SPIRE BSM Development Plan
v 5.1

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Record of Issue

Date	Index	Remarks
13 Mar.00	0.1	Creation of the document
19 May.00	0.2	Revision of the document prior to PDR (draft version)
13 Jun.00	1.0	PDR release
10.Nov.00	2.0	Update - DRAFT in progress
18.Dec.00	3.0	Update, calendar
12.Apr.01	4.0	Update, added model philosophy
29.Jun.01	4.1, 4.2	Internal Working Draft for release as v 5.0
20 Jul 01	5.0	Release for DDR
30.Jan.01	5.1	Update prior to IBDR

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1. 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 2.1.

2. Documents

2.1 Applicable documents

	Title	Author	Reference	Date
AD1	SPIRE Beam Steering Mirror Mechanism Subsystem Specification	I.Pain	SPIRE-ATC-PRJ-000460 V 3.2	10.Jul.01
AD2	SPIRE Project Development Plan	K.J.King	SPIRE-RAL-PRJ-000035	Apr.01
AD3	SPIRE Major Milestone List	K.J.King	SPIRE-RAL-PRJ-000455 1.2 Draft 2	12.Apr.01
AD4	SPIRE AIV plan	B.Swinyard	SPIRE-RAL-DOC-000410 issue 2.0	23.Feb.01

2.2 Reference documents

	Title	Author	Reference	Date
RD 1	Instrument Requirements Document	B.M.Swinyard	SPIRE-RAL-PRJ-000034 Iss .30	May 2000
RD 2	Instrument Development Plan	K.King	SPIRE WE Review viewgraphs	6 Dec 1999
RD 3	Proposal for Beam Steering Mirror	R.Sidey		
RD 4	Assessment of System Level Failure	B.M.Swinyard	SPIRE-RAL-NOT-000319	04.Apr.01
RD 5	SPIRE BSM Design Description Document	Ian Pain	SPIRE-ATC-PRJ-000587 v4.0	Jun.01
RD 6	Short Form Verification Plan for the SPIRE Instrument	Bruce Swinyard	RAL 19/12/2000	19/12/2000
RD 7	ECSS-E30(a)-part3 Mechanism Design	ESA	ECSS-E30(a)-part3	
RD 8	Spectrometer Mirror Mechanism Subsystem Development Plan	D.Pouliquen	LAM.PJT.SPI.NOT.200001 Ind 8	03.Apr.01
RD 9	Herschel-SPIRE BSM PA Plan	I.Pain	SPIRE-ATC-PRJ-000711 v1.0	26.Jun.01

2.3 Glossary

Abbrev	Meaning	Abbrev	Meaning
AD	Applicable Document	LAT	Lot Acceptance Tests
ADP	Acceptance Data Package	MAC	Multi Axis Controller
ATC	United Kingdom Astronomy Technology Centre	MAPTIS	Materials and Processes Technical Information Service
BSM	Beam Steering Mirror	MSFC	Marshall Space Flight Center
BSM	Beam Steering Mirror dummy	MCU	Mechanism Control Unit
BSMe	Beam Steering Mirror electronics	MIP	Mandatory Inspection Point
BSMm	Beam Steering Mirror mechanism	MGSE	Mechanical Ground Support Equipment
BSMs	Beam Steering Mirror structure	MPIA	Max Planck Institute for Astronomy
CAE	Computer Aided Engineering	MSSL	Mullard Space Science Laboratory
CDR	Critical Design Review	NASA	National Aeronautical Space Agency
CoG	Centre of Gravity	NA	Not Applicable
CIL	Critical Items List	NCR	Non Conformance Report
CQM	Cryogenic Qualification Model	NCRP	Non Conformance Review Panel
CTD	Change to Drawing/Document	OGSE	Optical Ground Support Equipment
DCL	Declared Components List	PA	Product Assurance
DDR	Detailed Design Review	PAD	Part Approval Document
DM	Development Model	PFM	Proto Flight Model
DML	Declared Materials List	PPARC	Particle Physics and Astronomy Research Council
DPA	Destructive Physical Analysis	PI	Principal Investigator
DSP	Digital Signal Processor	PID	Proportional – Integral - Derivative
ECSS	European Cooperation for Space Standardization	QA	Quality Assurance
EGSE	Electrical Ground Support Equipment	RAL	Rutherford Appleton Laboratory
ESA	European Space Agency	RAL SSD	RAL Space Science Department
FMEA	Failure Modes and Effects Analysis	RD	Reference Document
FMECA	Failure Modes, Effects and Criticality Analysis	rms	Root mean square
FPGA	Field Programmable Gate Array	SDOF	Single Degree of Freedom
FPU	Focal Plane Unit	SMEC	Spectrometer Mechanism
FS	Flight Spare	SPIRE	Spectral and Photometric Imaging REceiver
FSM	Flight Spare model	TBC	To Be Confirmed
GSFC	Goddard Space Flight Center	TBD	To Be Defined
GSE	Ground Support Equipment	TBW	To Be Written
HoS	Head of Specialism	UK ATC	United Kingdom Astronomy Technology Centre
Herschel	ESA Mission name (formerly FIRST)	UK SPO	UK SPIRE Project Office
ICD	Interface Control Document	WE	Warm Electronics
IBDR	Instrument Baseline Design Review		
KIP	Key Inspection Point		
LAM	Laboratoire d'Astrophysique de Marseilles		

3. Description of the Beam Steering mirror mechanism subsystem

3.1 Outline Description of the Beam Steering mirror mechanism subsystem

The Beam Steering Mirror mechanism subsystem (BSM) is a critical part of the SPIRE Instrument. It is used to steer the beam of the telescope on the photometer and spectrometer arrays in 2 orthogonal directions, for purposes of fully sampling the image, fine-pointing and signal modulation.

