SPIRE

Blue: Comments (with date)

SUBJECT: **INSTRUMENT REQUIREMENTS DOCUMENT**

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Change Record

ISSUE	DATE	
1	2 July 1999	First proper issue just prior to PDR
2	September 1999	Radically re-arranged separate instrument and sub-system reqs.
2-1	November 1999	Updated following comments from Berend Winter – this issue sent out for Warm Electronics Review

Table of Contents

1. INTRODUCTION

1.1 Purpose

This documents describes the capabilities required of the SPIRE instrument and the constraints placed upon its design and operation in the context of the FIRST mission.

The instrument requirements are derived from the scientific requirements placed on the instrument in the SPIRE Science Requirements Document (SRD); the constraints imposed upon the instrument design by the satellite interface specification as detailed in the Instrument Interface Document parts A and B (IID-A and IID-B) and the operational constraints on the instrument design given in the FIRST/Planck Operations Interface Requirements Document (OIRD).

This document goes beyond the general instrument level requirements to place specific requirements on individual sub-systems within the context of the conceptual instrument design. It thus forms the starting point for the SPIRE sub-system specification documents that will be written for each SPIRE sub-system.

The requirements set out in this document will be used to verify the performance of the instrument during instrument level Assembly, Integration and Verification (AIV). The sub-system requirements will be used as the bench mark for sub-system acceptance at instrument level.

1.2 Scope

This documents deals with the requirements on the SPIRE instrument hardware and software from the optical input from the FIRST telescope through to the interfaces with the spacecraft. It does not deal with the requirements on the SPIRE Instrument Control Centre or any other part of the instrument ground segment.

1.3 Glossary

AIV	Assembly Integration and Verification
AOCS	Attitude and Orbit Control System
ASIC	Application Specific Integrated Circuit
AVM	Avionics Model
BBM	BreadBoard Model
BSM	Beam Steering Mechanism
CDMU	Central Data Management Unit (on Spacecraft)
CQM	Cryogenic Qualification Model
CVV	Cryostat Vacuum Vessel
DCRU	Detector Control and Readout Unit
DHSS	Data Handling Sub-System (on Spacecraft)
DPU	Digital Processing Unit
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FINDAS	FIRST Integrated Network and Data Archive System
FOV	Field of View
FPU	Focal Point Unit

FS	Flight Spare
FTS	Fourier Transform Spectrometer
HIFI	
IID-A	Instrument Interface Document part A
IID-B	Instrument Interface Document part B
JFET	Junction Field Effect Transistor
MGSE	Mechanical Ground Support Equipment
NEP	Noise Equivalent Power
OBDH	On Board Data Handling (on Spacecraft)
OGSE	Optical Ground Support Equipment
OPD	Optical Path Difference
PACS	
PFM	Proto-Flight Model
PLM	Payload Module
QLF	Quick Look Facility
S/C	Space Craft
SPIRE	Spectral and Photometric Imaging Receiver
SRD	Science Requirements Document
SVM	Service Module
TBD	To Be Determined
TBC	To Be Confirmed

Table A: Glossary of acronyms and abbreviations

1.4 References

Where there are differences in requirements or specification details, the applicable and reference documents enumerated here take precedence over the Instrument Requirements Document. This is particularly the case with the IID-A and IID-B which will contain the interface specification between the SPIRE instrument and the FIRST satellite.

Notes:
The applicable and reference documents are shown here for illustrative purposes. This is because the most important documents from ESA are very out of date; namely the telescope specification, or not issued – the Satellite System Specification .

The IID-A sections 4 and 5 has just been re-issued – please refer to this version.

1.4.1 Applicable Documents

Document Reference	Name	Number/version/date
AD1	FIRST Instrument Interface Document Part A (IID-A)	PT-IID-A-04624 draft 0-1 31 August 1998
AD2	SPIRE Scientific Requirements Document (SRD)	Version 0.2 11 March 1999
AD3	FIRST/PLANCK Operations Interface Requirements Document (OIRD)	FP-ESC-RS-0001 Draft 1 August 1997

AD4	FIRST Science Operations Implementation Requirements Document (SIRD)	PT-03646 Draft 3 30th September 1997

Table B: Applicable Documents
The abbreviations in brackets are used throughout the present document.

1.4.2 Reference Documents

Document Reference	Name	Number/version
RD1	FIRST/SPIRE Instrument Interface Document Part B (IID-B)	PT-SPIRE-02124 0-1CRC2 12 March 1999
RD2	FIRST L2 Radiation Environment	PT-04040 4 March 1997
RD3	FIRST Telescope Specification	PT-RQ-04761 Issue 1 January 1998
RD4	ESA Packet Utilisation Standard	ESA-PSS-07-101 Issue 1, May 1994
RD5	FIRST/Planck Satellite System Specification	PT-RS-05991 Draft (issued?)
RD6	Fax from T. Passvogel 5/10/1998	PT-05908
RD7	SPIRE Optics Alignment Requirements (title TBD)	

Table C: Reference documents
The abbreviations in brackets are used throughout the present document.

1.5 Document Overview

The context within which the SPIRE instrument is to be operated and for which it is designed is outlined in section 2.1 together with an outline description of the conceptual design of the instrument. The requirements placed on the instrument performance in the Science Requirements Document are enumerated in section 2.2 and the requirements placed on the operation of the instrument in order to meet the scientific requirements are described in section 2.3. Sections 2.4-2.7 give the requirements placed upon the instrument design by the satellite launch and operations environments.

In chapter 3 the specific requirements placed on each sub-system of the SPIRE instrument are detailed. This starts from the generic requirements on all sub-systems for qualification and verification in sections 3.1 and 3.2. Each sub-system is then taken in turn, starting with the cold focal plane unit and ending with the warm electronics.

The details of various aspects of the qualification tests and the expected mass, power and thermal dissipation budgets available for the various sub-systems are given in the appendices.

2. INSTRUMENT AND SATELLITE LEVEL REQUIREMENTS

2.1 General Description

2.1.1 Instrument Description

SPIRE (Spectral & Photometric Imaging REceiver) is a bolometer instrument comprising a three-band imaging photometer covering the 200-600 μm range and an imaging Fourier Transform Spectrometer (FTS) with a spectral resolution of at least 0.4 cm^{-1} (corresponding to $\lambda/\Delta\lambda = 100$ at 250 μm), covering wavelengths between 200 and 670 μm. The detectors are bolometer arrays cooled to 300 mK using a ^3He refrigerator. The photometer is optimised for deep photometric surveys, and can observe simultaneously the same field of view of at least 4 x 4 arcminutes in all three bands.

2.1.2 Mission Context

SPIRE is one of three instruments to be placed on board the ESA Far InfraRed and Submillimetre Telescope (FIRST) satellite. This mission is dedicated to astronomical observations in the 85 to 700 μm waveband.

The FIRST satellite provides a 3.5 m telescope for receiving and imaging the FIR and submillimetre radiation from astronomical sources. The three instrument Focal Plane Units (FPUs) share the 0.25 degree focal plane of the FIRST telescope and each instrument provides re-imaging optics to take its the portion of the focal plane onto its detectors. The signals from the SPIRE instrument are, after suitable conditioning and conversion to digital format, sent to the ground via the spacecraft On-Board Data Handling (DHSS) sub-system.

In order to prevent the instrument detectors being swamped by self emission, the FPUs are located in the FIRST cryostat. This is a liquid helium (LHe) cryostat providing various temperature levels, the lowest of these is the super-fluid LHe tank at 1.7 K. There are also two cold gas vent lines – the actual temperatures these provide are dependent on the details of the instrument thermal dissipation and the cryostat design (see section 2.1.4.1). The three instrument FPUs mechanically interface to the cryostat via a common optical bench with separate thermal straps to the cryostat. The signal conditioning “warm electronics” units will be placed on the satellite service module (SVM). The electrical connections between the warm electronics and the cold FPU are made through a cryo-harness that will be provided as part of the satellite system.

The FIRST mission will be controlled from the Mission Operations Centre (MOC) via a remote ground station. The SPIRE instrument will be controlled from the SPIRE Instrument Control Centre (ICC) which communicates to the MOC via the FIRST Integrated Network and Data Archive System (FINDAS). The FIRST observers will interface to the mission via the FIRST Science Centre (FSC) which also communicates to the MOC via FINDAS.

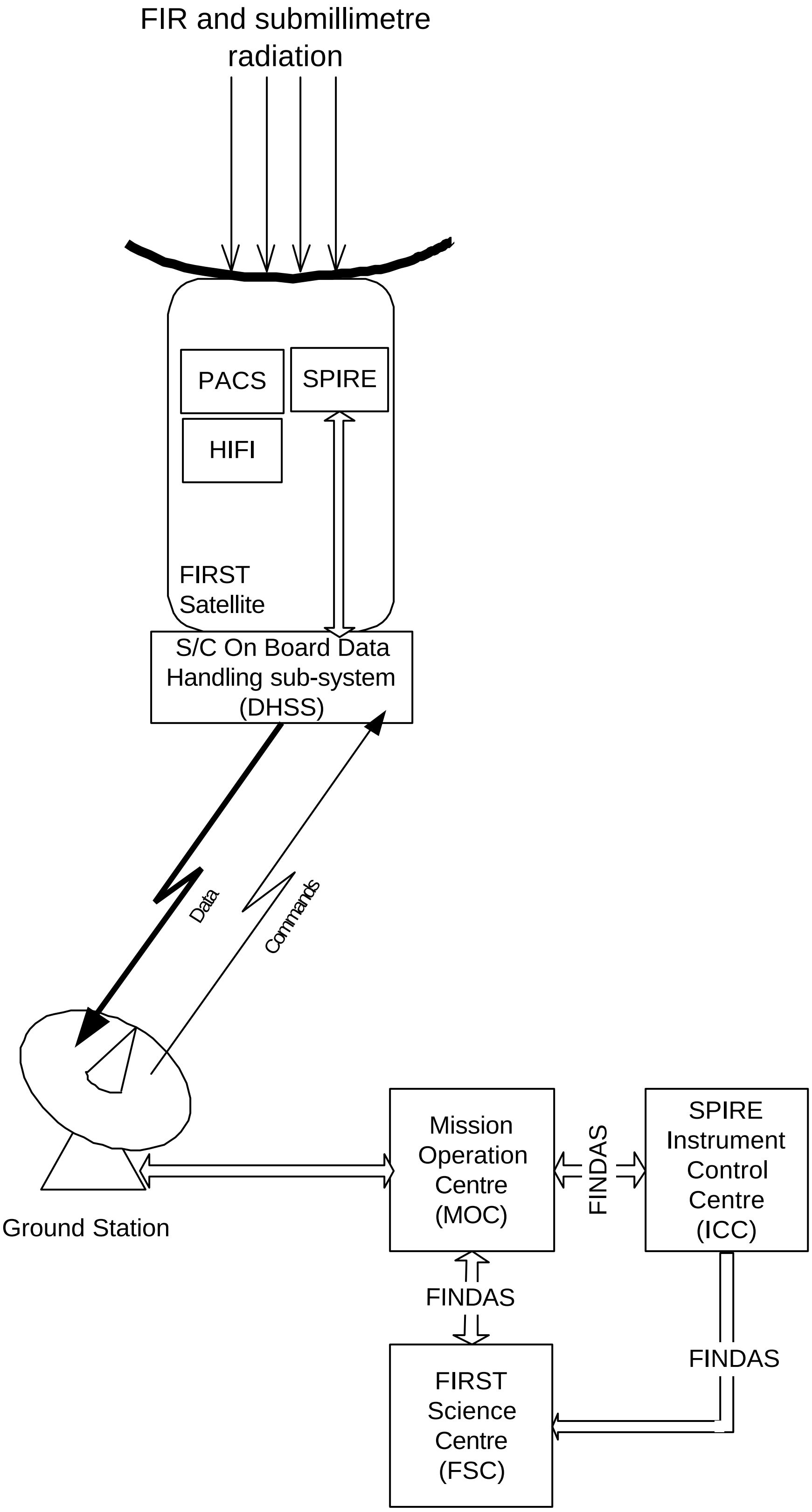

Figure 2-1: The FIRST Mission showing the communication between the various elements

2.1.3 Definition of Instrument Elements and Instrument Location

The SPIRE instrument consists of several “units” as defined in the IID-B and recapitulated in table 2.1-1 together with brief descriptions of their functions and their locations on the FIRST satellite. These are subject to revision as the detailed design of the instrument proceeds but are given here for reference.

Instrument unit	**Function**	**ESA code**	**Location**
Cold Focal Plane Unit (FPU)	Contains the optics; mechanisms and detectors.	FSFPU	On FIRST optical bench inside cryostat
Focal plane JFET and/or RF filter box (FTB)	For one detector option (feedhorns) this contains the cold read-out electronics. For all options it contains the RF filtering necessary to keep EMI to a minimum.	FSFTB	On FIRST optical bench inside cryostat
Buffer Amplifier Unit (BAU)	For two of the detector options (CEA and feedhorns) this contains extra amplification of the detector signals. For the TES option it may not be required.	FSBAU	On outside of cryostat vacuum vessel (CVV)
Detector Read-out and Control Unit (DRCU)	This warm electronics unit contains the circuitry necessary to read-out the detectors; control the various mechanisms and provide instrument control and data handling functions	FSDRC	On spacecraft service module (SVM)
Digital Processing Unit (DPU)	This warm electronics unit provides the instrument interface to the S/C DHSS sub-system; receives and interprets instrument commands and formats the instrument data for telemetry to the ground	FSDPU	On SVM
Warm interconnect harnesses (HARNESS)	This connects the warm electronics units.	FSHAR	On SVM

Table 2.1-1: Definition and location of the elements of the SPIRE instrument.

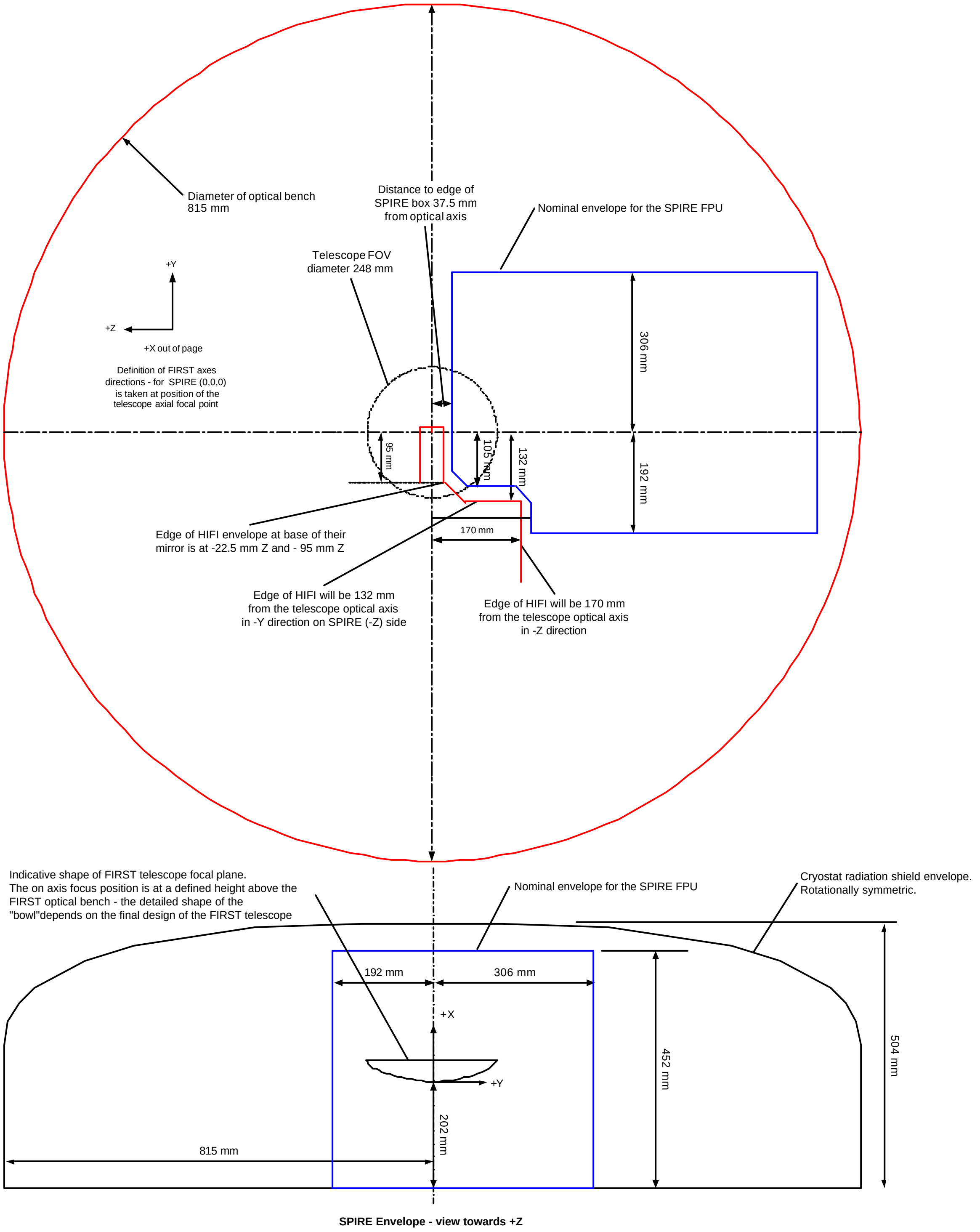

Figure 2-2: Cold FPU location and envelope constraints in the FIRST cryostat. The cryostat cover is rotationally symmetric and defines the X-Z envelope of the instrument box as well (not shown). The details of the box shape are subject to revision as the design evolves.

