SPIRE

SUBJECT: SPIRE BSM Development Plan

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SPIRE BSM Development Plan

v 4.0

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1. Table of Figures

2. Scope of the document

This document describes the development plan of the Herschel/SPIRE Beam Steering Mirror mechanism subsystem.

The development plan is based on the applicable documents cited in paragraph 3.1.

3. Documents

3.1 Applicable documents

	Title	Author	Reference	Date
AD1	SPIRE Beam Steering Mirror Mechanism Subsystem Specification	I.Pain	**SPIRE-ATC-PRJ-001**	latest
AD2	SPIRE Development plan	K.King	To be written	

3.2 Reference documents

	Title	Author	Reference	Date
RD1	Instrument Requirements Document	B.M.Swinyard	SPIRE-RAL-PRJ-000034 Iss .30	May 2000
RD2	Instrument Development Plan	K.King	SPIRE WE Review viewgraphs	6 Dec 1999
RD3	Proposal for Beam Steering Mirror	R.Sidey		
RD4	System Level Crticality	B.M.Swinyard	??	??
RD5	SPIRE Beam Steering Mirror Design Description	I.Pain	**SPIRE-ATC-PRJ-002**	latest
RD6	Short Form Verification Plan for the SPIRE Instrument	Bruce Swinyard	RAL 19/12/2000	19/12/2000
RD7	ECSS-E30(a)-part3 Mechanism Design	ESA	ECSS-E30(a)-part3	

3.3 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
Hersche	Far InfraRed Space Telescope	UK ATC	United Kingdom Astronomy

I			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

4. Description of the Beam Steering mirror mechanism subsystem

4.1 Baseline Design Overview

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 as required for SPIRE system level integration,** (BSMd)

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

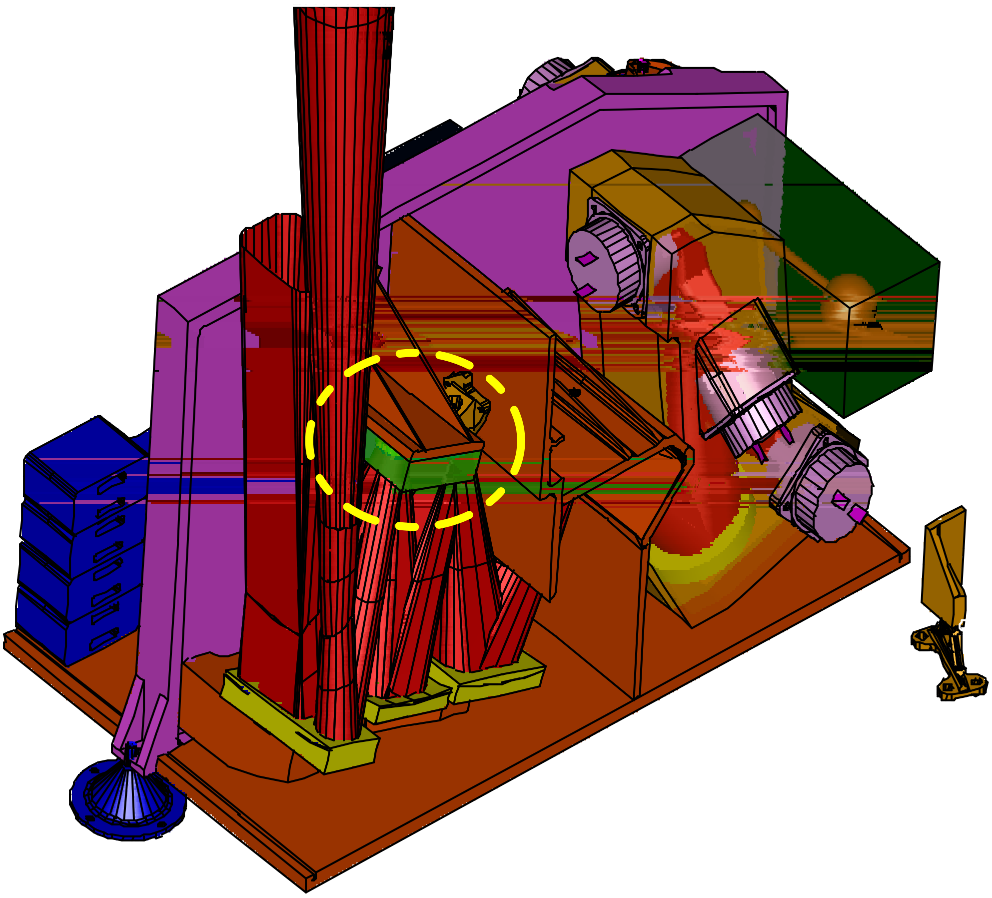

Figure 1 Photometer Layout, BSM in green, highlighted with yellow oval

The BSMs consists of an aluminium alloy mirror, nominal diameter 30mm, 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 BSMs is a cryogenic device with nominal temperature 4K. Nominally, the chop axis provides 2.5 ° of mirror motion at 2 Hz and the jiggle axis provides 0.5° of motion at 1 Hz.

The BSM 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 BSMm integrates to the SPIRE Photometer Calibration Source (QMW), a baffle (RAL…TBC) and the SPIRE optical bench (MSSL). The BSMs is a cryogenic structure with nominal temperature 4K.

The BSMe provides 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 BSMe baseline design makes use of cryogenic motors and magneto-resistive sensors used in ISOPHOT. 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

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 (FSDRC) sub-system (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 largely complete.

4.2 Alternative design

We are developing an alternative design, under subcontract to CDL Systems Ltd, in order to provide an alternative should we meet severe difficulties during development, particularly with the flex pivots or position sensors. For a detailed description, see RD3. We will develop and test a prototype of this design in parallel with the flex-pivot design, and plan to have prototypes of both options available before detailed design review.

