SPIRE Beam Steering Mirror Subsystem Specification Document

v 3.2

Ian Pain

DISTRIBUTION LIST

SPIRE-Project	Ken J. King	**x**
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	Matt Griffin	**x**
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Record of Issue

Date	Index	Remarks
13.Jun.00	1.0	Issue for PDR
06.Nov.00	2.0	Update following additional technical data. Reformatting.
31.May.01	3.0	revising stability specification. ; Updated cross references ; Updated TBC's of mirror dimensions; Updated vibration environment; Added reliability and safety requirements; Expanded compliance matrix. Distributed internal to ATC for comment.
19.Jun.01	3.1	(working draft - internal to ATC). Confirmed 20msec risetime. Minor tweaks . updated vibration load and interfaces, updated outline description.
10.Jul.01	3.2	Amended reflectivity/ emmisivity spec (non measurable). Updated compliance & ICD tables.

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File Description

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Highlighting notes:

Text highlighted in yellow needs checking or updating, or indicates a missing reference (e.g. ???) or a TBD/TBC/TBW

Text highlighted in green is a substantial change new since the last released issue

1. Scope

This specification defines the requirements applied to the performance, design and qualification of the Beam Steering Mechanism for the SPIRE photometer. It includes a brief description of the proposed design to meet these requirements. The complete design description is found in RD1.

The Beam Steering Mechanism forms a sub-system of the SPIRE instrument. This specification is applicable to the CQM, the PFM and the FS. Where relevant, it is also applicable to the STM (deliverable to SPIRE but not ESA).

2. Documents and Glossary

2.1 Applicable documents

Ref	Title	Author	Reference	Date
AD1	Instrument Requirements Document (IRD)	B.M.Swinyard	SPIRE-RAL-PRJ-000034 v0.30	May 2000
AD2	ICD Structure - Mechanical I/F	B.Winters	SPIRE-MSS-PRJ-000xxx v1.0	April 2001
AD3	Deleted	N/A		
AD4	Optics - BSM ICD	T.Peacocke, I.Pain	SPIRE-ATC-PRJ-000587 Annex E	Jun.01
AD5	Baffles - BSM ICD	T.Peacocke, I.Pain	SPIRE-ATC-PRJ-000587 Annex E	Jun.01
AD6	Photometer Bolometer Arrays - BSM ICD	B.Winters	ICD Structure - Mechanical I/F SPIRE-MSS-PRJ-000xxx v1.0	April 2001
AD7	Spectrometer Bolometer Arrays - BSM ICD	B.Winters	ICD Structure - Mechanical I/F SPIRE-MSS-PRJ-000xxx v1.0	April 2001
AD8	Photometer Calibration Source - BSM ICD	I.Pain	SPIRE-ATC-PRJ-000587 Annex C	Jun.01
AD9	Deleted	N/A		
AD10	On Board Software - BSM ICD	B.Stobie	SPIRE-ATC-PRJ-000587 Annex G	TBW
AD11	Analogue Simulator - BSM ICD	TBD	TBD	
AD12	Instrument Simulator - BSM ICD	TBD	TBD	
AD13	Current Optical Configuration	???	PHT 126 I	Check status
AD14	Operating Modes for the SPIRE Instrument	B.M.Swinyard	SPIRE-RAL_PRJ 000320 issue 2.2	Check status
AD15	BSM Sub-system Development Plan	I.Pain	SPIRE-ATC-PRJ-000466 v4.0	08.Apr.01
AD19	MCU-BSM ICD	I.Pain	SPIRE-ATC-PRJ-000587 Annex G	Jun.01
AD20	SPIRE Product Assurance plan	D.Kelsh	SPIRE-RAL-PRJ-00017 v1.0	11.Apr.01
AD21	ATC Interface drawing	ATC	SPIRE-BSM-021-002-001 r.1	15.Jun.01
AD22	BSM Product Assurance Plan	Ian Pain	SPIRE-ATC-PRJ-000711 Internal Draft 0.4	26.Jun.01

Ref	Title	Author	Reference	Date
AD23	Optical System Design Description	K.Dohlen, B.Swinyard	SPIRE-LAM-PRJ-000447 Draft 1	18.Dec.00

2.2 Reference documents

Ref	Title	Author	Reference	Date
RD1	SPIRE BSM Design Description Document	Ian Pain	SPIRE-ATC-PRJ-000587 v4.0	Jun.01
RD2	HERSCHEL Telescope Specification		PT-RQ-04761 Issue 1/A SPIRE-ESA-DOC-000195	Jan.98
RD3	SPIRE Systems Budgets	C.Cunningham	SPIRE-ATC-PRJ-000450	latest
RD4	Radiation environment memo:	J. Sørensen TOS-EMA ,	réf. 00-010/JS,	14 May 2001
RD5	SPIRE mirrors specification	K.Dohlen and D.Pouliquen	LAM.PJT.SPI.SPT.200007 Ind 1	6.Jun.00
RD6	IID-A	HERSCHEL/Planck Project Team	SCI-PT-IIDA-04624 rev 1/0	latest
RD7	IID-B	ESA HERSCHEL/Planck Project Team	SCI-PT-IIDB/SPIRE-02124 rev 1/0	latest

2.3 Glossary

Abbrev	Meaning	Abbrev	Meaning
AD	Applicable Document	LAT	Lot Acceptance Tests
ADP	Acceptance Data Package	MAC	Multi Axis Controller
ATC	United Kingdom Astronomy Technology Centre	MAPTIS	Materials and Processes Technical Information Service
BSM	Beam Steering Mirror	MSFC	Marshall Space Flight Center
BSM	Beam Steering Mirror dummy	MCU	Mechanism Control Unit
BSMe	Beam Steering Mirror electronics	MIP	Mandatory Inspection Point
BSMm	Beam Steering Mirror mechanism	MGSE	Mechanical Ground Support Equipment
BSMs	Beam Steering Mirror structure	MPIA	Max Planck Institute for Astronomy
CAE	Computer Aided Engineering	MSSL	Mullard Space Science Laboratory
CDR	Critical Design Review	NASA	National Aeronautical Space Agency
CoG	Centre of Gravity	NA	Not Applicable
CIL	Critical Items List	NCR	Non Conformance Report
CQM	Cryogenic Qualification Model	NCRP	Non Conformance Review Panel