2.1.4 Satellite Level Constraints and Assumptions

The specification and capabilities of the FIRST satellite are given in RD5 and the IID-A. As these two documents are under review and are unlikely to be finalised in the near term, the assumptions that should be made about the FIRST satellite for the purposes of the SPIRE instrument requirements are described in this section.

2.1.4.1 FIRST Cryostat

The FIRST cryostat will provide thermal interfaces at the following temperatures:

Description	Cooling Method and Comments	Nominal Temperature
FIRST Optical Bench "Level 2"	Strapped to helium gas vent line **after** heat exchanger. That is the temperature of the gas will depend on the thermal dissipation from the instruments	11 K
Gas cooled heat exchanger "Level 1"	Cooled by cryostat boil off gas – temperature will depend on rate of boil off	4.3 K
LHe tank "Level 0"	The pumped LHe will be super-fluid and provide a very large thermal sink	1.7 K

Table 2-2: Temperature stages available from the FIRST cryostat.

The permissible dissipation from the FPU at the various temperatures is TBD but is likely to be no more than a few 10's mW total. An illustration of the expected levels of dissipation is given in the appendices.

The FIRST cryostat defines the available space envelope for the instruments. The SPIRE envelope is further restricted by the neighbouring HIFI instrument. Figure 2-2 shows the approximate location of the SPIRE instrument, the definition of the spacecraft axes and the available space envelope.

The shape of the FIRST cryostat cover that defines the cold FPU space envelope is given in RD6 and repeated in table 2-3 for completeness.

X (mm)	Y (mm)	Z (mm)
0	0	815
271	0	815
315	0	807
350	0	787
379	0	758
431	0	662
461	0	563
497	0	337
504	0	135

Table 2-3: Dimensions of the FIRST cryostat shield that defines the envelope for the instruments. The shield is rotationally symmetric and, when this definition was provided, the hole in the top had a radius of 135 mm. This is subject to revision depending on the detailed design of the telescope.

2.1.4.2 Warm Electronics Power

The SPIRE instrument has requested up to 181 W total (see IID-B). How much power is actually available for the instruments is not defined at present.

2.1.4.3 Telemetry Rates

The average telemetry rate available to each instrument over the operational cycle of the FIRST satellite is 100 kbps. This is subject to review.

2.1.4.4 FIRST Telescope

The FIRST telescope defines the optical "environment" in which the SPIRE instrument has to operate. In particular the field of view; the plate scale and speed of the beam. The current specification for the FIRST telescope is given in the 'FIRST Telescope Specification' (RD3). It is base lined as having the following optical specification:

Primary mirror diameter: 3.5 m
Focal length: 28.5 m
Focal Ratio: f/8.68
Back focal length: 975 mm – defined from the primary vertex
Field of view: circular - radius 0.25 degrees
Height of on-axis focus above optical bench: 202 mm
Plate scale: 7.237 arcsec/mm
Diameter of unvignetted field of view at the focal plane: 248.7 mm

The f/number of the primary and, therefore, the size of the secondary have not been finally decided. The telescope design is under review and the precise optical description is not finalised.

2.1.4.5 Pointing

The pointing capabilities of the FIRST satellite are given in AD1 and RD5. The satellite has a requirement to "blind point" to within 3.7 arcsec and a goal to do this within 1.5 arcsec. Both these figures are 1-sigma values and are referred to the optical axis. If the goal is not achieved, and the SPIRE instrument implements the feedhorn type detectors, then a "peak-up" operation mode will be required – see section 2.3.1.

The satellite has the ability to perform both pointed raster observations and fast scans across the sky. For the raster mode the relative accuracy between pointings will be better than 0.5 arcsec. In scan mode the satellite can be scanned over a large angular range from 0.1 arcsec/sec to 60 arcsec/sec with a resolution of 0.1 arcsec/sec. The satellite can be scanned from 1 arcmin to 110 degrees with a resolution of 1 arcmin. This mode can be used in "line scan" to build up maps of large areas of the sky.

The satellite can be nodded from one position to another with a duty cycle of at least 80% for a throw of 5 arcmin with a dwell time of 72 seconds at each position. The details of any actual SPIRE specific requirement on the nodding capability of the satellite are to be determined.

2.1.4.6 Launch Environment

The satellite will be launched on an Ariane V from Kourou. The expected environment is specified in the IID-A and the test requirements on the instrument are given in appendix 4.1.

The cold FPU and JFET/Filter box (FTB) will be launched in vacuum and at cryogenic temperatures. The warm electronics units and the BAU will be launched at ambient temperatures and atmospheric pressure.

2.1.4.7 Orbit

The FIRST satellite will be placed into a Lissajous orbit around the L2 libation point 1.5×10^6 km from the Earth on the Earth-Sun line.

What is the maximum excursion of this orbit from the Earth-Sun axis?
How does it evolve?
What are the implications for pointing restrictions?

2.1.4.8 Mission Lifetime

The expected mission lifetime is 4.25 years. This should be the figure used for estimation of number of operations and reliability of SPIRE sub-systems and the corresponding life tests that will be required.

2.1.4.9 Radiation environment

RD2 gives calculated fluence and doses for the mission. The integrated dose for silicon behind 2 mm of aluminium is estimated at 12 kRad and behind 5 mm of aluminium as 3.5 kRad. These figures will be taken as the radiation tolerance for components in the warm electronics boxes and inside the cryostat respectively (TBC).

2.1.4.10 Operational Environment

In normal operations the satellite is expected to have a 24-hour operational cycle with data being collected autonomously for 22 hours and a 2 hour ground contact period – the Data Transfer and Commanding Period (DTCP). During the DTCP the data will be telemetered to the ground and the commands for the next 22-hour observation period will be uplinked.

This operational environment requires the instrument to undertake autonomous health and safety monitoring and to be capable of reacting to safety critical situations in real time to prevent damage to the instrument. It is expected that some health and safety tasks will be undertaken by the satellite DHSS.

It is expected that the observing schedule will be carried out as a series of fixed time operations. It is also expected that the satellite DHSS will store the instrument commands and provide the commands at the appropriate time intervals to the instrument to carry out the fixed time observation schedule. This implies that the instrument does not need to store a large number of commands or to know the absolute time a command should be executed.

2.2 Instrument Level Requirements

2.2.1 Photometer Requirements

The basic scientific requirements for the SPIRE photometer are described in the SRD (AD2). The predicted instrument sensitivities, based on the current instrument design assumptions, and which are compatible with the scientific requirements, are given in Table 2.2-1. The assumptions used in the calculation of the sensitivities are given in the IID-B (RD1) Chapter 4.

Requirement ID	Description	Wavelength Range			Reference
		250 mm	350 mm	500 mm	
IRD-PHOT-R01	Nominal passband ($\lambda/\Delta\lambda$)	3	3	3	IID B Chap 4
IRD-PHOT-R02	Field of View (Arcmin) Req. Goal	4 x 4 4 x 8	4 x 4 4 x 8	4 x 4 4 x 8	IID B Chap 4
IRD-PHOT-R03	Beam FWHM (Arcsec)	18 (TBC)	25 (TBC)	36 (TBC)	IID B Chap 4
IRD-PHOT-R04	Point source sensitivity 1 σ -1 sec (mJy) 1 σ -1 hr (mJy)	34 (TBC) 0.6 (TBC)	35 (TBC) 0.6 (TBC)	41 (TBC) 0.7 (TBC)	IID B Chap 4
IRD-PHOT-R05	Mapping sensitivity for one FOV 1 σ -1 hr (mJy)	1.4 (TBC)	1.5 (TBC)	1.9 (TBC)	IID B Chap 4

Table 2.2-1: Summary of Photometer scientific requirements and sensitivities

In addition to the basic requirements, the SRD specifies “design” drivers and goals for the photometer design – these are described in Table 2.2-2.

Requirement ID	Description	Reference
IRD-PHOT-R06	Maximising 'mapping speed' at which confusion limit is reached over a large area of sky is the primary science driver. This means maximising sensitivity and field-of-view (FOV) but NOT at the expense of spatial resolution.	SRD Appendix item A1
IRD-PHOT-R07	Filling the FOV at three wavebands is more important than having more wavelength channels	SRD Appendix item A2
IRD-PHOT-R08	Chopping is highly undesirable for confusion-limited deep survey observations	SRD Appendix item A3
IRD-PHOT-R09	Small-scale "jiggling" or "micro-stepping" is essential.	SRD Appendix item A4
IRD-PHOT-R10	Field distortion must be <10% across the FOV	SRD Appendix item A5
IRD-PHOT-R11	Electrical crosstalk should be <0.4% between nearest-neighbour pixels and <0.05% between all other pixels. Achieving this goal would result in crosstalk being dominated by the telescope surface errors. This may not be achievable	SRD Appendix item A6

Requirement ID	Description	Reference
	in practice.	
IRD-PHOT-R12	NEP variation should be < 10% across each array.	SRD Appendix item A7
IRD-PHOT-R13	Instantaneous dynamic range should be > 12 bits.	SRD Appendix item A8
IRD-PHOT-R14	Absolute photometric accuracy should be ~10%.	SRD Appendix item A9
IRD-PHOT-R15	Detector linearity should be less than or calibratable to less than 10% across the full dynamic range of SPIRE, including any gain ranges.	SRD Appendix item A10
IRD-PHOT-R16	If the feedhorn arrays are selected then the three arrays need to be co-aligned to within 1 arcsecond.	SRD Appendix item A11

Table 2.2-2: Summary of Photometer design drivers from the SPIRE Science Requirements Document.

2.2.2 Spectrometer Requirements

The basic scientific requirements for the SPIRE FTS are described in the SRD. The predicted instrument sensitivities, based on the current instrument design assumptions, and which are compatible with the scientific requirements, are given in Table 2.2-3. The assumptions used in the calculation of the sensitivities are given in the IID-B Chapter 4.

Requirement ID	Description	Value	Reference
IRD-SPEC-R01	Wavelength range: Band A Band B	200 – 300 μm (TBC) 300 – 700 μm (TBC)	IID B Chap 4
IRD-SPEC-R02	Maximum Resolution (cm^{-1}) Req. Goal	0.4 0.04	IID B Chap 4
IRD-SPEC-R03	Minimum Resolution (cm^{-1}) Req. Goal	2 4	IID B Chap 4
IRD-SPEC-R04	Field of View (Arcmin)	>2x2 square for filled arrays 2.6 diameter circular for feedhorns	IID B Chap 4
IRD-SPEC-R05	Beam FWHM (Arcsec) Band A (250 ? m) Band B (350 ? m)	18 (TBC) 25 (TBC)	IID B Chap 4
IRD-SPEC-R06	Point source continuum sensitivity (mJy; 1 σ -1 hr; 0.4 cm^{-1} resolution) Point source unresolved	Band A 47 (TBC) Band B 300-400 μm 43 (TBC) Band B 400-700 μm TBD Band A 5.6 x 10^{-18}	IID B Chap 4

Requirement ID	Description	Value	Reference
	line sensitivity (W m^{-2}; 1 σ -1 hr)	(TBC) Band B 300-400 μm 5.1 x 10^{-18} (TBC) Band B 400-700 um TBD	
IRD-SPEC-R07	Map continuum sensitivity (mJy; 1 σ -1 hr; 0.4 cm^{-1} resolution) Map line sensitivity (W m^{-2}; 1 σ -1 hr)	Band A 108 (TBC) Band B 300-400 μm 104 (TBC) Band B 400-700 μm TBD Band A 1.3 x 10^{-17} (TBC) Band B 300-400 μm 1.3 x 10^{-17} (TBC) Band B 400-700 μm TBD	IID B Chap 4

Table 2.2-3: Summary of Spectrometer scientific requirements and sensitivities.

In addition to the basic requirements, RD2 specifies “design” drivers and goals for the photometer design – these are given in Table 2.2-4.

Requirement ID	Description	Reference
IRD-SPEC-R08	Sensitivity is the primary science driver for the spectrometer, so that the maximum number of survey sources can be followed-up as rapidly as possible.	SRD Appendix item B1
IRD-SPEC-R11	The effective resolution should not vary more than 10% across the FOV of the spectrometer.	SRD Appendix item B4
IRD-SPEC-R12	Extending the short wavelength coverage of the FTS would be scientifically very useful and also assist cross calibration of SPIRE and PACS data.	SRD Appendix item B5
IRD-SPEC-R13	The telescope background should be compensated for using a calibration source in the second input port. This compensation should be as near to perfect as possible given the constraints of the knowledge of the telescope emission spectrum.	SRD Appendix item B6

Table 2.2-4: Summary of Spectrometer design drivers from the SPIRE Science Requirements Document.

2.3 Instrument Operations Requirements

2.3.1 Instrument Operations

Requirement ID	Description	Source
IRD-OPS-R01	It shall be possible to calculate the execution time of an instrument command to within 1 sec (TBC). *This will allow the calculation of the time taken to execute any observation.to be made, for example, when generating a timeline.*	
IRD-OPS-R02	The instrument shall be capable of limiting the average data rate to the DHSS, during a 24hr period, to 100kbps (TBC) *The on-board software should provide functionality to allow observing sequences to be generated that will keep the data rate within this limit. This functionality will include, general purpose data compression, data reduction by integration of science data over time and selection of subsets of science data (i.e. selected pixels).*	
IRD-OPS-R03	The SPIRE instrument shall be identified as a single subsystem within the satellite. *That is, the instrument will utilise a single APID (to be defined by the FIRST Project) to identify both telecommands to the instrument and telemetry from the instrument.*	OIRD

Table 2.3-1: Requirements on the instrument operations

2.3.2 Operating Modes

This section describes the expected operating modes for the SPIRE instrument.

Requirement ID	Description	Source
IRD-MODE-R01	The instrument shall be capable executing all operating modes. *These modes are described in the SPIRE Operating Modes Document (RD8) and briefly, below*	

Table 2.3-2: Requirements on the instrument operating modes.

2.3.2.1 Off Mode

All instrument sub-systems will be switched off - including the DPU and there will be no instrument telemetry.

2.3.2.2 On Mode

The DPU will be switched on and can receive and interpret instrument commands, but no other sub-systems will be switched on. For engineering purposes it will be possible to command the instrument to switch on individual sub-systems from this mode. Full housekeeping data will be telemetered.

2.3.2.3 Standby Mode

The spacecraft may be pointed in an arbitrary direction (observing with another instrument for instance). The instrument will telemeter only housekeeping information, and perhaps some degraded science data - see below, at a rate very much lower than the full telemetry bandwidth.

2.3.2.4 Observe Mode

The following are the observing modes so far identified for the SPIRE instrument - for all photometer operations the absolute calibration of the instrument will be maintained using periodic calibrations by switching on the on-board photometric calibration source. It is assumed that these calibrations will have no impact on spacecraft operations (TBC).

Obs 1 **Photometer** chop - the beam steering mirror is used to switch between two separate portions of the sky with the spacecraft pointed at a fixed position, thus modulating the signal onto the detectors. The full telemetry bandwidth will be required. The size and direction of chop is determined by the observer.

Obs 2 **Photometer** scan - This is an alternative method of mapping an area of sky larger than the instantaneous field of view of the instrument. The spacecraft will slew slowly over a given area. In this way the signal is modulated by chopping from one pixel to the next. A further variation is to use the beam steering mirror to switch to another portion of the sky in a direction orthogonal to the direction of slew. The speed of slew will be no more than 50 arcsec/sec and may be in an arbitrary direction with respect to the spacecraft axes. The full telemetry bandwidth will be required.

