Subsystem Specification Document

Beam Steering Mechanism

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Table of contents

Figures

1 Scope

This specification defines the requirements applied to the performance, design and qualification Beam Steering Mechanism of 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.

2 Documents and Glossary

2.1 Applicable documents

	Title	Author	Reference	Date
AD1	Instrument Requirements Document	B.M.Swinyard	SPIRE-RAL-PRJ-000034 Issue 0.30	May 2000
AD2	Structure - BSM ICD		SPIRE/ICD/1.1-1.5.1	
AD3	Thermometry - BSM ICD		SPIRE/ICD/1.1.1-1.5.1	
AD4	Optics - BSM ICD		SPIRE/ICD/1.2-1.5.1	
AD5	Baffles - BSM ICD		SPIRE/ICD/1.2.2-1.5.1	
AD6	Photometer Bolometer Arrays - BSM ICD		SPIRE/ICD/1.4.1-1.5.1	
AD7	Spectrometer Bolometer Arrays - BSM ICD		SPIRE/ICD/1.4.2-1.5.1	
AD8	Photometer Calibration Source - BSM ICD		SPIRE/ICD/1.5.1-1.6.1	
AD9	FSDRC - BSM ICD		SPIRE/ICD/1.5.1-2.2	
AD10	On Board Software - BSM ICD		SPIRE/ICD/1.5.1-2.6	
AD11	Analogue Simulator - BSM ICD		SPIRE/ICD/1.5.1-3.1	
AD12	Instrument Simulator - BSM ICD		SPIRE/ICD/1.5.1-3.3	
AD13	Current Optical Configuration		PHT 126 I	
AD14	Operating Modes for the SPIRE Instrument	B.M.Swinyard	SPIRE-RAL_PRJ 000320 issue 2.2	
AD15	BSM Sub-system Development Plan		SPIRE/ATC/DOC/xxxx	13 June 00

2.2 Reference documents

	Title	Author	Reference	Date
RD1	Design Description Document	C.R. Cunningham	Draft	5 June 00

2.3 Glossary

AD	Applicable Document	QMW	Queen Mary & Westfield College
ATC	UK Astronomy Technology Centre	RAL	Rutherford Appleton Laboratory
BSM	Beam Steering Mirror	RD	Reference Document
CQM	Cryogenic Qualification Model	RMS	Root Mean Square
DPU	Digital Processing Unit	SMEC	Spectrometer Mechanism
DSP	Digital Signal Processor	TBD	To Be Decided
FEA	Finite Element Analysis	TBC	To Be Confirmed
FS	Flight Spare		

ICD	Interface Control Document		
PID	Proportional – Integral - Derivative		
PFM	Proto-Flight Model		
MAC	Multi Axis Controller		

3 Subsystem description

3.1 Introduction

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

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

The BSM operates under control of the Detector Readout and Control (FSDRC) sub-system.

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

The BSM comprises 3 main parts; the cryogenic mechanism (BSMm), the structural support (BSMs), and the warm electronics (BSMe). The structural support may be integral to the BSMm housing, or attached as a distinct entity (TBD).

3.2 Mission profile

TBD

3.3 Subsystem Description

The BSM subsystem consists of the following parts.

BSMs - BSM structural support	This forms the support for the BSM cryogenic mechanism, and attaches the cryogenic mechanism to the optical bench.
BSMm - BSM cryogenic mechanism	The cryogenic mechanism comprises the mirror, chop and jiggle stages, pivots, mirror structure, motors, position sensors and thermometers.
BSMe - BSM warm electronics	The warm electronics provide drive signals for the motors and read the signals from the position sensors.

In addition there is a BSM mass and alignment dummy (BSMd). This is a model of the cryogenic mechanism with the correct mass and a non-moving mirror. It is used for vibration testing and optical alignment.

3.4 Design Assumptions

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.

This value is derived from the SPIRE optical design (see AD13).

3.5 Definition of Axes

The FIRST 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.

3.6 BSMm Chop and Jiggle Mechanism

The following descriptions of the BSM are for information only. The Design Description Document (RD1) describes the design in detail.

The BSMm comprises a mirror of nominal diameter 30mm, mounted so as to pivot on two axes to provide chop and jiggle motion. Each axis houses a rare-earth (eg Cobalt-Samarium) magnet moving pole piece and is driven by a motor coil fixed to the mechanism housing/structure. Lucas flex-pivots, or equivalent, provide low friction motion and a small restoring torque.