Abbrev	Meaning	Abbrev	Meaning
CTD	Change to Drawing/Document	OGSE	Optical Ground Support Equipment
DCL	Declared Components List	PA	Product Assurance
DDR	Detailed Design Review	PAD	Part Approval Document
DM	Development Model	PFM	Proto Flight Model
DML	Declared Materials List	PPARC	Particle Physics and Astronomy Research Council
DPA	Destructive Physical Analysis	PI	Principal Investigator
DSP	Digital Signal Processor	PID	Proportional – Integral - Derivative
ECSS	European Cooperation for Space Standardization	QA	Quality Assurance
EGSE	Electrical Ground Support Equipment	RAL	Rutherford Appleton Laboratory
ESA	European Space Agency	RAL SSD	RAL Space Science Department
FMEA	Failure Modes and Effects Analysis	RD	Reference Document
FMECA	Failure Modes, Effects and Criticality Analysis	rms	Root mean square
FPGA	Field Programmable Gate Array	SDOF	Single Degree of Freedom
FPU	Focal Plane Unit	SMEC	Spectrometer Mechanism
FS	Flight Spare	SPIRE	Spectral and Photometric Imaging REceiver
FSM	Flight Spare model	TBC	To Be Confirmed
GDFC	Goddard Flight Center	TBD	To Be Defined
GSE	Ground Support Equipment	TBW	To Be Written
HoS	Head of Specialism	UK ATC	United Kingdom Astronomy Technology Centre
Herschel	ESA Mission name (formerly FIRST)	UK SPO	UK SPIRE Project Office
ICD	Interface Control Document	WE	Warm Electronics
IBDR	Instrument Baseline Design Review		
KIP	Key Inspection Point		
LAM	Laboratoire d'Astrophysique de Marseilles		

3. Subsystem description

3.1 Outline Description of the Beam Steering mirror mechanism subsystem

The Beam Steering Mirror mechanism subsystem (BSM) is a critical part of the SPIRE Instrument. It is used to steer the beam of the telescope on the photometer and spectrometer arrays in 2 orthogonal directions, for purposes of fully sampling the image, fine-pointing and signal modulation.

The BSM comprises 4 main deliverables:

1. **The cryogenic <u>mechanism</u>** (BSMm).
2. **The <u>structural</u> interface** (BSMs).
3. **The warm <u>electronics</u>** (BSMe)
4. **Mass and optical alignment <u>dummies</u> as required for SPIRE system level integration,** (BSMd)

The position of the BSMm & BSMs are indicated in Figure 1.

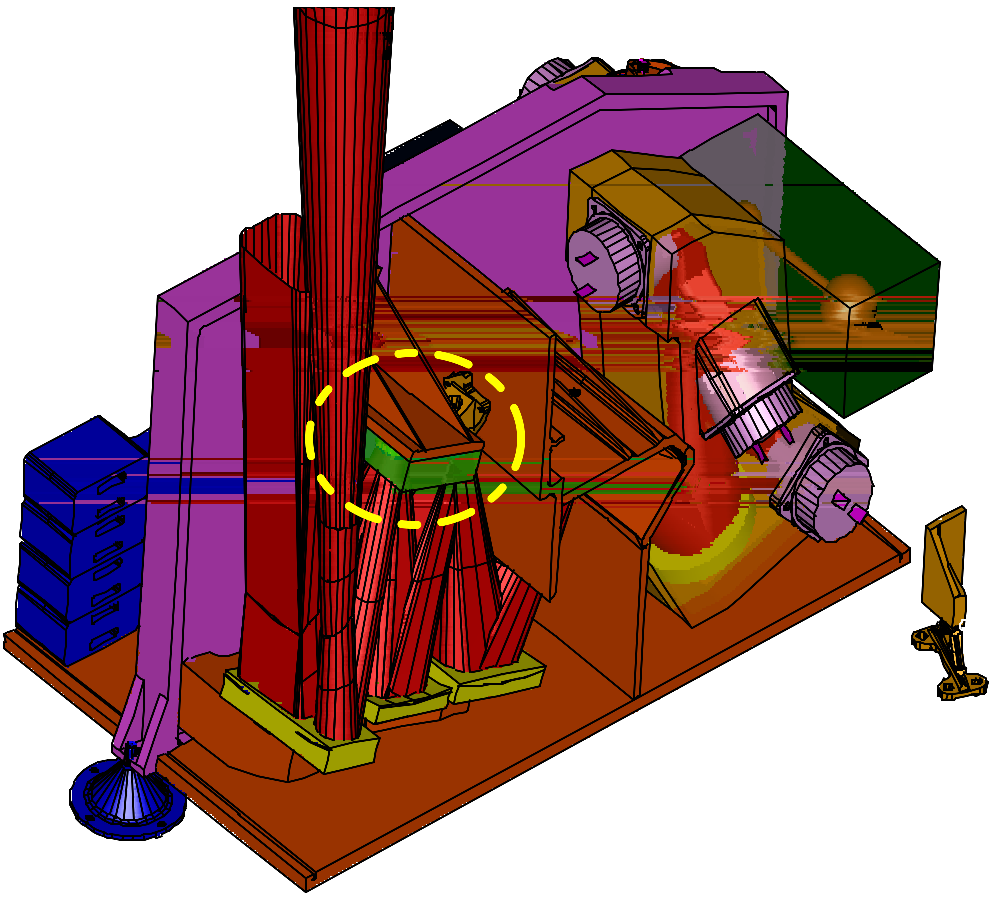

Figure 1 Photometer Layout, BSM in green, highlighted with yellow oval

The <u>BSMm</u> consists of an aluminium alloy mirror, nominal diameter 32mm, machined as part of the chop axis. This is mounted orthogonally within a gimbal-type frame which provides for jiggle axis motion. The axes are suspended by flex-pivot mounts. The BSMm is a cryogenic device with nominal temperature 4-6K. Nominally, the chop axis provides 2.4 ° of mirror motion at 2 Hz and the jiggle axis provides 0.6° of motion at 1 Hz. The mirror also provides an aperture through which the Photometer Calibration Source is directed towards the detector arrays

The BSMs provides location of the BSMm on the SPIRE optical bench, and will also provide for a light tight enclosure and structural support for harnessing and thermometry. The BSMs integrates to the SPIRE Photometer Calibration Source (PCAL), supplied by the University of Wales, Cardiff, a baffle (supplied by RAL or ATC…TBC) and the SPIRE optical bench (MSSL). The BSMs is a cryogenic structure with nominal temperature 4-6K.