Obs 3 **Photometer** peak up - if the absolute pointing error of the spacecraft is too poor to allow for instantaneous acquisition of a given target to within 2 arcsec (TBC), then a peak up procedure will be required for the feedhorn type detectors. This will use the beam steering mirror to identify the position of a source by executing a small cross raster across the pointing given by the spacecraft. If this mode is required it will involve moderately sophisticated on-board signal processing and the ability to communicate the calculated off set to the AOCS independently of ground communication.

Obs 4 **Photometer** Jiggle-photometry - in this case as well as chopping in a fixed direction, the beam steering mirror will be used to move the field-of-view in small steps in two directions in order to allow the field-of-view to be fully-sampled. This mode will be implemented which ever type of detector is employed.

Obs 5 **Photometer** partner mode - It is envisaged that PACS and SPIRE will sometimes be used to make simultaneous observations of the same portion of the sky. In this case a reduced telemetry rate will be available to each instrument. In the case of the SPIRE this will mean that either the data will have a reduced resolution or that there will be on-board integration of images (TBC).

Obs 6 **Photometer** serendipity mode - During spacecraft slews scientifically useful information can be obtained without the necessity of using the focal plane chopper - essentially these are rapid scan maps. It is assumed that at least half the bandwidth will be available to the bolometer instrument (PHOC may have a similar mode) and this will be filled with science data from the photometer arrays (only). The chopper and spectrometer mechanisms will be switched off in this mode. Accurate pointing information will be required from the AOCS to reconstruct the slew path in the data analysis on the ground.

Obs 7 **Photometer** parallel mode - When observations are being made with another instrument, that are not partner observations, then scientifically useful data may be obtainable from the photometer, albeit with degraded intensity and spatial resolution. In this mode a science data packet will be telemetered alongside the standard housekeeping data. The chopper and spectrometer mechanisms will be switched off in this mode.

Obs 8 **Spectrometer** - The spectrometer mirrors will be constantly scanned over the distance required for the requested spectral resolution. The spacecraft will be pointed at a fixed position the beam steering mirror may be switched on to allow for peak up operations. The spectral calibrator will be on during all spectrometer operations. The full telemetry bandwidth will be required and there will be on-board integration of spectra.

Obs 9 **Spectrometer** Jiggle-spectral-imaging - In the feed detectors are implemented, then to obtain a fully sampled spectral map the beam steering mirror will be used to 'jiggle' the detectors around the field of view; at each position a fully-sampled spectrum will be taken. This mode of operation is more complex than would be the case with a focal plane array that fully samples the field of view.

2.3.2.5 Cooler Recycle

The 3He cooler requires recycling every 46 hours (TBC). During this time the instrument will be switched off except for vital housekeeping and cooler functions (TBC). The recycling takes 2 hours (TBC) to complete with another N hours (TBD) before instrument operations can recommence. During the 2 hours recycling the heat load on the helium bath is 50-100 mW (TBC).

2.3.2.6 Real Time Commanding

During ground contact it may be necessary to command the instrument in real time and analyse the resultant data on the ground in near real time for instrument testing and debugging purposes. In this case the full telemetry bandwidth will be required for the duration of the instrument test in question. It is not anticipated that this will occur frequently.

2.3.2.7 Commissioning and Calibration

During the commissioning and performance verification phases of mission operations, many housekeeping and other health check parameters will be unknown or poorly defined. This mode allows the limits on selected health check parameters to be ignored by whatever real time monitoring systems are in place on the spacecraft/instrument.

2.3.3 Commanding Requirements

Instrument operations will be controlled by commands passed from the DHSS to the instrument in the form of telecommand packets (see RD4). The DHSS will be responsible for handling the command timeline uplinked from the ground and issuing the commands to the instrument at the appropriate time. The instrument, therefore, is normally expected to execute the commands it receives from the DHSS (or DHSS simulator) in the order in which it receives them. Commands will be provided to modify the order of execution if required.

Requirement ID	Description	Source
IRD-CMD-R01	The instrument shall be capable of accepting telecommand packets from the DHSS at speeds up to the maximum rate delivered by the DHSS, without loss. *This implies that the instrument should be able to buffer a number of telecommands received from the DHSS while a command is being executed. However, it may be assumed that the timing of command distribution to the instrument will be managed so that the maximum number of commands in the buffer will be limited.*	
IRD-CMD-R02	The instrument shall validate each telecommand packet as it is received. *Telecommand packets will contain a checksum to allow validation.Invalid commands should be rejected*	
IRD-CMD-R03	The instrument shall verify execution of the telecommands in each packet. *Normally, each telecommand packet will contain only one instrument command* *Commands which take a long time to execute (longer than ~5 secs, TBC) should have their progress verified also.*	
IRD-CMD-R04	The instrument shall report the result of all telecommand validation/verification in telemetry *The format of these telecommand report packets are defined in RD4*	
IRD-CMD-R05	The instrument shall provide commands to allow control of all individual devices (e.g. switch, latch) within the instrument.	
IRD-CMD-R06	All commands to individual devices shall explicitly set the state of the device *I.e. there shall be no commands to 'toggle' the state of a switch or commands to step to the next location.*	
IRD-CMD-R07	The action of all commands affecting an individual device shall	

Requirement ID	Description	Source
	be verifiable by an independent parameter available in the nominal housekeeping packet. *For example the change of state of a switch shall be verified by the change in voltage at the output of the switch rather than the status of the latch controlling the switch*	
IRD-CMD-R08	The instrument shall provide commands to execute the functions required to implement the instrument operating modes *These functions are defined in the SPIRE Operating Modes document (RD8). They usually invoke one or more device control actions in order to perform teir function.*	
IRD-CMD-R09	The instrument shall provide the facility to define and execute 'macro' commands. *These commands will invoke stored sequences of commands with appropriate control steps to allow a given task to be performed. They will be invoked with supplied parameters to modify the actions performed. The intention is to minimise the number of telecommand words required to execute a given command sequence.*	
IRD-CMD-R10	The instrument shall provide commands to modify the execution sequence of commands. *Normally, commands are executed in the order in which they are received. These commands should provide the facilty to interrupt the currently executing command, modify the command queue and continue execution of commands in the queue.*	
IRD-CMD-R11	The instrument shall provide commands to allow identification of the steps within an observation. *For processing of the data from the instrument it will be necessary to be able to identify the observation/step from which the data has come. These commands should modify software parameters onboard so that this information is reported in the telemetry*	
IRD-CMD-R12	The instrument shall provide commands to modify data values/tables held in the instrument memory. *The on-board software will use data tables to control the operations onboard. These tables may need to be maintained.*	
IRD-CMD-R13	The instrument shall provide commands to enable on-board software maintenance *It should be possible to update the on-board software code either as a whole, or replace a single subroutine/function.*	

Table 2.3-3: Instrument level requirements on telecommanding

2.3.4 Telemetry Requirements

All data generated by the instrument will be transmitted from the instrument to the satellite DHSS in the form of telemetry packets. These packets will be store onboard by the DHSS, until the opportunity arises to transmit them to the ground.

Requirement ID	Description	Source
IRD-TLM-R01	The instrument shall be capable of transferring telemetry packets to the DHSS (or simulator) at up to the maximum rate allowed by the telemetry interface. *This is approximately 1Mbps*	
IRD-TLM-R02	The instrument shall be able to buffer telemetry packets until they are requested by the DHSS *The DHSS will poll each subsystem on the satellite in turn for data. The instrument should be able to buffer sufficient packets to not lose data waiting for the DHSS.*	
IRD-TLM-R03	It shall be possible to validate the content of each telemetry packet. *The telemetry packet standard identifies the location of a checksum of the data contained within the packet. This checksum may be used to validate the packet*	
IRD-TLM-R04	All telemetry packets shall contain information identifying the observation/step being executed. *This will allow data processing software to identify significant steps in an observation in order to apply the appropriate processing*	
IRD-TLM-R05	The instrument shall generate housekeeping data packets in all operating modes. *These data packets contain the values of both hardware and software parameters internal to the instrument.*	
IRD-TLM-R06	It shall be possible to define TBC alternative housekeeping packet structures with different rates of generation. *The normal housekeeping packet will be generated once per second (TBC) and contain, at the least, all hardware parameters.* *Housekeeping packets generated at higher rates (up to 1000 per second (TBC) may contain a subset of the instrument parameters*	
IRD-TLM-R07	The instrument shall generate science data packets in all observing modes.	

Requirement ID	Description	Source
	These packets shall contain data from the detector arrays associated with the observing mode, plus all instrument parameters that may be required to enable the processing of the detector data (e.g mechanism positions, temperatures of units which may affect the detector data, monitoring parameters for the subsystems being used).	
IRD-TLM-R07	It shall be possible to define TBC alternative science data packets structures. *This will allow the set of detector data and instrument parameters included in the science data to be optimised for different observation modes.*	
IRD-TLM-R08	Ths instrument shall generate event packets in all operating modes. *These packets notify the DHSS and/or ground monitoring equipment of instrument anomalies and significant actions taken by the instrument. The ESA packet Utilisation Standard identifies many of thesereport packet types. These packets should identify the type of anomaly and the data used to identify it.*	

Table 2.3-4: Instrument level requirements on the data packets

2.3.5 Data Handling Requirements

Requirement ID	Description	Source
IRD-DATA-R01	All data tranferred between the DHSS and the instrument shall be contained in packets conforming to the ESA Packet Utilisation Standard (RD4) *It is assumed that in the interests of commonality with other spacecraft systems and scientific instruments the data handling of the SPIRE instrument will follow this standard. The detailed definition of the contents of each packet will formally be defined in a FIRST Space/Ground Interface Document to be written and agreed later.*	OIRD
IRD-DATA-R02	The instrument shall provide all mandatory packet handling services defined for the mission. *The OIRD (AD3) defines the list of mandatory services*	OIRD
IRD-DATA-R03	The instrument shall be capable of buffering data generated during an observation. *It is possible that data will be generated during an observation, at a rate greater than that which can be transferrred to the DHSS. The instrument should buffer this data and transfer it to the DHSS at a later time (even if a new*	

	observation has begun). The size of the buffer is TBD	
IRD-DATA-R04	The instrument shall be capable of compressing telemetry data to reduce the average data rate to the DHSS to 20kbps. *This may be required to cope with a reduced telemetry downlink rate or 'partner mode' observations. The science content of the telemetry may be degraded.*	
IRD-DATA-R05	The packing of science data into scienec data packets shall minimise loss of information if packet is lost or corrupted. *Science data packets should include data from one or more detectors over a given time period (or for a single interferogram) rather than one sample from all detectors. In this way if a data packet is lost the impact on the science is reduced.*	

Table 2.3-5: Instrument level data handling requirements

2.4 Instrument Model Philosophy

The instrument models to be built are as follows:

BBM - Breadboard Model. This is an electrical representation of the instrument consisting of models of the warm electronics boxes built with commercial parts where possible and an electrically representative simulator to replace the focal plane unit. The warm electronics units may undergo a partial EMC test (only) but will essentially be used to test interfaces between the various electrical sub-systems; as a test bed for the on-board software (both in the Signal Processing Unit and the Digital Processing Unit) and to test the Quick Look Facility. This model will **NOT** be delivered to ESA

AVM – Avionics Model. The IID-A states that this is: "…to validate electronics and software for its interface with the S/C, including anything that exchanges information with, for example, the AOCS. In addition all tasks relevant to SPIRE autonomy shall be verified."

We have interpreted this as being a DPU plus a simulator of the DRCU; BAU and cold FPU – this is termed the DRCU Simulator. As the schedule demands that this model will be delivered almost simultaneously with the CQM we intend using the CQM DPU plus a DRCU simulator as the AVM – see section 3.4 for a description of the warm electronics.

CQM - Cryogenic Qualification Model. For both the cold FPU and the warm electronics it is assumed that this is built to flight standards, but not necessarily using flight quality electronic components. The performance capabilities of the instrument may be less than the proto-flight model - i.e. fewer pixels in the focal plane arrays, but it will mimic as exactly as possible the thermal, electrical and mechanical properties of the flight instrument and will be capable of under going the full environmental qualification programme

PFM – Proto-Flight Model. This will be the instrument model that is intended for flight. It will be built to full flight standards and will only have minor differences in thermal, electrical and mechanical properties to the CQM. It will have the same mechanical, thermal and electrical interfaces to the satellite as the CQM but, may, however, have minor internal design changes compared to the CQM. For instance the bolometer arrays may have many more pixels. The PFM will therefore undergo environmental test to qualification levels for acceptance times (**TBD)** - this applies to both the warm electronics boxes and the cold FPU

FS – Flight Spare. The flight spare cold FPU will be made from the refurbished CQM (TBC). The flight spare warm electronics will consist of spare electronics cards.

Requirement ID	Description	Source
IRD-INST-R14	The SPIRE instrument shall provide the instrument models as specified in the IID-A	

Table 2.4-1: Instrument level model requirements.

2.5 Instrument level Qualification

It is required that the instrument be qualified at unit level – i.e. the cold FPU; warm electronics boxes etc must undergo individual qualification testing and be shown to be flight worthy. The tests that are required for each model and unit are outlined in Table 2.5-1 and described in more detail in appendix 4.1.

Test Matrix

	CQM Cold Focal Plane Units	CQM Warm Electronics Units	PFM Cold Focal Plane Units	PFM Warm Electronics Units	FS Cold Focal Plane Units	FS Warm Electronics Cards
Vibration:	**Q**	**Q**	**QA**	**QA**	**A**	**A**
Thermal cycle:	**Q**	**Q**	**QA**	**QA**	**A**	**A**
Vacuum cycle	**x**	**x**	**x**	**x**	**x**	**x**
Thermal range:	**x**	**x**	**x**	**x**	**-**	**-**
EMC (Instrument Level)	**x**	**x**	**x**	**x**	**-**	**-**
EMC (Satellite Level):	**-**	**-**	**x**	**x**	**-**	**-**

Table 2.5-1: Test matrix for the instrument level testing.
Q indicates a test carried out at qualification level for qualification times; QA a test carried out at qualification levels for acceptance test times and A a test carried out at acceptance level for acceptance times. An x indicates that this test is carried out and is a characterisation type test or the level is irrelevant. A dash indicates that no test will be done on this model/unit.

Requirement ID	Description	Source
IRD-INST-R15	The instrument units are required to undergo an enviromental test programme that demonstrates the design and build standard of the flight model is compatible with the launch and operational environment of the FIRST satellite.	

Table 2.5-1: Instrument level qualification requirements.

2.6 Verification

For the purposes of verification requirements, the instrument models consist of the units specified in section 2.4. It is also assumed that there will be present some form of EGSE to allow testing of the instrument models in the absence of the spacecraft and that there will be some computer hardware and software to allow the receipt; storage and analysis of the test data.

Requirement ID	Description	Source
IRD-VER-R01	The AVM verification testing shall demonstrate that the instrument will fulfil the requirements on the following: 1. Communication between the satellite DHSS and the DPU. 2. Correct transfer and receipt of instrument commands from the satellite 3. Correct transfer and receipt of instrument data packets form the instrument to the satellite 4. Correct execution of instrument commands 5. Correct transfer of instrument data from the FPU simulator to the DPU 6. Correct execution of DPU on-board software for any data compression algorithms and packet generation for all instrument data packet types.	
IRD-VER-R02	The CQM verification testing shall, in addition to the requirements on the AVM verification, demonstrate the following: 1. Correct operation of all FPU sub-systems at cryogenic temperatures for all instrument operation modes for both prime and redundant systems. 2. Correct operation of all instrument sub-systems with warm electronics units operating over a range of temperatures (see section 2.5) 3. The instrument cold FPU and JFET/Filter box thermal dissipation is within requirements for all instrument operation modes. 4. The BAU thermal dissipation at 77 K is within requirements for all instrument operation modes. 5. The warm electronics thermal dissipation at room temperature is within requirements. 6. Correct operation of CQM version of all on-board software. 7. The instrument straylight environment is within requirements 8. The instrument optics performance is within requirements 9. The performance of the instrument meets the	

Requirement ID	Description	Source
	scientific requirements expected for the CQM for all instrument observing modes 10. Development and test of all functional test sequences required for Integrated Systems Testing (IST) at satellite level. 11. The correct functioning of the instrument for all Astronomical Observing Templates (AOTs) and calibration sequences. 12. Development and test of all in-flight functional and performance test sequences	
IRD-VER-R03	The PFM and FS verification testing shall, in addition to the requirements on the CQM and AVM verification, demonstrate the following: 1. The performance of the flight and flight spare instruments meets the scientific requirements for all instrument observing modes. 2. Correct operation of flight version of all on-board software. 3. The characterisation of the PFM and FS instrument performance for all instrument observing modes – including generation of data for instrument calibration and functional testing both during IST and in-flight. 4. The characterisation of the instrument performance with the warm electronics operating over a range of temperatures (see section 2.5) 5. Final test of all functional test sequences for IST. 6. Final test of all AOTs 7. Final test of all in-flight functional and performance test sequences.	