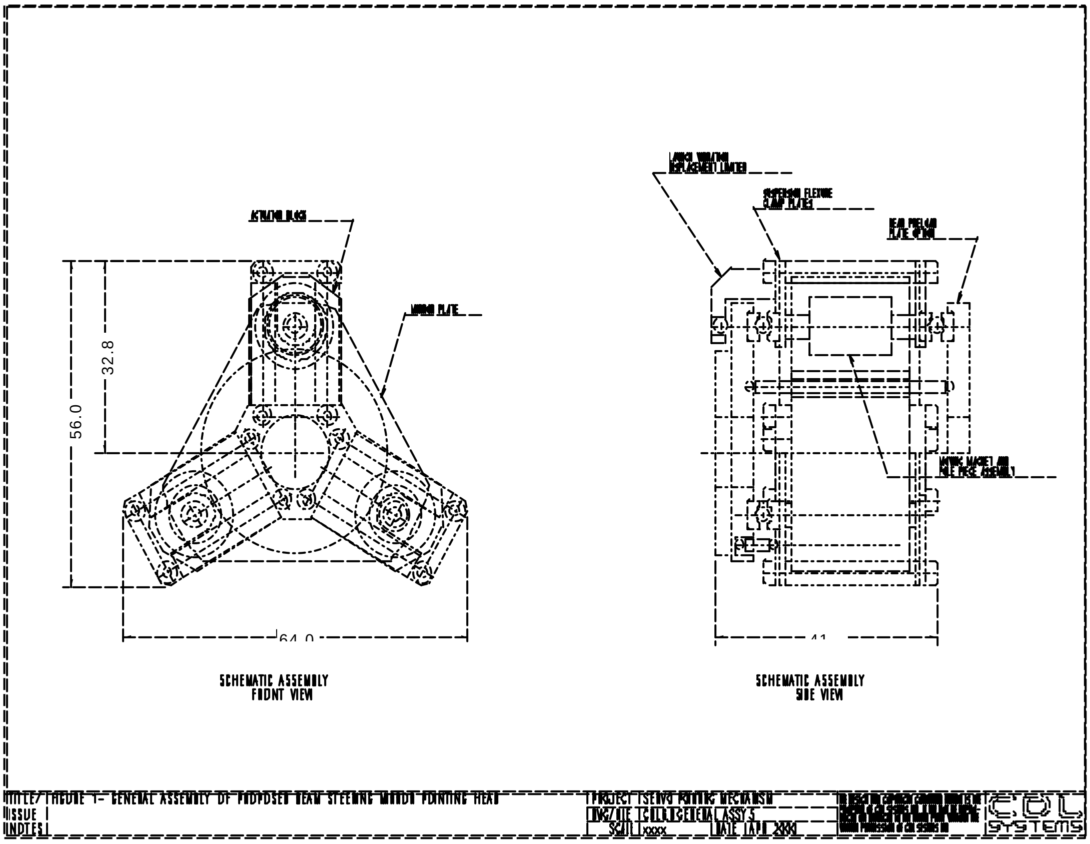

Figure 2: Alternative 3 axis mechanism

An overall assembly of the proposed two axis pointing mechanism for the SPIRE beam steering subsystem is shown in Figure 2 Based around a system of short stroke positioning actuators, the mechanism achieves two-axis control of mirror tilt by applying direct linear drive to three equispaced driving points located at the edges of the mirror. To avoid overconstraint in the system, the linear drive is applied via a system of ball joints, these featuring a preload arrangement to ensure rigid or positive contact between the drives units and the mirror mounting plate. For the arrangement shown in, rotation about the vertical axis is achieved by applying complementary displacements to the lower pair of actuators B C, with actuator A stationary.

For rotation about the normal axis, actuators B C are fed with the same driving function and actuator A with the complement. In this case, however, the relative amplitudes of the complementary driving functions are scaled to compensate for the difference in the vertical distances of the driving points from the centre of rotation.

The stationary winding assemblies of the linear drive units are housed within an actuator block assembly, this forming the mounting base for the subsystem. An arrangement of doubly built-in cantilever flexures is configured on both faces of the actuator block, this providing a smooth friction-free suspension for the moving magnet assemblies of the linear actuators. Rotation of the moving ends of each suspension is prevented by linking the front and rear flexure clamping plates with spacer rods. The flexure suspensions on each face of the actuator block are configured from a single sheet of photo-etched stainless spring steel. This form of construction conveniently provides both accurate profiles for the cantilevers and precise location for the actuator moving part within the actuator block and hence the winding assemblies.

As a result of the out of plane deflection of the suspension flexures, a small radial inward component of movement is superimposed on the axial displacement of the linear drive assemblies. To accommodate this translation and the required two-degree of freedom rotational movement of the mirror, the driving assemblies are coupled to the mirror by means of a system of ball cup or pivot joints. As mentioned above, these joints are preloaded to ensure that there is no lost motion. In the proposed design, a symmetrical dual cup joint is proposed where the radius of curvature of the bearing seating surfaces is slightly larger than that of the ball. This allows the joint to accommodate the small radial movements introduced by the cantilever suspension and gives a useful relaxation of mating tolerances where they do not contribute to the pointing performance of the assembly. It ensures that small lateral movements are accommodated by rolling contact within the joints. Preload of the ball joints is achieved by means of tension springs attached to the mirror and to the actuator driving plate, that is, across the joint. It is proposed to employ Sapphire or Tungsten Carbide ball and cup joints. The combination afforded by these materials of extreme hardness and the ability to sustain a very high surface finish, will give the joints resistance to wear and negligible rolling friction.

An important feature of this alternative tilting plate design of pointing head is the SLP (Servo Linear Positioner) technology proposed for the three linear actuator units. This technology combines the functions of linear thrust motor and position sensor in one integrated assembly, with the particular advantage that only a single system of windings is used.

Based around a moving magnet design, both the moving part and the system of windings are entirely symmetrical, this resulting in a rugged, compact and stable assembly. Position is derived by sensing the displacement of both pole pieces of the moving part relative to the windings. This produces incremental inductance changes in all four of the winding elements. The windings are interconnected to sum incremental increases and decreases in inductance to yield a differential half-bridge sensor. This is energised by anti-phase ac drive voltages which, for equal amplitude functions, yields a signal at the centre junction of the windings proportional in sign and magnitude to the shift of the moving assembly from centre position.

The thrust motor function is preserved in this winding partition by ensuring in the interconnection that the through current flow gives rise to the same direction of reaction force on all windings.

5. Constraints

5.1 Development constraints

5.1.1 Technical constraints

Here we outline some of the key specifications for the BSM, for information only. The applicable specifications are in [AD1], which refers to [RD1].

The main performance specifications are:

<u>Chop axis:</u>
amplitude: ± 2.4°
maximum frequency: 2Hz
settling time: 25 ms
stability: 0.02° rms

<u>Jiggle axis:</u>
amplitude: ± 0.6°
maximum frequency: 0.5Hz
settling time: 100 ms
stability: 0.02° rms

5.1.2 System constraints

The main system technical constraints are (from RD1):

- SPIRE lifetime in orbit: 4.25 years
- SPIRE Photometer operating time in orbit: 9 months
- BSMm Operating temperature: 4K
- BSMm power: less than 4 mW average during operation
- BSMm mass = 600g including 20% margin and including mirror (goal = 500g).
- BSMs structural interface mass = 500g (TBC) including 20% margin and including fasteners to structure
- BSMm Space envelope = 130mm x 130mm x 60mm (TBC)
- BSMm and BSMe Level of radiation = TBD
- BSMm vibrations level = TBD at 4K
- BSMm shock level = TBD at 4K
- Cleanliness = TBD
- Transit loads = not to exceed BSMm vibration and shock loads.
- Storage = Storage in a dry Nitrogen environment for up to 5 years.
- Bake-out temperature on AIV integration = 80 °C for 48 hours

5.1.3 Development Responsibility

During its lifetime the BSM is developed as follows:

The BSMm is:

- Designed under ATC responsibility.
- Manufactured under ATC responsibility.
- Integrated to the BSM structural interface.
- Qualified/accepted and calibrated under ATC responsibility, part at ATC, part at RAL (cryo vibrations). The qualification/acceptance program includes thermal cycling, warm and cold vibrations, life testing, EMI-EMC. The calibration program verifies the performance requirements.
- Transported to LAM under ATC responsibility.
- Integrated at LAM with the SMEC and controller under ATC responsibility
- Transported to RAL under ATC responsibility
- Integrated at RAL in the SPIRE FPU Structure under RAL responsibility
- The SPIRE-FPU is to undergo the project qualification/acceptance program under RAL responsibility.