The BSMe provides electrical actuators which 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 BSMe baseline design makes use of cryogenic motors used in PACS and magneto-resistive sensors used in ISOPhot. Each axis houses a rare-earth (NdFeB VACODYM 344) permanent magnet moving pole piece and is driven by a motor coil fixed to the mechanism housing/structure.

The cryogenic electronics are connected to the analogue power and amplifier electronics on the Warm Electronics (WE) by a cryogenic harness which will also feed out signal cables from thermocouples on the BSMs. The BSM operates under control of the Detector Readout and Control (HSDRC) sub-system’s Mechanism Control Unit (MCU) supplied by LAM. The BSMe will be specified and designed by the UK ATC, then manufactured by LAM in conjunction with the SMEC electronics. Integration and test will be at LAM, with support from ATC.

The BSMd may comprise several actual dummies, with at least (1) an optical dummy for initial alignment work and (2) a mass-representative model for structural vibration tests. Designs for mass and optical alignment dummies will not be specified in detail until the BSMs/BSMm design is complete.

3.2 Mission profile

The BSM is developed as a sub-system and then integrated to the SPIRE FPU. The SPIRE instrument is subsequently integrated to Herschel. The instrument is to be cryogenically cooled, and will be cold during launch. Launch is scheduled for 2007 to an L2 orbit. The mission duration is a minimum of 4.25 years.

Per AD1, in normal operations the satellite is expected to have a 24-hour operational cycle with data being collected autonomously for 21 hours and a 3 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 24-hour period will be up-linked.

3.3 BSM Block Diagram

The block diagram below is adopted from AD1 Fig 3.1-1 and shows the relationships between the sub-systems of the SPIRE instrument.

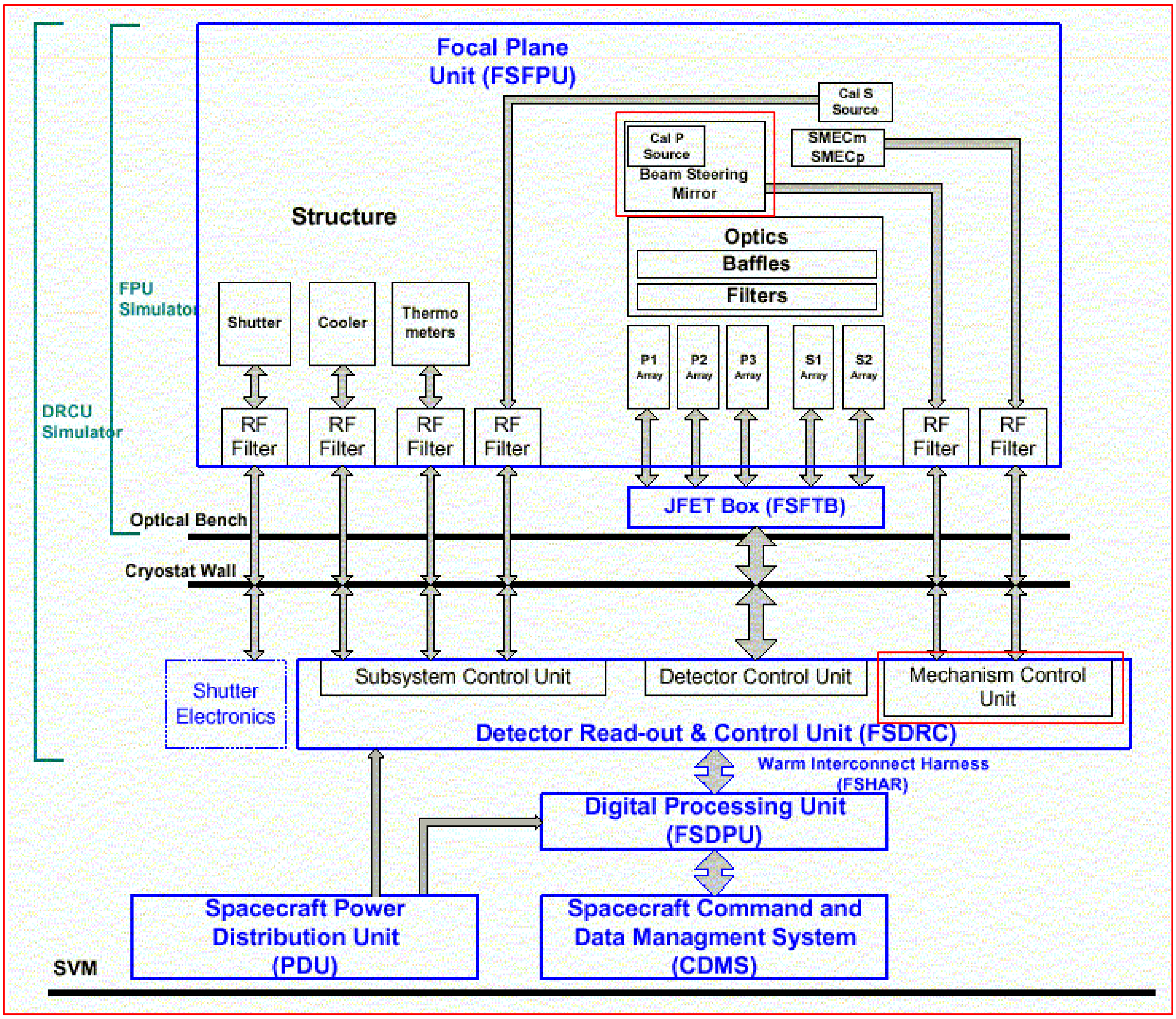

Figure 2 SPIRE Block Diagram[1] showing BSM, Mechanism Control Unit (MCU).

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[1] *Note that the terminology in this figure is in need up an update, as the spacecraft has been re-named Herschel, formerly FIRST. Hence FIRST-SPIRE Focal Plane Unit, or FSDPU should now read HSDPU.*

3.4 Design Assumptions

3.4.1 Optical Scaling Factor

A scaling factor between the movement of the mirror and movement of the beam on the sky of 1° (at the mirror) per 50 arcsec (on the sky) is assumed; i.e. a scaling factor of 72:1. This value is derived from the SPIRE optical design (AD13).

