SPIRE Beam Steering Mirror Subsystem Specification Document

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DOCUMENT APPROVAL

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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.
29.Jan.02	3.3	Optical scaling factor and FoV change: chop now +/-2.53°. Added degraded modes

Date	Index	Remarks
30.Nov.02	3.4	Close out of RID HR-SP-ATC-RID-05
07.Apr.03		Added distribution list. Amended table of contents. Removed highlights except on TBC/D's. Updated AD table and moved mirrors specification to an AD §4.1.7 : updated inline with ECR: HR-SP-ATC-003. §4.1.8 : updated inline with ECR: HR-SP-ATC-003., §4.2.1 : corrected typographic error : 20mm should read 120mm. §4.2.6 noted ellipsoid specification, moved flatness to this area. Added tolerance to PCAL dia (rather than 'less than'). §4.2.7 added area obscuration spec. §4.2.11 Changed Position of Rotation Axes per AD27 and achievable ATC targets §4.2.12 TBC changed to an ATC goal §4.3.2 removed TBC on OL5, 6 §4.3.3 removed number of modes §4.3.7 removed TBC. §4.4.1 & 2 : updated telemetry in line with latest issue AD19 §4.4.3 reworded micro-vibration export §4.4.4 added IID-A magnetic mask §4.4.5 referred to IID-A EMC requirements §4.5 added PCAL ICD doc number. Updated all document numbers.
23.Apr.03	3.5	§4.1.8 accuracy & resolution terminology clarified §4.1.9 settling angle on the sky added from IRD to improve traceability of requirement. §4.2.14 fail safe position wording changed. Added asymmetric FOV of spectrometer §4.2.11 added generic ATC tolerance goals on position of mirror centroid with respect to rotation axes (no formal requirements from SPIRE optical team).
24.Apr.03	3.6	Added Requirements numbering to aid traceability (format BSM-SSD-R-xx) §4.1.9 included both axes in settling time (ie covers cross talk too) §3.3 removed block diagram and replaced with RD8
10.Sep.03	3.7	Revised Verification Matrix Revised Applicable Document List

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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 v1.1	10.Jan.02
AD2	SPIRE Structure Mechanical ICD	B.Winters	MSSL/SPIRE/SP004.11 (formerly SPIRE-MSS-PRJ-00617)	29.Nov.01
AD3	ICD drawing: Structure: BSM	N/A	Drg No A2/5264/907 issue 6	
AD4	Optics - BSM ICD	T.Peacocke, I.Pain	SPIRE-ATC-PRJ-000713 v3.0 (SPIRE-ATC-PRJ-001171)	Sep.03
AD5	Baffles - BSM ICD	T.Peacocke, I.Pain	SPIRE-ATC-PRJ-000713 v3.0 (SPIRE-ATC-PRJ-001171)	Sep.03
AD6	Incorporated in AD2			
AD7	Incorporated in AD2			
AD8	Photometer Calibration Source - BSM ICD	I.Pain	SPIRE-ATC-PRJ-000713 v3.0 (SPIRE-ATC-PRJ-001171)	Sep.03
AD9	Deleted	N/A		
AD10	On Board Software - BSM ICD	B.Stobie	SPIRE-ATC-PRJ-000713 v3.0 (SPIRE-ATC-PRJ-001171)	Sep.03
AD11	Deleted			
AD12	Deleted			
AD13	Applicable Optical Configuration	T.Richards	PH154B , SP501E	Per AD26
AD14	Operating Modes for the SPIRE Instrument	B.M.Swinyard	SPIRE-RAL_PRJ 000320 issue 3.0	1.Oct.01
AD15	BSM Sub-system Development Plan	I.Pain	SPIRE-ATC-PRJ-000466 v5.1	30.Jan.02
AD19	MCU-BSM ICD	I.Pain	SPIRE-ATC-PRJ-000713 v3.0 (SPIRE-ATC-PRJ-001171) MPU/DPU Command List ICD Iss3.0 15/01/03	Sep.03
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 v1.4	9.Jul.03

Ref	Title	Author	Reference	Date
AD23	Optical System Design Description	K.Dohlen, B.Swinyard	SPIRE-LAM-PRJ-000447 Draft 1	18.Dec.00
AD 24	SPIRE Cleanliness Plan	B.Swinyard	SPIRE-RAL-PRJ-1070 V1.0	09.Jan.02
AD 25	Identification of primary and secondary chop pixels in the SPIRE photometer arrays	B.Swinyard	SPIRE-RAL-NOT-001013 Issue: 1.0	15 Nov 01
AD 26	Angular Scaling Factors for the chop and jiggle movements of the BSM	T.Richards	SPIRE-RAL-NOT-001050	13.Dec.01
AD 27	Optical System Design Description	D.Pouliquen	SPIRE-LAM-PRJ-000457 (LAM.PJT.SPI.SPT.200007 Ind 7)	12.Jul.01
AD 28	Email discussion of scratch/dig/obscuration	K.Dohlen	Re: BSM Sub-system Spec Doc.	15.Nov.02
AD 29	Herschel/SPIRE revised random and static spec for SOB mounted sub-systems	B.Winters	Email	25Jan03