The BSMe is :

- Specified and designed in outline under ATC responsibility
- Designed in detail under LAM responsibility
- Manufactured under LAM responsibility
- Integrated at CEA-SAp in the SPIRE DRCU (in SPIRE WE) under CEA-SAp responsibility.
- The SPIRE-WE is to undergo the project qualification/acceptance/calibration program under CEA-SAp responsibility.
- The SPIRE WE and the SPIRE FPU are integrated under RAL responsibility and undergo the project calibration program under RAL responsibility.

SPIRE is delivered to ESA under RAL responsibility.

SPIRE is integrated in the Herschel satellite under ESA responsibility.

SPIRE CQM is to undergo the ESA cryo qualification program under ESA responsibility.

SPIRE PFM is to undergo the ESA Acceptance program.

On the launch pad, before launching, the SPIRE FPU is cooled down to its operating temperature and launched.

SPIRE FS is prepared in the event of SPIRE PFM failure.

5.1.4 Work Flow

The work flow between ATC, MPAI, LAM and RAL is shown below. An important point to note is that the BSM & SMEC mechanisms and controllers are integrated and verified to together at LAM, after initial testing of the BSM at ATC using a PC-based simulator of the controller .

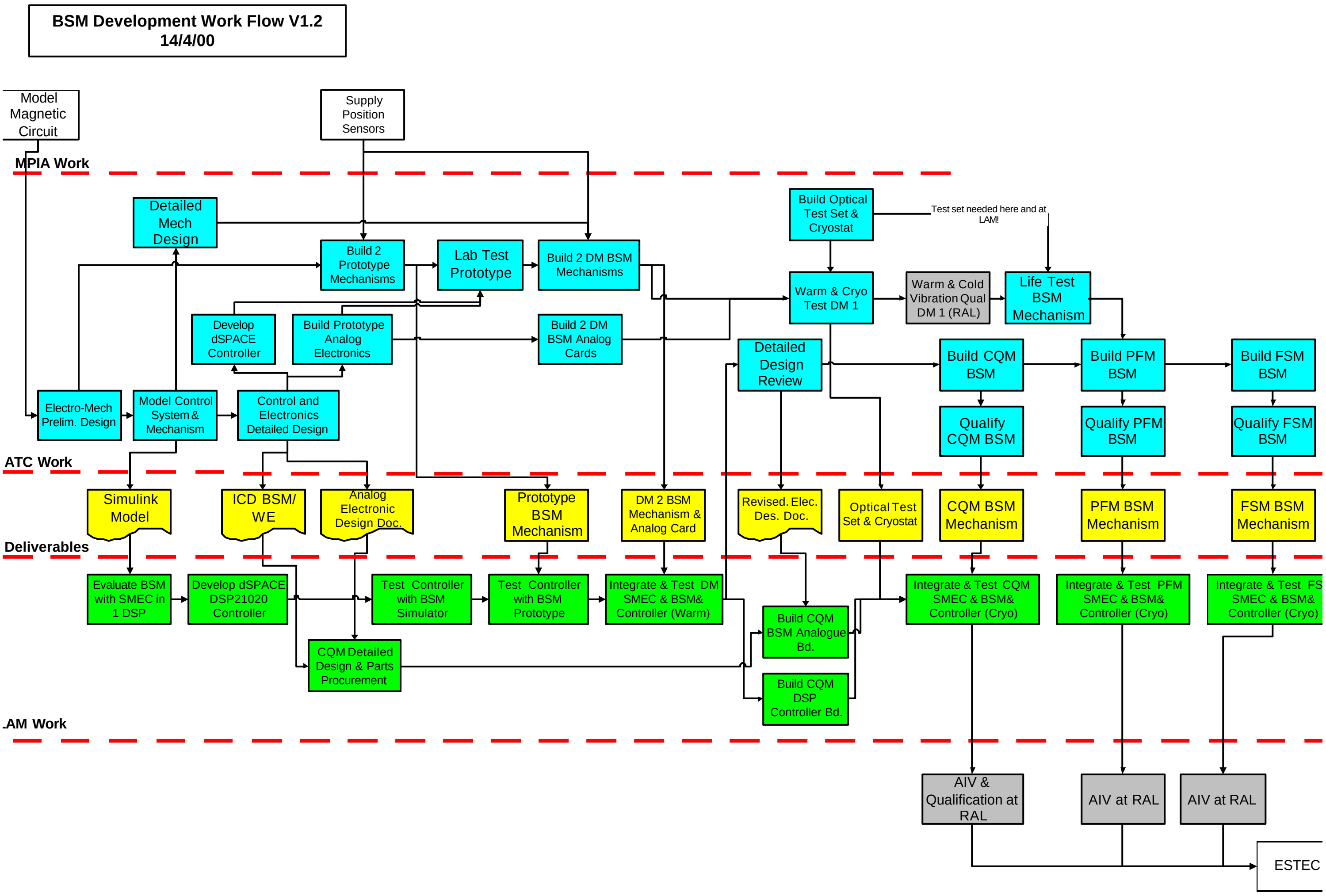

Figure 3: BSM Development Work Flow and Deliverables

5.1.5 Organisation

- ATC is responsible for the BSM, i.e. BSMm, BSMs, BSMd and BSMe.
- ATC is responsible for the control algorithms.
- ATC designs the electronics of the subsystem and builds the relevant breadboards.
- LAM is responsible for building the BSMe and the digital controller.
- LAM is responsible for implementing the control algorithms in the digital controller.
- SAp-CEA is responsible for SPIRE DRCU inside which the BSMe is implemented.
- MSSL is responsible for the structure inside which the BSMm is integrated.

5.1.6 Calendar constraints

The main SPIRE project dates are [RD2]:

PDR	26/27 Jun 2000
DDR – Interface Review	9/10th Oct 2000
DDR – BSM & SMEC	Jul 2001
BSM STM delivery to RAL	Jun 2002
BSM CQM delivery to LAM	Feb 2002
BSM CQM delivery to RAL	Oct 2002
CDR	Apr 2003
SPIRE CQM delivery to ESA	Jun 2003
BSM PFM delivery to LAM	Aug 2003
BSM PFM delivery to RAL	Sep 2003
BSM FS delivery to LAM	Nov 2003
SPIRE FS delivery to ESA	Apr 2005
Herschel launch	2007

5.2 *Risk analysis*

In this document, the risk analysis concerns only the risks which would result in this development plan not being completed to a schedule compatible with the project.

Risk	Impact	Preventive action	Note
ATC Effort constraints (mechanical, Electronic, control)	Delay in design work Delay in structural design	Freeze structural ICD at earliest possible date Recruitment at ATC. Sub-contract	Recruitment at ATC underway.
PACS Motor design produces insufficient torque for envisaged redundancy mode	Reduced performance Or Delays to allow changes to BSMe/MAC architecture	Early analysis of motor torque LAM and ATC consider/plan to mitigate implications of late design switch Investigate improved motor design	Collaborate with MPIA on motor optimization
Problems in procurement of space rated PACS motor (via Zeiss)	Cost Or Delay	Early liaison with MPIA/Zeiss, involvement of SPIRE/PACS PI's as required.	
Flex-Pivot life problems	Extended testing required, Late-stage redesign work	Prototyping Alternate design scheme in parallel	provision for re-test & rework in plan. Backup design scheme (CDL) in hand
Flex-Pivot strength problems (launch loads)	Launch lock required	Launch damper assumed in plan (short coils on launch) Flex Pivot protection sleeves required. Contingency design of full launch lock. Alternate design scheme in parallel	
Sensor stability performance below specification	Problem meeting requirements	Early testing Alternate sensors – LVDT	LAM are also investigating an LVDT fallback. The CDL alternate prototype will use LVDTs

5.3 Redundancy

5.3.1 Redundancy philosophy

The system level criticality analysis (RD4) shows that the BSM is not a single point failure for all operating modes of SPIRE. As long as it fails without vignetting a significant number of detectors, and that it has sufficient internal damping to be stable to external disturbances, the instrument can be used in scan mode.