The BSM comprises 4 main deliverables:

1. **The cryogenic mechanism** (BSMm).
2. **The structural interface** (BSMs).
3. **The warm electronics** (BSMe)
4. **Mass and optical alignment dummies, , and Ground Support Equipment (GSE) as required for SPIRE system level integration,** (BSMd)

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

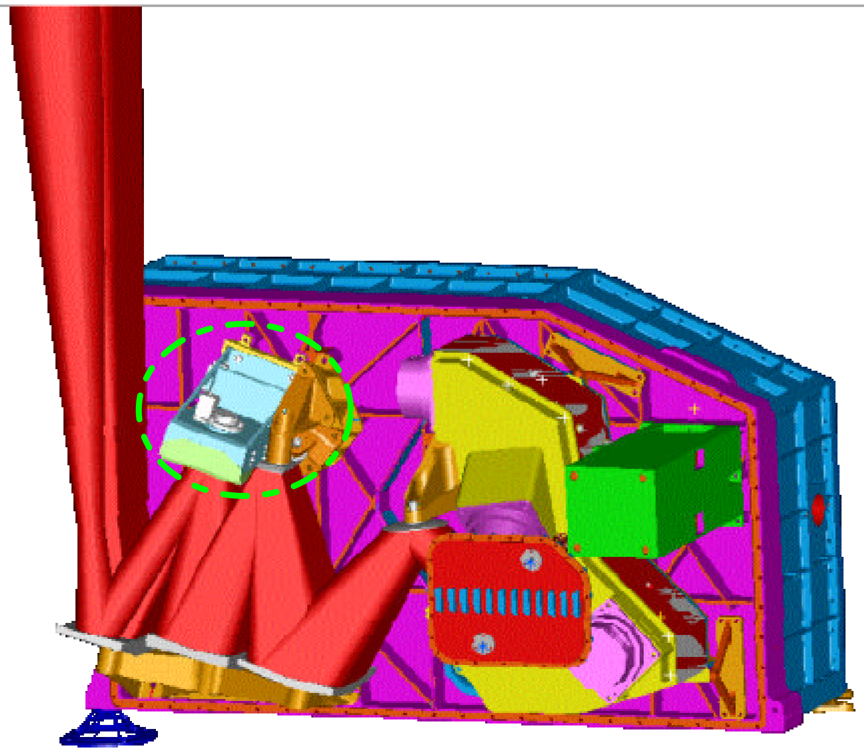

Figure 1 Photometer Layout, BSM in green, highlighted with green dashed oval

The BSMm consists of an aluminium alloy mirror, nominal diameter 32mm, machined as part of the chop axis. This is mounted orthogonally within a gimbal-type frame which provides for jiggle axis motion. The axes are suspended by flex-pivot mounts. The BSMm is a cryogenic device with nominal temperature 4-6K. Nominally, the chop axis provides 2.53 ° of mirror motion at 2 Hz and the jiggle axis provides 0.57° of motion at 1 Hz. The mirror also provides an aperture through which the Photometer Calibration Source is directed towards the detector arrays

The BSMs provides location of the BSMm on the SPIRE optical bench, and will also provide for a light tight enclosure and structural support for harnessing and thermometry. The BSMs integrates to the SPIRE Photometer Calibration Source (PCAL), supplied by the University of Cardiff, a baffle (supplied by ATC) and the SPIRE optical bench (MSSL). The BSMs is a cryogenic structure with nominal temperature 4-6K.

The BSMe provides electrical actuators which are used to provide motion of the mirror. Electrical transducers are used to measure the mirror position to allow control of the mirror position. The BSMe baseline design makes use of cryogenic motors used in PACS and magneto-resistive sensors used in ISOPhot. Each axis houses a rare-earth (NdFeB VACODYM 344) permanent magnet moving pole piece and is driven by a motor coil fixed to the mechanism housing/structure.

The cryogenic electronics are connected to the analogue power and amplifier electronics on the Warm Electronics (WE) by a cryogenic harness which will also feed out signal cables from thermocouples on the BSMs. The BSM operates under control of the Detector Readout and Control (HSDRC) sub-system's Mechanism Control Unit (MCU) supplied by LAM. The BSMe will be specified and designed by the UK ATC, then manufactured by LAM in conjunction with the SMEC electronics. Integration and test will be at LAM, with support from ATC.

The BSMd may comprise several actual dummies, with at least (1) an optical dummy for initial alignment work and (2) a mass-representative model for structural vibration tests. Designs for mass and optical alignment dummies will not be specified in detail until the BSMs/BSMm design is complete.

3.2 Mission profile

The BSM is developed as a sub-system and then integrated to the SPIRE FPU. The SPIRE instrument is subsequently integrated to Herschel. The instrument is to be cryogenically cooled, and will be cold during launch. Launch is scheduled for 2007 to an L2 orbit. The mission duration is a minimum of 4.25 years.

