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Record of Issue

Date	Index	Remarks
09/Jan/02	1.0	Creation of the document : extract from DDR design description
22.Jan.02	2.0	Update, response to BSM DDR and design updates since DDR : see full change table

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FMECA change notes for v2.0

ID	Change requested at	Note	Change Action
1	DDR, FMECA review	Although the necessary information is available in the sheets it is recommended that the same terminology is used by all contractors for the separate columns in order to ease the review of the analysis and avoid misunderstandings. In column "d" it should be made clear which are the local and end effects, for instance by using bullets for all cases. If there is only a local effect and no end effect, it should be clearly stated that the end effect is "none". See the template distributed earlier.	Done. Also brought into line with ECSS-Q-30-02A 7.Sep.01
2	DDR, FMECA review	RDB-7A/8A/9A failure modes 7-11 have not been filled out.	Done
3	DDR, FMECA review	The short circuit case for the DRCU should be carefully considered concerning propagation to the DPU. Propagation of shorts between separate boards and the internal protection should also be considered.	Not done at BSM level - an MCU issue
4	DDR, FMECA review	Some of the prevention or compensation methods as stated in column g are not really prevention methods. This column considers means that should be taken in order to compensate for a failure when the failure occurs, in order to minimize or neutralize the effect of the failure, i.e. redundancy, latching current limiters, operator actions. Measures as "prevented by clean room procedures" (RBD-2A-2) and others, RBD-2A-3/4, RBD-5-8, etc should be entered into the remarks column when one wants to highlight the importance of following certain procedures for certain parts. These comments can in some cases also be entered into column h, recommendations, when the corrective action for a critical item that has to be followed up is connected with a certain critical process.	Done
5	DDR, Reliability Block Diagram review	Concerning RBD-15 and 16A/B, is 1 out of 2 enough to operate and is C then a fallback if both fail?	Clarified
6	DDR, Reliability Block Diagram	The RBD-11A/B/C are connected in parallel, but these are not redundant blocks are they. Is the intention here to illustrate the possibility to operate in a degraded mode?	Clarified
7	General comment (email)	However on interfaces It should be to component level (Cryostat Harnesses should include each individual wire as a component)	Done at Harness level by component (not by wire) full harness & BSMe/MCU FMECA required
8	Reliability Block Diagram	Some redundant blocks are connected in series with the nominal blocks when they should be in parallel, and some blocks are in parallel when they should be in series, if I understood this correctly. For instance RBD-2A (Jiggle axis flex pivot) and RBD-2B (jiggle axis flex pivot sleeve) should be in series connection with each other, while the redundant blocks of these parts should be in parallel with these (same thing for RBD-6A and RBD-6B)?	Diagram amended to show load path and retention functions separately
9	Design update, post DDR	Added common backplane as RBD-8A2	Done
10	DDR report comment	Coil Shorting (b) Redundancy: If the relay failed in the closed position, thereby shorting out the motor coil, then this could prove to be a single point failure mechanism depending on the exact implementation scheme adopted. The compliance to the Herschel redundancy philosophy and the effect of the motor coil damping relays on the reliability would have to be formally evaluated in the BSM FMECA.	Not done at BSM level. BSMe/MCU level issue. Coil shorting may not be implemented with Al coils.

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1. Scope of the document

This document describes the failure modes effect and criticality analysis of the Herschel/SPIRE Beam Steering Mirror mechanism subsystem.

The document is based on the applicable documents cited in paragraph 2.1.

2. Documents

2.1 Applicable documents

ID	Title	Author	Reference	Date
1.	Instrument Requirements Document	B.Swinyard	SPIRE-RAL-PRJ-000034 v1.1	10.Jan.02
2.	BSM Sub System Design Description	I.Pain	SPIRE-ATC-PRJ-000587 v4	20.Jul.01
3.	BSM Sub System Specification Document	I.Pain	SPIRE-ATC-PRJ-000460 v3.2	Jul.01

2.2 Reference documents

	Title	Author	Reference	Date
1	Failure Modes, Effects and criticality analysis (FMECA)	ESA ECSS	ECSS-Q-30-20A	7.Sep.01

2.3 Glossary

AD	Applicable Document	MAC	Multi-Axis Controller
CEA	Commissariat à l' Energie Atomique	MCE	Mechanism Control Electronics
CDR	Critical Design Review	MGSE	Mechanical Ground Support Equipment
CNES	Centre National des Etudes Spatiales	MPIA	Max Planck Institute for Astronomy
CoG	Center of Gravity	MSSL	Mullard Space Science Laboratory
CQM	Cryogenic Qualification Model	NA	Not Applicable
DDR	Detailed Design Review	OGSE	Optical Ground Support Equipment
DESPA	Département des Etudes SPAtiales	PFM	ProtoFlight Model
DM	Development Model	RAL	Rutherford Appleton Laboratory
DRCU	Digital Read-out and Control Unit	RD	Reference Document
EGSE	Electrical Ground Support Equipment	BSM	Beam Steering Mirror
Herschel	Far InfraRed Space Telescope	UK ATC	United Kingdom Astronomy Technology Centre
FPU	Focal Plane Unit	BSM	Beam Steering Mirror
FS	Flight Spare model	SPIRE	Spectral and Photometric Imaging REceiver
LAM	Laboratoire d'Astrophysique de Marseille	TBC	To Be Confirmed
FTS	Fourier Transform Spectrometer	TBD	To Be Defined
		WE	Warm Electronics

3. Reliability & Redundancy

3.1 Overview

In the BSM design redundancy principles have been implemented so as to avoid single point failures, and the propagation of failures to other subsystems, by means of dedicated redundancy and specific protection devices. Where redundancy can not be realised the architecture is designed to limit the effects of a failure.