2.2 Reference documents

Ref	Title	Author	Reference	Date
RD1	SPIRE BSM Design Description Document	Ian Pain	SPIRE-ATC-PRJ-000587 v4.1	20.Feb.02
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	Moved to AD27			
RD6	IID-A	HERSCHEL/Planck Project Team	SCI-PT-IIDA-04624 rev 3.0	24Jul02
RD7	IID-B	ESA HERSCHEL/ Planck Project Team	SCI-PT-IIDB/SPIRE-02124 rev 2/2	01Jul02
RD8	SPIRE Block Diagram	J.Delderfield	SPIRE-RAL-DWG-000646 (issue 5.3)	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
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	SOB	SPIRE Optical Bench
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 mechanism** (BSMm).
2. **The structural interface** (BSMs).
3. **The warm electronics** (BSMe)
4. **Mass and optical alignment dummies, and Ground Support Equipment (GSE) as required for SPIRE system level integration,** (BSMd)

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

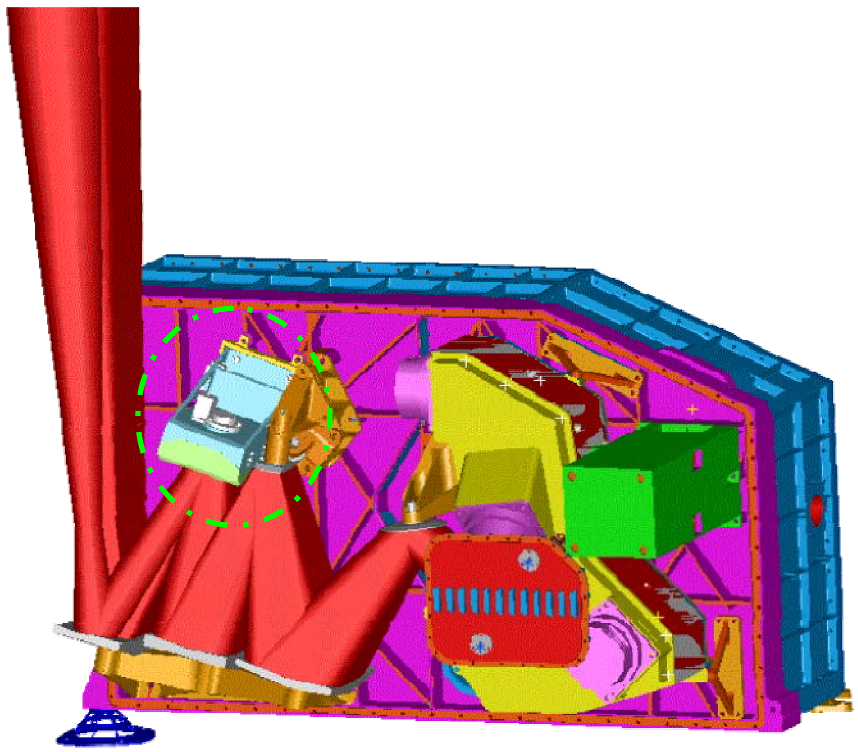

Figure 1 Photometer Layout, BSM, highlighted with green dashed oval

The BSMm 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 2.53 ° of mirror motion at 2 Hz and the jiggle axis provides 0.57° 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 ATC) 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 grade N42) 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 SPIRE block diagram showing the BSM is contained in a self contained document RD8 and shows the relationships between the sub-systems of the SPIRE instrument.

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 applies, as given in AD26.

Chop :	51.37 arc.sec/degree, or a scaling factor of	70.08:1
Jiggle :	52.36 arc.sec./degree, or a scaling factor of	68.75:1

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

BSM-SSSD-R 1 The BSM shall allow angular movement of the mirror surface through an angle of ±130 arc.sec on the sky. This is +/-2.53° in the mirror chop axis. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R01 IID-B SRD-R9 IRD-PHOT-R17
BSM-SSSD-R 2 The minimum available chop throw shall be +/- 0.1° (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-B SRD-R9
BSM-SSSD-R 3 The plate-scale varies from top to bottom and left to right of the image by a few percent, the maximum distance to the outer of these pixels is 129.5 arcsec if the arrays are well aligned. The maximum displacement of the arrays could be up to 2 arcsecs, therefore to use these pixels for point source chopping the BSM should have the capability chop to at least 132 arcsec.	AD25

4.1.2 Angular Travel - Jiggle Axis

BSM-SSSD-R 4 The BSM shall allow angular movement of the mirror surface through an angle of +/- 30 arc.sec on the sky. This is ±0.573° in the mirror jiggle axis. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R02