The redundancy philosophy adopted for SPIRE is to duplicate every part that would be a single point failure for the instrument, where possible. The baseline architecture for BSM redundancy is completely parallel as shown in section 3. The option of one BSM analogue card which can switch out failed motor coils is a backup solution, should it not be possible to reach the performance requirements with parallel redundant motors.

The mechanism design will be such as to fail safe with the mirror in a useable attitude.

In addition to planned redundancy, the MAC will monitor motor voltage for back emf damping in open loop control – one channel per axis. This will allow a backup mode in the event of position sensor failure where at least vibration damping will be available, even if the position is open-loop.

5.3.2 Launch damper

The baseline assumption is that a launch damper will be incorporated by shorting all motor windings. This will damp vibrations around the chop and jiggle axes. The launch latch will consist of switches across the motor coils, as for the proven ISOPHOT design. It will be made up of two identical items, mounted in series. If one fails, the other is able to free the mechanism.

5.3.3 Launch lock

Flex pivot protection sleeves are the baseline preferred methodology for preventing failure. If tribologically possible the sleeves would additionally be so designed as to provide a redundant bearing surface in the event of the flex pivots failing. With a redundant bearing surface and the motor coils operative, the BSM could be steered and actively damped to at least a null position.

A preferred option to a full launch lock could be the use of a “deployable end-stop”. This would constrain the range of motion of the mirror to the spectrometer field of view (~1.5°) as compared to the full range of motion. Thus any deployable end-stop failure to retract would leave the mirror in a usable attitude, whilst any flex pivot failure would be caged with a useable field of view. However, this presumes that the BSM with damaged flex-pivots would remain sufficiently stable to be useable.

If subsequent design proves it necessary to provide a physical launch latch, it would also be designed for serial operation. Additionally, design would be such that in the event of the launch latch not unlocking after launch (i.e. both latches fail), the SPIRE instrument would not be completely lost, as the latch design would be such as to fail with the mirror in a useable attitude. Scan mode would still be possible.

The optimal trade-off of the above options requires detailed failure mode and performance analysis.

6. Work description

6.1 *Development and model philosophy*

The model philosophy is compliant with the SPIRE project requirements and meets the ATC development needs. At least eight models of the BSM are envisaged in support of the Preliminary, Detailked and post CDR design phases. Briefly these include: Two prototypes are used to inform the design process. Three or four models are required for development prior to build of the final flight units, including models to complete qualification and life tests. Finally, a flight model and spare are delivered

Model	Abbrev.	Quantity	Delivered to	Purpose
Single axis prototype	-	1	ATC	Initial proof of concept work
Two Axis prototype	-	1	ATC	Detailed cryogenic, vibration and cross talk tests. Refinement of design.
Development Model	DM	1 (or 2)	ATC, LAM	Detailed engineering development. Tests of LAM electronics with ATC hardware
Structural & Thermal Model	STM	1	ATC, RAL	Mass and thermal model. Representative vibration load on structure to obtain qualification loads. May also serve as the BSM alignment fixture.
Qualification Model	QM	1 (refurb DM)	ATC	Full verification of survivability, performance, life tests.
Cryogenic Qualification Model	CQM	1	RAL, ESA	Science performance of SPIRE at cryogenic temperature.
Proto-Flight Model	PFM	1	RAL, ESA	Flight Hardware.
Flight Spare Model	FSM	1	RAL, ESA	Flight spare if required (TBC). May be refurbished from CQM,STM,QM (TBD)

For development, the preferred ATC approach is to build three substantially identical mechanisms to meet the DM, QM and CQM delivery.

The DM, STM and CQM requirements would be met (overmatched) by the proposed QM, and it is deemed more cost effective to deliver an over-matched unit than to apply design effort to modify a reduced functionality simulator.

Therefore, the primary changes between DM, QM and CQM would be in the grade of flex pivots, redundancy implementation and precise motor functionality (shielding, optimization of air gaps etc). Desirably we would save cost by only manufacturing one DM and then morphing into the CQM for further testing, though this needs to be considered carefully in conjunction with LAM.

In practice, whilst we could build the STM to the same standard as the DM or QM, the STM should not contain flex pivots if these are unproven at that point in the development and will as a minimum have flex-pivots replaced with fixed spigots. Given similarities between the required STM (thermal and mass compliance, fixed mirror, no motors) and the required 'alignment tool' used for integration to the instrument optical bench these two units may be satisfied by a single design, if not indeed a single unit.

The DM may not have a fully documented set of engineering drawings, nor full structural verification: it will be the presence of the correct configuration control which will define the QM and CQM models as distinct from the DM.

Following the BSM life tests on the QM and results of the SPIRE CQM tests, some modifications may have to be implemented in the design. The design changes are to be implemented in the flight design and be validated using the BSM-DM/QM. The models are discussed further below:

6.2 Single Axis Prototype

6.2.1 Purpose:

A test bed to provide experience of hardware for initial tests and problem definition.

The emphasis is on speed of build and flexibility. Parameters will then be used to revise the dynamic model in order to determine the control algorithm required to meet requirements, particularly positional accuracy and drift.

6.2.2 Tests:

- Component manufacturability and optimization.
- Mechanical assembly
- develop experience with PACS motor type.
- Confirm electronic circuit practicality.
- Explore Interfaces with D-Space and Simulink .
- Stability and dynamic response of position sensors.
- Develop test procedures with CDL laser measurement device.

6.2.3 Configuration:

A single axis device, with a simple plate interface to external mounts.

Chop axis and integral mirror as intended for flight design, with non-optical finish on mirror and reduced light-weighting (to reduce manufacture costs).

Moving core magnet housing initially to ISOPhot design (square magnet), later modified to suit PACS design (round magnet). A single PACS motor clamped in place.

Non-precision electronic circuits.

Brazed construction (ex-stock) flex-pivots.

An optical grade mirror will be bonded temporarily to the mirror structure for tests.

6.2.4 Build Standard

Non-deliverable. Non-flight unit.
Few flight grade components except where readily available – e.g. PACS motor, Infeon Sensor (encapsulated).

6.3 Two Axis Prototype

6.3.1 Purpose:

It is intended as a ‘brassboard’ prototype i.e. will be modified in parallel with design changes to verify performance and as procured hardware becomes available. A brassboard prototype is justified (rather than use of the DM only) to allow design changes to match changes to the PACS-style motors, motor shielding, baffle interfaces and thermal path (eg thermal end-stops).

At an early stage, position sensors for the both axes will be in place to test cross-talk. Most significantly, thermal cooldown via the representative thermal path will be confirmed. A warm vibration test will be performed. As control and electronics parameters are confirmed , additional data will be passed to LAM.

Following use of the two axis prototype at the ATC to verify design assumptions, it will be delivered to LAM to test the controller with actual hardware.