The BSMe consists of two complete separate circuits (situated on the same double Eurocard, but supplied by separate connectors). This provides complete parallel redundancy, with main and redundant position sensors and motors, driven by separate main and redundant analogue boards, which are in turn supported by separate main and redundant MACs and DPUs as shown in Figure 1 below. The harnesses, both warm and cryogenic, are also maintained as separate systems.

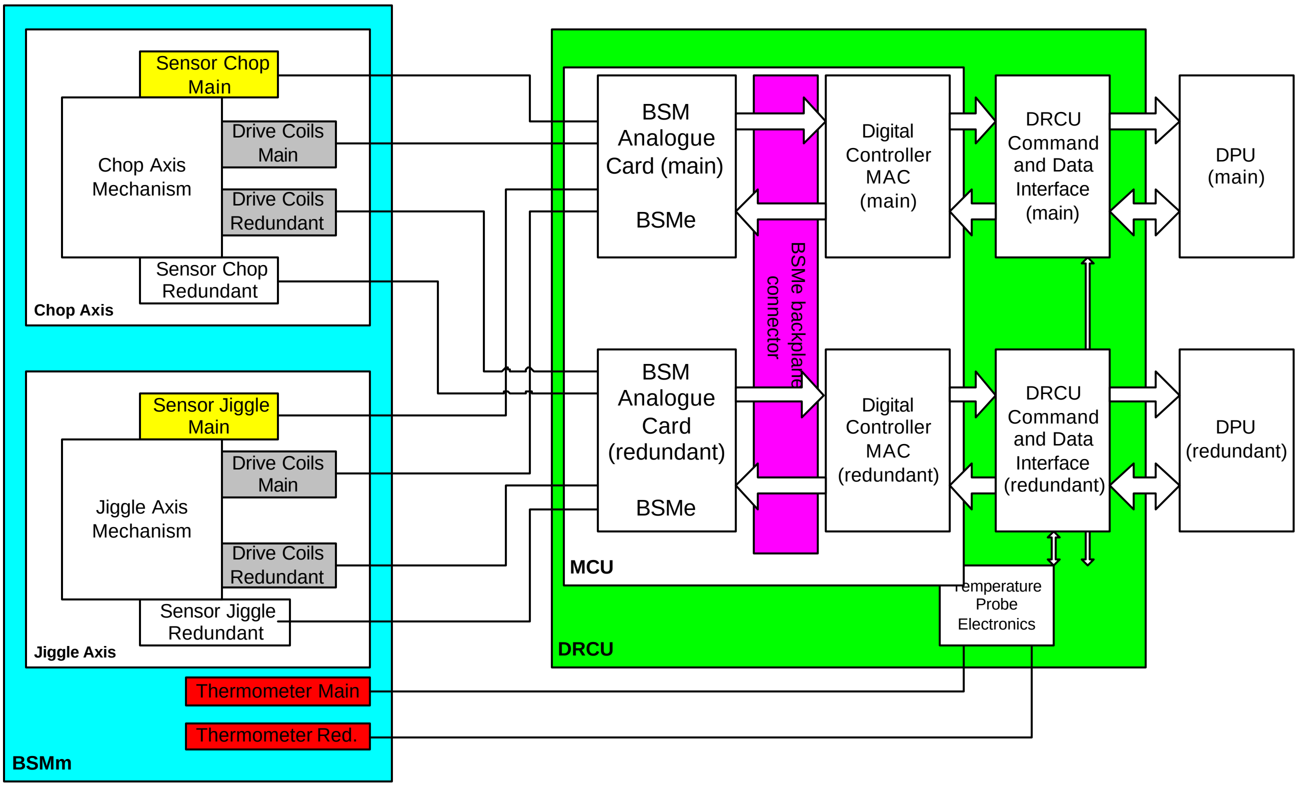

Figure 1 : BSM electronics architecture showing parrallel redundancy

The BSMe redundancy scheme will not be able to operate independently of the SMEC mechanism. A failure in the primary system of either mechanism results in both switching to the redundant schemes. Equally, the PCAL and thermometry units carried aboard the BSMs would be required to switch at the same time.

The BSMs and BSMm mechanical design incorporates little redundancy. The structural parts are in general over-designed from a strength viewpoint in order to give adequate stiffness. The structures are maintained at very low stress levels during launch and even lower stresses during orbit. The primary sources of stress will be those induced on assembly and thermal cooldown. The components are manufactured from space-proven materials with good fatigue and stress corrosion cracking properties. The design includes the ability to limit the motion of the BSM during launch, to protect the flexures, and physical limits to the motion in the event of a component failure.

The design of the BSMs and BSMm should be such that the BSM will meet the reliability requirements for SPIRE as set out in the IRD (AD-1). In summary this is that a failure of the BSM should not lead to a total loss of the instruments ability to do science, albeit with loss of efficiency due to the need to use a backup observing mode. If for some reason the BSM were unable to move in either axis at all, then science could be obtained using the scan mapping mode - although there would be a serious loss of efficiency/sensitivity. The jiggle axis would provide some limited ability to modulate signal in event of a catastrophic failure in the chop axis and much worse than expected 1/f noise. In order to ensure that SPIRE can obtain data in the event of a BSMm failure, the mechanism must fail such the field of view of the FTS is still available, and that large or unpredictable offsets of the photometer field are not required.