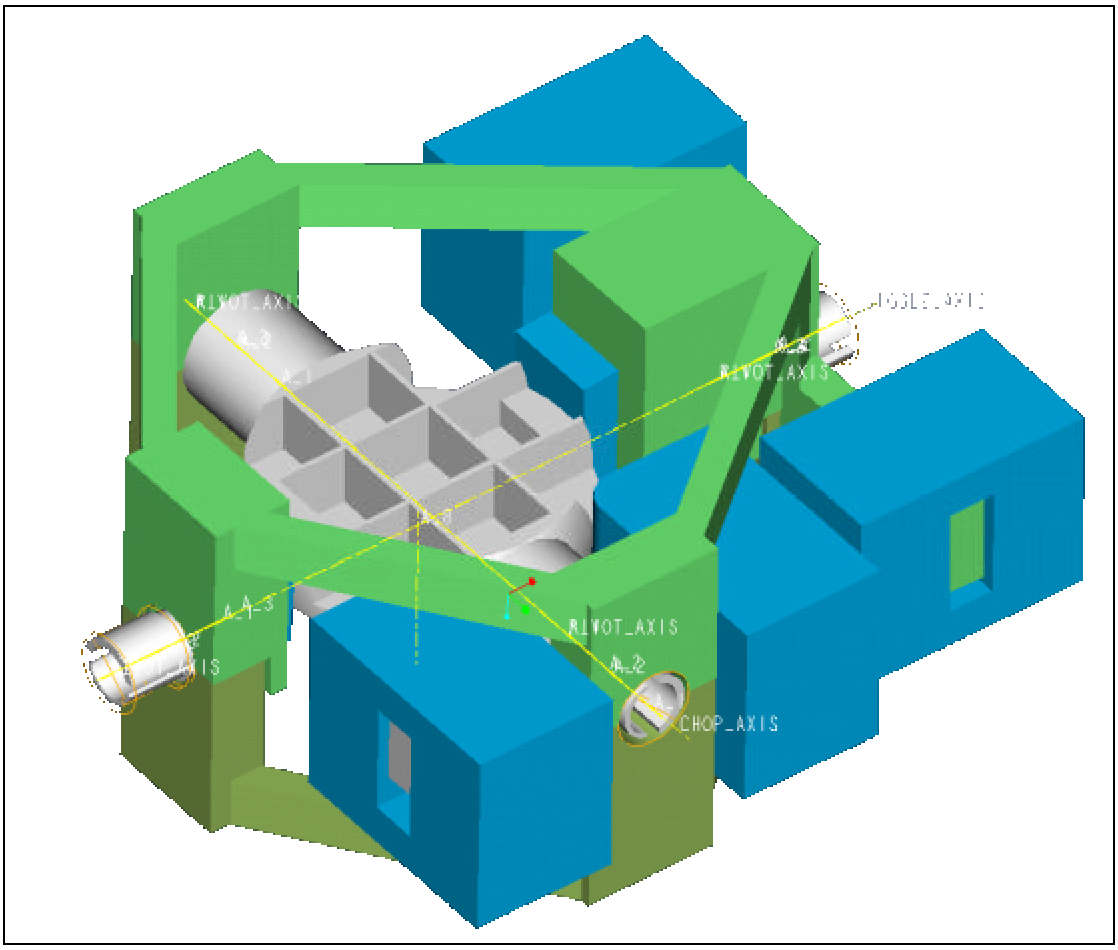


Figure 1: View on underside of mirror - Chop stage grey, jiggle stage green, motors and sensors blue

The chop and jiggle stages are shown in Figure 1 (The outer rings of the flex-pivots, and the housing are not shown for clarity.). The chop stage is monolithic with the mirror machined integrally, The mirror surface is diamond machined to a finish suitable for dynamic verification using a retro-reflective laser tilt measurement device, made by CDL Systems. The underside of the mirror is light-weighted and has pockets for the iron plates for the magneto-resistive position sensors. The chop direction is along the long axis of the array (the spacecraft y-axis). A 2mm diameter (TBC) hole in the centre provides an optical path for the calibrator mounted behind the BSMm. The moment of inertia of the chop stage has been minimised to reduce power consumption during chop transitions. At 2.1 $Kg.mm^2$, it is little more than the ISOPHOT rotor which was 1.57 $Kg.mm^2$, resulting in an estimated power consumption of 0.4 mW when chopping at 2Hz with maximum amplitude. Mass is also minimised to keep loads on the flex pivots down during qualification and launch. Current estimate of static loads on the chop axis pivots with a 50g force is 9N, compared with pivot load capacity of 25N.