4.1.3 Minimum Step Size

BSM-SSSD-R 5 The BSM shall allow movements of the mirror surface in both chop and jiggle axes in minimum increments of 2 arc.sec on the sky in either chop or jiggle. This is 0.038° jiggle, 0.039° chop. (see assumption 3.4 for corresponding on-sky motion).	AD1 : IRD-BSMP-R03

4.1.4 Chop Frequency

BSM-SSSD-R 6 The BSM shall allow movements of the mirror in the chop axis at any frequency, continuously variable or in 16 steps, up to 2Hz for nominal operation and power dissipation	AD1 : IRD-BSMP-R04
BSM-SSSD-R 7 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

BSM-SSSD-R 8 The BSM shall allow movements of the mirror in the jiggle axis at any frequency up to 0.5Hz.	AD1 : IRD-B SMP-R05
BSM-SSSD-R 9 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

BSM-SSSD-R 10 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

BSM-SSSD-R 11 The angle on the sky must not vary by more than 0.2 arcsec (on the sky) per axis over 60 seconds at the commanded mirror position. The mirror position shall also have stability equivalent to 0.2 arcsec (rms) per axis in the 0.03 - 25Hz frequency band.	AD1 : IRD-BSMP-R06 SPIRE-RAL-NOT-001457 ECR : HR-SP-ATC-003

4.1.8 Position Measurement

BSM-SSSD-R 12 The knowledge of the mirror position shall be equal to or less than the equivalent of 0.025 arcsec on the sky in each axis (Equivalent requirement on mirror position = 0.00049° chop axis and 0.00048° jiggle axis).	AD1 : IRD-BSMP-R07 SPIRE-RAL-NOT-001457 ECR : HR-SP-ATC-003
In standard engineering terms, this requirement to define both 'accuracy' (0.004° on mirror) and 'resolution' (0.0005° on mirror)	This document

4.1.9 Settling Time

BSM-SSSD-R 13 The angular position of the mirror surface shall be within 1 arc.sec on the sky (i.e. 0.019° on the mirror) of the mean steady state position (in both axes) in less than 20 milliseconds from the application of a demand in the chop axis.	AD1 : IRD-BSMP-R08
BSM-SSSD-R 14 The angular position of the mirror surface shall be within 0.019° of the mean steady state position (in both axes) in less than 0.100 sec from the application of a demand in the jiggle axis.	This document
BSM-SSSD-R 15 As a goal, the angular position of the mirror surface shall be within 0.019° of the mean steady state position (in both axes) in less than 0.050 sec from the application of a demand in the jiggle axis.	This document

4.1.10 Chop repeatability

BSM-SSSD-R 16 The steady state repeatability between successive chop cycles shall be less than 0.004° (rms) on the mirror over 4 hours.	This document

4.2 Technical Specifications

4.2.1 Mechanical Dimensions

BSM-SSSD-R 17 The BSMm shall fit within a volume of 130x130x30 mm (excluding mounting structure).	AD1 : IRD-BSMP-R09
BSM-SSSD-R 18 The BSM, including mounting structure, shall fit within a volume of 132x95x120mm	AD21
BSM-SSSD-R 19 The BSM mounting structure footprint is as defined in MSSL Interface drg. A2-5264-907 and ATC Interface drawing SPIRE-BSM-SPIRE-BSM-024-002 (latest revision)	AD2 AD21

4.2.2 Operating Temperature

BSM-SSSD-R 20 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)
BSM-SSSD-R 21 The BSM shall be capable of operation (with reduced performance) at temperatures up to 300K.	AD1 : IRD-BSMP-R10

4.2.3 Thermal Isolation

BSM-SSSD-R 22 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

BSM-SSSD-R 23 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

Removed : IRD issue 1.0, now in WE requirements	AD1 : IRD-BSMP-R13

4.2.6 Mirror Surface Dimensions & Form

BSM-SSSD-R 24 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
BSM-SSSD-R 25 The mirror shall include a central hole of 2.8+/-0.1mm diameter to allow the Photometer Calibrator to be seen by the detectors. ***BSM-SSSD-R 26*** Goal – the design shall accommodate a central aperture up to 8mm without significant structural alteration being required.	AD13 (this)
BSM-SSSD-R 27 The mirror shall encompass an ellipse 30x32mm	AD27
BSM-SSSD-R 28 The mirror surface of the BSM shall be flat to <1µm rms (at the mirror, 2µm rms at the wavefront) at 4K . This should be validated by cold testing.	AD13, AD27

4.2.7 Mirror Surface Finish

BSM-SSSD-R 29 The mirror shall have a surface roughness of <10nm (rms) at 4K This may be established by room temperature testing.	AD13, RD5
BSM-SSSD-R 30 The area obscuration due to combined scratch, dig and other defect shall be less than 0.1%.	AD27, AD28

See also 4.6.3.1.