3.4.2 Definition of Axes

The HERSCHEL spacecraft axes are defined in AD1, as follows:

- The X axis is the spacecraft boresight
- The Y axis is away from the HIFI instrument
- The Z axis is towards the sun shield.

The BSM is positioned in the SPIRE optical system such that the two rotation axes of the mirror produce nominal movements of the beam in the XY plane (around the Z axis) and in the XZ plane (around the Y axis) respectively.

The rotation axes of the BSM mirror shall be referred to as follows:

- Rotation producing a movement of the beam around the spacecraft Z axis - Chop axis
- Rotation producing a movement of the beam around the spacecraft Y axis - Jiggle axis

The mirror orientation is defined by two angles - the chop angle and the jiggle angle (θ_c,θ_j). The nominal zero position ((θ_c,θ_j) = (0,0)) is defined as the orientation such that the centre of the photometer detector arrays are aligned along the nominal SPIRE boresight.

4. Functional Requirements

4.1 Performance requirements

These requirements are not dependent on the particular design of the BSM.

4.1.1 Angular Travel - Chop Axis

The BSM shall allow angular movement of the mirror surface through an angle of ±2.4° in the mirror chop axis. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R01 IID-B SRD-R9
The minimum available chop throw shall be +/- 0.1° (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-B SRD-R9

4.1.2 Angular Travel - Jiggle Axis

The BSM shall allow angular movement of the mirror surface through an angle of ±0.6° in the mirror jiggle axis. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R02

4.1.3 Minimum Step Size

The BSM shall allow movements of the mirror surface in both chop and jiggle axes in minimum increments of 0.04°. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R03

4.1.4 Chop Frequency

The BSM shall allow movements of the mirror in the chop axis at any frequency up to 2Hz Hz for nominal operation and power dissipation	AD1 : IRD-BSMP-R04
As a goal, the BSM shall allow movements of the mirror in the chop axis at any frequency up to 5Hz. At frequencies above 2Hz, a degradation in power dissipation performance and settling time of the BSM is acceptable.	AD1 : IRD-BSMP-R04

4.1.5 Jiggle Frequency

The BSM shall allow movements of the mirror in the jiggle axis at any frequency up to 0.5Hz.	AD1 : IRD-B SMP-R05
As a goal, the BSM shall allow movements of the mirror in the jiggle axis at any frequency up to 1Hz. At frequencies above 0.5Hz, a degradation in power dissipation performance and settling time of the BSM is acceptable.	AD1 : IRD-B SMP-R05

4.1.6 Holding position/ Drift Constraint

The BSM shall be capable of moving to, and holding at, any commanded position within its range of movement, to within 0.004 degrees rms, for periods of up to 4 hours	AD1 : IRD-BSMP-R05

4.1.7 Stability

After settling, the mirror position shall remain within 0.004° (rms) of the mean steady state position, in the frequency range 0.03 - 25Hz.	AD1 : IRD-BSMP-R06
As a goal, after settling, the mirror position shall remain within 0.002° (rms) of the mean steady state position, in the frequency range 0.03 - 25Hz.	AD1 : IRD-BSMP-R06

4.1.8 Position Measurement

The BSM shall provide measurements of the angular orientation of the mirror surface in both chop and jiggle axes to a resolution of 1/8 of the requirement, 1/4 of the goal. i.e. a requirement of 0.0005°. The rate at which the position measurements need to be made is TBD. This requires modelling at instrument level of what is needed to deconvolve the signal. A "past experience estimate" would be 5 - 10 measurements per half chop cycle, i.e. a requirement of 40Hz, a goal of 80Hz.	AD1 : IRD-BSMP-R07

4.1.9 Settling Time

The angular position of the mirror surface shall be within 0.02° of the mean steady state position in less than 20 milliseconds from the application of a demand in the chop axis.	AD1 : IRD-BSMP-R08
The angular position of the mirror surface shall be within 0.02° of the mean steady state position in less than 0.100 sec from the application of a demand in the jiggle axis.	???
As a goal, the angular position of the mirror surface shall be within 0.02° of the mean steady state position in less than 0.050 sec from the application of a demand in the jiggle axis.	???

4.1.10 Chop repeatability

The steady state repeatability between successive chop cycles shall be less than 0.004° (rms) over 4 hours.	???

4.2 Technical Specifications

4.2.1 Mechanical Dimensions

The BSMm shall fit within a volume of 130x130x30 mm (excluding mounting structure).	AD1 : IRD-BSMP-R09
The BSM, including mounting structure, shall fit within a volume of 132x95x20mm	AD21
The BSM mounting structure footprint is as defined in MSSL Interface drg. A2-5264-907 And ATC Interface drawing SPIRE-BSM-021-002-001 r.1	AD2 AD21

4.2.2 Operating Temperature

The operational temperature of the BSM shall be at Thermal Interface Level 1 per RD6: nominally 4K, but in the range 3.5-6.0K .	AD1 : IRD-BSMP-R10 RD6 (Table 5.7.7.1-1)
The BSM shall be capable of operation (with reduced performance) at temperatures up to 300K.	AD1 : IRD-BSMP-R10

4.2.3 Thermal Isolation

No part of the BSM visible to the optical path shall rise by no more than 1K from the nominal operating temperature of the surrounding structure after 1 hour of operation in any mode.	AD1 : IRD-BSMP-R11

4.2.4 Cold Power Dissipation

The average power dissipation of the BSM Cryogenic Mechanism (BSMm) and the BSM Support Structure (BSMs) shall be less than 4mW in any operating mode, when operating at the temperature defined in section 4.2.4	AD1 : IRD-BSMP-R12

4.2.5 Warm Electronics Power Dissipation

The average power dissipation of the BSM Warm Electronics (BSMe) shall be less than TBD Watts when chopping at 2Hz in any operating mode.	AD1 : IRD-BSMP-R13

4.2.6 Mirror Surface Dimensions

The mirror clear diameter after allowing for any obscuration by the baffle shall be greater than 32mm.The clear diameter is the visible diameter (when viewed orthogonal to the mirror surface with the mirror held at the 0,0 position) .	AD13
The mirror shall include a central hole of no less than 2.8mm diameter to allow the Photometer Calibrator to be seen by the detectors.	AD13

4.2.7 Mirror Surface Finish

The mirror surface of the BSM shall be flat to <1µm (rms) and shall have a surface roughness	AD13, RD5

of <10nm (rms).	