The jiggle stage is in the form of a split frame split and clamps together around the flex pivots. To balance the jiggle stage the framework in the opposite corner to the coils has been made solid. This also increases the stiffness of the structure. This structure carries the chop stage, and is inevitably heavier. Fortunately, the requirements call for lower amplitude and frequency in this axis, so we can use stiffer flexures, resulting in average power consumption of 1.6 mW when jiggling at 1 Hz with maximum amplitude. The static load on the jiggle axis flex-pivots at 50g is 27N, well below the 245N load capacity.

Both stages are designed to be stiff, so that the first resonant frequencies are high enough (> 700 Hz) that the system modelling can regard them as rigid bodies.

Space envelopes for the coils and sensors are shown in blue. There are four coils for each of the two motors, which are similar to those used in the ISOPHOT chopper. Position sensors for the chop axis are mounted on the jiggle stage, which means flexible cable connections are required, unlike the jiggle stage position sensors, which mount directly on the non-moving housing. Position sensors similar to those used in ISOPHOT.

3.7 BSMs Support Structure

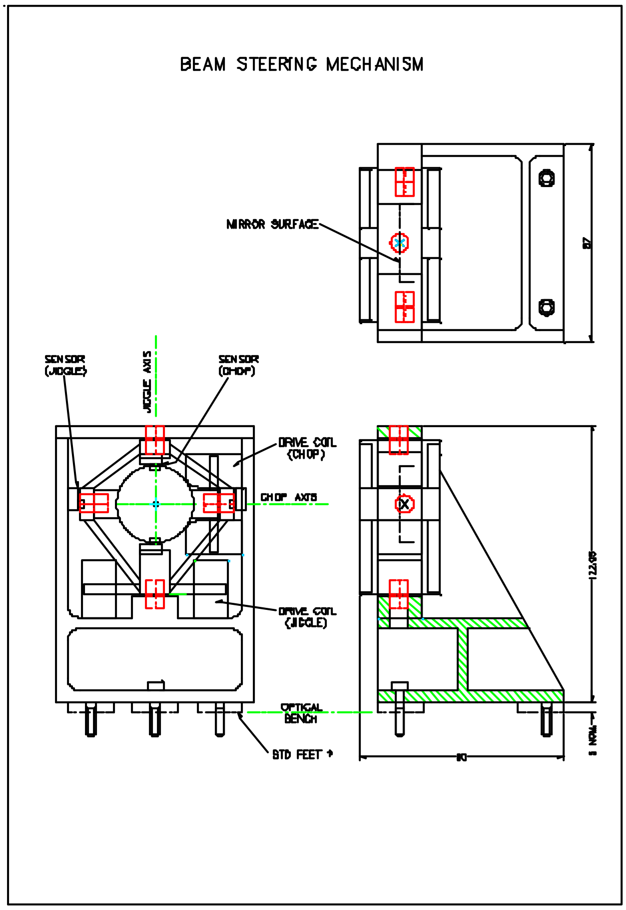


Figure 2: BSMm in support structure

The support structure mounts the beam steering mirror mechanism from the SPIRE optical bench. Note that there will be a baffle incorporated to minimise straylight and emission into the optical beam. Electrical wiring and connectors are not shown. The photometer calibrator will also be mounted on this structure, and its wiring incorporated into the BSM harness. The outline design shown here is at present non-optimised, and will be further refined following FEA.

3.8 BSMe Control Electronics

The two axes of the BSM are controlled using the DSP which also controls the Spectrometer Mechanism (SMEC). Consequently, the analogue board which directly drives the BSM motors and reads the position is very simple. The complete Mechanism Control Electronics is shown the following diagram.