This is achieved by ensuring *by design* that in the event that there is no drive signal reaching the BSM the mirror will be within +/- 0.18 degrees of the nominal bore-sight, and that in the event of a complete mechanical failure the mirror will be within. within + 1.5/-2.4 (the Spectrometer Field of View) degrees[1] of its nominal position

[1] Note that a careful check will be made as to whether this is +1.5/-2.4 or -1.5/+2.4

3.2 Reliability Block Diagram

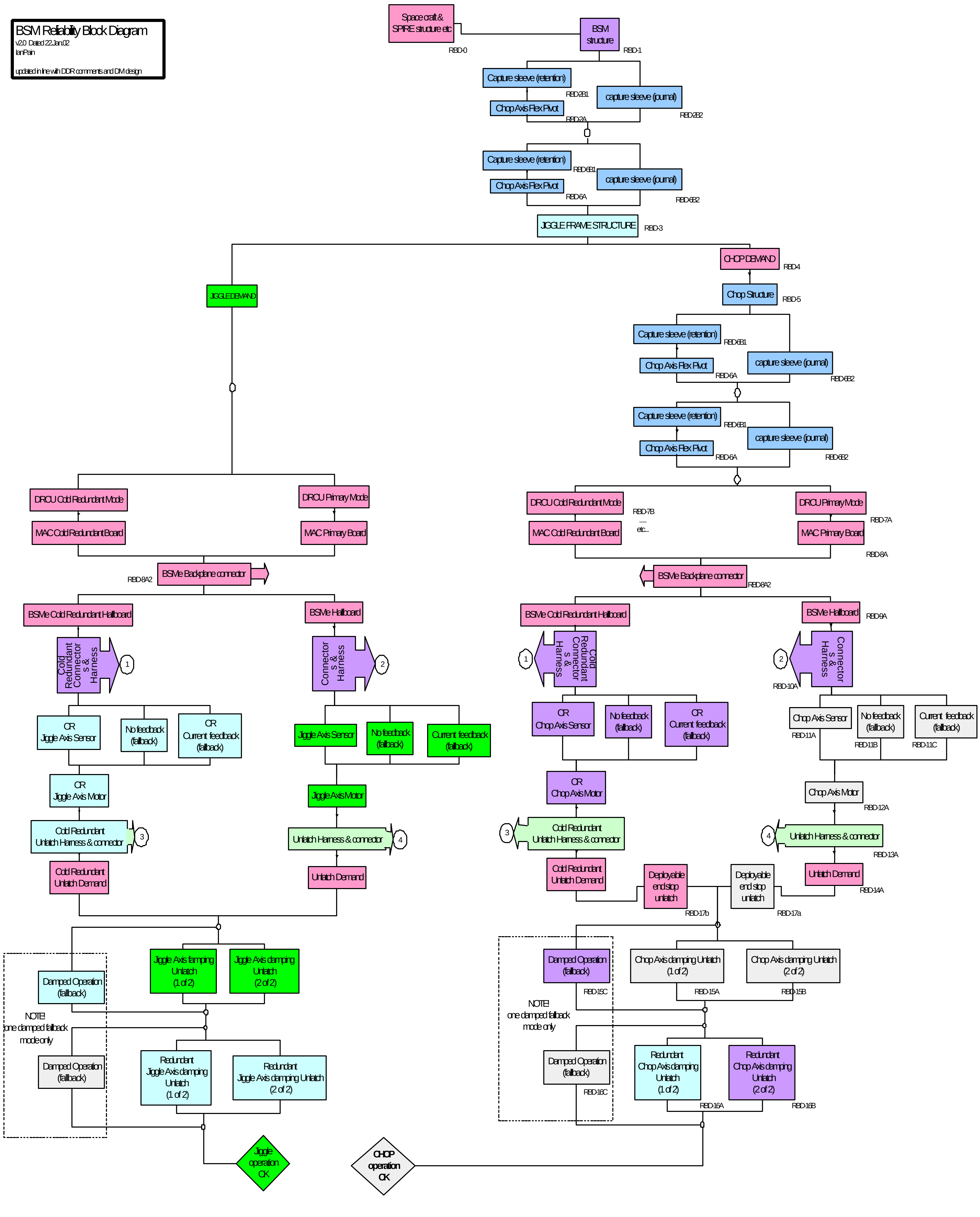

Figure 2 Reliability Block Diagram, BSM

Block Diagram Notes

1. Concerning RBD-15 and 16A/B, 1 out of 2 is enough to operate and C is then a fallback if both fail.

2. The RBD-11A/B/C are connected in parallel, but these are not redundant blocks. The intention here to illustrate the possibility to operate in a degraded mode.

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3.3 Single Point Failures

A Reliability Block Diagram is considered above. At this level it is apparent that

1. The wiring harness is a potential Single point failure, unless both the BSMe 'half' boards have an individual cable harness with it's own connectors.
2. The BSM structure and jiggle frame are SPF's. No surprise, but it reinforces the requirement for analysis of these structures for survival, and possible additional tests (e.g. to verify the FEA).
3. Assuming we have a launch damper (shorted motor coils), In the primary operations mode the launch damper 'unlatch' command must unlatch the primary mode motor coil, BUT MUST ALSO unlatch the cold redundant motor coils latching circuit. Vice versa for the redundant mode. This is discussed in the BSME schematic Subsystem Specification Document (Beam Steering Mechanism, Figure 4).
4. The same comment as (1) applies for the cables which send the unlatch command - they should remain separate and parallel.
5. The common connector at the BSMe board is undesirable but is advised by LAM on the grounds of space constraints and the problem that alignment tolerances could lead to an over stress of components if a single board is to be mated via two back-plane connectors simultaneously. Clearly, fully redundant connectors and boards would be preferred, and is being investigated by LAM

3.4 FMECA

A failure modes, effects and criticality analysis (FMECA) has been performed, in accordance with the product assurance plan. The full detail is presented in the FMECA work-sheets included as appendix 1.