In the event of delays in ATC testing, a second copy of the prototype will be manufactured and released to LAM. If ATC testing is in advance of schedule, the Development Model will be provided to LAM. If the LAM program is in advance of the ATC program the LAM electronics may instead be delivered to ATC for integration testing (TBC).

6.3.2 Tests:

- Component manufacturability and optimization.
- Mechanical assembly
- PACS Motor optimization to suit BSM.
- Motor-sensor cross-talk and motor shielding requirements
- Stability and dynamic response of position sensors with high precision circuits.
- Initial Cryoenic cooldown to demonstrate cooling rate through flex-pivots and thermal end-stops (if required).
- Cryogenic functionality of sensors and motors.
- Vibration at room temperature to confirm structural integrity & flex pivot survival.

6.3.3 Configuration:

A two axis device. Chop axis and integral mirror as intended for flight design, with round magnet pockets. A non-optical finish on mirror and reduced light-weighting (to reduce manufacture costs). An optical grade mirror will be bonded temporarily to the mirror structure for tests as required, but removed for vibration tests

The structural interface should be representative of the flight design.

Initially a single PACS motor mounted in a representative way. Additional motors added as the design is confirmed as acceptable. A launch damper (coil shorting) device will be tested.

Brazed construction (ex-stock) flex-pivots replaced with electron beam flex pivots as available. Flex-pivot protection sleeves added as available.

Representative (but non-flight grade) connectors and wiring, but non-representative harness.

Representative (but non-flight grade) electronic components, but with bread-board assembly.

6.3.4 Build Standard

Non-deliverable. Non-flight unit. Precision and flight grade components added as available.

6.4 Back-up Design : CDL Prototype

6.4.1 Purpose:

Because of concerns regarding flex-pivot and sensor technology, a parallel prototyping exercise has been initiated with CDL systems LTD to explore an alternative three axis concept which uses integrated actuators and LVDTs. This will include cryogenic and vibration testing, and is intended to improve confidence in fallback design technologies in the event of late-emerging problems with the baseline design. The design will not be qualified beyond the basic feasibility level.

6.4.2 Tests:

- Component manufacturability and optimization.
- Mechanical assembly
- Ability to meet BSM specification warm tests – particularly power dissipation, precision, risetime
- Familiarity with electronics
- Vibration tests to demonstrate survivability.
- As resources permit, cryogenic cooldown to demonstrate cooling rate and functionality.

6.4.3 Configuration:

A three axis device using integrated LVDT's and motors, foil flexures and jewel bearings. Mechanically as intended for flight design

A non-optical finish on mirror (to reduce manufacture costs). An optical grade mirror will be bonded temporarily to the mirror structure for tests as required, but removed for vibration tests. .

The structural interface will not be representative of a flight design.

Representative (but non-flight grade) connectors and wiring, but non-representative harness.

Representative (but non-flight grade) electronic components, with PCB assembly and integrated power supply etc to allow stand-alone testing.

6.4.4 Build Standard

Non-deliverable. Non-flight unit.

6.5 Development Model (DM)

6.5.1 Purpose:

The development model (DM) provides for continuous development of the BSM at ATC and at LAM and which will evolve towards a flight representative configuration as hardware choices are confirmed.

As a baseline only one DM should be required. However, dependent on the integration program and requirements at LAM, two DM's may be constructed simultaneously. The DM model is used to identify control parameter changes on the BSMe as compared to warm behavior. These will be passed to LAM for incorporation in the control simulation. Subsequently, adequacy of the design to survive launch and environment loads will be confirmed.

Dependent on program constraints, two DM models may be manufactured to allow LAM and ATC work to proceed in parallel (TBC). One DM is refurbished later as a QM or CQM (TBC – depends whether configuration is flight representative) and used to qualify the cold performance of the design. The second DM (if built) will be retained in the event that further prototyping is required as a result of late stage problems with the CQM or PFM, for example to allow tests of a flight grade launch lock mechanism.

6.5.2 Tests:

- Motor-sensor cross-talk and motor shielding requirements
- Verify all envisaged control modes and refine control models.
- Cryogenic functionality
- verification of the basic mechanical parameters (Mass, stiffness, resonance frequencies)
- performance verification
- thermal cycling (bakeout)
- Vibration at room temperature to confirm structural integrity & flex pivot survival. Cold vibration test if facilities available/affordable.
- Launch damper tests
- Short cold life tests (eg. 1 month duration) to verify that accelerated tests produce no anomalies, prove dewar hold time and refine procedures for full life test of QM
- Performance against specification.
- Acceptance test development
- The PCAL DM is integrated and electronic cross talk (PCAL harness/BSM motors/sensors) tested.

6.5.3 Configuration:

Representative of the flight design. Dummies are mounted first to replace the position sensors and the motors. The resonance frequencies of the BSMm with dummies are verified by vibrations. Then, the real components are mounted.

Full suite of PACS-type motors. Redundancy may not be fully implemented. Non-flight grade components for the warm electronics. Electron beam welded flex pivots will be used initially; replaced if full flight grade flex-pivots are available. A launch lock mechanism mock-up is built to prove by tests that the design is flyable. The tests are warm vibrations, thermal cycles and operation at cryogenic temperature.

6.5.4 Build Standard

Non-deliverable. Non-flight unit. Precision and flight grade components as available.
Supporting engineering drawings. Traceable components and test documentation. Integration documentation.

Note that the BSM-DM is not a formal deliverable and documentation supplied with it will be in a format to meet only the requirements of the LAM and ATC tests, and to ensure traceability of test results fed into the flight hardware .

6.6 Structural and Thermal Model (STM).

6.6.1 Purpose:

The Structural and Thermal Model (STM) is required to act as a representative load in vibration and cool down tests of the integrated instrument. In line with RD1 the STM is to have as a minimum a valid mass/thermal model with correct mass, cog, heat load, structural, thermal and connector interfaces. Alignment interfaces are assumed to require an optical finish on the mirror.

The STM should not contain flex pivots if these are unproven in vibration at that point in the development and will as a minimum have flex-pivots replaced with fixed spigots. Given similarities between the required STM (thermal and mass compliance, fixed mirror, no motors) and the required 'alignment tool' these two units may be satisfied by a single design , if not indeed a single unit.

The STM is deliverable to RAL, but not ESA. Appropriate documentation will be provided - probably in the form of drafts of the intended CQM and PFM documentation.

6.6.2 Tests:

- Cryogenic cooldown at ATC and RAL.
- Vibration at room temperature to confirm behavior integrated with structure
- Cold vibration (if possible).
- Alignment procedures using alignment tool.
- Acceptance test development

6.6.3 Configuration:

A fixed mass dummy, Representative of the flight design interfaces with resistive loads to simulate motors. implemented. A representative harness for the cold electronics/cabling and thermal links.

A launch lock mechanism mass dummy may be incorporated for tests. The tests are warm vibrations, thermal cycles and operation at cryogenic temperature.

The PCAL STM or a mass dummy are integrated prior to delivery to RAL.

6.6.4 Build Standard

Non-deliverable. Non-flight unit.
Supporting engineering drawings. Traceable component. Clean room assembly

6.6.5 Schedule

See RD6.