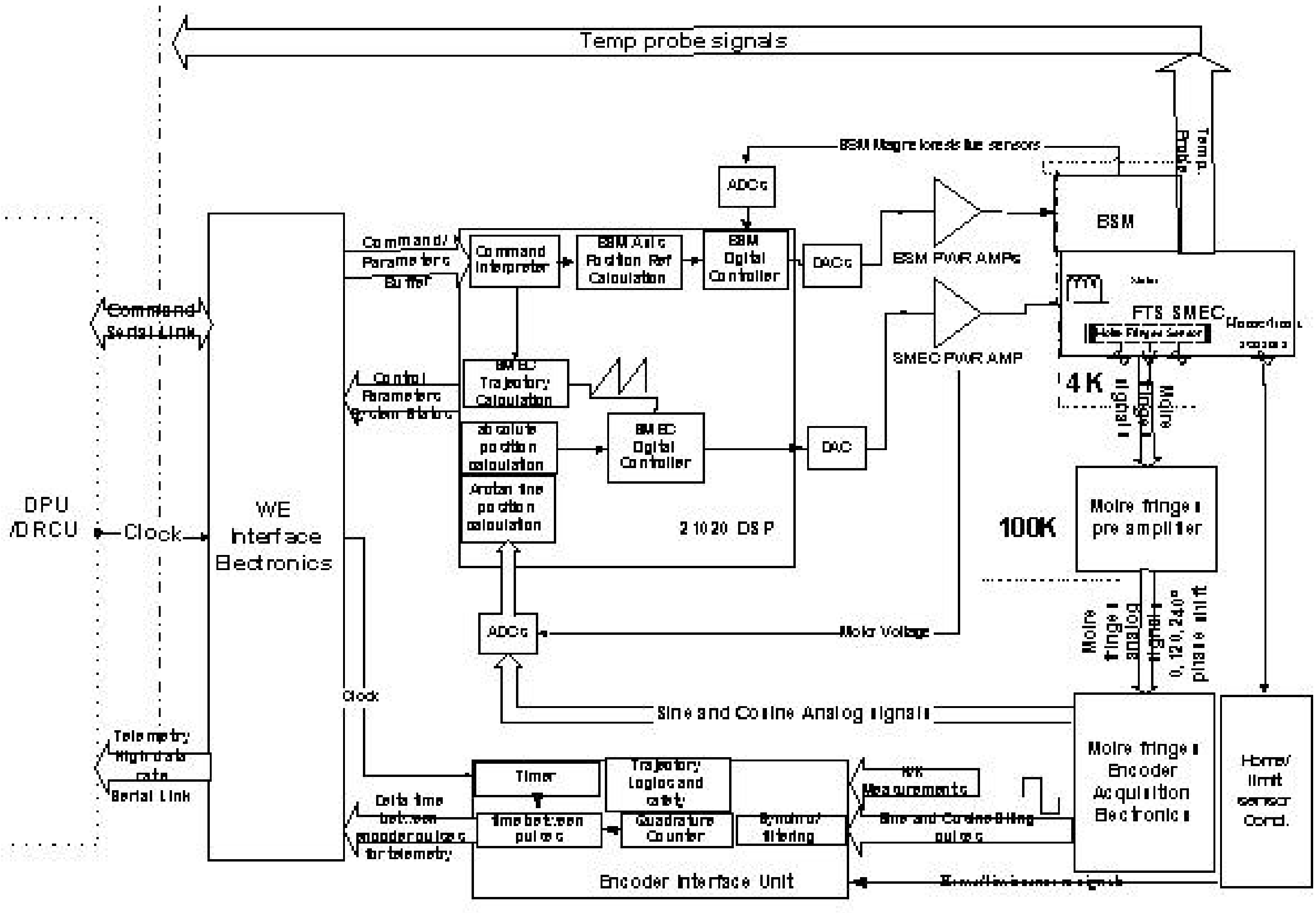


Figure 3: Mechanism Control Electronics

The analogue electronics card has readout circuits for the position sensors, using circuits very similar to those used on ISOPHOT, and power amplifiers to drive the motors, which will be as near as practical to the circuits used to drive the SMEC motor.

At present we have two options for system architecture to deal with redundancy. Our prime option is to have complete parallel redundancy, with main and redundant position sensors and motors, driven by separate main and redundant analogue boards, in turn driven by main and redundant MACs and DPUs, as shown in Figure 4. This option is dependent on being able to get enough power from each of the main and redundant coils to meet the rise time requirements. If this proves too difficult so that all motor coils must be used, an alternative scheme is proposed where one analogue board is controlled by either MAC, and a switching scheme is used to short out failed coils. This switched redundancy method is less attractive, because it also needs a switching scheme to choose which of the main and redundant MACs and power supplies to use.