Table 2.6-1: Requirements on the instrument level verification.

2.7 Safety

Requirement ID	Description	Source
IRD-SAFE-R01	During all mission phases, there shall be no requirement for commands to be sent from the ground to the instrument with an immediate response time (i.e. less than 2 minutes TBC). *Any such situations must be handled on board.*	OIRD-CTRL-1
IRD-SAFE-R02	Situations which require response from the ground within a short time (i.e. less than 30 mins) shall be reduced to a minimum, be well identified and agreed by ESA	OIRD-CTRL-2
IRD-SAFE-R03	Situations which require response from the ground within a short time (i.e. less than 30 mins) shall be unambiguously recognisable in the instrument housekeeping telemetry, without complex processing	OIRD-CTRL-3
IRD-SAFE-R04	Housekeeping telemetry shall be generated during all nominal modes of the instrument. *This includes any instrument Safe Modes*	OIRD-CTRL-4
IRD-SAFE-R05	The instrument shall be able to accept all telecommand packets sent to it at the nominal transfer rate from the DHSS	OIRD-CTRL-5 OIRD-CTRL-6
IRD-SAFE-R06	It shall not be possible by command, or lack of command, to place the instrument into a configuration that will, or is likely to cause damage to any subsystem	
IRD-SAFE-R07	All telecommands received by the instrument shall be checked to be correctly formatted and complete before execution. *Incorrect telecommands will be rejected by the instrument*	
IRD-SAFE-R08	Failure of any sub-system, or one of its components, shall not affect the health of any other subsystem, the instrument or the interface with the satellite.	
IRD-SAFE-R09	Failure of any component in a subsystem shall not damage any redundant or backup component designed to replace that component in the subsystem	
IRD-SAFE-R10	No ASICs or FPGAs shall be capable of affecting instrument operations until they are in a defined state. This state shall be confirmed in the housekeeping telemetry.	
IRD-SAFE-R11	No commands shall be sent to ASICs or FPGAs until they are in a defined state confirmed by the on-board software	
IRD-SAFE-R12	As far as possible all electronic control loops shall be implemented through the use of on-board software.	
IRD-SAFE-R13	It shall be possible to break all electronic control loops implemented in hardware. *This will allow the control of the loop through the on board software (this may be a degraded mode of operation)*	

Table 2.7-1: Instrument level safety requirements.

2.8 Autonomy

The instrument is required to be "autonomous" during 22 hours when not in ground contact. This implies that the warm electronics must monitor critical housekeeping parameters to ensure that any sub-system failure is detected and the appropriate action taken. It is assumed that the basic action will be to switch instrument in to safe mode with only the DPU on and housekeeping telemetry.

Requirement ID	Description	Source
IRD-AUT-R01	The SPIRE instrument shall have a defined safe mode. *The configuration of this mode shallbe agreed with ESA*	
IRD-AUT-R02	The SPIRE instrument shall define housekeeping parameters to be used for autonomous health and safety monitoring	
IRD-AUT-R03	The SPIRE instrument shall provide a method of monitoring the defined housekeeping parameters and taking appropriate action in the case of error or failure.	
IRD-AUT-R04	The SPIRE instrument shall provide a method of alerting the S/C DHSS of any failure requiring the instrument to be controlled by the DHSS (e.g. switched off). *Actions to be taken in the case of failure will b defined by the instrument and stored as procedures in the DHSS*	
IRD-AUT-R05	The instrument shall continuously monitor the integrity of the on-board software and take appropriate action in case of error. *The on-board software can itself calculate a checksum over the OBS code and compare this to a stored value.*	
IRD-AUT-R06	The instrument shall monitor the operational status of the instrument on-board computers and take appropriate action in case of error. *A watchdog function will be implemented to identify if the on-board computer(s) have crashed.*	

Table 2.8-1: Requirements for autonomous health and safety monitoring.

2.9 Reliability and Redundancy

It is assumed that reliability will be maintained by use of a combination of hardware redundancy and flexibility in the onboard software such that a failure of a single hardware device will not lead to a loss of instrument capability, although it may lead to loss of instrument performance.

Requirement ID	Description	Source
IRD-REL-R01	As far as possible the total failure of a single sub-system shall not lead to the total loss of instrument operations.	
IRD-REL-R02	Backup modes of operation should be available for all nominal observing modes. These shall be designed to allow the continued use of that mode, albeit with degraded performance or efficiency.	
IRD-REL-R03	Cold redundant hardware shall be provided wherever practicable within the instrument design.	
IRD-REL-R04	As far as possible all control loops shall be implemented through the use of on-board software.	
IRD-REL-R05	It shall be possible to break all control loops implemented in hardware. *This will allow the control of the loop through the on board software (this may be a degraded mode of operation)*	

Table 2.9-1: Instrument level reliability and redundancy requirements.

2.10 EMC

To be written
The EMC environment – and hence the requirements – will be the subject of a joint study between the instrument teams and ESA at some future date (30/11/99)

3. SUBSYSTEMS REQUIREMENTS

3.1 Assumptions

The SPIRE instrument will consist of the sub-systems indicated in figure 3.1-1 and table 3.1-1. Figure 3.1-1 also shows the interface relationship between the SPIRE sub-systems; harnesses etc.

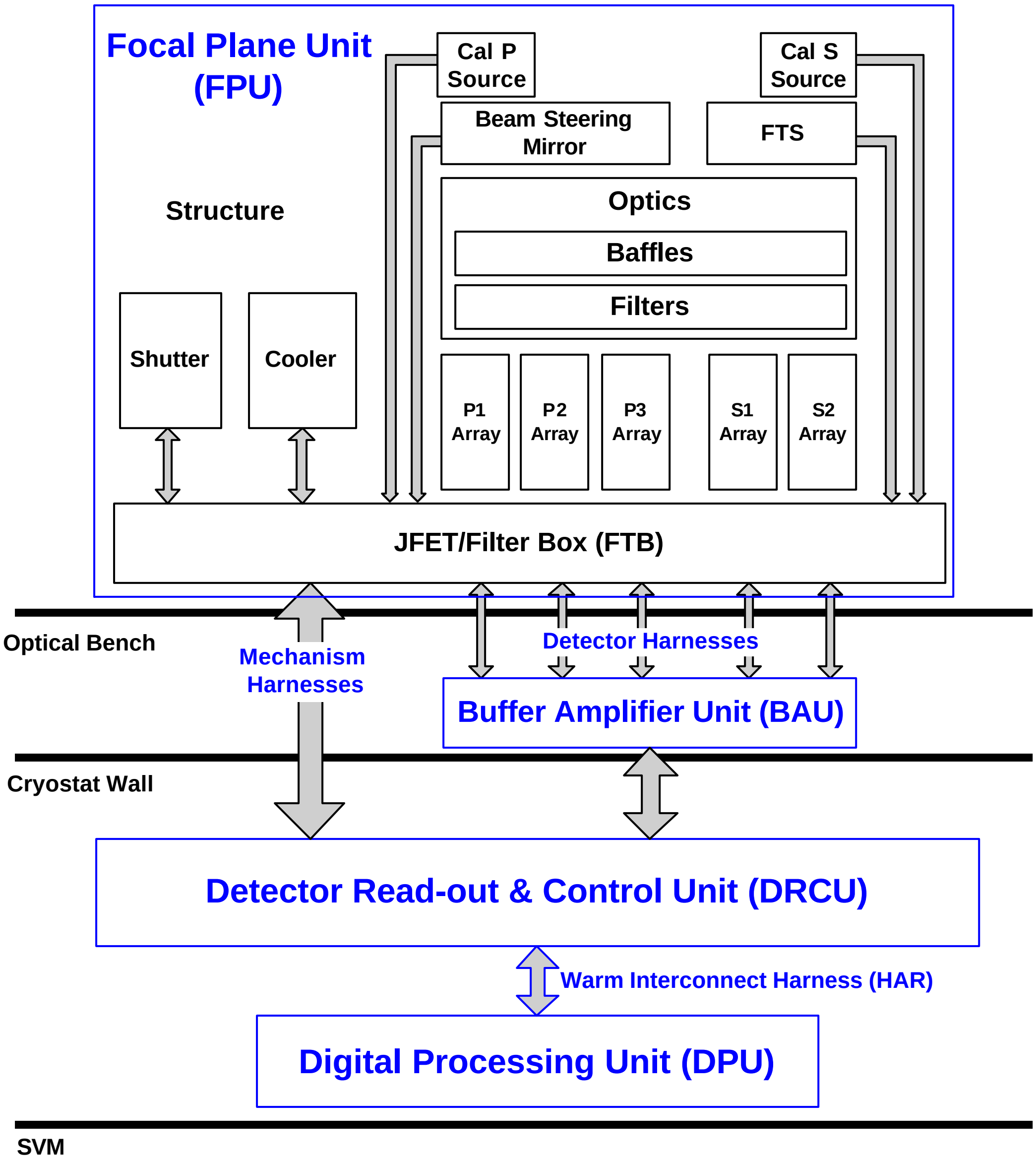

Figure 3.1-1: SPIRE sub-system block diagram

Subsystem Name	Description	Unit	Number
Structure	Focal plane unit structure to hold all cold sub-systems in the focal unit.	FSFPU	1.1
Thermometry	Thermistors to monitor instrument temperature	FSFPU	1.1.1
Optics	All mirrors for the photometer and spectrometer channels	FSFPU	1.2
Filters	All filters; beam splitters and dichroics for the photometer and spectrometer channels The requirements on these are included with those for the optics.	FSFPU	1.2.1
Baffles	Straylight control baffles for the photometer and spectrometer channels	FSFPU	1.2.2
Cooler	^{3}He cooler unit cools the photometer and spectrometer detector arrays to 300 mK	FSFPU	1.3
Photometer Bol Arrays	Bolometer array modules for the photometer	FSFPU	1.4.1
Spectrometer Bol Arrays	Bolometer array modules for the spectrometer	FSFPU	1.4.2
Beam Steering Mechanism	This mechanism allows the photometer and spectrometer fields of view to be stepped or chopped across the sky.	FSFPU	1.5.1
FTS Mechanism	The FTS moving mirrors drive mechanism and position measurement system	FSFPU	1.5.2
Shutter Mechanism	A shutter is required in the instrument for ground test to allow the detectors to see the correct radiation environment.	FSFPU	1.5.3
Photometer Calibration Source	Calibration source for photometer	FSFPU	1.6.1
Spectrometer Calibration Source	Calibration source for the spectrometer	FSFPU	1.6.2
JFET/Filter Box	JFET pre-amplifiers for JPL/Caltech detector option. This box will also contain the RF filters required for all detector options. All wiring for the focal plane sub-systems will be routed through this box.	FSFPU	1.7
Buffer Amplifier Unit	Booster amplifier on outside of CVV – required for the CEA and JPL/Caltech detector options.	FSBAU	2.1
Detector Read-out & Control	Detector amplifier and digitisation chain and instrument control electronics.	FSDRC	2.2
Digital Processing Unit	Instrument on board computer – forms interface to DHSS	FSDPU	2.3
Warm Interconnect Harness	Harness between warm boxes	FSHAR	2.4
On Board Software	ALL on board software – whether in DRCU or DPU	FSOBS	2.5

Table 3.1-1: Listing of SPIRE sub-systems.
The unit column refers to the ESA designation for the unit in which the sub-system is located. The sub-system number is that allocated for the purposes of interface control.

3.2 Scope

This chapter details the requirements on the cold focal plane unit sub-systems, the JFET/Filter box and the Buffer Amplifier Unit. The detailed requirements on the warm electronics will be dealt with in the *SPIRE WE Requirements* document (SPIRE-SAp-xxxx-99).

3.3 Subsystem Qualification Requirements

Assumptions

It is assumed that all sub-systems will have been through a type approval programme of one or more models before the Cryogenic Qualification version of the sub-system is delivered for the instrument AIV. This implies:

1. The testing carried out on the CQM instrument should NOT be considered to be the qualification test for each individual sub-system. The tests carried out on the instrument CQM will be neither exhaustive nor at the correct level for sub-system qualification.
2. It is intended that the tests listed here be carried out on a specific type approval model or models. It is expected that acceptance tests will be done on each delivered model (CQM, Flight and Flight Spare) as part of the general instrument AIV – these will be detailed in the instrument AIV plan. The type approval test programme does not replace the need for acceptance testing of each model.

Test Matrix:

	Structure	Optics	FTS Mechanism	Chopper	Detector arrays	Cooler	Filters/grids/dichroics	Calibration Sources	DCRU	SPU	DPU
Vibration:	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Thermal cycle:	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**			
Vacuum cycle			**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Lifetime:		**P**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Soak/cycle:			**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**
Radiation tolerance:			**P**	**P**	**X**	**P**	**X**	**X**	**X**	**X**	**X**
Thermal range:			**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Thermal stability:		**P**	**X**	**X**	**X**	**X**	**P**	**X**	**X**	**X**	**X**
Microphonics:		**P**	**X**	**X**	**X**	**X**	**P**	**P**			
Ionising radiation:					**X**						
EMI:			**X**	**X**	**X**	**P**		**P**	**X**	**X**	**X**
EMC:			**X**	**X**	**X**	**P**		**P**	**X**	**X**	**X**

Table 3.3-1: Test matrix for the SPIRE sub-systems qualification programme.

Tests marked with an X are mandatory, those marked with a P are possibly required depending on the detailed design of the sub-system and/or the new of novel materials. The requirement to carry out the test programme indicated here has a requirement ID of IRD-SUBS-01.

For some sub-systems the qualification and lifetime testing will be more appropriately carried out at component or test item level rather than at the level of the integrated sub-system. At what stage and under what conditions the tests are to be carried out is a matter for detailed consideration by the groups responsible for the sub-systems delivery.

3.4 Focal Plane Unit

3.4.1 Assumptions

3.4.1.1 Plate Scale

The nominal optical design of the SPIRE optics for both the photometer and spectrometer has a final focal ratio onto the detectors of f/5. This implies, given the design of the FIRST telescope (see section 2.1.4.4), that the nominal plate scale at the SPIRE focal plane is 12.564 arcsec/mm. This value will be used throughout this section to determine the required size of the focal plane arrays.

3.4.1.2 Vacuum

The cold focal plane unit will be launched and operated in a vacuum of TBD mBar.

3.4.2 Structure and Covers

Conceptual Design

The SPIRE structure will consist of three enclosures, each at a different temperature. The structure is mounted off a "Base" which forms the primary mechanical interface to the FIRST optical bench. The present concept is that all SPIRE components mount from the Base which is held at the highest temperature available from the cryostat – nominally 11 K. This may change in the light of further design developments – especially in the light of the cryostat interface study currently underway at DASA (30/11/99).

The outer enclosure, the "Outer Cover", will be of lightweight construction and serves the function of RF and straylight shielding; no major components are mounted from the cover. The Outer Cover mounts directly onto the base and will be held at the same temperature as the base – nominally 11 K.

The major element of the SPIRE structure is the common optical bench and enclosure – hereafter called the "4-K Common Structure". This will be mounted on thermally isolating struts from the base. As currently envisaged almost all of the photometer and spectrometer optical and mechanical components and the ^{3}He cooler will mount from the 4-K Common Structure. This will have integral covers that form part of the structure.

The photometer and spectrometer will also have separate "2-K Enclosures" that form the final enclosure around the detectors for the purpose of controlling the straylight and providing the correct thermal environment. These will mount from the 4-K Common Structure either directly or through the detector mounts. They will be thermally isolated from the 4-K Common Structure. In the case of the photometer there will be optical components and possibly the detectors mounted from the 2-K Enclosure; for the spectrometer it will form a lightweight cover only.

The details of the components to be mounted at each temperature are the subject of the detailed specification of each sub-system.