- Delivery of BSM STM – July 2002
- Warm Vibration – beginning of September 2002
- STM interim test review – September 2002 (vibration levels for sub-systems confirmed integrity of structure design confirmed)
- Cold thermal verification and cold vibration tests completed by early October 2002
- STM is de-integrated and STM sub-systems are available December 2002

6.7 Unit Level Qualification model (QM)

6.7.1 Purpose

See RD6:

> *" For SPIRE Unit level QMs should be produced and tested at unit level (see Verification Requirements). Ideally the QM testing should happen in parallel with the instrument level CQM program. If the STM units are to be upgraded to QM status this gives ~4 months to upgrade and environmentally test the unit level QMs if the results of the testing are to feature in the CDR – which ideally they should as this is the final release of the PFM designs. The QMs MUST have undergone a rigorous environmental test program including cold vibration (temperature may be negotiable)."*

For the BSM, the duration of life tests preclude the re-use of the STM to provide input data to the CDR. An additional model is therefore required. All critical components will be of flight grade, but parallel mode redundancy will not be implemented. The QM will be manufactured by upgrading or refurbishing the DM

6.7.2 Tests:

- Cryogenic cooldown.
- Vibration at room temperature
- Cold vibration (at RAL).
- Launch damper tests.
- Launch lock tests (if required)
- Non-parallel redundancy
- Redundant modes
- Cold life tests (1.2-2.5 months duration), per RD3
- Performance against specification.
- Acceptance test demonstration

The launch lock mechanism (if required) may be qualified separately using the DM as a mount. The EGSE/OGSE complement used for the BSM STM will also be used for the QM.

6.7.3 Configuration:

Representative of the flight design, though no redundancy need be implemented.

Full suite of PACS-type motors. Representative harness for the cold electronics/cabling and thermal links.

Electron beam welded flex pivots may be used initially; replaced as full flight grade flex-pivots are available. This also prevents damage or life reduction of the flight grade pivots in initial tests.

A launch lock mechanism mass dummy may be incorporated for tests. The PCAL STM or a mass dummy is fitted.

For the verification of the BSM, a DRCU simulator and an OGSE are to be developed. The DRCU simulator provides the DRCU/BSMe interfaces and the power supply. Dependent on progress, LAM may supply a WE DM instead (TBC).

An OGSE (CDL systems laser head unit) is used to check optically the mirror displacement. For the verification of the BSMe, a BSMm simulator is built (using D-SPACE/Simulink) which simulates the relevant BSMm parameters as seen from BSMe.

For the verification of BSMm, the BSMm EGSE allows for control and measurement of the mechanism during tests. All the simulators and tools are needed since all subsystems are to be tested at approximately the same time.

6.7.4 Build Standard

Non-deliverable. Non-flight unit. Precision and flight grade components as required for qualification of cryogenic performance.

Supporting engineering drawings. Traceable components and test documentation. Clean room assembly

6.7.5 Schedule

See RD6.

- Results required for CDR by April 2003.
- life tests therefore must commence no later than ~Oct.02 and preferably before Aug.02.

6.8 Cryogenic qualification model (CQM).

6.8.1 Purpose

This is a model of the instrument that will be used to characterize and verify the instrument scientific performance with functionally representative cold sub-systems and WE units. The BSM CQM will need to function and have close to the expected flight performance. The BSM CQM is deliverable (to RAL and ESA).

The CQM includes all the functions of the flight design, except redundancies. After the BSM-CQM delivery, the SPIRE CQM is tested at project level. The results of the qualification tests are to be presented at the SPIRE CDR which is the start point of the PFM and FS manufacture. Then, the SPIRE CQM is delivered to ESA for cryogenic tests of the FIRST FPU.

6.8.2 Tests:

- Cryogenic cooldown at ATC and RAL.
- The CQM does not undergo vibration or life tests.
- Performance against science specification when cold.
- (performance against power dissipation not required)

Final CQM tests of both BSMm and SMEC mechanisms will be performed at 20K at LAM (TBC) then, following integration of SPIRE hardware at RAL , tested at 4K.

6.8.3 Configuration:

Representative of the flight design, though no redundancy need be implemented. Military grade components, where applicable.

PACS-type motors, no redundancy required. Mass dummies in place of redundant motors. Representative harness for the cold electronics/cabling and thermal links. Electron beam welded flex pivots may be used.

A launch lock mechanism mass dummy (minimum, ideally a functioning mechanism) will be incorporated if required for flight. The PCAL CQM is integrated prior to delivery to RAL.

The BSMe-CQM is to be used as an elaborate EGSE to operate the BSMm-CQM as is SPIRE-WE CQM with respect to the SPIRE-CQM. Two CQM BSMe boards are required, MQ1 for Mechanism Qualification, MQ2 for Warm Electronics Qualification.

6.8.4 Build Standard

Deliverable. Non-flight unit.

Supporting engineering drawings. Traceable components and test documentation. Clean room assembly

6.8.5 Schedule

See RD6.
- BSM-CQM delivery required late November 2002 (planning date should be October 2002)
- Integration complete January 2003
- Instrument first cold test Jan/Feb 2003
- Instrument second cold test March/April 2003
- Post test review (CDR) April 2003

- Delivery to ESA end April 2003

6.9 *Proto-Flight Model (PFM) and Flight Spare model (FSM)*

6.9.1 Purpose

The PFM is the flight model.

6.9.2 Tests:

- Performance verification and acceptance tests at ATC
- Integration tests with PCAL PFM.
- Environmental tests to qualification levels for acceptance times (TBD).
- Integration at RAL, SPIRE instrument tests as required.
- Launch lock tests if fitted.

6.9.3 Configuration:

Full flight configuration.

If required the BSM-FS is a duplicate of the BSM-PFM and is manufactured at the same time as the BSM-PFM, or substantially refurbished from CQM and STM components. The BSM-FSM undergoes the acceptance tests and performance verification after the BSM-PFM.

6.9.4 Build Standard

Full flight configuration.

6.9.5 Schedule

See RD6

- BSM PFM delivery September 2003
- Warm electronics (QM2) required at the latest September 2003
- Integration and initial cold test September – December 2003
- Cold Vibration Campaign December 2003 – January 2004
- Instrument verification cold test February-March 2004
- PFM Warm Electronics required at the latest March 2004 (planning date should be February 2004)
- Instrument Calibration March – end May 2004
- Post Test Review June 2004
- Instrument Delivered to ESA planned date 14/6/2004

6.10 *Preliminary Design*

The mechanical design is based on the ISOPHOT design, adapted to 2 axis operation by incorporating the chop axis within a gimbal frame. The mirror is manufacture integral to the chop axis.

The first resonance frequencies, structural rigidity (for control purposes) and the mass are verified by FE analysis.

The motor core design and material is optimised to minimise power consumption.

The preliminary design is presented at the Preliminary Design Review, in June 2000. The PDR freezes the technical specifications. The interfaces are frozen at the Interface Review. Design refinements internal to the BSM will continue, and will be verified by prototype. In particular, attention is focused on the system resonant modes and the life and strength performance expected of the Lucas flex-pivots.

The motor magnetic material differs from the ISOPHOT design. Modelling of the magnetic circuits is carried out by MPIA based on their experience with the PACS chopper: initial indications are that the circuit behaviour is not sensitive to material changes (the air gap dominates over the material permeability). Subsequently, to obtain a wider experience base, the PACS type motor coils have been adopted as complete units in the BSM design.

The first prototype will have only one operating axis, Performance of the position sensors will be tested statically in a jig (which may be combined with the first prototype) to verify noise, drift and accuracy. These parameters will then be used to revise the dynamic model in order to determine the control algorithm required to meet requirements, particularly positional accuracy and drift.