4.2.8 Mirror Surface Reflectivity

BSM-SSSD-R 31 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

BSM-SSSD-R 32 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 0 . ***BSM-SSSD-R 33*** 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

BSM-SSSD-R 34 The position of the Rotation Axes shall be established accurately prior to delivery to RAL to better than 0.5 mm and 0.5°, allowing a positive allowance for machining of interface shoe on integration. ***BSM-SSSD-R 35*** After machining of the interface shoe on integration to SOB the BSM axes must be in the nominal design position +/- 0.25mm and +/-0.05°.	This document
BSM-SSSD-R 36 The BSM shall be designed such that it may be repositioned on the SPIRE optical bench within a repeatability of 0.05 mm and 1 arc.minute	AD 27
BSM-SSSD-R 37 ATC Goal: Rotational motions of the axes shall produce a lateral de-centre of the axis of rotation of less than 10 microns	This document
BSM-SSSD-R 38 ATC Goal: the mirror surface centroid shall be correctly assembled at the theoretical design point defined by intersection of the boresight with the axis of jiggle rotation to within 0.5mm spherical.	This document
BSM-SSSD-R 39 ATC Goal: the mirror surface centroid shall be correctly assembled at the theoretical design point defined by intersection of the boresight with the axis of chop rotation to within 0.3mm spherical.	This document

4.2.12 Orthogonality of Rotation Axes

BSM-SSSD-R 40 ATC Goal: The orthogonality of the rotation axes shall be within 0.15°.	This document

4.2.13 Fail Safe (No Drive Signal) Position

BSM-SSSD-R 41 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

BSM-SSSD-R 42 The BSM design shall mitigate against any single failure on launch making the beam unusable by the spectrometer instrument, i.e. That in the event of a failure of flex pivots the mirror surface is either retained, or can be returned, perpendicular to the nominal (0,0) mirror position to within +0.573 to -2.53° in the chop axis.	ECR HR-SP-ATC-002

4.2.15 Mass

BSM-SSSD-R 43 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

BSM-SSSD-R 44 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.	Source unknown

4.2.17 Reliability

BSM-SSSD-R 45 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
BSM-SSSD-R 46 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
BSM-SSSD-R 47 Cold redundant hardware shall be provided wherever practicable within the instrument design.	AD1 : IRD-REL-R03

4.2.18 Failure Modes

BSM-SSSD-R 48 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
BSM-SSSD-R 49 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
BSM-SSSD-R 50 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

BSM-SSSD-R 51 The BSM shall operate safely in any normal operating mode.	This document

4.3.2 Lifetime

BSM-SSSD-R 52 The BSM shall be capable of operation in any normal mode for periods in excess of 1/6 of the nominal mission lifetime.	AD1
BSM-SSSD-R 53 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
BSM-SSSD-R 54 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 nominal	6 months for subsystem acceptance 6 months for SPIRE acceptance 6 months for HERSCHEL acceptance Broken down, nominally: 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	Based on 5/6 of the mission duration
OL6	On Orbit powered but not chopping (servo control only)		Up to 3.5 years cumulative time	This is the baseline design assumption and is required in the event that self-damping is inadequate in the spacecraft micro-vibration environment

4.3.3 Operating modes

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

BSM-SSSD-R 55 Jiggle	AD14
BSM-SSSD-R 56 Chopping	AD14
BSM-SSSD-R 57 Scan mapping	AD14
BSM-SSSD-R 58 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 the baseline.

4.3.8 Degraded modes

4.3.8.1 Slow Chop Mode

AD 14, section 6.2 : If the BSM suffers a failure that prevents it from chopping at the default frequency due to sticking or excessive dissipation, it may be that it may have to be chopped very much more slowly. This implies that :

BSM-SSSD-R 59 the control circuitry and algorithms must be capable of driving the BSM at any frequency from DC up to the maximum allowable by the design. A range of chop frequencies must be identified and the instrument response at these frequencies characterised before launch.	This document

4.3.8.2 BSM Open Loop

AD 14, section 6.3: In the event of a failure of the position sensor on the BSM chop axis, it must still be possible to operate the BSM by commanding the current to the actuators directly. This mode of operation may lead to a loss of efficiency as the chopping mirror will not be under control and may take some time to become stable after movement.

BSM-SSSD-R 60 The behaviour of the BSM under open loop control must be characterized and suitable current demand algorithms devised to allow at least the chopped mode to be carried out in the event of loss of the chop axis position sensor.	This document

4.3.8.3 Single Axis BSM Operation

AD 14, section 6.4 : It may be that one axis of the BSM stops working during the mission. In this case it must be possible to use the other axis on its own to chop or, if the chop axis is lost, at least to pixel-swap on one of the detector arrays. It may be that there is some mechanical cross talk between the axes and demand will be required on both axes during nominal operation to achieve accurate positioning. If this is the case:

BSM-SSSD-R 61 the operation of each axis in the absence of the other must be possible and this mode of operation fully characterized before launch.	This document

4.3.9 Combinations of Modes

BSM-SSSD-R 62
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

BSM-SSSD-R 63 Chop axis position	@ 4,16 or 64 Hz depending on Instrument Scientific Mode	AD19
BSM-SSSD-R 64 Jiggle axis position	@ 4,16 or 64 Hz depending on Instrument Scientific Mode	AD19
BSM-SSSD-R 65 Engineering/Trace data (e.g. Motor volts/current	@ 2.778 kHz	AD19

Thermometry data is passed directly to the thermometry sub system, for which no specification is placed on the BSM or MCU.

