|---|
| | |
| FPU IF passband ripple | 1.2 dB |
| FPU-HRS harness ripple | 0.1 dB |
| FPU-HRS harness slope | 0.2 dB |
| | |
| Total excluding internal HRS ripple | 1.5 dB |
| | |
| Internal HRS ripple | 2.0 dB |
| | |
| Total including internal HRS ripple | 3.5 dB |

Table 4.5.7.2-1 WBS passband ripple and dynamic range budget.

| Applicable bandwidth | 4 GHz |
|---|---|
| | |
| signal variation during chop cycle | 3.0 dB |
| FPU IF passband ripple | 3.0 dB |
| FPU-spectrometer harness ripple | 0.1 dB |
| FPU-spectrometer harness slope ~~(equalised in WBI)~~ | 2.0 dB |
| spectrometer attenuator setting accuracy or resolution | 1.0 dB |
| | |
| Total excluding internal WBS ripple | 12 dB |
| | |
| Total including internal WBS ripple | 15 dB |

Table 4.5.8-1 HRS total power dynamic range budget.

| signal variation during chop cycle | 3.0 dB |
|---|---|
| spectrometer attenuator setting accuracy or resolution | 0.5 dB |
| | |
| Total required instantaneous dynamic range | 3.5 dB |

Table 4.5.10 The LO signal power loss budget between the LOU and the mixer stated in dB. These figures exclude the internal mixer losses.

| **band** | **1** | **2** | **3** | **4** | **5** | **6 L** | **6 H** |
|---|---|---|---|---|---|---|---|
| LO injection loss | 20 | 10.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| dual polarization splitting | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| dewar window (20%) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| LOU to FPU coupling loss (16 to 19%) | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 |
| Total coupling loss between the LOU and mixer | 24.8 | 14.8 | 5.3 | 5.3 | 5.3 | 5.4 | 5.4 |

Table 4.5.11-1 The required frequency ranges, nominal, maximum and minimum power levels to be delivered by the LOU.

| LO Band | Lowest Frequency, GHz | Highest Frequency, GHz | Nominal Power, µW | Maximum Power, µW | Minimum Power, µW |
|---|---|---|---|---|---|
| 1a | 488 | 552 | 210 | 410 | 21 |
| 1b | 563.4 | 628.2 | 210 | 410 | 21 |
| 2a | 642.2 | 710 | 95 | 190 | 9.5 |
| 2b | 724 | 793 | 95 | 190 | 9.5 |
| 3a | 807 | 852 | 19 | 38 | 1.9 |
| 3b | 866 | 953 | 19 | 38 | 1.9 |
| 4a | 967 | 1042 | 27 | 53 | 2.7 |
| 4b | 1056 | 1113 | 27 | 53 | 2.7 |
| 5a | 1116 | 1178 | 17 | 33 | 1.7 |
| 5b | 1192 | 1242 | 17 | 33 | 1.7 |
| 6La | 1408 | 1575 | 1.4 | 2.7 | 0.14 |
| 6Lb | 1528 | 1696 | 1.4 | 2.7 | 0.14 |
| 6Ha | 1710, goal 1664 | 1845 | 1.4 | 2.7 | 0.14 |
| 6Hb | 1719 | 1908 | 1.4 | 2.7 | 0.14 |

*Note: the LO frequency coverage is predicated by the mixer band, the IF band of 4-8 GHz, a requirement for a 2 GHz overlap between adjacent mixer bands, and the requirement that a spectral line at 1900 GHz be observable in both upper and lower sideband.*

Table 6.4-1 The cleanliness levels of HIFI flight model hardware at the time of delivery to ESA.

| Hardware | Requirements | | | | Remarks |
|---|---|---|---|---|---|
| | Inside | | Outside | | |
| | Mol. | Dust | Mol. | Dust | |
| FPU | 4 | 300 | - | 300 | Bake-out |
| LOU | 4 | 300 | - | 300 | |
| Units on SVM | - | 300 | - | 300 | |
| Harness | - | - | - | 300 | |
| | | | | | |

Molecular contamination levels expressed in: $10^{-6}$ gr.cm$^{-2}$
Particulate contamination levels expressed in: PPM