SPIRE Beam Steering Mirror Detailed Design Review Board Draft Report 10 December 2001

CIRCULATION

Eric Clark, RAL – SPIRE PA
Colin Cunningham, ATC – Systems Engineer
John Delderfield, RAL – SPIRE Systems Engineer
Matt Griffin, University of Wales – Cardiff, SPIRE PI
Ken King, RAL, SPIRE Project Manager
Ian Pain, ATC – BSM Program manager
Tully Peacock, ATC Optical Systems
Eric, Sawyer, RAL – Hardware Manager
Brian, Stobie, ATC – BSM Control and Electronics Engineer
Bruce, Swinyard, RAL – SPIRE Instrument Scientist
Gillian Wright, ATC – SPIRE Co-I

ATTENDEES

External:
Douglas Griffin (RAL) - Chair
Eric Clark (RAL)
Berend Winter (MSSL)
Patrick Levacher (LAM)
Wim Aalders (SRON)
Peter Hargrave University of Wales

Written comments:
Ralph Hofferbert (MPIA)
Jan Rautakoski
RAL Project Office

ATC:
Colin Cunningham
Ian Pain
Gillian Wright
Brian Stobie
Tom Paul
Tully Peacocke
Ken Wilson (project technician)
Brenda Graham (electrical engineer)
Ian Laidlaw
Gayle Reynolds (minutes)

LAM:
Patric Levacher

1. INTRODUCTION AND PURPOSE

The meeting was a Detailed Design Review aimed at confirming that the design and development program of the SPIRE Beam Steering Mirror (BSM) fulfils all technical and programmatic requirements. Once the Review Item Discrepancies (RIDs) arising from the material and documentation presented at the meeting and cross referenced in this document have been adequately dealt with, the design will be frozen and approval will be given by the SPIRE project office for the ATC to enter into the manufacture and procurement phase of the programme.

The specific items to be reviewed were as follows:

(i) Confirm that the following controlling documentation are ready to be signed off;
   a. BSM ICD
   b. BSM PA Plan
   c. BSM Subsystem Specifications
   d. BSM Development Plan
(ii) Review the technical design of the BSM;
(iii) Review development programme.

The BSM system comprises the cryogenic, focal plane items, the harness and the warm electronics (and software) located on the SVM in the FCU. The ATC is designing and procuring the cryogenic items and producing specifications and supplying interface information for the warm electronics. The LAM is responsible for the final design and supply of the warm electronics associated with the BSM. Given this overlap in responsibilities between two institution for the warm components of the complete system, it was decided that the review would principally focus on the cryogenic components but would also review the warm electronics. The warm electronics would also be reviewed at the LAM in a separate DDR.

Copies of the RIDs arising from the meeting are attached to the end of the document.

2. Documentation

The following table compares the list of required documentation with the documentation supplied for the review.

Required Document	Comment
Subsystem Specification Document	Submitted. See HS-SP-ATC-XX
Interface Control Document	Submitted as Annex to the BSM Design Description Document. See HS-SP-ATC-XX
Configuration Item Data List	
Configuration Status List	

Interface Drawings	
Top level drawings including drawing tree	
Electrical circuit diagrams	
Components List	
FMECA	Supplied as an Annex to the BSM Design Description Document
Materials List	
Parts list	
Subsystem Development Plan and Schedule	
Subsystem AIV plan	
Subsystem PA plan	Submitted. See HS-SP-ATC-XX
Preliminary Test Plan	
Test reports	

(i) SPIRE Beam Steering Mirror Design Description (v 4.0)
(ii) SPIRE Beam Steering Mirror Subsystem Specification Document (v. 3.2)
(iii) Herschel SPIRE Beam Steering Mirror Product Assurance Plan (v. 1.0)
(iv) SPIRE BSM Development Plan (v. 5.0)

Incorporated within the single BSM design description document were the BSM FMECA, ICD and various other technical attachments.