Per AD1, in normal operations the satellite is expected to have a 24-hour operational cycle with data being collected autonomously for 21 hours and a 3 hour ground contact period – the Data Transfer and Commanding Period (DTCP). During the DTCP the data will be telemetered to the ground and the commands for the next 24-hour period will be up-linked.

3.3 BSM Block Diagram

The block diagram below is adopted from AD1 Fig 3.1-1 and shows the relationships between the sub-systems of the SPIRE instrument.

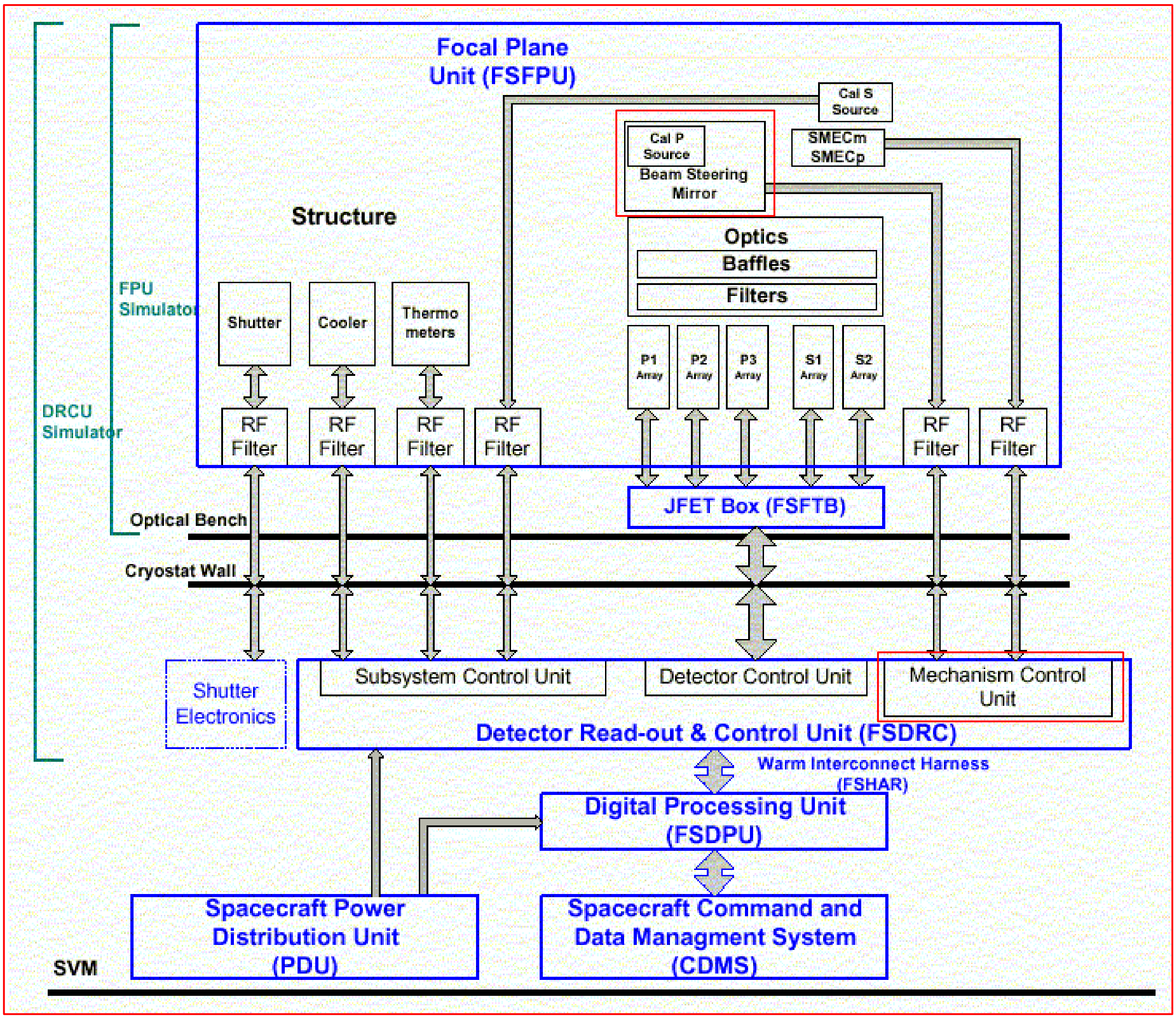

Figure 2 SPIRE Block Diagram[1] showing BSM, Mechanism Control Unit (MCU).

[1] *Note that the terminology in this figure is in need up an update, as the spacecraft has been re-named Herschel, formerly FIRST. Hence FIRST-SPIRE Focal Plane Unit, or FSDPU should now read HSDPU.*

3.4 Alternative design

In June 2000, the UK ATC placed a development contract for 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. This concept was down-selected in Jan.01, because the flight electronics were incompatible with the MCU baseline design.

4. Constraints

4.1 Development constraints

4.1.1 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:

Chop axis:

amplitude:	± 2.53°
maximum frequency:	2Hz
settling time:	20 ms
stability:	0.004° rms

Jiggle axis:

amplitude:	± 0.57°
maximum frequency:	0.5Hz
settling time:	50 ms
stability:	0.004° rms

4.1.2 System constraints

The system technical constraints are identified in RD1

4.1.3 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 (an alternative may be to split the integration with part of the integration at ATC, part at LAM - TBD)
- 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.

The WE is:

- 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.