Interfaces to other sub-systems and the FIRST satellite

The common structure is subsystem number **1.1** and has interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Structure/Therm	1.1.1	Thermometry	MSSL
Structure/Optics	1.2	Optics	LAS
Structure/Filters	1.2.1	Filters	QMW
Structure/Baffles	1.2.2	Baffles	Unalloc
Structure/Cooler	1.3	Cooler	CEA-Grenoble
Structure/Spec Array	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL
Structure/Chopper	1.5.1	Chopper Mechanism	ATC
Structure/FTS Mech	1.5.2	FTS Mechanism	LAS
Structure/Shutter	1.5.3	Shutter Mechanism	Unalloc
Structure/Phot Cal	1.6.1	Phot Calibration Source	GSFC
Structure/Spec Cal	1.6.2	Spec Calibration Source	GSFC

Structure/JFET Mod	1.7	JFET Module (Option)	JPL/Caltech
Structure/AIV Fac	4.2	AIV Facility	RAL
Structure/Cal Fac	4.3	Cal Facility	RAL
Structure/Thermal Vac	4.4	Thermal Vac Facility	RAL
Structure/Cold Vib Fac	4.5	Cold Vibration Facility	Unalloc
Structure/OGSE	5.2	EGSE	LAS
Structure/MGSE	5.3	MGSE	MSSL
IID/Structure	IID-B	IID-B	ATC

Notes:

Note ID	Interface name and type	Note
IIDB/1.1-N1	IID/Structure Mechanical/thermal interface	The structure will attach directly to the FIRST optical bench. In the IID-A referenced here (AD1) it is stated that the instruments should be "thermally isolated" from the optical bench and the temperature of the interface structure is determined by a thermal link to the cryostat vent pipe. We have argued that the optical bench should be directly cooled by the vent pipe and that we should be in direct thermal contact with it. There is also an implicit interface with the two other instruments on FIRST: HIFI and PACS, in that the space taken by these instruments will restrict the volume envelope of SPIRE.

Table 3.4-1: Common structure interfaces with other sub-systems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-STRC-R01	Items requiring support from the Base	JFET/RF filter box 4-K Common Structure Outer Cover	
IRD-STRC-R02	Surface finish of the Base	The inside and outside of the Base shall have a finish with a low emissivity. At least ε=0.2.	
IRD-STRC-R03	Alignment of the instrument w.r.t. the FIRST optical axis	The SPIRE common structure shall allow the alignment of the instrument and telescope optical axes to within +-2.5 (TBC) mm lateral and +- TBD arcmin rotational about any axis.	
IRD-STRC-R04	Items requiring support from the Outer Cover	Instrument input filter	
IRD-STRC-R05	Surface finish of the Outer Cover	The inside and outside of the Outer Cover shall have a finish with a low	

Requirement ID	Description	Value	Source
		emissivity. At least ε=0.2.	
IRD-STRC-R06	Pumping port	The total effective pumping conductance of the Base and Outer Cover assembly must be greater than or equal to 15.6 l/s (TBC)	
IRD-STRC-R07	Attenuation of radiation from cryostat environment	Requirement $<7\times10^{-5}$ (TBC) To illustrate this, the requirement is the equivalent of a ~12 mm diameter hole in a total area of the Base and Outer Cover assembly of 1.5 m^2 (TBC)	
IRD-STRC-R08	Attenuation of RF by outer cover	The outer cover as fitted on the instrument will attenuate all frequencies lower than TBD MHz by TBD dB.	
IRD-STRC-R09	Items requiring support from the 4-K Common Structure	**Photometer and common sub-systems** Photometer 4-K optics Photometer filters 4-K Thermal Strap ^{3}He Cooler 4-K Baffles All sub-system harnesses BSM Mechanism and structure Shutter mechanism and mount Photometer 2-K enclosure **Spectrometer** All spectrometer optics Beam splitters Mechanism structure Mechanism motor Calibration source and mount Spectrometer 2-K enclosure	
IRD-STRC-R10	Optics and associated sub-system alignment	The common structure shall be capable of maintaining the alignment of the photometer and spectrometer optics and associated components (i.e. filters; 2-K enclosures; BSM etc) to within the specifications given in RD7 both at room temperature and during cryogenic operation.	
IRD-STRC-R11	Surface finish of the 4-K Common Structure cover	The inside and outside of the box shall have a finish with a low emissivity. At least ε=0.2. Some parts of the structure walls may be blackened as part of the straylight control.	

Requirement ID	Description	Value	Source
IRD-STRC-R12	Pumping port	The total effective pumping conductance of the 4-K enclosure must be greater than or equal to 7.8 l/s (TBC)	
IRD-STRC-R13	Thermometry	The structure subsystem shall provide thermistors and associated wiring to allow the temperature of critical parts (TBD) to be monitored during in-flight operations.	
IRD-STRC-R14	Attenuation of radiation from 11-K environment	Requirement <2x10^{-5} (TBC) To illustrate this, the requirement is the equivalent of a ~4 mm diameter hole in a total area of the box cover of 1 m^2 (TBC)	

Table 3.4-2: Performance requirements for the instrument common structural elements.

System Requirements

Requirement ID	Description	Value	Source
IRD-STRC-R15	First natural frequency of the instrument assembly	The first eigenfrequency of the integrated instrument assembly shall be greater than 100 Hz (TBC) with a goal of greater than 120 Hz	
IRD-STRC-R16	Mass of Base	The mass of the Base shall be no more than M kg	
IRD-STRC-R17	Thermal isolation of Base	The Base will be in direct thermal contact with the FIRST optical bench (TBC)	
IRD-STRC-R18	First natural frequency of Outer Cover	The first eigenfrequency of the Outer Cover as mounted on the Base shall be greater than 100 Hz (TBC) with a goal of 120 Hz	
IRD-STRC-R19	Mass of the Outer Cover	The mass of the Outer Cover shall be no more than M kg	
IRD-STRC-R20	First natural frequency of 4-K Common Structure	The first eigenfrequency of the 4-K Common Structure on its mounts shall be greater than 100 Hz (TBC) with a gaol of 120 Hz	
IRD-STRC-R21	Mass of 4-K Common Structure	The mass of the 4-K structure shall be no more than M kg	
IRD-STRC-R22	Grounding	All parts of the SPIRE structure shall be electrically connected one to another. Resistance to be no more than TBD	

Requirement ID	**Description**	**Value**	**Source**
		Ω between any two parts of the structure	
IRD-STRC-R23	Electrical isolation from FIRST	All parts of the SPIRE structure shall be electrically isolated from the FIRST optical bench and cryostat. Resistance to be greater than TBD Ω.	
IRD-STRC-R24	Thermal isolation	The conductance from the level 2 to level 1 stage is required to be no more than 2 mW (TBC) with a goal of 1 mW (TBC)	

Table 3.4-3: System requirements on the instrument common structural elements

3.4.3 ^{3}He Cooler and detector temperature control

Conceptual Design

The SPIRE bolometer detectors will operate at 300 mK, whichever type is implemented. This temperature is not provided by the FIRST cryostat so a separate cooler will be placed in the SPIRE instrument. The design for the cooler is a ^{3}He sorption cooler with the sorption pump strapped to the FIRST LHe tank and the evaporator strapped to the detector arrays. The nominal configuration assumes there will be active temperature control of the detectors, either through heaters on the detectors themselves or using the temperature of the sorption pump to control the evaporator temperature.

Interfaces to other sub-systems and FIRST satellite

The cooler sub-system number is **1.3** it has interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
IID/Cooler	IID-B	IID-B	ATC
Structure/Cooler	1.1	Structure	MSSL
Cooler/Phot Array	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Cooler/Spec Array	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL
Cooler/DRCU	2.2	Detector Read-out & Control Unit	CEA-SAp
Cooler/OBS	2.6	On Board Software	CEA-SAp
Cooler/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Cooler/Instrument Sim	3.3	Instrument Simulator	Stockholm
Cooler/AIV Fac	4.2	AIV Facility	RAL

Notes:

Note ID	Interface name and type	Note
1.1/1.3-N1	Structure/Cooler Mechanical interface	Preferred interface is with the instrument 4-K structure
IIDB/1.3-N2	IID/Cooler Thermal interface	Pumped liquid helium tank for both sorption pump and evaporator

Table 3.4-4: Cooler interfaces with other sub-systems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-COOL-R01	Temperature at the detectors	Nominal 300 mK	
IRD-COOL-R02	Operating temperature control	Desirable to be able to vary the temperature of the detectors up to 320 mK and below 300 mK *if this is permitted by the temperature drop across the thermal link.* The evaporator cold tip temperature can be	

Requirement ID	Description	Value	Source
		varied by heating the sorption cooler. Electronic control shall be provided to do this in the flight electronics.	
IRD-COOL-R03	Temperature drop across thermal link between detectors and evaporator cold tip	Maximum of 25 mK	
IRD-COOL-R04	Temperature drift	The temperature of the evaporator cold tip should not drift by more than 10 mK/h	
IRD-COOL-R05	Temperature fluctuations at the evaporator cold tip	No more than 150 nK $Hz^{-1/2}$ in a frequency band from 0.1-100 Hz.	
IRD-COOL-R06	System low frequency temperature stability with active temperature control	TBD nK at 0.015 Hz at a maximum power dissipation of TBD µW	
IRD-COOL-R07	Heat lift at detectors	Minimum of 10 µW at 300 mK	
IRD-COOL-R08	Hold time	Minimum 46 hours	
IRD-COOL-R09	Recycle time	Maximum 2 hours	

Table 3.4-5: Performance requirements on the sorption cooler.

System Requirements

Requirement ID	Description	Value	Source
IRD-COOL-R10	Mechanical interface to instrument	Preferred interface is with the instrument 4-K structure	ICD 1.1/1.3
IRD-COOL-R11	Thermal Interface with FIRST cryostat	Pumped liquid helium tank at 1.8 K for both sorption pump and evaporator	ICD IIDB/1.3
IRD-COOL-R12	Thermal load onto He bath during cold operation	Maximum 1 mW 0.1 mW is allowed for the conduction from 4 K to 2 K through the support structure.	
IRD-COOL-R13	Time averaged thermal load onto He bath for 48 hour cycle	Maximum 3 mW (includes 20% margin)	
IRD-COOL-R14	Mass – including support structure	0.6 kg (includes 20%) margin (this will be revisited if more mass is required to	

Requirement ID	Description	Value	Source
		mount the cooler from 4-K)	
IRD-COOL-R15	Maximum envelope	200x100x100 mm	
IRD-COOL-R16	Preferred orientation	Horizontal with long axis along S/C Y-axis and evaporator at –Y end (see Fig. TBD)	
IRD-COOL-R17	Sorption pump heater	The baseline design has a heater resistance of 400 Ω implying a current of up to 20 mA for recycling. It is desirable that this heater resistance is increased so that the allowable resistance of the cryo-harness wiring can, in turn, be increased. The maximum resistance of the heater that can be driven by 28 V is about 5 kΩ.	
IRD-COOL-R18	Thermometers	Thermometers shall be provided on the cooler as set out in the table below. The absolute temperature measurement on the evaporator cold tip shall be 0.5% (<1.5 mK) with a resolution of TBD mK. Thermometers of the same specification shall also be provided on each detector array (*q.v.*).	
IRD-COOL-R19	Gas gap heat switches	It is noted that these are a potential single point failure in the instrument operation. Provision of some redundancy (i.e. doubling them up) is desirable *but not at the expense of severe limitations on the cooler performance.*	
IRD-COOL-R20	Ground Operation	The cooler must be capable of full operation on the ground, including recycling, when the instrument is in its normal orientation i.e. +Y horizontal and +X vertical and pointing skyward. Further it must be capable of operating with the instrument rotated to up to 90^{o} about the S/C Y-axis	
IRD-COOL-R21	Warm power dissipation	Less than TBD W during cold operation Less than TBD W during recycling	

Table 3.4-6: **Systems requirements on the sorption cooler**

3.4.4 Shutter

Conceptual Design

The radiant background during ground testing at spacecraft level may not replicate in-flight conditions (~ 4% of 80-K black body). This may make the testing of detector health and performance restricted or even impossible. A shutter would allow a controlled background to be applied and would be useful for ground testing generally, not just in the FIRST cryostat

It is assumed that the shutter will consist of an actuator mechanism with a vane attached that will cover, at least, the beam through the photometer. The vane will be coated with highly absorbing material and be capable of being heated to give a variable background flux onto the photometer detectors. The baseline assumption is that the shutter will only be used for ground test although provision may be made for flight electronics if this is deemed necessary.

All specifications and requirements on the shutter are under review. (30/11/99)

Interfaces to other sub-systems and the FIRST satellite

The shutter sub-system number is **1.5.3** it has interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Shutter/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Shutter/OBS	2.6	On Board Software	CEA-SAp
Shutter/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Shutter/Instrument Sim	3.3	Instrument Simulator	Stockholm
IID/Shutter	IID-B	IID-B	ATC
Structure/Shutter	1.1	Structure	MSSL
Therm/Shutter	1.1.1	Thermometry	MSSL
Optics/Shutter	1.2	Optics	LAS
Baffles/Shutter	1.2.2	Baffles	Unalloc

Table 3.4-7: Table 4.2.3.1: Shutter mechanism interfaces with other sub-systems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-SHUT-R01	Beam blanking	When the shutter vane is in place the throughput of the photometer optics shall be no more than N of the nominal throughput. Goal is to provide the same for the spectrometer	
IRD-SHUT-R02	Vane temperature	The temperature of the shutter vane shall be variable between 5 and 20 K	

Table 3.4-8: Performance requirements on the shutter

System Requirements

Requirement ID	Description	Value	Source
IRD-SHUT-R03	Failure mode	The shutter mechanism must fail with the vane out of the beam	
IRD-SHUT-R04	Operating temperature	Maximum 300 K Minimum 4 K	
IRD-SHUT-R05	Thermal dissipation of actuator in operation	< 1 mW	
IRD-SHUT-R06	Electrical resistance of heater	Of order 10 kΩ	
IRD-SHUT-R07	Max. thermal dissipation of heater < 5 mW	<5 mW	
IRD-SHUT-R08	Nominal envelope for actuator	45x45x45 mm	
IRD-SHUT-R09	Nominal mass	<200g	

Table 3.4-9: System requirements on the shutter

3.4.5 Harness

Conceptual Design

The electrical harness for each subsystem will be provided as an integral part of that subsystem. This will either be as a flying lead with a connector on the end or as a connector at the subsystem end and separate connector to connector cable. The control of electromagnetic interference within the SPIRE instrument is of paramount importance. To this end it is envisaged that the outer cover of the SPIRE instrument will form a Faraday cage sealed on to an RF filter box through which all the electrical connections will be routed.

Interfaces to other sub-systems and the FIRST satellite

The SPIRE FPU harness does not have a sub-system number as the present concept is that each sub-system within the FPU provides its own harness. However the interface between these harnesses and the rest of the FPU (structure; RF filter box etc) does need to be explicitly dealt with under each sub-system.

Performance Requirements

All harness requirements are under review and TBW (30/1199)

Requirement ID	Description	Value	Source
IRD-FPHR-R			

Table 3.4-10:

System Requirements

Requirement ID	Description	Value	Source
IRD-FPHR-R02	Generic implementation	All sub-system electrical connections shall be via a flying lead from the sub-system housing to the JFET/Filter Box. A connector shall provided at the end of the harness to interface to the JFET/Filter Box.	

Table 3.4-11: Requirements for the internal SPIRE harnesses.

3.4.6 Photometer

3.4.6.1 Photometer Optics and Filters

Conceptual Design

It is assumed that the photometer optical design is based on an all reflective optical train with an aperture stop placed at the beam steering mirror; an intermediate field image from which the spectrometer field of view is picked off; another aperture stop that forms the instrument pupil and a final field image at the detectors. The detectors see different wavebands determined by the use of passband filters and dichroics.

Interfaces to other sub-systems and the FIRST satellite

The photometer optics are a sub-set of the optics subsystem which is sub-system number **1.2.** They have the following interfaces to other sub-systems:

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Optics/Filters	1.2.1	Filters	QMW
Optics/Phot Array	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Optics/Chopper	1.5.1	Chopper Mechanism	ATC
Optics/Shutter	1.5.3	Shutter Mechanism	Unalloc
Optics/Phot Cal	1.6.1	Phot Calibration Source	GSFC
Optics/Cal Fac	4.3	Cal Facility	RAL
Optics/OGSE	5.2	OGSE	LAS
IID/Optics	IID-B	IID-B	ATC
Structure/Optics	1.1	Structure	MSSL

Table 3.4-12: Photometer optics interfaces to other sub-systems

Performance Requirements

Requirement ID	Description	Value	Source
IRD-OPTP-R00	Compatibility with FIRST telescope	The optical design of the photometer fore-optics shall be compatible with the FIRST telescope optical design.	
IRD-OPTP-R01	Nominal final focal ratio	As close to F/5 as practical	
IRD-OPTP-R02	Variation in focal ratio	The focal ratio at any point in the must be within 20% (TBC) of that of the on-axis point.	
IRD-OPTP-R03	Distortion	The image of the telescope field of view is nominally rectangular. The position of any point within the image of the FOV at the detectors must be within 10% (TBC) of the actual position of the point at the telescope focal plane.	