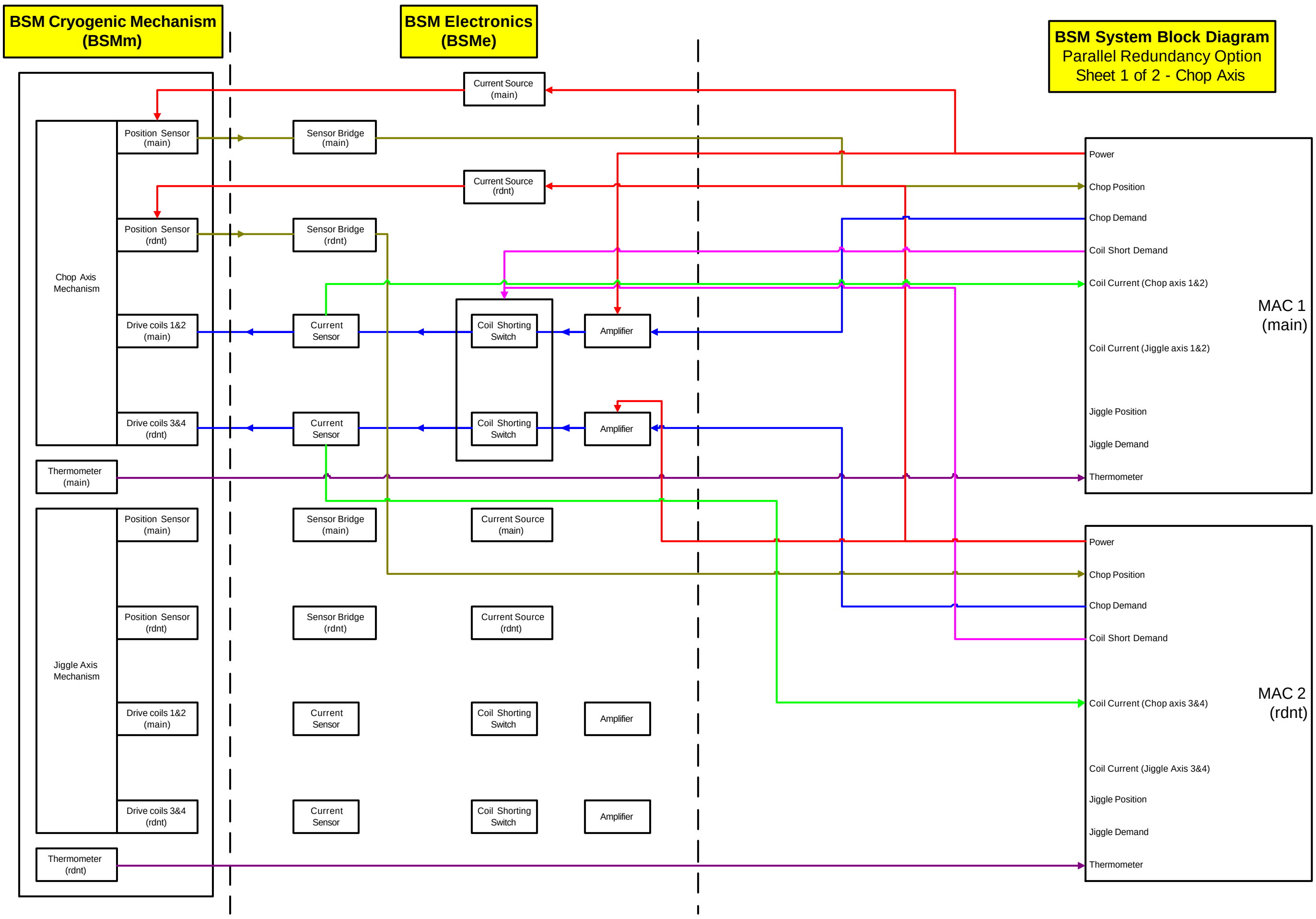


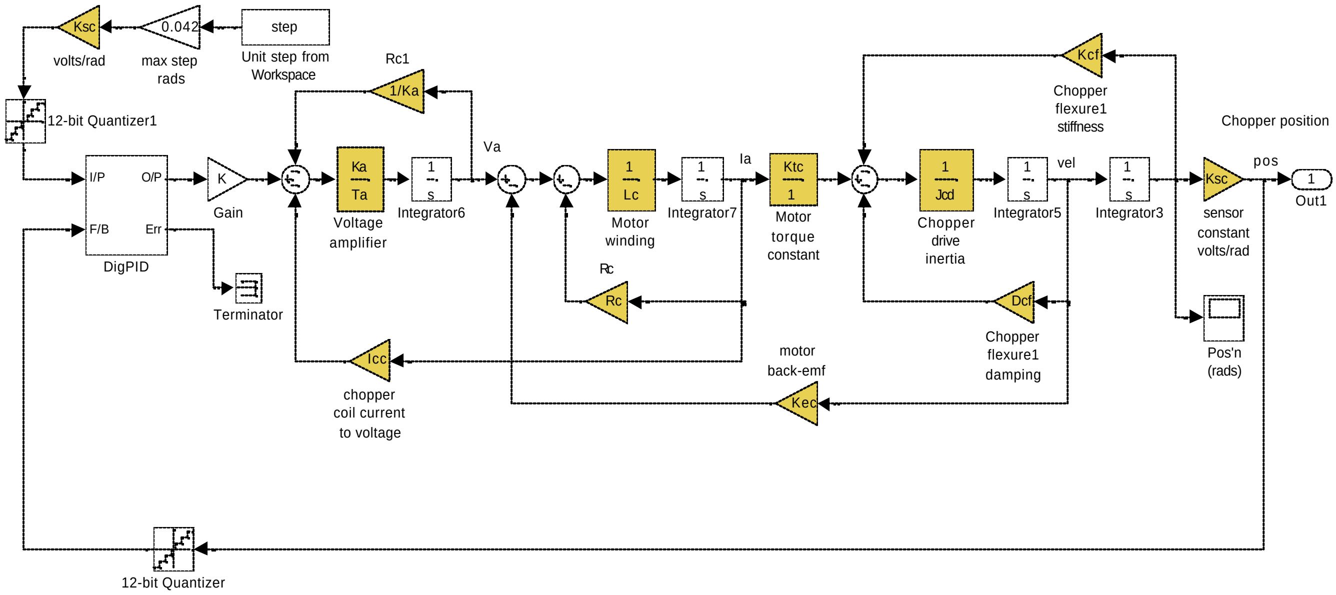
Figure 4: BSM Control Electronics – Parallel Redundancy

Figure 4 shows the chop axis control with parallel redundancy – the jiggle axis connections are not shown, for clarity.

3.9 Digital control

System simulation using MATLAB/Simulink shows that the rise time and power consumption requirements can be met using a standard digital PID control algorithm. Meeting the positional stability requirement is dependant on the performance of the position sensors, currently under study. An example of the controller and mechanism model for the chop axis is shown in

Figure 5.



SPIRE Beam Steering Mirror chopper axis simplified dynamics with digital controller: spire_chop_mod6dqpid.mdl