The FMECA ‘viewpoint’ is that of normal operation, with the observing mode being assumed to require combined chop and jiggle motion of the BSM.

A FMECA for the other states – off, standby, thermal cooldown, launch, have not been performed. For the first two the main implications are understood to be electronic; i.e incorporated in the MCU FMECA. Cooldown and Launch failures have been folded into the main FMECA, as this is more pragmatic than creating a duplicate analysis.

For each element of the reliability block diagram, a number of failure modes and their implications are considered. The analysis is limited to considering a single component failure at any one time, except for cold redundant components where the operation is exposed only after a prime mode has failed.

The principal recommendations resulting from the FMECA are :

3.4.1 Control Software

1. We need to guard against a software command to unlatch when we don't want to.
2. Observation Definition Software needs to be robust handling chop/jiggle requests (i.e. not forgetting them or sending wrong one, or out of range value ......)
3. The bistable deployable end stop relay may have an indeterminate state, in which case the MCU must be robust against it.
4. MCU needs voltage limiter on analogue outputs, and software needs similar check to prevent the system from being driven out of range.
5. need to set invalid sensor range flags in WE (MCU) software

3.4.2 Electronics :

1. for latch solenoid, must be able to turn off power to launch latch solenoid with good redundancy. leaving a solenoid switched on would boil of all the cryogens fast.

2. Single connector at BSMe backplane undesirable. The trade is between a single but rugged backplane connector and two less rugged single connectors. LAM to advise.
3. The short circuit case for the DRCU should be carefully considered in the MCU FMECA concerning propagation to the DPU.
4. Propagation of shorts between separate boards of the BSMe and the internal protection should also be considered. in the MCU FMECA

3.4.3 Mechanical :

1. Mirror surface should be tested for print through of light weighting
2. Good process control on magnet adhesive is required
3. The flex pivot mounting is critical.
4. End stops must be well characterised.

4. Critical Components Identification

We assume that items which require declaration here are those which "fail to meet the project requirements" for *failure tolerance*, or undetectable loss of redundancy.

As discussed above for SPIRE the failure tolerance is total loss of science - i.e. a failure of the BSM which would result in (a) large pointing offset for the photometer or/and (b) inability to take data with the FTS due to loss of its field of view. i.e. critical components would be those whose failure would result in the BSM failing to meet the required fail safe positions defined in SPIRE-ATC-PRJ-000460, 4.2.13 and 4.2.14.

No such components were identified, but the design must ensure that the fail-safe positions are met should one or more flex pivots or motors fail.

5. Appendix 1 : FMECA worksheets

(original in Excel Spreadsheet form. SPIRE_fmeca_v2.xls)

Mechanical Failure Modes Effect and Criticality Analysis		
Product: **SPIRE**	Prepared by:I.Pain	Document Reference: SPIRE-ATC-PRJ-0711
Project/Phase: **Mission Observing**	Approved by: G.Wright	Issue: 2
System/Subsystem/Equipment: **BSM**	Date: 22.Jan.02	Page 1 of 1

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
RBD-1	**1**	**BSM Structure**	thermal path	Failure to cool down	loose connector or thermal strap	Launch	A. component temperature high. B.degraded detector	2R	high background	redundant thermal path	tested at AIV	tested at system integration
	2		attachment to SPIRE bench	Fails on launch	loose or failed bolt, low cycle fatigue crack	Launch	A. pointing inaccuracy, damage to BSM components B.pointing inaccuracy, damage to SPIRE.	2R	lack of signal	three fasteners (2/3 redundant)		sizing calc on structural fasteners (MMSL responsible)
	3		mechanical support	Failure during operation	high cycle FATIGUE crack, loose bolt	Chop & Jiggle Mode	A. erratic resonance effects, loss of cooling path, motor housing damage B. pointing errors, higher background. PCAL support impaired	3	changes natural frequencies	back-up mode - drift map		performed FEA, use SCC OK material
	4		rigid mount	Degraded operation	resonance	Chop & Jiggle Mode	A. longer settling time B. longer settling time	3	longer settling time	reduce speed operation, waveform modifications	confirm micro-vibration spectrum	analysis of micro-vibration spectrum shows OK

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	1	**Jiggle axis flex pivot**	rotation bearing	Fails on launch	over-stress, SCC or low cycle FATIGUE crack	Launch	A.Loss of restoring torque. Increased friction to drive. B.loss of definition of pointing, Jiggle mode probably unusable	2R	-unstable pointing. -Cross coupling of chop with jiggle beyond normal parameters. Increase in drive currents. -Random noise on sensors	-prevention by flex pivot protecion sleeve. -redundant bearing surface (RBD-2B) - degraded operation. -Coarse control with motors to central position. -Scan-map back-up mode	increase test programme to cover failure modes if funds permit.	most likely to lose both flex pivots if one goes.
	2		rotation bearing	Failure during operation	icing	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	2	thermal history . Cured by warm up	back-up mode - drift map		only during AIV - not possible during on-orbit operations
	3		rotation bearing	Failure during operation	high cycle fatigue crack	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	2	deterioration in performance as crack progresses	back-up mode - drift map		flex pivot alignment procedure is critical
	4		rotation bearing	Failure during operation	debris ingress	Chop & Jiggle Mode	increase in friction & power usage	2	random sticking. Power consumption high	scan-map		prevented by clean room procedures
RBD-2b1	**1**	**Jiggle axis flex pivot protection sleeve**	protection sleeve	Failure during operation	icing	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	3	motors & sensors working OK but no motion results	scan-map		only during AIV - not possible during on-orbit operations
	2		protection sleeve	Failure during operation	debris ingress	Chop & Jiggle Mode	A. increase in friction B.increased power usage	2		scan-map		prevented by clean room procedures
	3		protection sleeve	friction or end-stop jamming	over-travel on small clearance	Chop & Jiggle Mode	A. increase in friction B.increased power usage	2	end-stop sticking	deployable end stop ensures spectrometer FoV retained	flex pivot mounting is important End stops to be well characterised	could consoider lead-ion plating of sleeve