Requirement ID	Description	Value	Source
IRD-OPTP-R04	Anamorphism	The anamorphic ratio of the image of a point source at the detectors must be no more than 6:5 (TBC) in any pair of orthogonal directions at any point in the FOV.	
IRD-OPTP-R05	Throughput	The throughput of the photometer mirrors, filters, dichroics and baffles shall be greater than 0.27 (TBC) over the instrument waveband. This includes losses due to manufacturing defects; surface finish and alignment tolerances.	
IRD-OPTP-R06	Image quality	The photometer optics shall give a Strehl ratio of greater than 0.9 (TBC) over the 4x8 arcmin FOV at 250 µm including all losses due to alignment; mirror quality etc	
IRD-OPTP-R07	Out of band radiation	The end to end filtering of the photometer shall control the out of band radiation to be no more than TBD of the in-band telescope background radiation.	
IRD-OPTP-R08	In-band straylight	The background power falling on the detectors with the optical beam blocked shall be no more than L of the in-band background power from the telescope over the 200-300 µm band; M over the 300-400 µm band and N over the 400-670 µm band.	

Table 3.4-13: Performance requirements on the photometer optics.

System Requirements

Requirement ID	Description	Value	Source
IRD-OPTP-R11	Mass	The mass of all photometer mirrors shall be no more than 2 kg	

Table 3.4-14: System requirements on the photometer optics.

3.4.6.2 Photometer Structure

Conceptual Design

The majority of the photometer optics will mount from the common 4-K structure. Only the final re-imaging mirror; the dichroics; the fold mirrors and the detectors themselves will mount at 2-K. The present concept is to have a separate box strapped directly to the LHe tank that will hold these items and provide a straylight shield around the detectors.

Interfaces to other sub-systems and the FIRST satellite

The photometer 4-K structure is a sub-set of the common structure sub-system (**1.1**) and shares the same interfaces. See section 4.2.1. The photometer 2-K structure is nominally independent of the spectrometer 2-K structure and has the following interfaces with other sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Structure/Therm	1.1.1	Thermometry	MSSL
Structure/Optics	1.2	Optics	LAS
Structure/Filters	1.2.1	Filters	QMW
Structure/Baffles	1.2.2	Baffles	Unalloc
Structure/Phot Array	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL

Table 3.4-15: Photometer 2-K structure interfaces with other subsystems

Performance Requirements

Requirement ID	**Description**	**Value**	**Source**
IRD-STRP-R01	Items requiring support	The photometer 2-K structure shall support: Photometer 2-K optics; dichroics and filters Detector array modules Detector thermal straps TBD	
IRD-STRP-R02	Optics and filters alignment	The 2-K photometer structure shall be capable of maintaining the alignment of the photometer 2-K optics; filters and dichroics to within the requirements set out in RD7 at room temperature and during cryogenic operation.	
IRD-STRP-R03	Array module alignment	The 2-K photometer structure shall be capable of maintaining the position of the detector array modules to within +-TBD mm lateral and TBD arcmin rotational about any axis during cryogenic operation of the instrument.	
IRD-STRP-R04	Surface finish	The outside of the box shall have a finish with a low emissivity. At least ε=0.2 The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	

Requirement ID	Description	Value	Source
IRD-STRP-R05	Pumping port	The total effective pumping conductance of the 2-K box must be greater than or equal to 5.6 l/s (TBC)	
IRD-STRP-R06	Attenuation of radiation from 4-K environment	Requirement $5x10^{-7}$; goal is $5x10^{-8}$ (TBC) To illustrate this, the requirement is the equivalent of a 0.5 mm diameter hole in a total area of the box cover of 0.5 m^2	

Table 3.4-16: Performance requirements on the photometer 2-K structure.

System Requirements

Requirement ID	Description	Value	Source
IRD-STRP-R07	First natural frequency	The first eigenfrequency of the photometer 2-K structure on its mounts shall be greater than 100 Hz (TBC) with a gaol of > 150 Hz	
IRD-STRP-R08	Mass	The mass of the 2-K structure shall be no more than M kg	
IRD-STRP-R09	Thermal isolation	The conductance of from the 4-K to 2-K stage shall be no more than 0.75 mW (TBC)	

Table 3.4-17: System requirements on the photometer 2-K structure

3.4.6.3 Photometer Detectors

Conceptual Design

With the assumption for the FIRST telescope design (section 2.1.4.4) and the final focal ratio of the photometer and spectrometer optics (section3.4.1.1), the size of the SPIRE Photometer focal plane is 19.10x19.10 mm for 4x4 arcmin field of view and 19.10x38.20 mm for 4x8 arcmin.

The background power falling on the photometer detectors from the telescope is assumed to be:

2Fλ : (250, 350, 500): (7.4, 5.3, 4.8) pW
0.5Fλ: (250, 350, 500): (1.9, 1.3, 1.2) pW

Interfaces to other sub-systems and the FIRST satellite

The photometer bolometer arrays are sub-system number **1.4.1** and interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Phot Array/Chopper	1.5.1	Chopper Mechanism	ATC
Phot Array/FTS Mech	1.5.2	FTS Mechanism	LAS
Phot Array/JFET Mod	1.7	JFET Module (Option)	JPL/Caltech
Phot Array/BAU	2.1	Buffer Amplifier Unit	CEA-SAp
Phot Array/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Phot Array/OBS	2.6	On Board Software	CEA-SAp
Phot Array/Analogue	3.1	Analogue Inst. Simulator	Stockholm
Phot Array/Instrument	3.3	Instrument Simulator	Stockholm
Filters/Phot Array	1.2.1	Filters	QMW
Baffles/Phot Array	1.2.2	Baffles	Unalloc
Cooler/Phot Array	1.3	Cooler	CEA-Grenoble
IID/Phot Array	IID-B	IID-B	ATC
Structure/Phot Array	1.1	Structure	MSSL
Therm/Phot Array	1.1.1	Thermometry	MSSL
Optics/Phot Array	1.2	Optics	LAS

Table 3.4-18: Photometer bolometer array interfaces with other sub-systems.

Performance Requirements

Note: These will be described and specified in more detail in the Detector Array Selection Criteria and our formal issue of the detector sensitivity model. (30/11/99)

Requirement ID	Description	Value	Source
IRD-DETP-R01	Detective Quantum Efficiency at 5 Hz at nominal incident power levels	> 0.6 (2Fλ feedhorn arrays) > 0.6/α (0.5Fλ:filled arrays) α = 3 (TBC)	
IRD-DETP-R02	Time constant	8 ms or faster	

Requirement ID	Description	Value	Source
IRD-DETP-R03	Uniformity	NEP spec. shall be met over the whole array Responsivity variations shall be lass than TBD% across the array and calibrated to an accuracy of TBD%	
IRD-DETP-R04	Yield (good pixels)	≥90% for each array	
IRD-DETP-R05	Electrical crosstalk	TBD	
IRD-DETP-R06	Detector angular response	2Fλ Feedhorns : TBC 0.5Fλ filled arrays : TBC	
IRD-DETP-R07	Spectral response	≥ 90% at the nominal edge frequencies of the appropriate passband	

Table 3.4-19: Performance requirements on the photometer detectors.

System Requirements

Requirement ID	Description	Value	Refers to:
IRD-DETP-R08	Microphonic susceptibility	TBD	
IRD-DETP-R09	EMI susceptibility	TBD	
IRD-DETP-R10	Sensitivity to ionising radiation	TBD	
IRD-DETP-R11	Mass of detector module	Each detector module – including its structural support – shall be no more than 500 g (TBC).	
IRD-DETP-R12	Volume envelope	The detector modules shall fit within a cylinder of diameter 75 mm (goal 60 mm) and length 100 mm.	
IRD-DETP-R13	300 mK thermal load	The thermal dissipation and parasitic load at 300 mK shall be no more than TBD µW for all three arrays	
IRD-DETP-R14	Mechanical interface	The detector modules shall mechanically interface to either the 4-K or 2-K stage. Note: If the interface is at 4-K then the conducted thermal load from 4-K to 2-K shall be less than 0.2 mW per module (TBC).	

Table 3.4-20: System requirements on the photometer detectors.

3.4.6.4 Beam Steering Mechanism

Conceptual Design

The BSM is used to steer the optical beam of the SPIRE photometer channel over the detector arrays.

The BSM comprises a flat mirror which is mounted on a two axis pivot system. This pivot system allows precise angular motion of the mirror over a small range of angular travel in two orthogonal axes. Electrical actuators are used to provide motion of the mirror. Electrical transducers are used to measure the mirror position to allow control of the mirror position.

The BSM also provides an aperture through which the Photometer Calibration Source is directed towards the detector arrays. The Photometer Calibration Source is mounted behind the BSM.

Interfaces to other sub-systems and the FIRST satellite

The beam steering mirror – also called the chopper mechanism – is subsystem number **1.5.1** and interfaces to the following subsystems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Chopper/Phot Cal	1.6.1	Phot Calibration Source	GSFC
Chopper/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Chopper/OBS	2.6	On Board Software	CEA-SAp
Chopper/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Chopper/Instrument Sim	3.3	Instrument Simulator	Stockholm
Phot Array/Chopper	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Spec Array/Chopper	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL
IID/Chopper	IID-B	IID-B	ATC
Structure/Chopper	1.1	Structure	MSSL
Therm/Chopper	1.1.1	Thermometry	MSSL
Optics/Chopper	1.2	Optics	LAS
Baffles/Chopper	1.2.2	Baffles	Unalloc

Table 3.4-21: Beam steering mirror interfaces with other sub-systems.

Performance Requirements

Requirement ID	**Description**	**Value**	**Source**
IRD-BSMP-R01	Maximum throw in chop axis	The BSM shall move the imaged field of view of the detectors by a maximum of ± 2 arcmin on the sky in the ± Y axis of the satellite	
IRD-BSMP-R02	Maximum throw in jiggle axis	The BSM shall move the imaged field of view of the detectors by a maximum of ±30 arcsec (TBC) in the ± Z axis of the satellite	

Requirement ID	Description	Value	Source
IRD-BSMP-R03	Minimum step in both axis	The minimum step size in either chop or jiggle axes shall be equivalent to a movement of ¼ of the smallest pixel in the short wavelength array in the photometer. For the filled arrays this will be ~1.7 arcsec. For the feedhorn arrays this will be ~7 arcsec.	
IRD-BSMP-R04	Frequency of chop	The chop frequency in either axis shall be continuously variable or selectable in TBD steps from 0 to 5 Hz. Note: This implies that the mirror shall be capable of selecting a given position on the sky and holding over a long time period; shall be capable of continuous or pseudo continuous scanning and chopping a given frequency from TBD to 5 Hz.	
IRD-BSMP-R05	Stability	The field of view must not vary by more than TBD (very small) arcsec over N seconds at any given mirror position. The mirror shall also have a stability equivalent to TBD arcsec Hz$^{-1/2}$	
IRD-BSMP-R06	Position Measurement	The knowledge of the mirror position shall be equivalent to a stability of TBD (very small) arcsec Hz$^{-1/2}$ The absolute knowledge of the mirror position shall be equivalent to less then TBD arcsec.	
IRD-BSMP-R07	Duty Cycle	The loss in observing time due to the BSM settling to a given position shall be less than 5% (TBC)	

Table 3.4-22: Performance requirements on the beam steering mirror.

System Requirements

Requirement ID	Description	Value	Source
IRD-BSMP-R08	Mass	Less then 600 g required –500 g goal.	
IRD09-BSMP-R10	Volume envelope	The BSM shall fit within a volume of NxMxL mm	
IRD-BSMP-	Operating	4 K	

Requirement ID	**Description**	**Value**	**Source**
R11	temperature		
IRD-BSMP-R12	Thermal isolation	The beam steering mirror temperature shall rise by no more than TBD K from the nominal temperature of the surrounding temperature after one hour operation in any mode.	
IRD-BSMP-R13	Cold power dissipation	The power dissipation at 4 K shall be no more than 4 mW (TBC) in any operating mode.	
IRD-BSMP-R14	Warm power dissipation	The power dissipation in the warm electronics shall be no more than TBD W in any operating mode.	

Table 3.4-23: System requirements on the beam steering mirror.

3.4.6.5 Photometer Calibration Source

Conceptual Design

The photometer calibration source will provide repeatable signal for monitoring of detector health and responsivity. It is not required to provide absolute calibration or flat fielding, although it might be used as part of the overall absolute calibration scheme in flight.

The calibration source aperture will be located at the centre of the BSM. The calibrator may be located behind the mirror. If necessary, a light pipe can connect the aperture in the centre of the mirror to an integrating cavity in which the thermal source is mounted. The beam steering mirror shall be switched off when the calibrator is operating. Some clearance will be needed to ensure the mirror does not foul on the light pipe when chopping.

Interfaces to other sub-systems and the FIRST satellite

The photometer calibration source is sub-system number **1.6.1** and interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Phot Cal/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Phot Cal/OBS	2.6	On Board Software	CEA-SAp
Phot Cal/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Phot Cal/Instrument Sim	3.3	Instrument Simulator	Stockholm
Chopper/Phot Cal	1.5.1	Chopper Mechanism	ATC
IID/Phot Cal	IID-B	IID-B	ATC
Structure/Phot Cal	1.1	Structure	MSSL
Therm/Phot Cal	1.1.1	Thermometry	MSSL
Optics/Phot Cal	1.2	Optics	LAS
Filters/Phot Cal	1.2.1	Filters	QMW
Baffles/Phot Cal	1.2.2	Baffles	Unalloc

Table 3.4-24: Photometer calibration source interfaces with other sub-systems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-CALP-R01	Nominal operating output	Equivalent to $\varepsilon T=40$ K for $200<\lambda<700$ μm	
IRD-CALP-R02	Operating range	4-80 K for $200<\lambda<700$ μm commandable in 256 (TBC) steps.	
IRD-CALP-R03	Equivalent obscuration of the entrance aperture	<0.2%	
IRD-CALP-R04	Speed of response	Requirement 150 ms Goal 30 ms	

Requirement ID	Description	Value	Source
IRD-CALP-R05	Repeatability	RMS better than 1% over 20 operations Drift less than10% over lifetime of the mission.	
IRD-CALP-R06	Operation	Nominally once per hour for no more than 10 seconds	
IRD-CALP-R07	Frequency	Continuously or pseudo continuously variable between 0 and 5 Hz.	

Table 3.4-25: Performance requirements for photometer calibration source

System Requirements

Requirement ID	Description	Value	Source
IRD-CALP-R08	Interface	The calibrator will be integrated into the beam steering mechanism.	
IRD-CALP-R09	Mass	Less than 20 g	
IRD-CALP-R10	Volume envelope	30 x 15 x 10 mm	
IRD-CALP-R11	Thermal isolation	The temperature of the surrounding structure (including the beam steering mirror) shall rise by no more than TBD K after 10 seconds when the calibrator is operated unmodulated at nominal power output.	
IRD-CALP-R12	Operating temperature	4-K	
IRD-CALP-R13	Cold power dissipation	Less than 2 mW when operated unmodulated at nominal power output.	
IRD-CALP-R14	Warm power dissipation	Less than TBD W when operated unmodulated at nominal power output	
IRD-CALP-R15	Operating voltage	Less than 28 V at input power level of 5 mW	
IRD-CALP-R16	Redundancy	Cold redundancy for the thermal source	

Table 3.4-26: Systems requirements for the photometer calibration source.

3.4.7 Spectrometer

The SPIRE photometer will be an imaging FTS employing intensity beam splitters in a Mach-Zehnder configuration. Figure 3.4-1 shows the conceptual layout for spectrometer optical path.