Figure 5: BSM chop axis model

For information, the chop axis position when driven with a smoothed trajectory demand to minimise self-induced vibration is shown below. It meets our requirement.

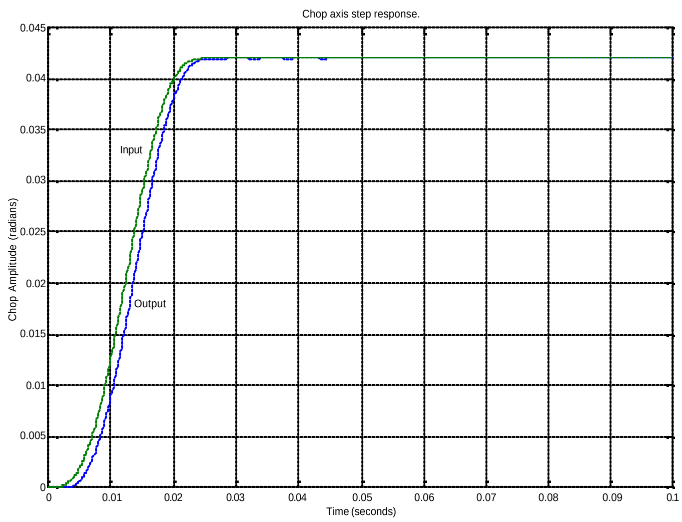


Figure 6: BSM chop axis rise time

4 Requirements

4.1 Functional requirements

4.1.1 Performance requirements

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

4.1.1.1 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.	IRD-BSMP-R01

4.1.1.2 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.	IRD-BSMP-R02

4.1.1.3 Minimum Step Size

The BSM shall allow movements of the mirror surface in both chop and jiggle axes in increments of 0.04° or larger.	IRD-BSMP-R03