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	4		protection sleeve	friction or end-stop jamming	vacuum welds during launch rubbing contact	Chop & Jiggle Mode	A. Stuck B. no jiggle mode.Fixed stare mode, not (0,0)	2	motors & sensors working OK but no motion results	back-up mode - drift map	dissimilar metals (aluminium, inconel)	
RBD-2b2	**1**		redundant journal bearing function	friction or end-stop jamming	vacuum welds during launch rubbing contact	Launch	increase in friction & power usage	2R	erratic torque-position plot	back-up mode - drift map	dissimilar metals,passivated/ alo-cromed	consider tests of this mode.
RBD-3	**1**	**Jiggle frame structure (includes fasteners)**	thermal path	Failure to cool down	loose connector or thermal strap	Launch	A. component temperature high. B.degraded detector	3	high background	thermal end-stop. Controlled cooldown rate for instrument	tested at AIV	Flex pivot differential thermal stresses
	2		mechanical support	Fails on launch	low cycle fatigue crack	Launch	loss of chop axis position definition	2	erratic torque-position plot			perform FEA, use SCC OK material
	3		attachment to BSM stricture	Fails on launch	loose or failed bolt	Launch	loss of chop axis position definition	2R	erratic torque-position plot	redundant fasteners (4/8)		locking fasteners, torque control
	4		mechanical support	Failure during operation	high cycle FATIGUE crack, loose bolt	Chop & Jiggle Mode	erratic resonance effects	2	changes natural frequencies	back-up mode - drift map		perform FEA, use SCC OK material
	5		mechanical support	Degraded operation	resonance	Chop & Jiggle Mode	A. longer settling time B. longer settling time	3	longer settling time	reduce speed operation, waveform modifications	confirm micro-vibration spectrum	unlikely
RBD4	**1**	**Chop demand**	initiate chop	no chop requested	error in ODF, telemetry, operator error	Chop & Jiggle Mode	A. nil B.delay to troubleshoot problem	3	no chopping	nil in BSM	ODF software needs to be robust handling chop requests	higher level system needs to provide protection

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	2		initiate chop	excessive chop angle or frequency requested	error in ODF, telemetry, software, operator error	Chop & Jiggle Mode	A. flex pivot overload or excess power dissipation. B. delay to trouble shoot problem	2	as RBD2a	nil in BSM	MCU needs voltage limiter, software needs sanity check	higher level system needs to provide protection
	3		initiate chop	chop demand short circuits	electrical short	Chop & Jiggle Mode	A. no control B. excess power dissipation, no control	2R	excess power dissipation, fixed offset	reset higher level system; power off at MCU		MCU relays to switch off BSM power amps
RBD5	**1**	**Chop Structure**	thermal path	Failure to cool down quickly	loose connector	Launch	A. component temperature high. Differential thermal stress B.degraded detector	3	high background	thermal end-stop. Controlled cooldown rate for instrument	tested at AIV	
	2		attachment to jiggle frame	Fails on launch	, low cycle fatigue crack	Launch	A. pointing inaccuracy, damage to BSM B.pointing inaccuracy, mirror surface degraded	2	erratic torque-position plot		perform FEA, use SCC OK material	unlikely
	3		attachment to jiggle frame	Fails on launch	loose or failed bolt	Launch	A. pointing inaccuracy, damage to BSM B.pointing inaccuracy	2R	erratic torque-position plot	flex pivots would act as journal bearing.		locking fasteners, torque control
	4		retain magnet & sensor actuator iron core	Fails on launch	magnet loosens	Launch	A. chop axis jams anywhere in range of travel B. jam in indeterminate position	2	chop jams or high friction load	try cycling prime and redundant motor coils and restore to zero position. Fall back is scan map	good process control on magnet adhesive required	
	5		mechanical support	Failure during operation	high cycle FATIGUE crack, loose bolt	Chop & Jiggle Mode	A. erratic resonance effects B. pointing errors	2	changes natural frequencies	back-up mode - drift map	perform FEA, use SCC OK material	unlikely