***See also* 4.6.3.1.**

4.2.8 Mirror Surface Reflectivity

The reflectivity of the mirror surface of the BSM shall be =99% in the wavelength range 200 - 670 µm by design. This requirement will not be measurable.	AD13, RD5

***See also* 4.6.3.2.**

4.2.9 Mirror Surface Emissivity

The emissivity of the mirror surface of the BSM shall be <1% in the wavelength range 200 - 670µm by design. This requirement is the complement of 4.2.8 and will not be measurable	AD13, RD5

4.2.10 Baffle

The presence of a Baffle is assumed, and will be of the hole-in-plate type if internal component temperatures can meet the requirement of 4.2.3 . The opening in the stray light baffle will be sufficient to allow the 20% oversized beam to cross it with a positive margin of no more than 0.5 mm.	AD2 (section 2.5.9) This document

4.2.11 Position of Rotation Axes

The position of the Rotation Axes shall be established accurately within 0.5 mm (TBC) and 0.5° (TBC) of nominal design position.	This document
The BSM shall be designed such that it may be repositioned on the SPIRE optical bench within a repeatability of 0.1 mm (TBC)and 0.05° (TBC)	This document
Rotational motions of the axes shall produce a de-centre of the axis of rotation of less than (10 microns) (TBC)	This document

4.2.12 Orthogonality of Rotation Axes

The orthogonality of the rotation axes shall be within 0.15° (TBC).	This document

4.2.13 Fail Safe (No Drive Signal) Position

When no drive signals are applied to the BSM, the mirror shall take up a position such that the mirror surface is perpendicular to the nominal (0,0) mirror position to within ±0.18°. For information, this is intended to place the BSM within 50% of the beam FWHM.	This document

4.2.14 Fail Safe (Mechanical Failure) Position

In the event of mechanical failure on launch, the mirror shall take up a position such that the beam remains useable by the spectrometer instrument, i.e. That the mirror surface is perpendicular to the nominal (0,0) mirror position to within ±1.0°.	This document

4.2.15 Mass

The BSM cryogenic mechanism (BSMm) and the BSM support (BSMs) shall have a combined mass of less than 1100g; including harness but excluding contingency and PCAL	IRD-SUBS-R03 (SPIRE Sub-system Budget Allocations)

4.2.16 Cool-down time

Upon integration to the SPIRE optical bench, the BSM shall reach a temperature of 4K within 15 hours of the commencement of cooldown. This assumes a maximum average cooldown rate of 20K/hour.	???

4.2.17 Reliability

As far as possible the total failure of a single sub-system shall not lead to the total loss of instrument operations.	AD1 : IRD-REL-R01
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.	AD1 : IRD-REL-R02
Cold redundant hardware shall be provided wherever practicable within the instrument design.	AD1 : IRD-REL-R03

4.2.18 Failure Modes

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.	AD1 : IRD-SAFE-R08
Failure of any component in a subsystem shall not damage any redundant or backup component designed to replace that component in the subsystem	AD1 : IRD-SAFE-R09
No electronics sub-unit shall be capable of affecting instrument operations until it is in a defined state. This state shall be confirmed in the housekeeping telemetry.	AD1 : IRD-SAFE-R10

4.3 Operational Specification

4.3.1 Operational Safety

The BSM shall operate safely in any normal operating mode.	This document

4.3.2 Lifetime

The BSM shall be capable of operation in any normal mode for periods in excess of 1/6 of the nominal mission lifetime.	AD1
All sub-systems are required to demonstrate that they will operate successfully over the 4.25 years of expected mission operations.	AD1 : IRD-SUBS-R02
Lifetime tests of items operating <100000 times will use factors as specified in RD 16; i.e. Lifetime tests of the chop/jiggle mode will use a multiplier of 1.25x for on-orbit cycles and 4x for ground test cycles.	RD16

Life time breakdown

#	Parameter	IRD	Value	Note
OL1	Ground Storage lifetime		2 years	A guess
OL2	Ground Integrated lifetime		4 years	A guess
OL3	Ground operational lifetime		1.5 years TBC	6 months for subsystem acceptance 6 months for SPIRE acceptance 6 months for HERSCHEL acceptance Broken down, nominally (TBC): 1M cycles during BSM check out at ATC 1M cycles during BSM check out at RAL 1M cycles during system integration, e.g. checking for cross talk, vibration, EMC. 1M cycles during observing mode checkout. 1M cycles for ESA/Herschel integration. 0.3M cycles spare.
OL4	On orbit operational (chop & jiggle mode) Lifetime		Minimum 8.5 months cumulative time	Operating during 1/6 of the mission duration (4.25 years)
OL5	On orbit de-powered operational Lifetime		Up to 3.5 years cumulative time	TBD
OL6	On Orbit powered but not chopping (servo control only)		Up to 3.5 years cumulative	TBD May be required if self-damping inadequate in face of micro-vibration environment

			time	

4.3.3 Operating modes

AD14 defines the required modes of operation in detail. There are 14 (TBC) operational modes, but from the point of view of the BSM motion they fall into three categories :

Jiggle	AD14
Chopping	AD14
Scan mapping	AD14

Additionally holding the 'stare' position may require active servo control.

4.3.4 Jiggle Mode

Jiggle Mode is used to optimize the sampling of the detector arrays. In this mode, the mirror is stepped in small angular increments. Jiggling may be done in any angular orientation (i.e. jiggling is not confined to the jiggle axis, and will usually be a combination of movements in the chop and jiggle axes).

Jiggle movements may be demanded in both chop and jiggle axes simultaneously. The fine pointing mode is executed as a jiggle pattern, and the difference lies in the processing/use of the data.

Jiggle mode will be used with both the photometer and the FTS. When the FTS is in use no chop will be required. During a photometer jiggle operation the BSM is also required to chop. i.e. at each jiggle position a number of chop cycles will be executed.

4.3.5 Chopping Mode

Chopping Mode is used to provide removal of 1/f noise in the photometer detectors. The mirror is used to move the source of interest between two separate detectors.