The second prototype will include two axes. It is intended as a ‘brassboard’ prototype i.e. will be modified in parallel with design changes to verify performance and as procured hardware becomes available. At an early stage, position sensors for the both axes will be in place to test cross-talk.

Because of concerns regarding flex-pivot and sensor technology, a parallel prototyping exercise has been initiated to explore an alternative three axis concept which uses integrated actuators and LVDTs. This will include cryogenic and vibration testing, and is intended to improve confidence in fallback design technologies in the event of late-emerging problems with the baseline design. Details of this proposal are included in Appendix A.

Detailed design of the analogue board which drives the motors and measures BSM angles is carried out. The interfaces with SPIRE WE are defined during this phase. Subsequently, and prototypes (bread-board) are made, which are used to drive the prototype mechanisms from PC-based controller simulators.

The Simulink model of both axes, including modelling of the mechanism, analogue electronics and controller will be delivered to LAM, where it will be integrated with the Spectrometer model to determine whether the single processor (DSP21020) can control both mechanisms, with a sensible margin on processing resources. The control loop design is verified for preliminary design by simulation. The input variables (sensor noise, flexural stiffness) are provided by bench tests or detailed modelling of components.

Following use of the two axis prototype at the ATC to verify design assumptions, it will be delivered to LAM to test the controller with actual hardware. In the event of delays in ATC testing, a second copy of the prototype will be manufactured and released to LAM. If ATC testing is in advance of schedule, the Development Model will be provided to LAM

6.10.1 Procurement of long lead-time cryogenic components

Once the preliminary design has been validated by the PDR, and further refined internally, the procurement for long delay components is initiated. These components include actuators, position sensors, flex pivots, cryogenic connectors, to be mounted on the BSMm QM, CQM, PFM and FS.

*6.11 Detailed design and CQM manufacture (*Phase C/D*)*

The detailed design encompasses all the functions of the subsystem. The design is verified by more detailed modelling where necessary.

ATC provide detailed operational modes and control algorithm, including all processing steps, to enable a draft of the MAC DSP software to be written.

Before the DDR, a launch latch mechanism (if design proves it to be necessary) mock-up is built to prove by tests that the design is flyable. The tests are warm vibrations, thermal cycles and operation at cryogenic temperature.

The detailed design is presented at the Detailed Design Review (Jul.01). The DDR must have happened before CQM manufacture can begin. The typical tests are developed using the DM and QM frozen before the the CQM.

To verify the design, a complete qualification and life tests are to be conducted.

Multiple models are necessary because the available design data from the SPIRE structural vibration loads and design information for motors, flex pivots and sensors is expected to become available over an extended period. Life tests last at least 1-2 months and would lead to a delivery date too late in the planning would only one model be built. The model philosophy is fully described in section 6.1-6.9 above.

The design verifications by tests of the various models include:

- verification of the basic mechanical parameters (Mass, stiffness, resonance frequencies) : dummies are mounted first to replace the position sensors and the motors. The resonance frequencies of the BSMm with dummies are verified by vibrations. Then, the real components are mounted.
- performance verification
- qualification tests
- life tests

For the verification of the BSM, a DRCU simulator and an OGSE are to be developed. The DRCU simulator provides the DRCU/BSMe interfaces and the power supply. The OGSE is used to check optically the mirror displacement.

For the verification of the BSMe, a BSMm simulator is built which simulates the relevant BSMm parameters as seen from BSMe.

For the verification of BSMm, the BSMm EGSE allows for control and measurement of the mechanism during tests. All the simulators and tools are needed since all subsystems are to be tested at approximately the same time.

Final CQM tests of both BSMm and SMEC mechanisms will be performed at 20K at LAM then, following integration of SPIRE hardware at RAL , tested at 4K.

Two CQM BSMe boards are required, MQ1 for Mechanism Qualification, MQ2 for Warm Electronics Qualification.

After the BSM-CQM delivery, the SPIRE CQM is tested at project level.

The results of the qualification tests are to be presented at the SPIRE CDR which is the start point of the PFM and FS manufacture.

Then, the SPIRE CQM is delivered to ESA for cryogenic tests of the Herschel FPU.

6.11.1 Flight design modifications and PFM/FS manufacture

Following the BSM QM life tests and SPIRE CQM tests, some modifications may have to be implemented in the design. The design changes are to be implemented in the flight design and be validated using the BSM-DM/QM as required.

The BSM-PFM is then manufactured and undergoes the acceptance tests and performance verification.

The BSM-FS is a duplicate of the BSM-PFM and is manufactured at the same time as the BSM-PFM. The BSM-FS undergoes the acceptance tests and performance verification after the BSM-PFM.

The BSM-FS and BSM-FS could be the BSM-CQM and BSM-CQM refurbished to flight level. This is TBC as it depends on ESA that the back delivery of the CQM arrives on time, and on the configuraion of the CQM. For the moment, it is planned to manufacture a full new BSM-FS (TBC).

6.12 Verification plan

The verification plan must be compliant with the project verification plan [AD2, RD1] and must fulfil the BSM development needs.

In the tables below,

X = a real test is realised
A = an analysis is conducted
NA = Non applicable

Basic performances are controlled during environmental testing. This control is based upon the typical test, defined during phase A, and always performed following the same procedure.

300K vibrations are conducted at RAL, MSSL or an equivalent facility.
Cryogenic vibrations are conducted at RAL.
Vacuum cycles, soak cycles, thermal cycles (temperature >=20K) are conducted at ATC.
Lifetime tests are conducted at ATC.
EMI/EMC tests are conducted at TBD.
Microphonics tests are conducted at TBD.
Performance tests are conducted at ATC and LAM.

6.12.1 BSMm/BSMs

Mechanism Test	BSMm-DM	BSM-QM	BSMm-CQM	BSMm-PFM	BSMm-FS
Nominal and backup stiffness check	X	X	X	X	X
Mass measurement	X	X	X	X	X
CoG measurement	X	X			
Launch latch test	X	X	X	X	X
Nominal and backup travel	X	X	X	X	X
Consumption measurement	X	X	X	X	X
Vibrations 300K	X	X	X	X	X
Vibrations 4K	TBD	X	X	X	X
Thermal/Vacuum cycle	X	X	X	X	X
Lifetime	TBC	X			
Radiation tolerance	NA	A(**)	NA	A(**)	A(**)
Microphonics		X		X(***)	
EMI / EMC		X	A(*)	X(*)	A(*)

(*) : EMI/EMC tests are to be conducted on the PFM only if design changes have occurred.
(**) : The radiation tolerance is verified by analysis only, taking into account the materials involved.
(***) : Microphonic tests are to be conducted on the PFM only if design changes have occurred.

6.12.2 BSMe

Mechanism **Test**	BSMe-DM	BSMe-QM	BSMe-CQM	BSMe-PFM	BSMe-FS
Power Consumption measurement	X	X	X	X	X
Vibrations 300K	NA	X	NA	X	X
Soak/Cycle	NA	X	NA	X	X
Radiation tolerance	A(**)	A (**)	NA	A (**)	A (**)
Thermal Range	A	X	NA	X	X
Thermal stability	A	X	NA	X	X
EMI / EMC	A(*)	X	A(*)	A(*)	A(*)

(*) : EMI-EMC is verified by analysis at subsystem level and verified by tests once integrated in SPIRE WE.
(**) : The radiation tolerance is verified by analysis only, taking into account the materials and the components involved.
(***) : Lifetime duration is verified by analysis only taking into account the materials and the components involved.