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	6		rigid mount	Degraded operation	resonance	Chop & Jiggle Mode	A. longer settling time B. longer settling time	3	longer settling time	reduce speed operation		unlikely
	7	Chop Mirror	optical surface	print through of lightweighting on mirror surface		Chop & Jiggle Mode	A. image degradation B. image degradation	2	waffle pattern		test mirror surface for print through	
	8		optical surface	contamination on mirror		Chop & Jiggle Mode	A. image degradation B. image degradation	2	loss of signal, spectrographic signature			clean room assembly
RBD-6A	1	Chop axis flex pivot	rotation bearing	Fails on launch	over-stress, SCC or low cycle FATIGUE crack	Launch	A.Loss of restoring torque. Increased friction to drive. B.loss of definition of pointing, chop mode probably unusable	2R	-unstable pointing. - Increase in drive currents. -Random noise on sensors	-prevention by flex pivot protection sleeve. -redundant bearing surface (RBD-6B) - degraded operation. -Coarse control with motors to central position. -Scan-map back-up mode	increase test programme to cover failure modes if funds permit.	most likely to lose both flex pivots if one goes.
	2		rotation bearing	Failure during operation	icing	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	2	thermal history . Cured by warm up	back-up mode - drift map		only during AIV - not possible during on-orbit operations
	3		rotation bearing	Failure during operation	high cycle fatigue crack	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	2	deterioration in performance as crack progresses	back-up mode - drift map		flex pivot alignment procedure is critical
	4		rotation bearing	Failure during operation	debris ingress	Chop & Jiggle Mode	increase in friction & power usage	2	random sticking. Power consumption high	scan-map		prevented by clean room procedures
RBD-6b	1	Chop axis flex pivot protection sleeve	protection sleeve	Failure during operation	icing	Chop & Jiggle Mode	A. sticky or stuck B. increase in friction & power usage	3	motors & sensors working OK but no motion results	scan-map		only during AIV - not possible during on-orbit operations

Ident.	number	Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	2		protection sleeve	Failure during operation	debris ingress	Chop & Jiggle Mode	A. increase in friction B.increased power usage	2		scan-map		prevented by clean room procedures
	3		protection sleeve	friction or end-stop jamming	over-travel on small clearance	Launch	A. increase in friction B.increased power usage	2	end-stop sticking	deployable end stop ensures spectormeter FoV retained	flex pivot mounting is important End stops to be well characterised	could consoider lead-ion plating of sleeve
	4		protection sleeve	friction or end-stop jamming	vacuum welds during launch rubbing contact	Chop & Jiggle Mode	A. Stuck B. no jiggle mode.Fixed stare mode, not (0,0)	2	motors & sensors working OK but no motion results	back-up mode - drift map	dissimilar metals (aluminium, inconel)	
RBD-6b2	5	**redundant journal bearing function**	redundant journal bearing function	friction or end-stop jamming	vacuum welds during launch rubbing contact	Chop & Jiggle Mode	increase in friction & power usage	2R	erratic torque-position plot	back-up mode - drift map	dissimilar metals,passivated/ alo-cromed	consider tests of this mode.
RDB 7A, 8A, 9A	1	**DRCU - MAC - BSMe Primary boards**	control	Premature operation	chop before unlatch or power surge?	Chop & Jiggle Mode	A. damage to motors or pivots B. loss of function	2	unknown	nil in BSM		DRCU to perform FMECA
	2		control	Failure to operate		Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode. No unlatch command.	2R	no chopping, jiggling. Latch and damping remain in place	scan map		DRCU to perform FMECA
	3		control	Failure to cease operation		Chop & Jiggle Mode	A. loss of control B. loss of control, excess power dissipation	2R	excess power dissipation, fixed offset	reset higher level system or switch to redundant unit		DRCU to perform FMECA
	4		control	Failure during operation - motors fail in on condition		Chop & Jiggle Mode	A. loss of control B. loss of control, excess power dissipation	2R	excess power dissipation, fixed offset	reset higher level system or switch to redundant unit		DRCU to perform FMECA

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	5		control	Failure during operation		Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2R	no chopping, jiggling. Latch indeterminate?	scan map or switch to redundant unit	indeterminate latch state should be avoided.	DRCU to perform FMECA
	6		control	Degraded operation		Chop & Jiggle Mode	A.degraded BSM function B. degraded BSM function	2R	degraded BSM function	scan map or switch to redundant unit		
	7		control	short circuit		Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2R	no chopping, jiggling. Latch indeterminate?	nil in BSM		
	8		control	open circuit		Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2R	no chopping, jiggling. Latch indeterminate?	nil in BSM		
	9		control	incorrect function	design error	Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2	no chopping, jiggling. Latch indeterminate?	nil in BSM		TESTED AT AIV
	10		control	Incorrect commands	(software error)	Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2	no chopping, jiggling. Latch indeterminate?	nil in BSM		TESTED AT AIV
	11		control	Incorrect software functions	(software error)	Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2	no chopping, jiggling. Latch indeterminate?	nil in BSM		TESTED AT AIV
RDB-8a2		**common backplane**	electrical connection	Incorrect software functions	(software error)	Chop & Jiggle Mode	A. loss of function B. no chop or jiggle mode.	2	no chopping, jiggling. Latch indeterminate?	nil in BSM		
RBD 10A	1	**Connectors and cryo-harness**	motor electrical connection	short circuit	short	Chop & Jiggle Mode	A. motor shorted, damping increased B. loss of chop or jiggle	2R	no motion	switch to redundant harness and operate against a damped motor		
	2		sensor electrical connection	short circuit	short	Chop & Jiggle Mode	A. sensor shorted B. loss of position data	2R	invalid or fixed sensor value	switch to redundant harness, or operate open loop	set invalid sensor range flags in WE software	check - does de-power of WE primary open the circuit?