The Photometer Calibrator, PCAL is:

- Designed, developed and tested by UoCW
- Transported to ATC under UoCW responsibility
- Integrated to the BSM
- Tested for interference with the BSM
- Delivered to RAL under ATC responsibility (note delivery may be via LAM with BSM and WE)

SPIRE is

- delivered to ESA under RAL responsibility.
- integrated in the Herschel satellite under ESA responsibility.
- The SPIRE CQM is to undergo the ESA cryo qualification program under ESA responsibility.
- The 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 Launch lock status is verified. Herschel is launched.
- The SPIRE FSM is prepared in the event of SPIRE PFM failure.

4.1.4 Work Flow

The work flow between ATC, MPAI, LAM, UoCW 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 and WE at the LAM and ATC sites using a PC-based simulator of the controller .

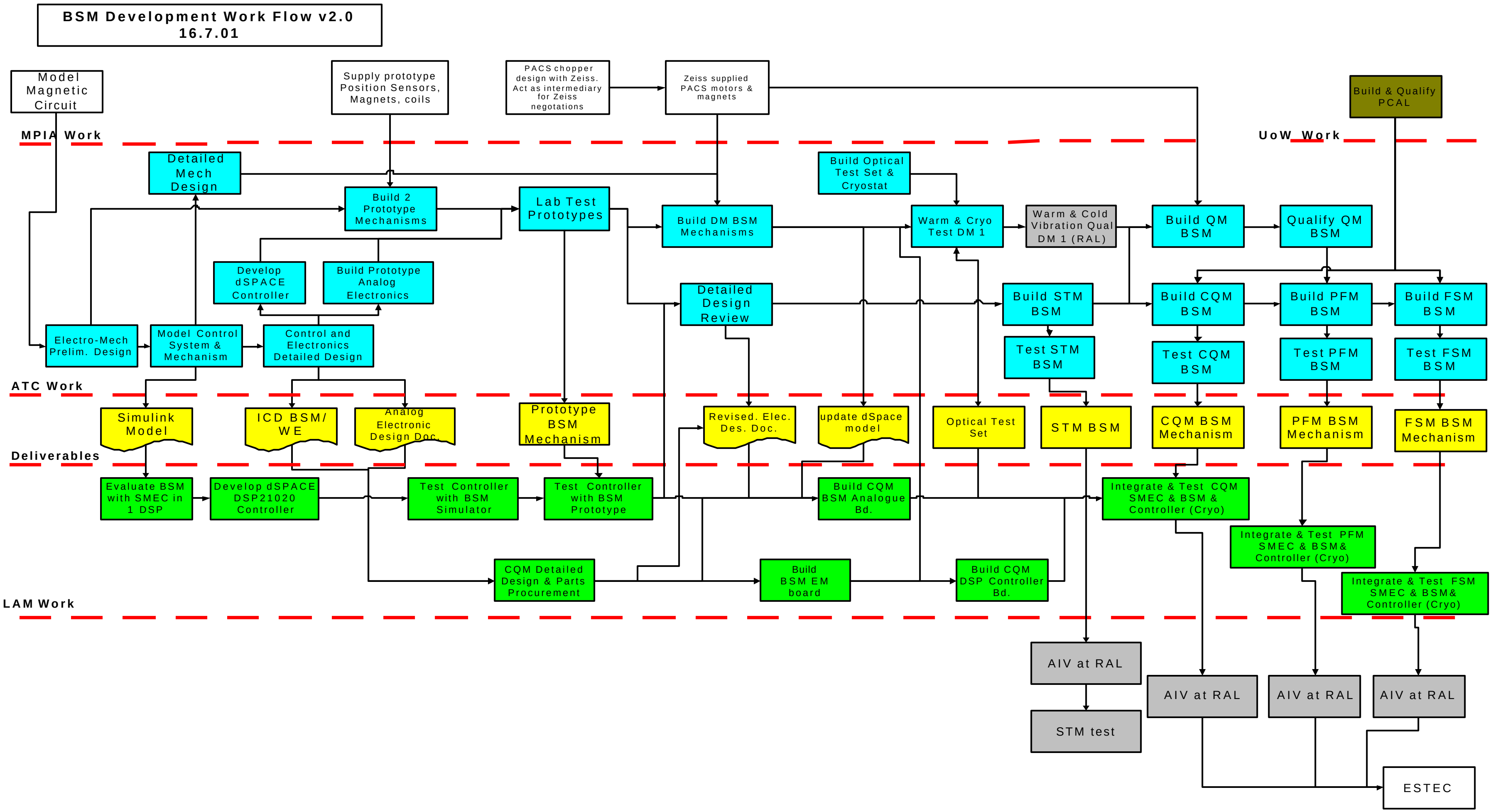

Figure 3: BSM Development Work Flow and Deliverables

4.1.5 Organisation

- ATC is responsible for the BSM, i.e. BSMm, BSMs, BSMd and BSMe.
- SAp-CEA is responsible for SPIRE DRCU inside which the BSMe is implemented.
- MSSL is responsible for the structure onto which the BSMm is integrated.
- UoCW is responsible for PCAL
- MPIA and ATC collaborate under an MoU to optimise magnetic circuit design
- RAL is responsible for integrating the SPIRE instrument

For the BSMe, per RD 8,

LAM responsibility covers :

- The performance requirements of the SMEC subsystem (SMECm+MAC+SMEC analog board).
- the technical requirements at the MCU level
- the technical requirements at the SMECm level.
- the interface requirements MCU – DPU, MCU – DRCU, MCU – BSMm and SMECm – Structure and optics.
- development, manufacture and qualification / acceptance of the SMECm and MCU.
- implementation of the UKATC electronic functional design on the BSMm analog board in the MCU.
- implementation of the UKATC BSMm control algorithms.
- delivery of the SMECm and MCU models, their associated simulators, tools and documentation to RAL.