Chopping is only required in one axis (the chop axis), and will only be used when the photometer is in use, not with the FTS

4.3.6 Scan mapping

Scan mapping with chopping may be required. The jiggle and chop axes are used to execute chopping either parallel to or perpendicular to the scan direction, with the frequency of chop set by the jiggle axis frequency limit.

4.3.7 Stare or 'holding' mode

Dependent on spacecraft vibration levels, the BSM may require active servo control in order to maintain the nominal 'power-off' hold position within adequate accuracy. This is TBD.

4.3.8 Combinations of Modes

The following combinations of the basic modes are required.

1. Chopping and Jiggling
2. Removal of optical or mechanical cross coupling during Chop-only or Jiggle-only operations.

4.4 Interface requirements

4.4.1 Data Outputs

The following data is provided by the BSMe via the MCU.

Data	Rate	Reference
Chop axis position	requirement 40Hz, TBC goal 80Hz.TBC	This document
Jiggle axis position	requirement 40Hz, TBC goal 80Hz.TBC	This document
Thermometer data	1Hz (TBC)	??? email
Motor voltage (or current, TBD) at a low rate for house-keeping	<100Hz (TBC)	ATC/LAM meeting May.00
Motor voltage (or current, TBD) at a high rate for trouble shooting of transient effects (e.g. control systems tuning)	TBD	ATC/LAM meeting May.00

4.4.2 Data Inputs

The following inputs are required to operate the BSM.

Data	Rate	Reference
Chop axis demand position	On Demand, max. 5Hz	AD19
Jiggle axis demand position	On Demand, max. 1Hz	AD19
Control system parameters (PID terms)	TBD, but slow	AD19
Trajectory parameters (3 for each axis)	TBD, but slow	AD19
Unlatch signal, if required	One-off	AD19

4.4.3 Exported vibration

The BSM will produce vibration in the region 0-5 Hz, with TBD harmonics and TBD amplitude.

The BSM shall induce micro-vibration measured on the optical bench (TBC at the detector sub-system mounting position), of less than 10 micro-g (9.81 µm/s²).	This document

4.4.4 Stray Magnetic fields

To prevent spurious signal generation, magnetic field strength at the BSM position sensors should not exceed TBD	This document

4.4.5 Electro-Magnetic Compatibility

TBD - Grounding, Radiated emissions, etc…

4.4.6 ICD's

The BSM interfaces with the following other subsystems in the SPIRE instrument. The interface to each subsystem is specified in the relevant Interface Control Document.

4.5 BSM interface reference table

The master reference table is located in RD1.

ID	Sub-System	Organization responsible[2]	External ICD document	Internal ATC ICD document	Internal ATC ICD drawing/ file
1	BSM-SPIRE	RAL	Instrument Requirements Document (IRD). SPIRE-RAL-PRJ-000034 v0.30 May.00	SPIRE-ATC-PRJ-000587 Annex A	SPIRE-BSM-021-001-001
2.1	Structure – BSM	MMSL	ICD Structure - Mechanical I/F SPIRE-MSS-PRJ-000xxx v1.0 April 2001	SPIRE-ATC-PRJ-000587 Annex B	SPIRE-BSM-021-002-001
2.2	Structure – BSM	MMSL			SPIRE-BSM-021-002-002 (IGES file)
2.3	Thermometry	RAL	TBD		SPIRE-BSM-021-002-003
3	Photometer Calibration Source - BSM	UoW, Cardiff	TBD	SPIRE-ATC-PRJ-000587 Annex C	SPIRE-BSM-021-003-001
4	Launch Latch – BSM	LAM (TBC)	Spectrometer mirror mechanism design description LAM.SPI.PJT.NOT.200008 Ind 3	SPIRE-ATC-PRJ-000587 Annex D	SPIRE-BSM-021-004-001
5.1	Optics – external finish	LAM	Optical System Design Description SPIRE-LAM-PRJ-000447 Draft 1 18.Dec.00	SPIRE-ATC-PRJ-000587 Annex E	SPIRE-BSM-021-005-001
5.2	Optics – BSM	RAL	???		SPIRE-BSM-021-005-002

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[2] i.e. responsible for feeding ICD info upwards to SPIRE system design

ID	Sub-System	Organization responsible[2]	External ICD document	Internal ATC ICD document	Internal ATC ICD drawing/ file
5.3	Baffles – BSM	RAL	???		SPIRE-BSM-021-005-003
6	Cryo-Harness	RAL / MSSL	SPIRE Harness Definition. SPIRE-RAL-PRJ-000608 Issue: 0.3 30.May.01 Harness routing : TBD (MSSL)	SPIRE-ATC-PRJ-000587 Annex F	SPIRE-BSM-021-006-001
7.1	MCU-BSM	LAM	???	SPIRE-ATC-PRJ-000587 Annex G	SPIRE-BSM-021-007-001
7.2	On Board Software - BSM	LAM	???		SPIRE-BSM-021-007-002
8	Photometer Bolometer Arrays - BSM	MSSL	ICD Structure - Mechanical I/F SPIRE-MSS-PRJ-000xxx v1.0 April 2001	Sub-System Specification EMC/ exported vibration ???	
9	Spectrometer Bolometer Arrays - BSM	MSSL	ICD Structure - Mechanical I/F SPIRE-MSS-PRJ-000xxx v1.0 April 2001	Sub-System Specification EMC/ exported vibration ???	
10	FPU Simulator - BSM	TBD	TBD	TBD	
11	Instrument Simulator - BSM	TBD	TBD	TBD	

4.6 Design, manufacture and test requirements

This section details additional requirements which are placed on the sub-system which are not necessary to meet the functional or operational requirements, but are necessary to enable the sub-system to be designed, manufactured or tested. These are encapsulated as Product Assurance requirements and are fully covered in the BSM Product Assurance Plan, AD22

4.6.1 Design requirements

UK Astronomy Technology Centre design procedures shall be adopted as applicable.

4.6.2 Electronics Card Format

All electronics associated with the BSMe shall be mounted on double eurocards [AD19].

4.6.3 Product Assurance Plan

The BSM deliverables will comply with the Spire Product Assurance Plan, AD20, and the BSM Product Assurance Plan AD22 .

Specific requirements are noted below, otherwise AD22 will be adopted.