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	3		PCAL electrical connection	short circuit	short	Chop & Jiggle Mode	A. nil B. PCAL shorted	3	nil in BSM	switch to redundant harness		
	4		thermistor electrical connection	short circuit	short	Chop & Jiggle Mode	A. nil B. thermistor shorted	4	nil in BSM	switch to redundant harness		
	5		electrical connection	intermittent short	short	Chop & Jiggle Mode	as short, but more annoying	2R	as short, but more annoying	switch to redundant harness		diagnose by extended telemetry?
	6		motor electrical connection	open circuit		Chop & Jiggle Mode	A. motor shorted, damping increased B. loss of chop or jiggle	2R	degraded motion	switch to redundant harness		
	7		sensor electrical connection	open circuit		Chop & Jiggle Mode	A. sensor shorted B. loss of position data	2R	no position feedback	switch to redundant harness or operate open-loop		
	8		PCAL electrical connection	open circuit		Chop & Jiggle Mode	A. nil B. PCAL shorted	3	nil in BSM	switch to redundant harness		
	9		thermistor electrical connection	open circuit		Chop & Jiggle Mode	A. nil B. thermistor shorted	4	nil in BSM	switch to redundant harness		
RBD 11A	1	**Chop Axis sensor**	sense position	Failure to operate	open circuit or short	Chop & Jiggle Mode	A. closed loop feedback lost B. increased settling time, noise or drift	2R	invalid sensor value	switch to redundant WE or operate open-loop	set invalid sensor flags in WE software	problem may be in WE or harness
	2		sense position	Failure to cease operation	open circuit or short	Chop & Jiggle Mode	A. closed loop feedback servo to end stop B. chop against end-stop	2R	no position feedback, excessive power dissipation	switch to redundant WE or operate open-loop		
	3		sense position	Failure during operation	open circuit or short	Chop & Jiggle Mode	A. closed loop feedback lost B. increased settling time, noise or drift	2R	unknown	switch to redundant WE		

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	4		sense position	Degraded operation	mechanical damage	Chop & Jiggle Mode	A. closed loop feedback lost B. increased settling time, noise or drift	2R	unknown	switch to redundant WE		
	5											deleted
	6											deleted
	7		sense position	Incorrect software functions	open circuit or short	Chop & Jiggle Mode	unexpected behaviour, please contact your systems administrator	2R	nil in BSM	nil in BSM	test all modes in ground	
RBD 11B	**1**	**Chop Axis control mode with no feedback**	backup mode closed loop control	Failure to operate	unknown	Chop & Jiggle Mode	A. closed loop feedback lost B. increased settling time, noise or drift	3	undamped motion	switch to redundant harness or operate open-loop or scan-map	test this mode on ground	this is a back-up degraded operation mode
	2		backup mode closed loop control	Incorrect software functions	unknown	Chop & Jiggle Mode	unknown	3	nil in BSM	nil in BSM	ensure this operating mode included in software	this is a back-up degraded operation mode
RBD 11c	**1**	**Chop Axis control mode with no feedback**	backup mode closed loop control	Failure to operate	unknown	Chop & Jiggle Mode	A. closed loop feedback lost B. increased settling time, noise or drift	3	undamped motion	switch to redundant harness or operate open-loop or scan-map	test this mode on ground	this is a back-up degraded operation mode
	2		backup mode closed loop control	Incorrect software functions	unknown	Chop & Jiggle Mode	unknown	3	nil in BSM	nil in BSM	ensure this operating mode included in software	this is a back-up degraded operation mode
RBD 12A	**1**	**Chop Axis Motor**	motive force	short circuit	short	Chop & Jiggle Mode	a. no motion b. no motion	2R	no motion	switch to redundant WE and operate against a damped motor		is the shorted condidtion detectable in WE by telemetry?

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	2		motive force	open circuit (broken wires)	open circuit	Chop & Jiggle Mode	a. no motion b. no motion	2R	no motion	switch to redundant WE		
	3		motive force	part-short circuit (motor windings reduced by short)	short	Chop & Jiggle Mode	A. degraded motion B. degraded motion	2R	increased settling time, changed power dissipation	switch to redundant WE and operate against a partly damped motor		
	4		mechanical support	mechanical damage - housing	structural support fails	Chop & Jiggle Mode	A. degraded motion B. degraded motion	2R	increase in friction & power usage (or stuck)	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap		housing damage can affect redundant motor so is SPF for chopping (but not SPIRE)
	5		mechanical support	mechanical damage - fasteners loose	loose or failed bolt	Chop & Jiggle Mode	A. degraded motion B. degraded motion	2R	increase in friction & power usage (or stuck)	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap		
	6		thermal path	mechanical damage - shield	loose or failed bolt, low cycle fatigue crack	Chop & Jiggle Mode	A. degraded motion or thermal hot spot B. degraded motion or increased background	2R	increase in friction & power usage (or stuck) , increased background temperature	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap		
	7		electrical connection	loss of electrical isolation	loose or failed bolt, low cycle fatigue crack	Chop & Jiggle Mode	unknown	2R	noise or erratic motion	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap	investigate	
RBD 12B	**1**	**Chop Axis Motor (cold redundant)**	motive force	short circuit (probably on launch)	short	Chop & Jiggle Mode	A. damping of primary motor B. increased settling time, power consumption	2	damped motion, increase in power dissipation	operate against a damped motor	test this mode on ground. Test redundant circuits on establishing orbit	cold redundant component