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)	occasional	AD19
Trajectory parameters (3 for each axis)	deleted	AD19
Unlatch signal, if required	One time only	AD19
Sensor Power on/off	On/off	AD19

4.4.3 Exported vibration

The BSM will produce vibration in the form of a couple and out-of-balance force, with a rise time of less than 5ms repeating every 250ms for 2Hz chopping. Harmonics and their amplitude will depend on SOB stiffness as well as the BSM structure.	This document
BSM-SSSD-R 66 At the BSM mounting position, the torque reaction about the chop axis to be less than 25 $x10^{-6}$ Nm (averaged over the chop rise time).	This document
BSM-SSSD-R 67 At the BSM mounting position, the torque reaction about the chop axis to be less than 20 $x10^{-6}$ Nm (averaged over the jiggle rise time).	This document

4.4.4 Stray Magnetic fields (H field radiated susceptibility)

BSM-SSSD-R 68 The BSM shall not be susceptible to spurious signal generation due to a magnetic field strength >0.01 mT in the freq range 30Hz-50kHz, (Note this is calculated from IID-A radiated susceptibility mask at 140 dBpT)	IID-A sec.5.14.3.12

4.4.5 Electro-Magnetic Compatibility

BSM-SSSD-R 69 The BSM shall comply with the general requirements of the IID-A on EMC. Notably: • The cryogenic subsystem is to be grounded at the warm electronics • The signal and power wires of the BSM shall be electrically isolated from the Chassis of the FPU with more than TBD MΩ • H Field Radiated Emission: Narrow-band electric fields generated by the subsystem equipment and measured at 1 m distance shall not exceed 60dBpT in the frequency range 30Hz to 50KHz. • Narrow-band electric fields generated by the subsystem equipment and measured at 1 m distance shall not exceed 50 dBµV/m in the frequency range 14kHz -0.5MHz, rising to 74 dBµV/m at 0.5-18GHz:	IID-A sec.5.14.

4.4.6 ICD's

The BSM interfaces with the following other subsystems in the SPIRE instrument. The interface to each sub-system 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 [1]	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-001171	SPIRE-BSM-024-002 Rev2
2.1	Structure – BSM	MMSL	MSSL/SPIRE/SP004.11 (formerly SPIRE-MSS-PRJ-00617) Drg No A2/5264/907 issue 6	SPIRE-ATC-PRJ-001171 Latest 3D model.	SPIRE-BSM-024-002 Rev2
2.2	Structure – BSM	MMSL			SPIRE-BSM-023-001_ASM.IGS / .STP (IGES/STEP file) (needs update to 024 series?)
2.3	Thermometry	RAL	N/A (lakeshore data sheets)		Wiring: SPIRE-BSM-???
3	Photometer Calibration Source - BSM	UoW, Cardiff	SPIRE Ref.: SPIRE-UCF-PRJ-001150 Cardiff Ref.: HSO-CDF-ICD-013 Issue: 2.0 dated 06.Feb.02	SPIRE-ATC-PRJ-001171	SPIRE-BSM020-001-004 Rev1 (needs update to 024 series?)
4	Launch Latch – BSM Deleted	LAM	Deleted	Deleted	Deleted
5.1	Optics – external finish	LAM	AD27, AD28	SPIRE-ATC-PRJ-001171	SPIRE BSM 023-004-001 Rev2
5.2	Optics – BSM	RAL	AD26, AD13		No up to date model exists
5.3	Baffles – BSM	RAL	AD13		No up to date model exists
6	Cryo-Harness	RAL / MSSL	SPIRE Harness Definition. SPIRE-RAL-PRJ-000608	SPIRE-ATC-PRJ-001171	FPU Subsystem Harness Procurement Spec SPIRE-RAL-DOC-001362
7.1	MCU-BSM	LAM	TBW	SPIRE-ATC-PRJ-001171	Various D-space files under config control
7.2	On Board Software-BSM	LAM	TBW		
8	Photometer Bolometer Arrays - BSM (micro-vibration)	MSSL	No Document - sign off of this document suffices.	SPIRE-ATC-PRJ-001171	N/A
9	Spectrometer Bolometer Arrays - BSM (micro-vibration)	MSSL	No Document - sign off of this document suffices.	SPIRE-ATC-PRJ-001171	N/A
10	FPU Simulator – BSM Deleted	RAL	Deleted	Deleted	Deleted
11	Instrument Simulator – BSM Deleted	RAL	Deleted	Deleted	Deleted

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

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

BSM-SSSD-R 70
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

BSM-SSSD-R 71
Per AD27 : to facilitate optical laboratory testing, the mirror surface shall have a surface shape error <1.0 micron rms. ATC shall also apply acceptance criteria of roughness of <10nm rms and P-V < 100nm

4.6.3.2 Mirror Reflectivity

BSM-SSSD-R 72
To facilitate optical testing laboratory testing, the mirror surface shall have a reflectivity of >80% at 633nm by design.