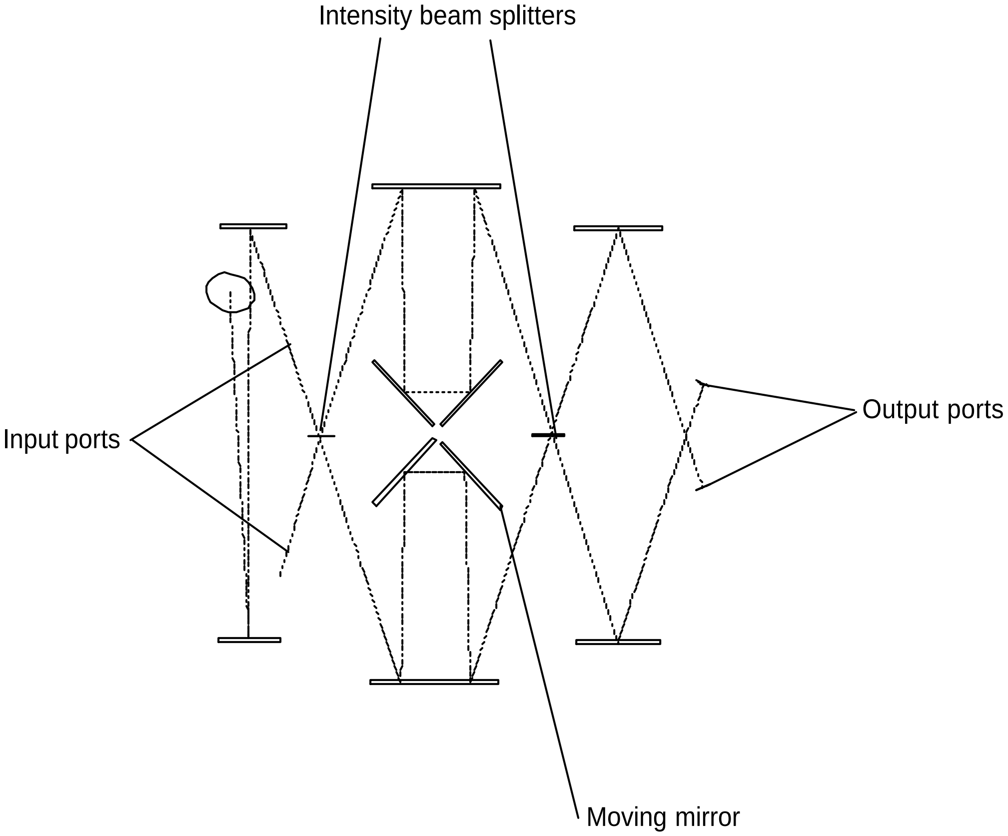

Figure 3.4-1: Basic optical layout for the SPIRE FTS

Although most of the requirements on the FTS can be assigned to one of its components – optics; mechanism etc - the requirement on the fringe contrast, which determines the achievable resolution of the instrument, must be placed on the instrument globally.

Requirement ID	Description	Value	Source
IRD-FTS-R01	Fringe Contrast	Greater than 80% for any point in the field of view for a resolution of 0.4 cm^{-1}.	

Table 3.4-27: Global requirements on the SPIRE FTS spectrometer

3.4.7.1 Spectrometer Optics and Filters

Conceptual design

It is assumed that the spectrometer optical design is based on an all reflective optical train that shares the its input optics with the photometer up to the intermediate field image where the beam for the spectrometer is picked off. That is M3; M4; and M5 are common to both the spectrometer and photometer. An aperture stop is placed just after the pick off mirror and another at the moving mirrors and another at the entrance to the 2-K enclosure that surrounds the detectors. The two detector arrays see different wavebands determined by the use of passband filters. The interferometer action is performed by the use of two broadband intensity beam splitters.

Interfaces with other subsystems and the FIRST satellite

The spectrometer optics are a subset of the optics sub-system. The spectrometer optics have the following specific interfaces with other sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Optics/Filters	1.2.1	Filters	QMW
Optics/Spec Array	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL
Optics/FTS Mech	1.5.2	FTS Mechanism	LAS
Optics/Cal Fac	4.3	Cal Facility	RAL
Optics/OGSE	5.2	OGSE	LAS
IID/Optics	IID-B	IID-B	ATC
Structure/Optics	1.1	Structure	MSSL

Table 3.4-28: Spectrometer optics interfaces to other subsystems.

Performance requirements

Requirement ID	Description	Value	Source
IRD-OPTS-R01	Nominal final focal ratio	As close to F/5 as practical	
IRD-OPTS-R02	Variation in focal ratio	The focal ratio at any point in the must be within 20% (TBC) of that of the on-axis point.	
IRD-OPTS-R03	Distortion	The position of any point within the image of the FOV at the detectors must be within 10% (TBC) of the actual position of the point at the telescope focal plane.	
IRD-OPTS-R04	Anamorphism	The anamorphic ratio of the image of a point source at the detectors must be no more than 6:5 (TBC) in any pair of orthogonal directions.	
IRD-OPTS-R05	Theoretical throughput	The theoretical throughput of the spectrometer mirrors; filters; beam splitters and baffles shall be greater than 0.2 (TBC) over the total instrument waveband (TBC)	

Requirement ID	Description	Value	Source
		including all losses due to manufacturing defects; surface finish and alignment tolerances.	
IRD-OPTS-R06	Image quality	The spectrometer optics shall give a Strehl ratio of greater than 0.9 (TBC) over the 2.6x2.6 arcmin FOV at 250 µm including all losses due to alignment; mirror quality etc	
IRD-OPTS-R07	Balancing of ports	In order that the two output ports shall have the same performance and to facilitate accurate compensation of the zero path difference maximum, the beam splitters shall have 4RT equal to R^2+T^2 to within 90% (TBC) over the waveband of the instrument.	
IRD-OPTS-R08	Out of band radiation	The end-to-end filtering of the spectrometer shall control the out of band radiation to be no more than N% of the in band telescope background radiation.	
IRD-OPTS-R09	In band straylight	The background power falling on the detectors with the optical beam blocked shall be no more than N% of the in band background power from the telescope over the 200-400 µm band and M% over the 400-670 µm band.	
IRD-OPTS-R10	Off axis resolution	The FWHM of the resolution element at any point in the FOV shall be no more than 10% greater than the on-axis value for a nominal resolution of 0.4 cm^{-1}.	

Table 3.4-29: Performance requirements for the spectrometer optics.

System Level Requirements

Requirement ID	Description	Value	Source
IRD-OPTS-R11	Mass	The mass of all spectrometer mirrors shall be no more than TBD kg	

Table 3.4-30: System requirements on the spectrometer optics.

3.4.7.2 Spectrometer Structure

Conceptual Design

In the baseline design all spectrometer components will mount from the common 4-K structure. Only the edge filter at the cold stops, and perhaps a fold mirror, will mount on the 2-K structure. The present concept is to have a separate lightweight box thermally strapped directly to the LHe tank that will be mounted from the 2-K part of the spectrometer detector array mounts.

Interfaces to other sub-systems and the FIRST satellite

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Structure/Therm	1.1.1	Thermometry	MSSL
Structure/Optics	1.2	Optics	LAS
Structure/Filters	1.2.1	Filters	QMW
Structure/Baffles	1.2.2	Baffles	Unalloc
Structure/Spec	1.4.1	Spectrometer Bol Arrays	CEA/GSFC/JPL

Table 3.4-31: Spectrometer 2-K structure interfaces with other subsystems

Performance Requirements

Requirement ID	**Description**	**Value**	**Source**
IRD-STRS-R01	Items requiring support	The spectrometer 2-K structure shall support: Cold Stop filters Fold mirror	
IRD-STRS-R02	Optics alignment requirements	The spectrometer 2-K structure shall be capable of maintaining the alignment of the spectrometer 2-K optical components to within the requirements set out in RD7	
IRD-STRS-R03	Surface finish	The outside of the box shall have a finish with a low emissivity. At least $\varepsilon=0.2$ The inside of the box shall have a low reflectivity finish on all non-optical surfaces.	
IRD-STRS-R04	Pumping port	The total effective pumping conductance of the 2-K box must be greater than or equal to 5.6 l/s (TBC)	
IRD-STRS-R05	Attenuation of radiation from 4-K environment	Requirement 5×10^{-7}; goal is 5×10^{-8} (TBC) To illustrate this, the requirement is the equivalent of a 0.5 mm diameter hole in a total area of the box cover of 0.5 m^2	

Table 3.4-32: Performance requirements on the spectrometer 2-K structure.

System Requirements

Requirement ID	Description	Value	Source
IRD-STRS-R06	First natural frequency	The first eigenfrequency of the spectrometer 2-K structure on its mounts shall be greater than 100 Hz (TBC) with a gaol of > 150 Hz	
IRD-STRS-R07	Mass	The mass of the 2-K structure shall be no more than M kg	
IRD-STRS-R08	Thermal isolation	The conductance of from the 4-K to 2-K stage shall be no more than 0.25 mW (TBC)	

Table 3.4-33: System requirements on the spectrometer 2-K structure.

3.4.7.3 Spectrometer Detectors

Conceptual Design

With the assumption of the FIRST telescope design (section 2.1.4.4) and the final focal ratio for the spectrometer optics (section 3.4.1.1), the size of the detectors for the spectrometer will be 9.5x9.5 mm square for the 2x2 arcmin field of view required for the filled arrays and 12.4 mm circular diameter for the 2.6 arcmin circular field of view required for the feedhorn detectors.

The background power falling on the photometer detectors from the telescope is assumed to be:

2Fλ : (Band A, B): (20, 13) pW
0.5Fλ: (Band A, B): (5, 3) pW

Interfaces to other sub-systems and the FIRST satellite

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Spec Array/Chopper	1.5.1	Chopper Mechanism	ATC
Spec Array/FTS Mech	1.5.2	FTS Mechanism	LAS
Spec Array/JFET Mod	1.7	JFET Module (Option)	JPL/Caltech
Spec Array/BAU	2.1	Buffer Amplifier Unit	CEA-SAp
Spec Array/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Spec Array/OBS	2.6	On Board Software	CEA-SAp
Spec Array/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Spec Array/Instrument Sim	3.3	Instrument Simulator	Stockholm
IID/Spec Array	IID-B	IID-B	ATC
Structure/Spec Array	1.1	Structure	MSSL
Therm/Spec Array	1.1.1	Thermometry	MSSL
Optics/Spec Array	1.2	Optics	LAS
Filters/Spec Array	1.2.1	Filters	QMW
Baffles/Spec Array	1.2.2	Baffles	Unalloc
Cooler/Spec Array	1.3	Cooler	CEA-Grenoble

Table 3.4-34: Spectrometer bolometer arrays interfaces with other subsystems.

Performance Requirements

Requirement ID	**Description**	**Value**	**Source**
IRD-DETS-R01	Sampling frequency	The spectrometer bolometer pixels shall be capable of being readout at the rate required by the FTS mechanism and position control system – nominally 200 Hz (TBC) (see section 3.4.7.4)	

Table 3.4-35: Spectrometer bolometer array performance requirements

System Requirements

Requirement ID	Description	Value	Source
IRD-DETS-R02	Microphonic susceptibility	TBD	
IRD-DETS-R03	EMI susceptibility	TBD	
IRD-DETS-R04	Sensitivity to ionising radiation	TBD	
IRD-DETS-R05	Mass of detector module	Each detector module – including its structural support – shall be no more than 500 g (TBC).	
IRD-DETS-R06	Volume envelope	The detector modules shall fit within a cylinder of diameter 75 mm (goal 60 mm) and length 100 mm.	
IRD-DETS-R07	300 mK thermal load	The thermal dissipation and parasitic load at 300 mK shall be no more than TBD μW for both arrays	
IRD-DETS-R08	Mechanical interface	The detector modules shall mechanically interface to either the 4-K or 2-K stage. Note: If the interface is at 4-K then the conducted thermal load from 4-K to 2-K shall be less than 0.2 mW per module (TBC).	

Table 3.4-36: Spectrometer bolometer array system requirements

3.4.7.4 Spectrometer Mirror Mechanism and Position Measurement

Conceptual Design

It is assumed that the FTS is to be implemented as a “rapid scan” type rather than a “step and integrate” type, the mirror mechanism therefore has to provide a linear motion of the roof-top mirrors with a continuous scanning action. The position measurement system has to provide accurate mirror positions and/or velocities to allow the synchronisation of the detector signals and reconstruction of the interferograms without additional “system” noise.

Interfaces to other sub-systems and FIRST Satellite

The FTS mirror mechanism is subsystem number **1.5.2** and has interfaces to the following sub-systems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
FTS Mech/DRCU	2.2	Detector Read-out & Control	CEA-SAp
FTS Mech/OBS	2.6	On Board Software	CEA-SAp
FTS Mech/Analogue	3.1	Analogue Inst. Simulator	Stockholm
FTS Mech/Instrument	3.3	Instrument Simulator	Stockholm
IID/FTS Mech	IID-B	IID-B	ATC
Structure/FTS Mech	1.1	Structure	MSSL
Therm/FTS Mech	1.1.1	Thermometry	MSSL
Optics/FTS Mech	1.2	Optics	LAS
Baffles/FTS Mech	1.2.2	Baffles	Unalloc
Phot Array/FTS Mech	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Spec Array/FTS Mech	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL

Table 3.4-37: Table 4.4.4.1: FTS mechanism interfaces with other sub-systems.

Performance Requirements

To illustrate the maximum requirements on the systems design, the goal resolution of 0.04 cm^{-1} is used throughout the rest of this section.

Requirement ID	Description	Value	Source
IRD-SMEC-R01	Linear Travel	Assumed folding factor of 4 for baseline design and single sided interferograms with short travel beyond zero path difference for phase correction. Total OPD required 14 cm. Maximum mirror travel required (wrt ZPD position): – 0.32 to +3.2 cm	
IRD-SMEC-R02	Minimum movement sampling interval	Band A minimum measurement interval of 5 µm is required (equivalent to 20 µm OPD) For Band B the requirement is 7.5 µm (equivalent to 30 µm OPD)	
IRD-SMEC-R03	Sampling step control	The measurement interval must be variable between 5 and 25 µm.	
IRD-SMEC-R04	Scan length	The system shall be capable of starting and	

Requirement ID	Description	Value	Source
		stopping a scan at any position within the required scan range	
IRD-SMEC-R05	Deadtime	A goal is to have a dead-time of no more than 10% per scan for when taking data at resolution of 0.4 cm^{-1}	
IRD-SMEC-R06	Mirror velocity	For assumed detector response of 20 Hz the maximum required rate of change of the OPD is 0.4 cm s^{-1}. Required max. mirror velocity 0.1 cm s^{-1}. A capability to have mirror velocity of 0.2 cm s^{-1} is desirable and is set as a goal.	
IRD-SMEC-R07	Velocity control	The mirror velocity should be selectable from 0.02 to 0.1 cm s^{-1} – or 0.2 cm s^{-1} if the goal performance is achieved.	
IRD-SMEC-R08	Velocity stability	The mirror velocity shall be within 1% r.m.s. of the nominal velocity over the scan range for both a single scan and from one scan to the next. This requirement is to be met when the system is operating at its nominal velocity for the required resolution. The velocity from scan to scan shall not vary by more than 1% over a period of 24 hours. For the conceptual design – mirror velocity will be 0.1 cm s^{-1} over ±0.32 cm and must be within ±0.001 cm s^{-1} of this value (1-σ) over the whole range and from one scan to another for a period of 24 hours under nominal operating conditions.	
IRD-SMEC-R09	Position measurement	Required OPD position accuracy is 1/50 of the smallest step size. Simulation confirms that this adds minimal system noise to the resultant interferogram. Required mirror position measurement accuracy 0.1 μm over +- 0.32 scan range and 0.3 μm thereafter.	
IRD-SMEC-R10	Sampling frequency	The position is sampled at the frequency required for Band A – i.e.(mirror velocity)/(measurement step size Band A) Required sampling rate = 200 Hz for the conceptual design mirror velocity of 0.1 cm s^{-1}.	

Table 3.4-38: Performance requirements on the FTS mirror mechanism.

System Level Requirements

Requirement ID	Description	Value	Source
IRD-SMEC-R09	Maximum thermal load onto 4 K during cold operation – mechanism and cold position measurement system.	Under zero-g maximum TBD mW Under 1-g maximum TBD mW	
IRD-SMEC-R10	Maximum mass – mechanism, position measurement system and support structure	1.2 kg (includes 20%) margin	
IRD-SMEC-R11	Maximum envelope	NxNxN mm	
IRD-SMEC-R12	Thermometers	At least one thermometer shall be provided on the FTS mechanism. The temperature range of the thermometer shall be 2 to 20 K (TBC). The absolute temperature measurement accuracy shall be 5% (TBC) with a resolution of TBD mK.	
IRD-SMEC-R13	Ground Operation	The mechanism and position measurement system must be capable of full operation on the ground when the instrument is in its normal orientation i.e. +Y horizontal and +X vertical. Further it must be capable of operating with the instrument rotated to up to 90^o about the Y-axis.	

Table 3.4-39: System requirements on the FTS mirror mechanism

3.4.7.5 Spectrometer Calibration Source

Conceptual Design

The spectrometer calibration source will be a standalone unit that will illuminate the second input port of the spectrometer with an equivalent spectrum to that generated by the FIRST telescope. In this way the telescope background will be nulled allowing a less precise mirror position measurement to be used and reducing substantially the dynamic range requirement on the detection system.