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
RBD 13	**1**	**unlatch harness and connector**	unlatch solenoid	short circuit	short	Chop & Jiggle Mode	A. latch shorted B. Restriced FoV	2R	no retract signal	switch to redundant harness and operate against a damped solenoid coil		details TBD by LAM (designing LL for SMEC, BSM to use same unit)
	2		unlatch sensor	short circuit	short	Chop & Jiggle Mode	A. sensor indicates closed, but chop motion restricted B. chop motion restricted, limited FoV	2R	sensor indicates closed, but chop motion restricted	switch to redundant harness		details TBD by LAM (designing LL for SMEC, BSM to use same unit)
	3		unlatch	intermittent short	short	Chop & Jiggle Mode	as short,	2R	as short,	switch to redundant harness, or repeat commands (one success is enough)		details TBD by LAM (designing LL for SMEC, BSM to use same unit)
	4		unlatch solenoid	open circuit	open circuit	Chop & Jiggle Mode	A. latch unpowered B. Restriced FoV	2R	no retract signal	switch to redundant harness		details TBD by LAM (designing LL for SMEC, BSM to use same unit)
	5		unlatch sensor	open circuit	open circuit	Chop & Jiggle Mode	A. sensor indicates closed, but chop motion is OK B. sensor indicates closed, but chop motion is OK	2R	sensor indicates closed, but chop motion is OK	switch to redundant harness or operate open-loop	incorporate in system checklists	false negative sensor reading.
RBD 14	**1**	**unlatch demand**	unlatch command	no unlatch requested	(software error)	Chop & Jiggle Mode	A. nil B. delay to troubleshoot problem	3	no retract signal	nil in BSM	MCU software to be robust	
	2		unlatch command	latch command set high	(software error)	Chop & Jiggle Mode	A. nil B. delay to troubleshoot problem	3	no retract signal	nil in BSM	MCU software to be robust	

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	3		unlatch command	unlatch demand short circuits	(software error)	Chop & Jiggle Mode	A. nil B. excess power dissipation	2	excess power dissipation	reset higher level system, operate BSM in limited range of travel.	must be able to turn off power to launch latch solenoid with redundant function	solenoid left on would boil off cryogens off if no provisdion to turn it off.
RBD 15 A,B,C	**1**	**chop axis damping unlatch relays**	open damping circuit	Premature operation (during launch)	open circuit, mechanical damage	Launch	A. no damping of coil during launch. Possible damage to flex pivots B. degraded BSM function	2R	none	redundant coils damped	test this mode on the ground	
	2		open damping circuit	Failure to operate before launch	short, mechanical damage, software error	Launch	A. no damping of coil during launch. Possible damage to flex pivots B. degraded BSM function	2R	detectable in MCU?	redundant coils damped	MCU feedback required on damping	
	3		open damping circuit	Failure to operate after launch	short, mechanical damage	Commisioning	A. damping of primary motor B. increased settling time, power consumption	3R	damped motion, increase in power dissipation	serial redundant switches, possible to operate against damped coil		
	4		open damping circuit	Failure during operation	short, mechanical damage	Chop & Jiggle Mode	indeterminate state	3R	unknown	serial redundant switches		
	5		open damping circuit	short circuit	short, mechanical damage	Chop & Jiggle Mode	A. damping of primary motor B. increased settling time, power consumption	2R	damped motion, increase in power dissipation	serial redundant switches, possible to operate against damped coil		

Ident. number		**Item/block**	**Function**	**Failure Mode**	**Failure Cause**	**Mission phase/ op.mode**	**Failure effects a. Local effects b. End effects**	**Severity**	**Failure detection method/ observable symptoms**	**Compensation provisions**	**Correction actions**	**Remarks**
	6		open damping circuit	Incorrect commands	(software error)	Launch	A. unlatch when not required B. damage to BSM, loss of prtection against flex pivot failure	2	detectable in MCU? HIDDEN FAILURE?	nil in BSM	software protection against premature unlatch demand required	
	7		open damping circuit	Incorrect software functions	(software error)	Launch	A. unlatch when not required B. damage to BSM, loss of prtection against flex pivot failure	2	detectable in MCU? HIDDEN FAILURE?	nil in BSM	software protection against premature unlatch demand required	
RBD 16A	1	**chop axis deployable end-stop unlatch**		Premature retraction (during launch)		Chop & Jiggle Mode	no limit of travel during launch. Possible damage to flex pivots	2R	none	motor coils damped, flex pivot sleeves, adequate reserve on pivots		could incorporate feedback into MCU?
	2		Restrain chop angle during launch	damage to pivots	Overconstrains pivots	Launch	A. induced flex pivot failure - see above	2R	as RDB2, 4	flex pivot sleeves, use of jiggle to address 1/f noise, scan map	test for this during vibration campaigns	
	3		Restrain chop angle during launch	Failure to cease operation	short or mechanical damage	Chop & Jiggle Mode	A. latch shorted B. Restriced FoV	3R	no retract signal obtained, hard stops at end of travel	redundant coil on solenoid, redundant harness		
	4		Restrain chop angle during launch	Failure during operation		Chop & Jiggle Mode	indeterminate state	3	unknown	unknown	test MCU / software for indeterminate state	unlikely as bi-stable magnet.
	5		Restrain chop angle during launch	short circuit	short	Chop & Jiggle Mode	damping of primary solenoid coil	3R	no retract signal obtained, hard stops at end of travel	redundant coil on solenoid, redundant harness		details TBD by LAM (designing LL for SMEC, BSM to use same unit)

Ident. number		Item/block	Function	Failure Mode	Failure Cause	Mission phase/ op.mode	Failure effects a. Local effects b. End effects	Severity	Failure detection method/ observable symptoms	Compensation provisions	Correction actions	Remarks
	6		Restrain chop angle during launch	Incorrect commands	(software error)	Launch	A. unlatch when not required B. damage to BSM, loss of prtection against flex pivot failure	2	detectable in MCU? HIDDEN FAILURE?	nil in BSM	software protection against premature unlatch demand required	
	7		Restrain chop angle during launch	Incorrect software functions	(software error)	Launch	A. unlatch when not required B. damage to BSM, loss of prtection against flex pivot failure	2	detectable in MCU? HIDDEN FAILURE?	nil in BSM	software protection against premature unlatch demand required	