4.6.3.3 Cleanliness

BSM-SSSD-R 73
The BSM shall be assembled to class 1000 cleanliness, but shall be class 100 compatible by design. Contamination on delivery for integration to SPIRE shall be, on delivery: [AD24].

- Particulate <440ppm (general) and <125ppm (mirror)
- Molecular contamination <1x10^{-4} g/cm^2

4.6.3.4 Material selection

BSM-SSSD-R 74
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.

BSM-SSSD-R 75
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, Eccobond 286, Stycast or Scotchweld 1838 will be used in visible applications under fastener heads.

4.6.3.5 Storage

BSM-SSSD-R 76
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	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
***BSM-SSSD-R** 77* 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	

Per AD29 Static is now reduced from 40 g to 25 g in any direction

4.7.1.3 Sine Vibration

BSM-SSSD-R 78 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-SSSD-R 79
Per AD 29 random vibration input is :

Axis (S/C)	**ramp up**	**Plateau**	**ramp down**	**g-rms**
X Launch direction	+3 dB/oct 20-100 Hz	0.185 g^2/Hz 100 - 350 Hz	-12 dB/oct 350-2000 Hz	~?
Y perpendicular to SOB	+3 dB/oct 20-100 Hz	0.117 g^2/Hz 100 - 400 Hz	-12 dB/oct 400-2000 Hz	~?
Z Sun pointing	+3 dB/oct 20-100 Hz	0.117 g^2/Hz 100 - 300 Hz	-12 dB/oct 200-2000 Hz	~?

Duration of qualification run 120 seconds.

4.7.1.5 Vacuum Level

BSM-SSSD-R 80 Less than 10^{-4} Pa	HR-SP-ATC-RID-05

4.7.1.6 Vacuum Outgassing

BSM-SSSD-R 81 Materials shall have a low outgassing rate with Total Mass Loss (TML) <1% and Volatile Condensable Material Loss (VCM) ≤ 0.1%	AD22

4.7.1.7 Temperature

BSM-SSSD-R 82 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 Deleted (see §4.4.4)

4.7.1.9 Survival Temperature

BSM-SSSD-R 83 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

BSM-SSSD-R 84 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.	AD1 section 2.1.4.9 RD2

BSM-SSSD-R 85 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	

BSM-SSSD-R 86 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 that are to be compliant with this specification, i.e. PFM, FS

Key:

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

Notes:

- 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.

SSSD Para	SSSD Reqt No	Title	Requirement	PFM	FS	Notes
4.1.1	R1	Angular Travel - Chop Axis	Angular range +/- 2.53 deg	T	T	
4.1.1	R2	Angular Travel - Chop Axis	Min chop throw 0.1 deg	T	T	
4.1.1	R3	Angular Travel - Chop Axis	Chop to at least 132 arcsec	T	T	
4.1.2	R4	Angular Travel - Jiggle Axis	Angular range +/- 0.573 deg	T	T	
4.1.3	R5	Minimum Step Size	0.038 deg jiggle, 0.039 deg chop	T	T	
4.1.4	R6	Chop Frequency	Up to 2 Hz	T	T	
4.1.4	R7	Chop Frequency	Goal up to 5 Hz, with degraded power and settling time	X	X	
4.1.5	R8	Jiggle Frequency	Up to 0.5 Hz	T	T	
4.1.5	R9	Jiggle Frequency	Goal up to 1 Hz, with degraded power and settling time	X	X	
4.1.6	R10	Holding position	Any position to 0.004 deg rms for up to 4 hrs	T	A	Reason for A in FS: This is affected by: 1 Electronic control - not included in BSMmech so not tested 2 Sensor stability - qualified by similarity with PFM
4.1.7	R11	Stability	0.2 arcsec sky (0.0038 deg) over 60 sec incl at 0.03 - 25 Hz	T	A	Reason for A in FS: This is affected by: 1 Electronic control - not included in BSMmech so not tested 2 Sensor stability - qualified by similarity with PFM
4.1.8	R12	Position Measurement	Knowledge of mirror pos to 0.00049 deg	A	A	By ref to other position tests
4.1.9	R13	Settling Time	Both axes within 0.019 deg in less than 20 ms from chop demand	T	T	
4.1.9	R14	Settling Time	Both axes within 0.019 deg in less than 100 ms from jiggle demand	T	T	
4.1.9	R15	Settling Time	Goal: Within 0.019 deg in less than 50 ms from jiggle demand	X	X	
4.1.10	R16	Chop repeatability	0.004 deg over 4 hrs	T	T	
4.2.1	R17	Mechanical Dimensions	Within 130x130x30 mm exc mounting	A	A	
4.2.1	R18	Mechanical Dimensions	Within 132x95x120 inc mounting	A	A	
4.2.1	R19	Mechanical Dimensions	Ref ICD	M	M	From part inspection reports
4.2.2	R20	Operating Temperature	4K (3.5 to 6)	T	T	By implication since performance parameters measured at this temperature