6.12.3 BSM

At the beam steering mirror mechanism subsystem level, the performances are thoroughly verified. They are checked at 300K where appropriate and at operating temperature. All performance requirements set out in the BSM Specification (AD1) are confirmed in the relevant operating modes.

In every operational mode :	BSM-DM	BSM-QM	BSM-CQM	BSM-PFM	BSM-FS
Travel range	X	X	X	X	X
Settling time	X	X	X	X	X
Minimum step increment	X	X	X	X	X
Stability	X	X	X	X	X
Repeatability	X	X	X	X	X
Power consumption	X	X	X	X	X

6.13 Ground associated equipment

The ground equipments are used to develop and test one item without the presence of the others. Only the equipment needed for BSM development are listed.

The simulators replace one or more items. Most simulators are PC based as it is the most flexible and economical solution.

The tools are used to operate, check or integrate an item.

6.13.1 Simulators

Simulator	Used for…	Functions
DRCU Simulator	…the control and monitoring of the BSMe during tests and commissioning	Replaces DRCU Receives position data, synchro signals and temperature signals. Simulates Interfaces: Serial, Parallel, Analogue and Synch. Bus Supplies power Sends commands.
BSMm Simulator	…BSMe development and testing and (enables programming of 21020 Evolution Board) …post DRCU / BSMe integration testing.	Replaces BSMm Receives actuator current values. Simulates the main parameters of the real BSMm : resonance frequencies, stiffness, noises. Delivers simulated position sensor signals and noise

6.13.2 Tools

Tool	Used for …	Functions
BSMm EGSE	… BSMm development and testing	Replaces BSMe. Receives commands : travel range, speed value. Is able to control and monitor BSMm Sends actuator current analogue values, powers the temperature sensors and the optical encoder Receives and processes temperature, actuator current, and position measurements.
BSMm Optical Test Set	…mirror kinematic checking and …mirror alignment with respect to BSMm base plate	Measures travel range, mirror position, mirror displacement around travel axis, rise time.
BSMm OGSE	…BSMm alignment in SPIRE structure	Allows BSMm position control and adjustment inside SPIRE structure. It is a dummy mirror fixed in a replication of the BSM structure
BSMm MGSE	…BSMm Integration in the SPIRE structure or in any test equipment	Allows BSMm handling during its integration in a structure.

7. Development calendar

Activity	**Start**	**End**
Preliminary Design	10 Apr '00	13 Feb '01
PDR	26 Jun '00	27 Jun '00
Detail Design & Prototypes	10 May '00	27 Aug '01
Detailed Design Review	19 Jun '01	22 Jun '01
DM	22 Mar '01	22 Mar '02
DM tests complete, indicate design concept valid	22 Mar '02	22 Mar '02
STM	04 Feb '02	09 Oct '02
confirm QM design loads	09 Oct '02	09 Oct '02
QM	22 Jun '01	27 Feb '03
QM tests complete, indicate flight design valid	27 Feb '03	27 Feb '03
CQM	04 Feb '02	05 Jun '03
Critical Design Review	02 Apr '03	04 Apr '03
PFM	13 Mar '01	20 May '04
Deliver FPU PFM to ESA	29 Oct '04	01 Nov '04
FSM	18 Apr '03	13 Dec '04
Deliver FPU FSM to ESA	19 Apr '05	21 Apr '05

Detailed planning in file BSM_feb_01d.mpp

8. Description of deliverables

8.1 Deliverable models

8.1.1 BSMe models

The FTS warm electronics cards are delivered to CEA.

Model	Flight representativity	Difference from flight	Deliverables
CQM	Dimensions, interface, functions	No redundancy (unless we have the non-parallel redundant option, which would need to be tested), military components (TBC)	1
PFM	100%	None	1
FS	100%	None	1

8.1.2 BSMm models

The BSMm models are delivered to RAL

Model	Flight representativity	Difference with flight	Deliverables
STM	Thermal and Mechanical Interfaces, Mass, CoG, resonant modes.	Non space rated. Mass dummies in place of motors	1 (to RAL, not ESA)
CQM	100%	No functional redundancy (unless non-parallel redundant option), only mass dummies. Mil-Spec components	1
PFM	100%	None	1
FS	100%	None	1

8.2 Associated equipment

The associated equipment is for integration and alignment.

Model	Use/Function	Associated with	Deliverable
BSMe SIM	Simulates the BSMe as seen from SPIRE WE	Any SPIRE WE model	1 to CEA
BSMm SIM	Simulates the electrical interfaces of the BSMm during WE integration	Any deliverable BSMe	1 to CEA
BSMm EGSE	BSMm control and monitor during integration and before and after transportation	Any deliverable BSMm	1 to RAL
BSMm MGSE	BSMm integration in the SPIRE Structure	Any deliverable BSMm	3 to RAL (1 with the CQM, 1 with the PFM, 1 with the FS)
BSMm OGSE	BSMm alignment after integration in SPIRE structure	Any deliverable BSMm	1 to MSSL

8.3 *Associated documentation*

The acceptance data pack (ADP) forms the primary deliverable document to accompany each model. Other document are TBD. The STM, CQM,PFM and FSM will be delivered with an ADP. The QM Adp will be maintained but is not deliverable.

The ADP collation within ATC will be managed via the ATC Product Assurance (PA) plan. The PFM ADP will contain the items below (TBC).

ADP Section	Contents	Required	Comments
1	Shipping Documents	Yes	
2	Procedures for Transport Handling & Installation	Yes	
3	Certificate of Conformance/Delivery Review board MOM AI Lists	Yes	
4	Qualification Status/Test Matrix	Yes	
5	Top Level Drawings incl Family Tree	Yes	
6	Interface Drawings	Yes	
7	Functional Diagrams (Block Diagram)	TBD	TBD
8	Electrical Circuit Diagrams	Yes	Flight circuitry from LAM
9	As built configuration lists	Yes	Incl drawing numbers & issues, mod sheets and manufacturing NCR's
10	Serialised Components List	Yes	Electronics as part of LAM ADP
11	List of Waivers	Yes	
12	Copies of Waivers	Yes	
13	Operation Manual	Yes	Liaison with LAM required, operation via MAC
14	Historical Record	Yes	Linear log of assembly & test activities
15	Logbook/Diary of Events	Not deliverable	Available as required, but not delivered
16	Operating Time/Cycle Record	Yes	
17	Connector Mating Record	Yes	Includes connector savers
18	Not used	N/A	
19	Test Record	Yes	
20	Calibration Data record	Yes	
21	Temporary Installation Record	Yes	Shipping locks, Red Tag (remove before flight), Green Tag (insert before flight) Items
22	Open Work / Deferred Work / Open Tests	TBD	Expected on STM, CQM
23	List of Non-Conformance reports (NCR's)	Yes	
24	Copies of Non-Conformance reports (NCR's)	Yes	Includes manufacturing NCR's and fault logs
25	Test Reports	Yes	
26	Not used	N/A	
28	Mass records / Power Budgets	TBD	Or Ref. to ADP section 6
29	Cleanliness Statement	Yes	
30	Compliance Matrix	Yes	
31	Photographs	Yes	Or Ref. to ADP section 13