ATC is responsible for

- the functional design of the BSMm analog board.
- the BSMm development, manufacturing and qualification / acceptance.
- the BSM end to end performances.
- the BSMm control algorithms.

4.1.6 Calendar constraints

Outlined in section 0

4.2 Risk analysis

A full risk assessment has been performed by the ATC BSM project team, and is maintained as an internal risk register. The following tables are extracted from the risk register, highlighting only those elements of sufficient severity to require a mitigation plan.

Table 1 Values used in assigning risk severity & probability

Severity	rating	value		
		slippage	extra duration	extra cost
Low	1-4	<5 days	<3 days	< £2k
Medium	5-7	5-25 days	3-13 days	£2-10k
High	8-10	>25 days	>13 days	>£10k
Probability	rating	value		
Low	1-4	<10%		
Med	5-7	10-30%		
High	8-10	>30%		

Table 2 Extracts from ATC risk register v1.6

ID		Risk	Probability	Severity	Owner	Expiry Date	Mitigation plan
B	16	Budget does not include adequate contingency - almost certain to overspend	9	9	IP	2004	ensure risks spelled out to UKSPO, prep descope options
B	24	Project Scientist distracted by NGST at key stages - lack of Project Scientist's input at critical time could reduce quality or cause delays	9	9	GSW	2002	supplement proj sci with student effort, or increase lab technician effort
B	18	VISTA may take effort - wouldn't meet schedule	8	9	IP/GSW	2004	maintain SPIRE profile though internal PR & PMM role. VISTA recruitments relieve pressure
B	8	Space schedules prohibit slip, but ATC culture allows slip - impact could be failure to deliver	8	9	IP/GSW	2004	maintain SPIRE priority as high. Manage to recover (not accept) slip
B	9	Success orientated schedule - cost or time overrun if anything is not perfect	9	8	IP	2004	aggressive Proj Mgmnt to recover slippage. Needs adequate resources

ID		Risk	Probability	Severity	Owner	Expiry Date	Mitigation plan
T	12	Insufficient resources for lab testing - delay to project	8	9	IP	2003	ensure adequate EAS requests, and supplement with student/contract effort
M	2	Flex pivots fail at vibration test stage - impacts cost/spec/schedule	7	10	IP	Dec.01	test flex pivot vibration on early prototype
T	15	Problems/failures encountered during test phase - increase in cost	8	8	IP	2002	build contingency into ATC EAS requests, monitor progress vs test plan
M	4	Flex pivots fail life test - impacts cost/spec/schedule	6	10	IP	Apr.02	test flex pivot life on DM
B	7	Components cost too much - may have to descope	7	8	IP/BS	Apr.02	investigate alternatives, common procurement or descope options. Opt for HIGH RISK low cost options
M	1	Documentation load high -	7	8	IP	2003	ensure project support maintained. Use Q-Pulse to manage docs. Restrict number of distinct ATC docs
Q	7	PA/QA costs us more than budgeted for	8	7	IP	2004	May be unavoidable if early estimate poor. Minimize PA where possible, and exploit other ATC or RAL PA activities in support
T	11	Redesign of major part required due to qualification test failure - increase in cost (manpower, hire of test facilities, procurement of parts)	8	7	IP	2003	Review quarterly.
T	2	Test Plan requires additional detail	8	7	GSW	Aug.01	Proj Sci to write test plan
T	6	Clean room isn't clean enough and costs time and money to fix - project delayed	7	8	BG	2003	measure cleanliness regularly. Test cleanliness on early models. Clean room is OK at class 1000. General lab an issue
B	1	Space instrumentation requires more formal processes than ATC used to	9	6	IP/GSW/ CRC	2003	Write and promote PA plan. Enforce it, and review monthly
B	22	Project small in ATC terms and not well known - may lose priority to other projects	6	9	IP/GSW/ CRC	2003	maintain SPIRE profile though internal PR & PMM role
B	23	Mythical man-month hits small project teams hard - delay, very sensitive to skills shortages	6	9	IP	2003	PM to try to hold core team. Weekly proj meetings. Overtime rather than new staff at crunch times

ID		Risk	Probability	Severity	Owner	Expiry Date	Mitigation plan
M	8	Movement of mirror in each axis during warm vibration due to lack of warm clamp fit. Prototype lost and re-work required.	6	9	TAP	Dec.01	early warm vibration. Check design has no loose fits when warm.
Q	1	QA plan - lots of documentation, at increased cost/time	9	6	IP	2004	ensure project support maintained. Use Q-Pulse to manage docs. Restrict number of distinct ATC docs
T	14	Problems/failures encountered during test phase - delay to project	6	9	IP	2002	build contingency into ATC EAS requests, monitor progress vs test plan
T	3	Failure of essential test equipment at a crucial time (maybe long lead time) - delay to project	6	9	IP	2003	procure spares where possible
T	5	Delay in procuring 20K dewar - impacts QM test schedule	9	6	IP	Aug.01	use 4K test dewar as backup, place 20K dewar request asap

4.2.1 Flex Pivot Selection

Flex pivots are a significant programme risk for the BSM, as well as other Herschel/Planck mechanisms. Technically, cryogenic rated materials such as 304 grade stainless steel, CuBe or Inconel 718 would be preferred. Until recently, only Lucas TRW has been available as a supplier but with lead times 6-9 months and minimum order quantities >$100 US these are beyond the reach of the BSM budget.