SSSD Para	SSSD Reqt No	Title	Requirement	PFM	FS	Notes
4.2.2	R21	Operating Temperature	Capable of reduced perf at up to 300K	T	T	Check for basic function
4.2.3	R22	Thermal Isolation	part vis to optical path < 1K above structure	A	A	Previous test on proto
4.2.4	R23	Cold Power Dissipation	<4mW average	T	T	
4.2.6	R24	Mirror Surface Dims (& Form)	Clear diam 32 mm	M	M	On part insp report
4.2.6	R25	Mirror Surface Dims (& Form)	Central hole 2.8 +/- 0.1mm	M	M	On part insp report
4.2.6	R26	Mirror Surface Dims (& Form)	Goal: central aperture up to 8mm	X	X	On part insp report
4.2.6	R27	Mirror Surface Dims (& Form)	Ellipse 30 x 32 mm	M	M	On part insp report
4.2.6	R28	Mirror Surface Dims (& Form)	Flat to < 1 um	T	T	
4.2.7	R29	Mirror Surface Finish	Surface roughness < 10nm rms	I/M	I/M	Component measurement
4.2.7	R30	Mirror Surface Finish	Obscuration due to defects <0.1%	I/M	I/M	Component measurement
4.2.8	R31	Mirror Surface Reflectivity	99% at 200-670 microns	A	A	
4.2.9	R32	Mirror Surface Emissivity	<1% at 200-670 microns	X	X	Complement of 4.2.11 & 4.2.8
4.2.10	R33	Baffle	Must pass 20% oversized beam with 0.5mm margin	M	M	Measurement will be against design drawings. Tests only performed on integration at RAL
4.2.11	R34	Position of Rotation Axes	Establish to 0.5mm, 0.5 deg	A	A	Design tolerances
4.2.11	R35	Position of Rotation Axes	Shoe m/c'g to allow integration to 0.25mm, 0.05 deg	A	A	Process of machining shoe
4.2.11	R36	Position of Rotation Axes	Repositionable on bench to 0.05mm, 0.05 deg	A	A	Test procedure relies on it
4.2.11	R37	Position of Rotation Axes	ATC Goal: lateral decentre < 10 um	X	X	
4.2.11	R38	Position of Rotation Axes	ATC Goal: Assy of mirror jiggle to < 0.5mm	X	X	
4.2.11	R39	Position of Rotation Axes	ATC Goal: Assy of mirror chop to < 0.3mm	X	X	
4.2.12	R40	Orthogonality of Rotation Axes	ATC Goal: Orthogonality to 0.15 deg	X	X	
4.2.13	R41	Fail Safe (No Drive Signal) Position	Pos with no drive to nominal 0 within 0.18 deg	T	T	

SSSD Para	SSSD Reqt No	Title	Requirement	PFM	FS	Notes
4.2.14	R42	Fail Safe (Mechanical Failure) Posn	If flex pivots fail mirror can be returned to nominal within +0.573 jiggle, -2.53 deg chop	A	A	Design restrains mirror to operating range
4.2.15	R43	Mass	BSMm and BSMs (exc PCAL) < 1100g	M	M	
4.2.16	R44	Cool-down time	Reach 4K within 15 hrs	A	A	Cooldown times will be dependent on cryostat configuration.
4.2.17	R45	Reliability	Failure of a subsystem shall not lead to loss of instrument ops	A(h)	A(h)	(h) demonstrated by DM programme and by design/analysis
4.2.17	R46	Reliability	Backup modes for nom observing modes	A(h)	A(h)	(h) demonstrated by DM programme and by design/analysis
4.2.17	R47	Reliability	Cold redundant h/w shall be provided where practicable	A(h)	A(h)	(h) demonstrated by DM programme and by design/analysis
4.2.18	R48	Failure Modes	Failure of subsystem shall not affect health of others subsysts, or the i/f	A(j)	A(j)	(j) demonstrated by DM programme and by design/analysis
4.2.18	R49	Failure Modes	Failure of component shall not damage redundant or backup component designed to replace it	A(j)	A(j)	(j) demonstrated by DM programme and by design/analysis
4.2.18	R50	Failure Modes	No elec sub unit shall affect inst ops until in a defined state	A(j)	A(j)	(j) demonstrated by DM programme and by design/analysis
4.3.1	R51	Operational Safety	Shall operate safely	A	A	Demonstrated by analysis/design/risk assessment
4.3.2	R52	Lifetime	Capable of operation for periods > 1/6th of normal mission lifetime	A(k)	A(k)	(k) demonstrated by DM programme and confirmation that the design is comparable
4.3.2	R53	Lifetime	Will operate over 4.25 yrs	A(k)	A(k)	(k) demonstrated by DM programme and confirmation that the design is comparable
4.3.2	R54	Lifetime	Lifetime tests will use 1.25x multiplier on orbit and 4x for ground test	A(k)	A(k)	(k) demonstrated by DM programme and confirmation that the design is comparable
4.3.3	R55	Operating modes	Jiggle: small angular steps	A	A	By test of other parameters
4.3.3	R56	Operating modes	Chopping	A	A	By test of other parameters
4.3.3	R57	Operating modes	Scan mapping: combined jiggle and chop	A	A	By test of other parameters
4.3.3	R58	Operating modes	Holding stare	A	A	By test of other parameters
4.3.8	R59	Degraded modes	Capable of driving from DC up to freq limit	A	A	By implication from other tests