4.1.1.4 Chop Frequency

The BSM shall allow movements of the mirror in the chop axis at any frequency up to 2Hz.	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.	IRD-BSMP-R04

4.1.1.5 Jiggle Frequency

The BSM shall allow movements of the mirror in the jiggle axis at any frequency up to 0.5Hz.	IRD-BSMP-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.	IRD-BSMP-R05

4.1.1.6 Holding position

The BSM shall be capable of moving to, and holding at, any commanded position within its range of movement, to within TBD° (RMS), for periods of up to 4 hours (TBC).	IRD-BSMP-R06

4.1.1.7 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.	IRD-BSMP-R07
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.	IRD-BSMP-R07

4.1.1.8 Position Measurement

The BSM shall provide measurements of the angular orientation of the mirror surface in both chop	IRD-BSMP-R08

and jiggle axes to a resolution of <0.002° (TBC), at a rate of TBD Hz.	

4.1.1.9 Settling Time

The angular position of the mirror surface shall be within 0.02° of the mean steady state position in less than 0.025 sec from the application of a demand in the chop axis.	IRD-BSMP-R09
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.	IRD-BSMP-R09
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.	IRD-BSMP-R09

4.1.1.10 Chop repeatability

The steady state repeatability between successive chop cycles shall be less than 0.004° (RMS).	IRD-BSMP-R10

4.1.3 System requirements

4.1.3.1 Mechanical Dimensions

The BSM shall fit within a volume of 130x130x60 mm (TBC).	IRD-BSMP-R09

4.1.3.2 Operating Temperature

The operational temperature of the BSM shall be 4K.	IRD-BSMP-R10
The BSM shall be capable of operation (with reduced performance) at temperatures up to 300K.	IRD-BSMP-R10

4.1.3.3 Thermal Isolation

The BSM mirror or structure temperature shall rise by no more than 1K from the nominal operating temperature of the surrounding structure after 1 hour of operation in any mode.	IRD-BSMP-R11

4.1.3.4 Cold Power Dissipation

The average power dissipation of the BSM Cryogenic Mechanism (BSMm) and the BSM Support Structrure (BSMs) shall be less than 4mW in any operating mode, when operating at the temperature defined in section 4.1.2.2.	IRD-BSMP-R12

4.1.3.5 Warm Electronics Power Dissipation

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

4.1.3.6 Mirror Surface Dimensions

The mirror clear diameter shall be greater than 32mm.	AD13
The mirror shall include a central hole of no greater than 2mm (TBC) to allow the Photometer Calibrator to be seen by the detectors.	AD13

4.1.3.7 Mirror Surface Finish

The mirror surface of the BSM shall be flat to <2µm (RMS) and shall have a surface roughness of <5nm.	AD13

See also 4.4.2.1.

4.1.3.8 Mirror Surface Reflectivity

The reflectivity of the mirror surface of the BSM shall be >99% in the wavelength range 200 - 670 µm.	AD13

See also 4.4.2.2.

4.1.3.9 Mirror Surface Emissivity

The emissivity of the mirror surface of the BSM shall be <1% in the wavelength range 200 - 670µm.	AD13

4.1.3.10 Position of Rotation Axes

TBD	TBD

4.1.3.11 Orthogonality of Rotation Axes

TBD	TBD

4.1.3.12 Fail Safe 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 ±0.36° (TBC).	TBD

4.1.3.13 Mass

The BSM cryogenic mechanism (BSMm) and the BSM support (BSMs) shall have a combined mass of less than 1100g.	Mass Budget

4.1.3.14 Self induced vibration

TBD

4.1.3.15 Electro-Magnetic Compatibility

TBD - Grounding, Radiated emissions, etc…

4.2 Operational requirements

4.2.1 Operational Safety

The BSM shall operate safely in any normal operating mode.	IRD??

4.2.2 Lifetime

AD1 defines the nominal mission lifetime as 4.25 years.