Therefore a high risk option was selected post DDR, to use off the shelf 420 grade stainless steel pivots, and attempt to upscreen these for selection as the baseline design before IBDR and/or QM procurement. This matches the financial constraints but contains significant technical risk which would require late deployment of very large contingency funds if activated.

In parallel to up-screening Lucas 420 grade pivots, we have identified an alternate supplier: C-Flex who may be a viable supplier of CuBe pivots at affordable prices.

4.3 Redundancy

4.3.1 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 BSM Design description, RD 5 includes a Failure Modes Effects and Criticality Analysis (FMECA) of the BSM. Briefly,
- The baseline architecture for BSM redundancy is completely parallel as shown in section 3, with the exception of the WE backplane mounting and the flex pivots.
- 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.

4.3.2 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. These are arranged such that if one fails, the other is able to free the mechanism. Complications in unlatching the launch dampers for the prime and redundant circuits make this scheme non ideal, and if tests or analysis demonstrate that it is not required it will be reviewed for deletion from the baseline design.

4.3.3 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/-2.4°) 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. This option is unlikely to be adopted as analysis by LAM for the SMEC has clearly indicated that over constraint of the flex pivots can lead to early failure in buckling.

The optimal trade-off of the above options requires a more detailed failure mode and performance analysis. The selection of a Launch Latch will be performed after the BSM DM tests.

5. Work description

5.1 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, Detailed and post-CDR design phases. Briefly these include: Two prototypes are used to inform the design process. Three 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, optimisation 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:

5.2 Single Axis Prototype

5.2.1 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.

5.2.2 Tests:

- Component manufacturability and optimisation.
- 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.

5.2.3 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.

5.2.4 Build Standard

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

5.3 Two Axis Prototype

5.3.1 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).

5.3.2 Tests:

- Component manufacturability and optimisation.
- Mechanical assembly
- PACS Motor optimisation to suit BSM.
- Motor-sensor cross-talk and motor shielding requirements
- Stability and dynamic response of position sensors with high precision circuits.
- Initial Cryogenic cooldown to demonstrate cooling rate through flex-pivots and thermal end-stops (if required).
- Cryogenic functionality of sensors and motors.

5.3.3 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 will be replaced with or CuBe brazed 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.

5.3.4 Build Standard

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

5.4 Back-up Design : CDL Prototype

5.4.1 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.

5.4.2 Tests:

- Component manufacturability and optimisation.
- 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.

5.4.3 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.

5.4.4 Build Standard

Non-deliverable. Non-flight unit.

5.5 Development Model (DM)

5.5.1 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.

The DM model is used to identify control parameter changes on the BSMe as compared to warm behaviour. 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, the DM is refurbished later as a CQM (TBC – depends whether configuration is flight representative) and used to qualify the cold performance of the design. A second DM (if built - TBD) 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.

5.5.2 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 [coil shorting]
- 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.

5.5.3 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. 420 grade brazed stainless steel flex pivots will be used initially; replaced by CuBe flex-pivots if 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. A test of broken flex pivots for retention/control would be desirable

5.5.4 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. To roll out the BSM PA plan, the DM will be used as a test bed and thus much of the hardware will be of suitable standard for CQM/STM.

5.6 Structural and Thermal Model (STM).

5.6.1 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. However, a 'free' cold vibration test would be a very valuable risk mitigation task and will be sought if at all possible.

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.

5.6.2 Tests:

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

5.6.3 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.

5.6.4 Build Standard

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

5.6.5 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

5.7 Unit Level Qualification model (QM)

5.7.1 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 (except where DM hardware may be used in STM)

5.7.2 Tests:

- Cryogenic cooldown.
- Vibration at room temperature
- Cold vibration (at RAL).
- Launch damper tests.
- Launch lock tests (if required, and LAM device available)
- 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.

5.7.3 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.

420 grade brazed flex pivots may be used initially; replaced as full flight grade/ CuBe brazed 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.

5.7.4 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

5.7.5 Schedule

See RD6.

- Results required for CDR by April 2003.
- Flight grade flex pivots must be available before Nov.02, and procurement/up-screening arranged accordingly.
- life tests therefore must commence no later than ~Oct.02 and preferably before Aug.02.

5.8 Cryogenic qualification model (CQM).

5.8.1 Purpose

This is a model of the instrument that will be used to characterise 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.

5.8.2 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.

5.8.3 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. 420 garde brazed 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.

5.8.4 Build Standard

Deliverable. Non-flight unit.

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

5.8.5 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

5.9 Proto-Flight Model (PFM) and Flight Spare model (FSM)

5.9.1 Purpose

The PFM is the proto flight model, the FSM is the flight spare model.

5.9.2 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.

5.9.3 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 QM components. The BSM-FSM undergoes the acceptance tests and performance verification after the BSM-PFM.

5.9.4 Build Standard

Full flight configuration.