4.6.3.1 Mirror Flatness

To facilitate optical laboratory testing, the mirror surface shall have a flatness of <100nm (P-V) TBC and an rms of TBD.

4.6.3.2 Mirror Reflectivity

To facilitate optical testing laboratory testing, the mirror surface shall have a reflectivity of >80% at 633nm by design.

4.6.3.3 Cleanliness

The BSM shall be assembled to class 1000 cleanliness, but shall be class 100 compatible by design.

4.6.3.4 Material selection

Structures will be a 6082 grade aluminium alloy to UK standards, and will be selected in consultation with the optical bench design body (MSSL). The BSM mirror may be specified in grade 6061-T6/T651 to ensure adequate thermal stability based on ATC practice.

Fasteners will be cryogenic grade stainless steel. Where practicable they will be of a self locking type. Fasteners may include UNS thread types where required on the grounds of availability in small sizes, or as required by ICD, otherwise will be metric thread. In cases where a self locking fastener is not available, Stycast or Scotchweld 1838 will be used in visible applications under fastener heads.

4.6.3.5 Storage

The BSM shall not suffer any performance degradation following storage in a dry nitrogen atmosphere for a period of up to 5 years.

Storage temperatures shall be in the range +5°C to +30°C.

4.7 Environmental requirements

These requirements describe the environment the subsystem will encounter during its life.

4.7.1 Operating environment

This section defines the environment for the BSM during operation. The BSM must meet all of the functional and operational requirements specified in section 4 when operating under this environment.

All subsystems are required to undergo an environmental test programme that demonstrates the design and build standard of the sub-system models will be compatible with the environmental test programme to be carried out on the appropriate integrated instrument model.	IRD-SUBS-R01

4.7.1.1 Shock

No Shock specification is applied (TBC). As a working figure 50g static acceleration loads in all three axes are assumed.	AD2

4.7.1.2 Quasi Static Loads

For the BSM sub-system these are derived from the random vibration specification (see 4.7.1.4) using the Miles SDOF approximation to estimate rms and peak acceleration.	AD2
For the SPIRE instrument as a whole the following Quasi-Static flight limit load are given. Per AD22 *"All subsystems will be subjected to the same environment as defined above. The in table 1.4-1 defined accelerations are very important for limiting interface loads for the various sub-systems subjected to either sine, random or shock loads".*	AD22, table 1.4-1

Quasi Static levels	Case 1	Case 2	Case 3
x-direction	25 g	-	-
y-direction	-	14 g	-
z-direction	-	-	14 g

4.7.1.3 Sine Vibration

The provisional Qualification sine input (2 oct/min) specification is (As specified in AD2, AD22 these include the qualification factor of 1.5) :	AD22 Table 2.9.6-1

Sine vibration levels	Frequency range	Input at base (QUAL)
X-direction	5-30 Hz 30-100 Hz	11 mm (0-peak) 40 g
Y-direction	5-30 Hz 30-100 Hz	11 mm (0-peak) 25 g
Z-direction	5-30 Hz 30-100 Hz	11 mm (0-peak) 25 g

4.7.1.4 Random Vibration

BSM random Specification			Ref. instrument co-ordinate system			Email B.Winters 26.Jun.01		
X 60 sec f	g^2/hz Accept	g^2/hz Qual	Y 60 sec f	g^2/hz Accept	g^2/hz Qual	Z 60 sec f	g^2/hz Accept	g^2/hz Qual
20	0.004	0.008	20	0.006	0.011	20	0.005	0.010
40	0.016	0.032	40	0.022	0.044	40	0.020	0.039
60	0.036	0.072	60	0.050	0.100	60	0.044	0.089
80	0.064	0.128	80	0.089	0.177	80	0.079	0.158
100	0.100	0.200	85	0.100	0.200	90	0.100	0.200
150	0.100	0.200	100	0.700	1.399	200	0.100	0.200
155	0.100	0.200	150	0.700	1.399	210	0.100	0.200
230	0.100	0.200	160	0.150	0.300	250	0.100	0.200
235	0.100	0.200	165	0.150	0.300	255	0.100	0.200
350	0.100	0.200	300	0.150	0.300	300	0.100	0.200
800	0.019	0.038	800	0.021	0.042	800	0.014	0.028
1000	0.012	0.024	1000	0.013	0.027	1000	0.009	0.018
1500	0.005	0.011	1500	0.006	0.012	1500	0.004	0.008
2000	0.003	0.006	2000	0.003	0.007	2000	0.002	0.004
g-rms	8.1	11.4	g-rms	11.1	15.7	g-rms	7.7	10.9

4.7.1.5 Vacuum Level

Less than 10-4 Pa TBC	???

4.7.1.6 Vacuum Outgassing

Materials shall have a low outgassing rate with Total Mass Loss (TML) <1% and Volatile Condensable Material (VCM) = 0.1%	AD22

4.7.1.7 Temperature

The BSM shall perform within specification at the operational temperature cited in 4.2.2. In addition, the BSM will operate with reduced performance at temperatures from 4-300K.	RD1

4.7.1.8 Magnetic Fields

To prevent spurious position signal input, stray magnetic fields must not exceed TBD at the chop and jiggle position sensors.	TBD

4.7.1.9 Survival Temperature

The BSM shall remain fully operational following exposure to temperatures of 80°C for periods of up to 72 hours. (bakeout)	AD1

4.7.1.10 Radiation environment

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).	RD2

Non-ionizing energy loss [MeV/g(Si)]				RD4
Shield thickness	3 Years	5 Years	10 Years	
2mm Aluminium	1.83E+08	1.86E+08	2.62E+08	
5mm Aluminium	7.57E+07	7.66E+07	1.03E+08	

Total ionizing radiation dose in Si [rad]				RD4
Shield thickness	3 Years	5 Years	10 Years	
2mm Aluminium	1.01E+04	1.04E+04	1.46E+04	
5mm Aluminium	3.79E+03	3.88E+03	5.11E+03	

4.8 Verification requirements

The BSM Development Plan (AD15) contains more detail on the actual tests to be carried out on the BSM. The table below shows how each of the functional and operational requirements in this document is to be demonstrated, for each of the deliverable BSM models. The deliverable models include the STM (deliverable to RAL but not ESA), CQM, PFM, FS

Key:

Test		T
Measurement		M
Analysis	, Reference to calculations and previous tests, assumption	A
Inspection		I
Not Applicable		X

Notes:

- The STM model may be delivered as a fixed mass with no mirror or a fixed mirror (TBD) The minimum requirements verification is specified accordingly. In the event that a representative rotating mirror is provided, the CQM test requirements will apply (TBC).
- Tests and measurements are distinguished in that measurements are simple procedures e.g. to measure dimensions, mass etc. A test will in most cases include some combination of measurement devices, set up procedures, inspection, calibration, calculation, etc in order to demonstrate a requirement.