Interfaces to other sub-systems and the FIRST satellite

The spectrometer calibration source is subsystem number **1.6.2** and has the following interfaces with other subsystems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
Spec Cal/DRCU	2.2	Detector Read-out & Control	CEA-SAp
Spec Cal/OBS	2.6	On Board Software	CEA-SAp
Spec Cal/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
Spec Cal/Instrument Sim	3.3	Instrument Simulator	Stockholm
IID/Spec Cal	IID-B	IID-B	ATC
Structure/Spec Cal	1.1	Structure	MSSL
Therm/Spec Cal	1.1.1	Thermometry	MSSL
Optics/Spec Cal	1.2	Optics	LAS
Filters/Spec Cal	1.2.1	Filters	QMW
Baffles/Spec Cal	1.2.2	Baffles	Unalloc

Table 3.4-40: Spectrometer calibration source interfaces to other subsystems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-CALS-R01	Radiated spectrum:	Null the central maximum to accuracy of 5% (goal 2%) [TBC] Replicate the dilute 80-K spectrum of the telescope to an accuracy of better than 20% (goal 5%) [TBC] over 200-400 μm.	
IRD-CALS-R02	Beam pattern	Replicate the appropriate beam pattern at the second input port pupil image	
IRD-CALS-R03	Adjustability:	Zero - maximum in 256 steps	
IRD-CALS-	Uniformity	The uniformity of the intensity from the calibration source across the second	

Requirement ID	Description	Value	Source
R04		input port pupil image shall be better than TBD%	
IRD-CALS-R05	Repeatability and drift	The output intensity of the calibration source shall drift by no more than 1% over one hour of continuous operation. The absolute change in the output intensity of the source shall be no more than 15% over the mission lifetime	
IRD-CALS-R06	Operation	The calibration source shall be capable of continuous operation for periods of up to 2 hours with no loss of operational performance.	
IRD-CALS-R07	Number of operations	The calibration source shall be capable of up to 12000 operational cycles	

Table 3.4-41: Spectrometer calibrator performance requirements

System Requirements

Requirement ID	Description	Value	Source
IRD-CALS-R08	Operating Voltage	No more than 28 V DC	
IRD-CALS-R09	Power dissipation in the focal plane	No more than 5 mW with a goal of 2 mW	
IRD-CALS-R10	Mass	<200 g (TBC)	
IRD-CALS-R11	Envelope	50x50x70 mm (TBC)	
IRD-CALS-R12	Thermal Isolation	The surrounding structure of the calibrator shall rise in temperature by no more than TBD K after one hour of continuous operation	
IRD-CALS-R13	Operating Temperature	4 K	
IRD-CALS-R14	Redundancy	Fully redundant systems shall be provided for the active elements.	

Table 3.4-42: Spectrometer calibrator systems requirements

3.5 JFET/Filter Box

Conceptual Design

If the NTD germanium feedhorn type bolometer arrays are selected, then they will require cold JFET amplifiers to be placed close to the focal plane unit. These amplifiers operate at 120 K and therefore require careful mounting within a sealed box that is heat sunk to either the 11-K temperature stage within the cryostat or to one of the higher temperature cryostat heat shields. This same box will also contain the necessary passive RF filtering for ***all*** FPU sub-systems. Therefore, all FPU sub-system wiring harnesses will interface to the FIRST cryoharness through the JFET/Filter boxes.

If the feedhorn option is not selected then this box will only contain the passive RF filtering. All sub-system harnesses will interface to the RF filter box in any event.

Interfaces to other sub-systems and the FIRST satellite

The JFET/RF Filter box is subsystem number **1.7** and has the following interfaces with other subsystems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
JFET Mod/BAU	2.1	Buffer Amplifier Unit	CEA/GSFC/JPL
JFET Mod/DRCU	2.2	Detector Read-out & Control	CEA-SAp
JFET Mod/OBS	2.6	On Board Software	CEA-SAp
JFET Mod/Analogue Sim	3.1	Analogue Inst. Simulator	Stockholm
JFET Mod/Instrument Sim	3.3	Instrument Simulator	Stockholm
IID/JFET Mod	IID-B	IID-B	ATC
Structure/JFET Mod	1.1	Structure	MSSL
Therm/JFET Mod	1.1.1	Thermometry	MSSL
Phot Array/JFET Mod	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Spec Array/JFET Mod	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL

Table 3.5-1: JFET/Filter box interfaces with other subsystems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-FTB-R01	Amplifier noise	For the feedhorn option the JFET amplifiers shall have a noise performance better than TBD nV Hz$^{-1/2}$ over a bandwidth of TBD to TBD Hz	
IRD-FTB-R02	RF rejection	The RF filters, as fitted in the box and with the correct harness, connectors and back-shells; shall reject all frequencies from TBD Hz to TBD Hz at TBD dB.	

Table 3.5-2: JFET/Filter box performance requirements

System Requirements

Requirement ID	Description	Value	Source
IRD-FTB-R03	Mass	The JFET/Filter Box shall be no more than 2.5 kg (TBC) not including margin.	
IRD-FTB-R04	Envelope	The JFET/Filter box shall be no more then 300x100x100 mm (TBD)	
IRD-FTB-R05	Dissipation	The dissipation of JFET amplifiers shall be no more than 33 mW (TBC) average for the case where the amplifiers are heat sunk to the 11-K cryostat stage. *Any change in the system design – i.e. changes in the cryostat temperatures - will lead to a revision of this requirement.*	
IRD-FTB-R06	Operating temperature range	The JFET amplifiers and RF filters shall be capable of operating in with the temperature of the mounting point of the box in the range 4 to 300-K	
IRD-FTB-R07	Nominal operating temperature	The JFET amplifier and RF filter performance requirements shall be maintained with the temperature of the mounting point of the box within the range 4 to 20 K.	
IRD-FTB-R08	First natural frequency	The first eigenfrequency of the FTB on its mounts shall be greater than 100 Hz (TBC) with a gaol of > 150 Hz	

Table 3.5-3: JFET/Filter box system requirements

3.6 Buffer Amplifier Unit

Conceptual Design

Both the CEA detector and the feedhorn option requires an external buffer amplifier to condition the detector signals after they emerge from the cryostat. This is because the detector readout and control unit is placed on the SVM and may be a further 5 metres from the cryostat wall. The buffer amplifier will be placed in a Buffer Amplifier Unit – BAU – that will be mounted on a platform on the CVV close to the feedthroughs for the cryo-harness.

Interfaces to other sub-systems and the FIRST satellite

The Buffer Amplifier Unit is subsystem number **2.1** and has the following interfaces with other subsystems.

Interface Name:	Subsystem Number	Subsystem Name	Institute responsible
BAU/DRCU	2.2	Detector Read-out &	CEA-SAp
BAU/AIV Fac	4.2	AIV Facility	RAL
BAU/Warm Vib Fac	4.6	Warm Vibration Facility	RAL
BAU/EMC Fac	4.1	EMC Test Facility	CEA-SAp
JFET Mod/BAU	1.7	JFET Module (Option)	JPL/Caltech
IID/BAU	IID-B	IID-B	ATC
Phot Array/BAU	1.4.1	Photometer Bol Arrays	CEA/GSFC/JPL
Spec Array/BAU	1.4.2	Spectrometer Bol Arrays	CEA/GSFC/JPL

Table 3.6-1: Buffer Amplifier Unit interfaces with other subsystems.

Performance Requirements

Requirement ID	Description	Value	Source
IRD-BAU-R01	Amplifier noise	For the feedhorn option the buffer amplifiers shall have a noise performance better than TBD nV $Hz^{-1/2}$ over a bandwidth of TBD to TBD Hz For the CEA option the buffer amplifiers shall have a noise performance better than TBD nV $Hz^{-1/2}$ over a bandwidth of TBD to TBD Hz	

Table 3.6-2: Buffer Amplifier Unit performance requirements

System Requirements

Requirement ID	Description	Value	Source
IRD-BAU-R02	Mass	The BAU shall be no more than 3 kg (TBC) not including any margin	
IRD-BAU-R03	Envelope	The mechanical envelope of the BAU shall not exceed 360x150x380 mm (TBC)	
IRD-BAU-R04	Power dissipation	The power dissipation of the BAU shall not exceed 2.5 W (TBC)	

Requirement ID	**Description**	**Value**	**Source**
IRD-BAU-R05	Operating temperature range	The BAU electronics shall be capable of operating with the temperature of the box mounting point in the range 120 to 300 K	
IRD-BAU-R06	Nominal operating temperature	The BAU electronics performance requirements shall be maintained with the temperature of the box mounting point at between 120 and 150 K	
IRD-BAU-R07	First natural frequency	The first eigenfrequency of the BAU on its mounts shall be greater than 100 Hz (TBC) with a gaol of > 150 Hz	

Table 3.6-3: Buffer Amplifier Unit system requirements

3.7 Warm Electronics

This section will be defined in a separate document

4. APPENDICES

4.1 Qualification Tests

Vibration:	All sub-systems are to be vibrated at levels appropriate to their location within the instrument. The temperature at which the vibration will be done is subject to negotiation between the project and ESA. The group responsible for the structure will define the level at which each sub-system will be vibrated. This will either be by calculation or vibration of test structures.
Thermal cycle:	All FPU sub-systems will be cooled down and warmed up a large number of times over the period leading up to launch. An accelerated thermal cycle test is therefore required for all FPU sub-systems. The temperatures, rate of temperature change and number of cycles are TBD.
Vacuum cycle:	All sub-systems will be operating *in vacuo*. The long-term performance of all sub-systems *in vacuo* as well as their response to vacuum cycling must be assessed. All sub-systems will be vacuum cycled and critical items will undergo long-term life tests under vacuum conditions.
Lifetime:	Where novel material processing or unqualified mechanisms are employed in a sub-system, accelerated life tests will be mandatory. For all ASICs and micro-machined components a programme of device selection will be required to guard against infant mortality.
Soak/cycle:	All electronic sub-systems and/or components will need to be soak tested and operationally cycled as part of their lifetime test programme.
Radiation tolerance:	All unqualified electronics sub-systems and/or components will have to be exposed to the appropriate level of radiation dose to ensure survival in orbit.
Thermal range:	The operating temperature range of a sub-system will be characterised. If a sub-system does not operate within specification, or at all, at temperatures that are within the expected limits, it cannot be considered qualified.
Thermal stability:	The response of a sub-system to thermal instabilities will be characterised as will the impact of sub-system operation on the thermal stability of the instrument. A sub-system that causes large thermal instability in the instrument during its normal operational cycle or is over sensitive to the expected level of thermal instability cannot be considered qualified.
Microphonics:	The level of mechanical vibration from a sub-system will be characterised as well as the response of the sub-system to microphonic interference. Any sub-system that causes excessive mechanical vibration during its normal operation

or is over sensitive to the expected level of mechanical vibration cannot be considered qualified.

Ionising radiation: The response of a sub-system (e.g. the detectors) to high energy ionising radiation (simulating cosmic ray proton hits), will be characterised. A sub-system will not be considered qualified if its performance is significantly reduced by the impact of high energy ionising radiation.

EMI: The sensitivity of a sub-system to electromagnetic interference will be characterised. If a sub-system is over sensitive to the expected level of electromagnetic emission it will be deemed not qualified.

EMC: The radiated and conducted electromagnetic emission of a sub-system will be characterised. Any sub-system that emits significant levels of electromagnetic radiation or interferes with power supplies or ground lines will not be considered qualified.

Materials conformance: All materials used in the manufacture of a sub-system must be approved for space use by ESA. Any materials not on an approved list must under go a materials approval test as laid down by ESA.

Test Levels

	Qualification	Proto-Flight	Acceptance
Vibration:			
Random x-axis	**7.4 g rms (TBC)**	**TBD**	**TBD**
y-axis	**7.4 g rms (TBC)**	**TBD**	**TBD**
z-axis	**7.4 g rms (TBC)**	**TBD**	**TBD**
Sine Sweep all axes 5-18 Hz	**22 mm p-p**	**TBD**	**TBD**
18-100 Hz	**15 g**	**TBD**	**TBD**
Thermal cycle:	**TBD**	**TBD**	**TBD**
Vacuum cycle	**TBD**	**TBD**	**TBD**
Thermal range:	**TBD**	**TBD**	**TBD**
EMC (Instrument Level)	**TBD**	**TBD**	**TBD**

EMC (Satellite Level):	**TBD**	**TBD**	**TBD**

Table 4.1-1: Levels for the instrument level environmental test.

4.2 Global Budgets

4.2.1 Thermal

This is complicated and highly dependent on detector choice! Here is the CEA option as an example…..

Package	Responsible:	Thermal load at '15K', mW	Notes:
Structure	MSSL	TBD	Radiation
Filters	QMW	TBD	Radiation on Blocking Filter
Wiring Harness	ESA	TBD	Harness from BAU and Warm electronics
JFET/Filter Box	CEA/JPL/GSFC	20.0	In photometer mode
Total		**20.0**	
Contingency	ATC	4.0	
Total including contingency		24.0	

Package	Responsible:	Thermal load at '4K', mW	Notes:
Structure	MSSL	2.6	Structural supports and Radiation
Beam Steering Mirror	ATC	4.0	
Phot Calibrator	GSFC	TBD	
FTS Calibrator	GSFC	TBD	
Shutter	UoSastn	0.0	Peak dissipation is TBD, but very intermiitent use
Wiring Harness	Several	1.1	Harnesses for detectors and housekeeping
FTS Mechanism	LAS	7.4	Note: BSM & FTS never operate together
Cooler	CEA	0.0	
Total		**15.1**	
Contingency	ATC	2.4	
Total including contingency		17.5	

Package	Responsible:	Thermal load at '2K'	Notes:
Structure	MSSL	1.0	
Wiring Harness	Several	0.1	Harnesses for detectors and housekeeping

Cooler	CEA	1.0	but see power profile
JFET/Filter Box	CEA/JPL/GSFC	0.0	
Total		**2.1**	
Contingency	ATC	0.4	
Total including contingency		2.5	

Table 4.2-1: Thermal load allocation for the FPU sub-systems allocated by workpackage for the CEA detector option.

4.2.2 Mass

Package/sub-system	Responsible:	Mass allowance, g	Includes:
Optics	LAS	2730	Fixations, FTS and BSM moving mirrors
Structure	MSSL	22320	Thermal straps, feed throughs, thermometry & harness
Baffles	LAS	900	
Phot Arrays	CEA/JPL/GSFC	1900	Harness for all arrays
Spec Arrays	CEA/JPL/GSFC	600	
Beam Steering Mirror	ATC	500	NOT mirror
Phot Calibrator	GSFC	100	Harness
FTS Calibrator	GSFC	200	Harness
Shutter	UoSastn	200	Harness
Filters	QMW	450	Fiittings
FTS Mechanism	LAS	900	NOT mirrors
Cooler	CEA	1300	Straps to 2K and 300 mK to arrays
JFET/Filter Box	CEA/JPL/GSFC	2000	
Total		**34100**	
Contingency	ATC	6800	
Total with contingency		40900	

Table 4.2-3: Mass allocations for the FPU sub-systems allocated by workpackage

4.2.3 Mechanical Interfaces

The space available to each sub-system with the FPU is given in table 4.1.3.1

Package	Responsible:	Space mmxmmxmm
Optics	LAS	-
Structure	MSSL	-
Baffles	?	TBD
Phot Arrays	CEA/JPL/GSFC	75diamx100
Spec Arrays	CEA/JPL/GSFC	75diamx100
Beam Steering Mirror	ATC	115x75x25
Phot Calibrator	GSFC	30x15x10
FTS Calibrator	GSFC	40x40x100
Shutter	UoSastn	45x45x45

Filters	QMW	-
FTS Mechanism	LAS	140x140x140
Cooler	CEA	200x100x100
JFET/Filter Box	CEA/JPL/GSFC	300x100x100

Table 4.2-4: Space envelopes available within the FPU for sub-systems allocated by work-package

4.2.4 Straylight

Control of the straylight from the warm parts of the telescope surround; cryostat and spacecraft structure will be a difficult problem and detailed specifications are model and system design dependent. A top-level specification on the straylight in the photometer channel is given in table 4.1.4.1 – no specification has yet been written for the spectrometer. (30/11/99)

Total In-band Straylight Signal at a SPIRE detector:		< 10% of direct signal from telescope mirrors + structure
Straylight uniformity		TBD
Maximum Radiative thermal loads from structure	location	TBD
	value	TBD

Table 4.2-5: Straylight specification for the photometer channel.