Comments and RIDs on supplied documentation

5. MEETING SUMMARY

5.1 Project overview (Gillian Wright)

A brief overview of the role of the BSM within the SPIRE instrument during the various observation modes was presented. The importance of avoiding the situation were the mirror failed in the fully chopped position preventing operation of the spectrometer was stressed.

5.2 Review of BSM Requirements (Ian Pain)

A presentation of the contents of the BSM Subsystem Sub-system Specifications was made highlighting the principal TBDs.

3. CONCLUSIONS

The design presented in the review documentation and at the meeting adequately fulfils the requirements outlined in the applicable documents for the subsystem. There are however several outstanding questions that need to be resolved before the review can be closed out. These issues are summarized below:

3.1. Motor winding material

The four motors used in the BSM are being procured in conjunction with PACS from Zeiss. At the moment, Zeiss are not in a position to decide whether the winding wire will be made from Copper or Aluminum. The tradeoff is motor efficiency against manufacturability. The Copper windings are less efficient and will produce a higher dissipation load to Level 1 and are relatively easy to wind and solder. Aluminum is more efficient but it more difficult to wind and solder. It was the impression of the ATC that they would not be able to influence the decision making process and would have to accept whatever solution was adopted by Zeiss. Material selection by Zeiss is not expected before summer 2002.

3.2. Flex Pivot selection

This is the primary outstanding issue for the BSM and needs to be resolved with some urgency. The design presented at the review requires that there be two types of flex pivot with different stiffness used in the device. The stiffer and stronger of the two pivots is to be used in the jiggle stage which must carry the mass of the jiggle stage frame and the mirror. The lighter pivots are selected for the chop stage. These pivots need only support the mass of the mirror. The procurement of space qualified flex pivots contains a component of batch cost and unit cost, hence selecting a single flex pivot type for use in both the chop and jiggle stages would significantly reduce the total cost as there would be only a single batch cost.

Budgetary constraints at the time of the meeting prevent ATC from adopting the optimal design of tailored pivots for the jiggle and for the chop stage. The primary detrimental impact of using a single type of pivot in the BSM is on the power budget. The power consumed by the BSM is primarily dissipated within the windings of the motors and is proportional to the square of the restoring torque.

If the ATC were constrained to procure a single type of flex pivot, they would need to select the type used in the jiggle stage, which would make the chop stage pivots too stiff. In this case, the power budget allocated to the BSM would be greatly exceeded to the extent that the whole Herschel Level 1 thermal budget of 10mW would be exceeded. (c.f. IRD-BSMP-R12 allocation is 4mW mean for the cryogenic components in any operating mode). Clearly, this would be

unacceptable to ESA. The problem would be compounded if the motor windings were fabricated from the less efficient Copper wire.

Given the possibility of having to accept a single flex pivot type, several means of reducing the power consumption were discussed in case a financial solution to the problem could not be found.

Sinusoidal chopping: A mathematical model of the power consumed by the BSM has been developed. This model calculates the amount of power consumed in (i) accelerating the mirror from one chop position to another, and (ii) the amount of power required to hold the mirror at the chop position. The model indicates that during a single cycle, most of the energy is consumed in holding the mirror still rather than in accelerating it. It was pointed out that a sinusoidal chopping profile would require less power than the square wave profile implied by the IRD (c.f. 20mS settling time, 2Hz chopping). It was agreed that this would violate the requirements laid out in the SSSD and would result in lower photometric efficiency but would however be a means for reducing the average power consumption.

Note: The power consumption is not significantly reduced by retaining square wave chopping at a reduced frequency since this does not alter the fraction of the time that the mirror is being held at a single position.

Reduced maximum chop throw
This was primarily discussed in relation to the need for a launch lock (see point 3 below) but is also relevant in the context of power consumption. Reducing the maximum throw of the chop stage would reduce the torque, and therefore power demands on the motor.
(b) Co-procurement: The possibility exists for the joint procurement of at least one type of flex pivot with SRON for use in the PACS instrument. At the time of the meeting it was unclear whether a commonality could be arrived at. This possibility is to be pursued by the ATC regardless of what budgetary scenarios are adopted.
(d) Stainless pivots: It has been assumed that Inconel pivots would be necessary as stainless becomes brittle at cryogenic temperatures. Vim Alders indicated during the meeting that stainless pivots had been flown in the past in cryogenic space instruments on ISO LWS and SWS. Obviously, a much higher level of risk of failure during launch would accompany this solution.