4.8.1 Performance Requirements

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.1.1	Angular Travel - Chop Axis	X	T	T	T	
4.1.2	Angular Travel - Jiggle Axis	X	T	T	T	
4.1.3	Minimum Step Size	X	T	T	T	
4.1.4	Chop Frequency	X	T	T	T	
4.1.5	Jiggle Frequency	X	T	T	T	
4.1.6	Holding position	X	T	T	T	
4.1.7	Stability	X	T	T	T	
4.1.8	Position Measurement	X	T	T	T	
4.1.9	Settling Time	X	T	T	T	
4.1.10	Chop repeatability	X	T	T	T	

4.8.2 System Requirements

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.2.1	Mechanical Dimensions	M	M	M	M	
4.2.2	Operating Temperature	T	T	T	T	
4.2.3	Thermal Isolation	T	T	T	T	
4.2.4	Cold Power Dissipation	X	T (a)	T	T	(a) Cold power dissipation of the CQM may not be compliant if non-space rated components are used for motor coils
4.2.5	Warm Electronics Power Dissipation	X	T	T	T	
4.2.6	Mirror Surface Dimensions	M (b)	M	M	M	(b) X if STM has no mirror
4.2.7	Mirror Surface Finish	I/M (c)	I/M	I/M	I/M	(c) X if STM has no mirror
4.2.11 & 4.2.8	Mirror Surface Reflectivity	A(d)	A	A	A	(d) X if STM has no mirror
4.2.9	Mirror Surface Emissivity	X	X	X	X	Complement of 4.2.11 & 4.2.8
4.2.10	Baffle	X	M/T	M/T	M/T	Measurement will be against design drawings. Tests only performed on integration at RAL
4.2.11	Position of Rotation Axes	M/I (e)	M/I	M/I	M/I	(e) X if STM has no mirror
4.2.12	Orthogonality of Rotation Axes	X	T	T	T	
4.2.13	Fail Safe (No Drive Signal) Position	X	T/A(f)	T/A(f)	T/A(f)	(f) May require supporting analysis of rest position in 1 g field is not (0,0)
4.2.14	Fail Safe (Mechanical Failure) Position	X	X	T/A(g)	T/A(g)	(g) Demonstrated on tests on QM or DM
4.2.15	Mass	M	M	M	M	
4.2.16	Cool-down time	T	T	T	T	Cooldown times will be dependent on cryostat configuration.

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.2.17	Reliability	X	X	A(h)	A(h)	(h) demonstrated by QM programme and by design/analysis
4.2.18	Failure Modes	X	X	A(j)	A(j)	(j) demonstrated by QM programme and by design/analysis

4.8.3 Operational Specification

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.3.1	Operational Safety	A	A	A	A	Demonstrated by analysis/design/risk assessment
4.3.2	Lifetime	X	X	A(k)	A(k)	(k) demonstrated by QM programme
4.3.3	Operating modes	X	T(l)	T	T	(l) CQM will not have redundant modes
4.3.4	Jiggle Mode	X	T	T	T	
4.3.5	Chopping Mode	X	T	T	T	
4.3.6	Scan mapping	X	X	X	X	Only applicable on spacecraft
4.3.7	Stare or 'holding' mode	X	T	T	T	
4.3.8	Combinations of Modes	X	T	T	T	

4.8.4 Interface requirements

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.4.1	Data Outputs	X	T	T	T	Fully demonstrated only on integration at LAM/ RAL . ATC tests will demonstrate compliance to ICD
0	Data Inputs	X	T	T	T	Fully demonstrated only on integration at LAM/ RAL . ATC tests will demonstrate compliance to ICD
4.4.3	Exported vibration	X	T	T	T	On integration to SPIRE at RAL
4.4.4	Stray Magnetic fields	X	T	T	T	On integration to SPIRE at RAL
4.4.5	Electro-Magnetic Compatibility	X	A/T	T	T	On integration to SPIRE at RAL
4.4.6	ICD's	I/M/T	I/M/T	I/M/T	I/M/T	

4.8.5 Design, manufacture and test requirements

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.6.1	Design requirements	A	A	A	A	Compliance indicated in ADP
4.6.2	Electronics Card Format	X	I	I	I	Inspection of LAM deliverables
4.6.3.1	Mirror Flatness	M(m)	M	M	M	(m) X if STM has no mirror
4.6.3.2	Mirror Reflectivity	A(n)	A	A	A	(n) X if STM has no mirror
4.6.3.3	Cleanliness	I	I	I	I	Compliance determined by TBC
4.6.3.4	Material selection	I	I	I	I	Compliance indicated in ADP
4.6.3.5	Storage	A	A	A	A	Compliance indicated in ADP

4.8.6 Environmental requirements

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.7.1.1	Shock	X	X	X	X	No requirement
4.7.1.2	Quasi Static Loads	T	X	A(o)	A(o)	(o) demonstrated by QM programme
4.7.1.3	Sine Vibration	T	X	A(p)	A(p)	(p) demonstrated by QM programme
4.7.1.4	Random Vibration	T	X	A(q)	A(q)	(q) demonstrated by QM programme
4.7.1.5	Vacuum Level	T	T	T	T	
4.7.1.6	Vacuum Outgassing	A	A	A	A	Demonstrated via materials selection and Compliance indicated in ADP
4.7.1.7	Temperature	T	T	T	T	
4.7.1.8	Magnetic Fields	X	TBD	TBD	TBD	EMC tests performed when integrated at RAL. Tests to be determined once specification exists

Reference	Requirement	STM	CQM	PFM	FS	Notes
4.7.1.9	Survival Temperature	T	T	T	T	
4.7.1.10	Radiation environment	X	X	TBD	TBD	EMC tests performed when integrated at RAL. Tests TBD

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