5.9.5 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

5.10 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 is initiated to explore an alternative three axis concept which uses integrated actuators and LVDTs. This could 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. (This design was down selected as the electronics were incompatible with the MCU)

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 integrated with a model of the MCU in a short campaign at to LAM to test the controller with actual hardware.

5.10.1 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.

5.11 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, such as extensive resonance analysis by FEA.

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

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 CQM.

Before the CDR, 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.

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

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 DM, QM 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 (partial for DM, full for QM)

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 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.

5.11.1 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. A major schedule risk is that the STM test results are available too late in the overall SPIRE programme. This delays the earliest QM vibration testing and thus prevents a logical BSM design/manufacture approach to be taken. In effect, the PFM BSM will have to be built in advance of final life test confirmations on the QM, and there will be no ability to fold in design changes without late delivery and/or cost over-runs

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

5.12 Verification plan

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

The table below shows how each of the functional and operational requirements in this document is to be demonstrated, for each of the deliverable BSM models. The deliverable models include the STM (deliverable to RAL but not ESA), CQM, PFM, FS

Key:

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

Notes:

- The STM model may be delivered as a fixed mass with no mirror or a fixed mirror (TBD) The minimum requirements verification is specified accordingly. In the event that a representative rotating mirror is provided, the CQM test requirements will apply (TBC).
- Tests and measurements are distinguished in that measurements are simple procedures e.g. to measure dimensions, mass etc. A test will in most cases include some combination of measurement devices, set up procedures, inspection, calibration, calculation, etc in order to demonstrate a requirement.

The typical tests are defined during the DM test programme and always performed following the same procedure. For subsequent test programmes.

Test Location:

- 300K vibrations are conducted at RAL, MSSL or an equivalent facility.
- Cryogenic vibrations are conducted at RAL.
- Vacuum cycles, soak cycles, thermal cycles 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.

5.12.1 Verification Tests

5.12.1.1 Performance Requirements

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
Controlled motion, cold operation	Angular Travel - Chop Axis	T	X	T	T	T	T	
	Angular Travel - Jiggle Axis	T	X	T	T	T	T	
	Minimum Step Size	T	X	T	T	T	T	
	Chop Frequency	T	X	T	T	T	T	
	Jiggle Frequency	T	X	T	T	T	T	
	Holding position	T	X	T	T	T	T	
	Stability	T	X	T	T	T	T	
	Position Measurement	T	X	T	T	T	T	
	Settling Time	T	X	T	T	T	T	
	Chop repeatability	T	X	T	T	T	T	

5.12.2 System Requirements

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
Inspection	Mechanical Dimensions	M	M	M	M	M	M	
Cooldown, cold operation	Operating Temperature	T	T	T	T	T	T	
	Thermal Isolation	T	T	T	T	T	T	
Cold operation	Cold Power Dissipation	T	X	T	T (a)	T	T	(a) Cold power dissipation of the CQM may not be compliant if non-space rated components are used for motor coils
None at ATC	Warm Electronics Power Dissipation	X	X	X	T	T	T	
Inspection, Cold operation	Mirror Surface Dimensions	M	M (b)	M	M	M	M	(b) X if STM has no mirror
	Mirror Surface Finish	I/M	I/M (c)	I/M	I/M	I/M	I/M	(c) X if STM has no mirror
	Mirror Surface Reflectivity	A	A(d)	A	A	A	A	(d) X if STM has no mirror
	Mirror Surface Emmissivity	X	X	X	X	X	X	Complement of 4.2.11 & 4.2.8
	Baffle	M/T	X	M/T	M/T	M/T	M/T	Measurement will be against design drawings. Tests only performed on integration at RAL
	Position of Rotation Axes	M/I	M/I (e)	M/I	M/I	M/I	M/I	(e) X if STM has no mirror
	Orthogonality of Rotation Axes	T	X	T	T	T	T	
Failsafe & Redundant modes	Fail Safe (No Drive Signal) Position	T	X	T/A(f)	T/A(f)	T/A(f)	T/A(f)	(f) May require supporting analysis of rest position in 1 g field is not (0,0)
	Fail Safe (Mechanical Failure) Position	T	X	T/A(g)	X	T/A(g)	T/A(g)	(g) Demonstrated on tests on QM or DM
Inspection	Mass	M	M	M	M	M	M	
Cooldown	Cool-down time	T	T	T	T	T	T	Cooldown times will be dependent on cryostat configuration.
none	Reliability	X	X	A(h)	X	A(h)	A(h)	(h) demonstrated by QM programme and

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
								by design/analysis
Failsafe & Redundant modes	Failure Modes	X	X	A(j)/T	X	A(j)	A(j)	(j) demonstrated by QM programme and by design/analysis

5.12.3 Operational Specification

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
None at ATC	Operational Safety	A	A	A	A	A	A	Demonstrated by analysis/design/risk assessment
Life Test	Lifetime	T (part)	X	T	X	A(k)	A(k)	(k) demonstrated by QM programme
Cold operations, Failsafe & Redundant modes	Operating modes	T (l)	X	T	T(l)	T	T	(l) DM, CQM will not have redundant modes
Controlled motion, cold operation	Jiggle Mode	T	X	T	T	T	T	
	Chopping Mode	T	X	T	T	T	T	
	Scan mapping	X	X	X	X	X	X	Only applicable on spacecraft
	Stare or 'holding' mode	T	X	T	T	T	T	
	Combinations of Modes	T	X	T	T	T	T	
	Degraded modes	T	X	T	T	T	T	