Since the power budget for the BSM has arisen as a critical issue, the method of calculating the average power needs to be refined. Specifically, the BSM power requirements model needs to be made more sophisticated to account for the average size of the chop throw used, the percentage of time the instrument will be used in different modes (64 point joggle map, point source, scan map etc.). The results of this analysis would give a better indication of the average power used under various scenarios.

3.Launch load survival – Launch Latch: It had been decided during a BSM review meeting that a launch latch be included to limit the extent of the travel of the mirror in the case of pivot failure during launch. This would prevent the mirror from failing at an extreme chop angle where spectrometer operation would not be possible. The ATC expressed some reluctance in incorporating such a device. Currently, the device is baselined in the design but they have stated

that they are hoping of eliminating it in the future. They have stated that they would do so on a rational basis after the evaluation of the following considerations:
(a) Results from cold vibration tests: It was stated that the results from the vibration qualification test would assist in providing information necessary to evaluate the need for the launch latch. It is unclear however how this would be done as it would require a cold vibration test with the launch latch (as this is the baselined solution) and a second without the launch latch removed.
(b) Alignment of the Center of Mass with the axis of rotation: The BSM has been designed to decouple rotational degrees of freedom of the two axes from linear accelerations of the entire assembly. This is achieved by the alignment of the center of mass of the chop and jiggle stages with their respective rational axes. There will however be a residual degree of coupling between rotation vibration modes and the mirror. Due to this decoupling, it could be argued that a launch latch would do little in reducing the rotation of the mirror in practice as there will only be low amplitude rotations without a launch latch.
(c) Load case: It could also be argued that a launch latch could reduce the rotational loads on the pivots by limiting the rotation but would not reduce the radial components. It is unclear what load is dominant.
(d) Demonstration of mirror control with broken pivots: It was also stated that a test was planned where the flex pivots would be intentionally broken and the mirror then placed under active feedback control. This test is intended to demonstrate the ability of the mechanism to stare in a stable fashion at a single position on the sky with broken pivots. This test would not be conclusive however as there is no guarantee that the pivots would fail in the same way under launch conditions.

Wim Aalders from SRON, stated that it was not necessarily normal design practice to incorporate such devices in space instrument mechanisms of this type.

Some desire was expressed by ATC for de-scoping the design to limit the maximum throw of the chop axis so that even in the event of failure of the pivots, the mirror could not fail outside the field of view of the spectrometer. This would remove the necessity for incorporating a launch latch.

3.3. Launch load survival – Motor coil shorting:

If the coils of the motors are shorted out, then the launch induced vibrational movements of the mechanism will be dissipated in the coils and thereby improve the launch survivability of the pivots. The ATC are keeping this option open and will include it if it proves to be effective in reducing the flex pivot loads. This will be done after consideration and investigation of the following factors:

(a) Cryoharness resistance: As it would be impractical to have relay switches on the cryogenic part of the BSM, the motors would be shorted within the MCU. The impedance of the cryoharness would reduce the level of damping provided by the motors by limiting the current flowing through the coils. If the impedance reduced the damping to a negligible extent, then this would be a valid argument for the omission of the feature.

(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.

Wim Aalders stated that the provision of motor coil damping is not usually provided.

3.4. Position telemetry rate

The telemetry rate of the BSM chop and jiggle position axes to the DPU is 40Hz (TBC) 80Hz (goal, TBC). 40Hz provides a signal every 25ms. The length of time that the mirror remains in a given position for 2Hz chopping is 250ms. The SPIRE project office need to confirm this.