The BSM shall be capable of operation in any normal mode for periods in excess of 1/6 of the nominal mission lifetime.	IRD??

4.2.3 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

4.2.3.1 Jiggle Mode

Jiggle Mode is used to optimise 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. **(TBC)**

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.

4.2.3.2 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

4.2.3.3 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.

4.2.3.4 Combinations of Modes

The following combinations of the basic modes are required.

- Chopping and Jiggling

4.2.4 Data Outputs

The following data is provided by the BSM.

Data	Rate	Reference
Chop axis position	TBD	
Jiggle axis position	TBD	
Thermometer data	1Hz (TBC)	
Motor voltage (or current, TBD)	TBD	

4.2.5 Data Inputs

The following inputs are required to operate the BSM.

Data	Rate	Reference
Chop axis demand position	On Demand, max. 5Hz	
Jiggle axis demand position	On Demand, max. 1Hz	
Control system parameters (PID terms)	Tbd, but slow	
Trajectory parameters (3 for each axis)	Tbd, but slow	

4.3 Interface requirements

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 Specification.

Sub-System	ICD Reference
Structure – BSM	AD2
Thermometry – BSM	AD3
Optics – BSM	AD4
Baffles – BSM	AD5
Photometer Bolometer Arrays - BSM	AD6
Spectrometer Bolometer Arrays - BSM	AD7
Photometer Calibration Source - BSM	AD8
FSDRC – BSM	AD9
On Board Software - BSM	AD10
Analogue Simulator - BSM	AD11
Instrument Simulator - BSM	AD12

4.4 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.

4.4.1 Design requirements

General rules, standards and specific rules applicable for the subsystem design

4.4.1.1 Electronics Card Format

All electronics associated with the BSM shall be mounted on double eurocards.

4.4.2 Manufacturing and testing requirements

4.4.2.1 Mirror Flatness

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

4.4.2.2 Mirror Reflectivity

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

4.4.2.3 Cooldown time

To facilitate laboratory testing, the BSM shall reach a temperature of 4K within TBD hours of the commencement of cooldown.

4.5 Logistic requirements

4.5.1 Storage

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

4.6 Environmental requirements

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

4.6.1 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.

4.6.1.1 Shock

TBD

4.6.1.2 Vibration

TBD

4.6.1.3 Vacuum Level

TBD

4.6.1.4 Vacuum Outgassing

TBD

4.6.2 Natural environment

This is the description of the natural environment around the subsystem during its life.

4.6.2.1 Survival Temperature

The BSM shall remain fully operational following exposure to temperatures of 80°C for periods of up to 72 hours.	PA plan

4.7 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 BSM models.

Test	T
Measurement	M
Analysis	A
Inspection	I

Performance Requirements

Reference	Requirement	CQM	PFM	FS
4.1.1.1	Angular Travel - Chop Axis	T	T	T
4.1.1.2	Angular Travel - Jiggle Axis	T	T	T
4.1.1.3	Minimum Step Size	T	T	T
4.1.1.4	Chop Frequency	T	T	T
4.1.1.5	Jiggle Frequency	T	T	T
4.1.1.6	Holding position	T	T	T
4.1.1.7	Stability	T	T	T
4.1.1.8	Position Measurement	T	T	T
4.1.1.9	Settling Time	T	T	T
4.1.1.10	Chop repeatability	T	T	T

System Requirements

Reference	Requirement	CQM	PFM	FS
4.1.3.1	Mechanical Dimensions	M	M	M
4.1.3.2	Operating Temperature	T	T	T
4.1.3.3	Thermal Isolation	T	T	T
4.1.3.4	Cold Power Dissipation	T	T	T
4.1.3.5	Warm Electronics Power Dissipation	T	T	T
4.1.3.6	Mirror Surface Dimensions	M	M	M
4.1.3.7	Mirror Surface Finish	I	I	I
4.1.3.8	Mirror Surface Reflectivity	A	A	A
4.1.3.9	Mirror Surface Emissivity	A	A	A
4.1.3.10	Position of Rotation Axes	I	I	I
4.1.3.11	Orthogonality of Rotation Axes	T	T	T
4.1.3.12	Fail Safe Position	A	A	A
4.1.3.13	Mass	M	M	M

4.1.3.14	Self induced vibration	T	T	T
4.1.3.15	Electro-Magnetic Compatibility	T?	T?	T?