SSSD Para	SSSD Reqt No	Title	Requirement	PFM	FS	Notes
4.3.8	R60	Degraded modes	Current demand algorithms devised to operate chop open loop	T	T	Report actual values
4.3.8	R61	Degraded modes	Each axis must operate in absence of the other	T	T	Basic function check
4.3.9	R62	Combinations of Modes	1: Chop and jiggle 2: Removal of x coupling during chop only or jiggle only	T	T	X coupling will be tested
4.4.1	R63	Data Outputs	Chop axis posn	S	S	
4.4.1	R64	Data Outputs	Jiggle axis posn	S	S	
4.4.1	R65	Data Outputs	Eng / trace data (eg motor volts / current)	S	S	
4.4.3	R66	Exported vibration	Torque reaction < 25 x10^-6 Nm average over chop rise	S	S	On integration to SPIRE at RAL
4.4.3	R67	Exported vibration	Torque reaction < 20 x10^-6 Nm average over jiggle rise	S	S	On integration to SPIRE at RAL
4.4.4	R68	Stray Magnetic fields	Not susceptible to spurious signal generation under field < 0.01mT	S	S	On integration to SPIRE at RAL
4.4.5	R69	Electro-Magnetic Compatibility	Grounding, isolation, H field radiated emission, Narrow band elec fields	S	S	On integration to SPIRE at RAL
4.4.6		ICD's (No ref. no.)	Must interface to the other subsystems as defined in the ICD	A	A	
4.6.2	R70	Electronics Card Format	On double eurocards	I	I	Inspection of LAM deliverables
4.6.3.1	R71	Mirror Flatness	Surface shape error < 1 um	A	A	Cold measurement. See above
4.6.3.2	R72	Mirror Reflectivity	> 80% at 633 nm by design	A	A	(n) X if STM has no mirror
4.6.3.3	R73	Cleanliness	Pariculate < 440 ppm general, < 125 ppm mirror Molecular contamination < 1x10^-4 g/cm^2	A	A	Compliance indicated in ADP
4.6.3.4	R74	Material selection	Structure 6082 Al. Mirror 6061 Al	A	A	Compliance indicated in ADP
4.6.3.4	R75	Material selection	Fasteners cryo grade s/s….	A	A	Compliance indicated in ADP
4.6.3.5	R76	Storage	Up to 5 yrs in dry N without degradation	A	A	Compliance indicated in ADP
4.7.1.2	R77	Quasi Static Loads	25g x, 14g y, 14g z	A(o)	A(o)	(o) demonstrated by DM programme and confirmation that the design is comparable

SSSD Para	SSSD Reqt No	Title	Requirement	PFM	FS	Notes
4.7.1.3	R78	Sine Vibration	25g x, 25g y,z	A(p)	A(p)	(p) demonstrated by DM programme and confirmation that the design is comparable
4.7.1.4	R79	Random Vibration	0.185g^2/Hz x, 0.117 y,z	A(q)	A(q)	(q) demonstrated by DM programme and confirmation that the design is comparable
4.7.1.5	R80	Vacuum Level	<10^-4 Pa	A	A	By implication from other tests
4.7.1.6	R81	Vacuum Outgassing	Materials TML<1%, VCM < 0.1%	A	A	Demonstrated via materials selection and Compliance indicated in DML
4.7.1.7	R82	Temperature	Within spec at operating, reduced perf at 300K	T	T	Specific performance tests done at operating temp. No specific tests at 300K, since no performance specified, but set up process relies on operation at 300K
4.7.1.9	R83	Survival Temperature	Up to 80 deg C	A	A	Demonstrated by bakeout of components at ATC in the course of assembly & test
4.7.1.10	R84	Radiation environment	Integrated dose	A	A	By approval of DML
4.7.1.10	R85	Radiation environment	Non ionizing energy	A	A	By approval of DML
4.7.1.10	R86	Radiation environment	ionizing radiation	A	A	By approval of DML

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