3.5. Inclusion of conformal stray light baffle:

A simple stray light baffle is baselined for inclusion on the flight mechanism. This baffle does not wrap intimately around the mirror and leaves a gap around the edges. A question remains open as to whether it is required, or indeed, if a more elaborate conformal baffle is required that extended below the front surface of the mirror and provided better baffling. Some form of baffle is beneficial to the structural performance of the BSM structure by providing a shear panel. ATC believe that they can guarantee that no exposed item will heat up more than 1K above the Level 1 SOB temperature. The ATC are planning on installing a series of thermistors on development models of the BSM to confirm that the temperature does not rise more than is tolerable.

RID Number: HR-SP-ATC-01

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000460
Instrument	SPIRE	Organisation	ATC
Document Title	SIPRE Beam Steering Mirror Subsystem Specification Document		

Action

The design assumption stated in §3.4.1, page 13 of the optical scaling factor of 72:1 is incorrect.

One degree mirror rotation in the chop axis yields a 57.23 arc second rotation on the sky; (approximately a ratio of 62.9)

One degree mirror rotation in the jiggle axis yields a 52.37 arc second rotation on the sky; (approximately a ratio of 68.7)

Reference: Email from Tony Richards, 18 September 2000.

The document needs to be updated with the correct information.

The implications for this on the current design needs to be evaluated and documented in a brief technical note.

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	21 August 2001	Due Date	

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-RID-02

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000587
Instrument	SPIRE	Organisation	ATC
Document Title	BSM Design Description Document		

Action

In the version of the Design Description Document submitted to the meeting as part of the review documentation, the BSM ICD was contained as an appendix. This ICD needs to be split from the main document and become a stand alone document.

The ICD needs to be issued under change control and be approved by adding the signatures of the following persons:

Author Ian Pain
ATC Checking Engineer (Colin Cunningham)
LAM Systems Engineer
University of Wales, Cardiff Systems Engineer (Peter Hargrave)
MSSL Systems Engineer (Berend Winter)
John Delderfield (SPIRE Systems Engineer)
SPIRE Instrument Development Manager (Eric Sawyer)

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	16 November 2001

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-03

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-466
Instrument	SPIRE	Organisation	ATC
Document Title	SPIRE BSM Development Plan		

Action

The Development Plan needs to be issued under change control and be approved by adding the signatures of the following persons:

Author Ian Pain
ATC Checking Engineer (Colin Cunningham)
LAM Project Manager
Instrument Scientist (Bruce Swinyard)
John Delderfield (SPIRE Systems Engineer)
SPIRE Instrument Development Manager (Eric Sawyer)

The TBD on Page 10 is to be closed out as follows, (ATC to supply baffle, RAL to approve design)

§4.3.2 Typo, second line, replace the word latch with damper.

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	16 November 2001

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-04

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000711
Instrument	SPIRE	Organisation	ATC
Document Title	Herschel SPIRE Beam Steering Mirror Product Assurance Plan		

Action

The PA Plan needs to be issued under change control and be approved by adding the signatures of the following persons:

Author/PA Manager Ian Pain
ATC Checking Engineer (Colin Cunningham)
SPIRE PA Manager (Eric Clark)
SPIRE Instrument Development Manager (Eric Sawyer)

Several sections with TBW placeholders need to be written.

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	16 November 2001

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-05

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000460
Instrument	SPIRE	Organisation	ATC

Document Title	SPIRE Beam Steering Mirror Subsystem Specification Document

Action

The SSSD needs to be issued under change control and be approved by adding the signatures of the following persons:

Author Ian Pain
ATC Checking Engineer (Colin Cunningham)
LAM Systems Engineer
University of Wales, Cardiff Systems Engineer (Peter Hargrave)
MSSL Systems Engineer (Berend Winter)
John Delderfield (SPIRE Systems Engineer)
SPIRE Instrument Development Manager (Eric Sawyer)

The following updates need to be made to the document:

1. Remove the TBD from §3.1 with "a baffle supplied by ATC"
2. §4.1.8 and §4.4.1 seem to contain the same information. The difference between them ought be made more explicit.
3. The wording of §4.1.8 needs to be made more clear to indicate as to what requirement is being met.
4. There is no reference in §4.1.8 to the absolute position requirements listed in IRD-BSMP-R07
5. The TBD in §4.2.5 needs closing.
6. The TBDs in §4.2.11 needs closing.
7. The TBD in §4.2.12 needs closing.
8. The TBD in §4.3.2 needs closing.
9. The TBD in §4.3.3 either needs closing or the number of operational mode deleted from the spec.
10. The typographical error in the title of §4.3.7 needs amendment along with closure of the TBD. The active control to maintain the mirror position correctly when the power is off is now baselined.
11. The TBD/TBCs in §4.4.1 needs closing. (The motor current should be more useful than the motor voltage for diagnostic purposes)
12. The TBD in §4.4.2 needs closing. If the actual telemetry rates are currently unknown then they could be bracketed by maximum and minimum rates.
13. The TBD in §4.4.3 needs closing. Colin Cunningham is currently writing a technical note on the topic. The most critical subsystem may well be the FTS mechanism and therefore the limit might need to be placed here. The statement that the BSM will export vibrations in the frequency band of 0-5Hz plus harmonics is misleading. The motor will produce a couple at the base of the BSM with a rise time of less than 5ms repeating every 250ms for 2Hz chopping.
14. The TBD in §4.4.4 needs closing. The IID-A Magnetic RS mask should apply here unless shielding from the FPU is being assumed. In any case, the FPU magnetic shielding will be negligible.
15. The TBD in §4.4.5 needs closing. The subsystem is grounded at the warm electronics. The signal and power wires of the subsystem will be electrically isolated from the chassis of the FPU with more than (TBD) MΩ. The limits on the RE, RS should be identical to the IID-A
16. The TBDs in §4.5 needs closing.
17. The TBC in §4.6.3.1. regarding mirror surface flatness needs closing, viz. <100nm P-V the TBD RMS needs closing. The SPIRE Mirrors Specifications Document, Release 7, 12 July 2001 states the surface roughness for the SPIRE mirror as being <10nm RMS and the surface shape error being <1μm.
18. The TBC in §4.7.1.1 needs closing. There is no shock mechanical load specifications on the BSM.
19. The TBC in §4.7.1.5 needs closing. Less than 10-4 Pa is acceptable.
20. §4.7.1.8 seems to duplicate part of §4.4.5
21. The TBC in §4.7.1.10 needs closing. It is OK.
22. The TBD and TBC in 4.8 needs closing.
23. The error in §4.8.6 needs correcting.
24. c.f. HR-SP-ATC-01. As of 14 September 2001, there is a pending ECR for the SPIRE IRD that changes the maximum chop throw will be changed to 132 arc seconds. §4.1.1 is to be updated according to this and HR-SP-ATC-01.

Source of Action	BSM Detailed Design Review

RID Number: HR-SP-ATC-05

Closure Comments			
Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	
RID Signatures and Closure Date required			
Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-06

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000587
Instrument	SPIRE	Organisation	ATC
Document Title	Design Description Document		

Action

The structural Finite Element Analysis described in Section 10, Appendix 3 was performed on a previous design iteration of the BSM. This needs to be repeated before the design can be signed off.

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	30 October 2001

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date

RID Number: HR-SP-ATC-07

Spacecraft/Project	Herschel	Document No	SPIRE-ATC-PRJ-000587
Instrument	SPIRE	Organisation	ATC
Document Title	BSM Design Description Document		

Action

The Declared Lists need to be removed form the Design Description Document and inserted into a single document with a change control list be internally approved and signed and be given a project number.

The FMECA needs to be removed form the Design Description Document and inserted into a single document with a change control list be internally approved and signed and be given a project number.

Source of Action	BSM Detailed Design Review

Closure Comments

Initiator	Douglas Griffin	Actionee	Ian Pain
Date Raised	12 September 2001	Due Date	

RID Signatures and Closure Date required

Project Manager	Date	PA Manager	Date