5.12.4 Interface requirements

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
Data exchange interface check	Data Outputs	T	X	T	T	T	T	Fully demonstrated only on integration at LAM/ RAL . ATC tests will demonstrate compliance to ICD
	Data Inputs	T	X	T	T	T	T	Fully demonstrated only on integration at LAM/ RAL . ATC tests will demonstrate compliance to ICD
None at ATC	Exported vibration	X	X	X	T	T	T	On integration to SPIRE at RAL
Magnetic Field Measurement	Stray Magnetic fields	T	X	T	T	T	T	On integration to SPIRE at RAL
None at ATC	Electro-Magnetic Compatibility	X	X	X	A/T	T	T	On integration to SPIRE at RAL
Interface measurement	ICD's	I/M/T	I/M/T	I/M/T	I/M/T	I/M/T	I/M/T	

5.12.5 Design, manufacture and test requirements

Reference	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
Inspection	Design requirements	A	A	A	A	A	A	Compliance indicated in ADP
	Electronics Card Format	X	X	X	I	I	I	Inspection of LAM deliverables
	Mirror Flatness	M	M(m)	M	M	M	M	(m) X if STM has no mirror
	Mirror Reflectivity	X	A(n)	A	A	A	A	(n) X if STM has no mirror
	Cleanliness	X	I	I	I	I	I	Compliance determined by TBC
	Material selection	X	I	I	I	I	I	Compliance indicated in ADP
PA plan	Storage	A	A	A	A	A	A	Compliance indicated in ADP

5.12.6 Environmental Requirements

Test	Requirement	DM	STM	QM	CQM	PFM	FS	Notes
No test	Shock	X	X	X	X	X	X	No requirement
Warm & Cold Vibration	Quasi Static Loads	Twarm	T	T warm T cold	X	A(o)	A(o)	(o) demonstrated by QM programme. Cold tests TBC dependent on cost
	Sine Vibration	Twarm	T	T warm T cold	X	A(p)	A(p)	(p) demonstrated by QM programme. Cold tests TBC dependent on cost
	Random Vibration	Twarm	T	T warm T cold	X	A(q)	A(q)	(q) demonstrated by QM programme. Cold tests TBC dependent on cost
Cooldown	Vacuum Level	T	T	T	T	T	T	
None	Vacuum Outgassing	A	A	A	A	A	A	Demonstrated via materials selection and Compliance indicated in ADP
Cooldown	Temperature	T	T	T	T	T	T	
Magnetic Field Measurement	Magnetic Fields	M	X	M	TBD	TBD	TBD	EMC tests performed when integrated at RAL. Tests to be determined once specification exists
Bakeout test	Survival Temperature	T	T	T	T	T	T	
None at ATC	Radiation environment	X	X	X	X	TBD	TBD	EMC tests performed when integrated at RAL. Tests TBD

5.12.7 BSMe

The BSM warm electronics are subject to the verification and test programme of the MCU, as noted in RD TBC (LAM MCU dev plan). These will include (TBC)

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

5.13 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.

5.13.1 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

5.13.2 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.

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6. Development calendar

6.1 Summary of activities

Activity	Start	End
Preliminary Design	10 Apr '00	13 Feb '01
PDR	26 Jun '00	27 Jun '00
Detail Design & Prototypes	10 May '00	31 Mar 02
Detailed Design Review	19 Jun '01	30 Jul '01
DM	13 Jul 01	12 Jul 02
DM tests complete, indicate design concept valid	N/A	30 Apr 02
STM	28 Feb '02	14 Feb 03
confirm QM design loads	N/A	04 Dec 02
QM	03 Apr 02	21 Apr 03
QM tests complete, indicate flight design valid	N/A	21 Apr 03
CQM	22 Mar 02	15 Jul 03
Critical Design Review	N/A	27 Jun 03
PFM	04 Jul 01	31 Mar 01
Deliver FPU PFM to ESA	N/A	15 Jun 04
FSM	03 Sep 03	10 Aug 05
Deliver FPU FSM to ESA	N/A	29 Nov 05

6.2 Key BSM Milestones

The following milestones are extracted from AD 3

Development programme Milestone	Responsible	Need Date	Planned Date	Margin (days)	Comments
Detector Array Selection	**SPIRE**		**01/02/00**		**Complete**
Delta PDR	**SPIRE**		**26/06/00**		**Complete**
BSM Simulink Model Delivery to LAM	ATC	11/08/00			Complete
BSM Analogue Board Design Delivery to LAM	ATC	11/08/00			Complete
Instrument Interface Review	**SPIRE**		**30/11/00**		**Complete**
ISVR	**ESA**		**30/11/00**		**Complete**
BSM Analogue Board Detailed Design Delivery to LAM	ATC	01/01/01			Complete
IIDR	**ESA**		**23/04/01**		Complete
SMEC, BSM Detailed Design Review	**SPIRE**	**31/01/01**	**Jul 01**		Complete
IBDR	**ESA**		**Mar 02**		

STM Programme Milestone	Responsible	Need Date	Planned Date	Margin	Comments
Test Facility Available	RAL	16/08/02	30/06/02	1.5 months	(10/04/01) Issue 3 Rev 0
STM BSMm Delivery to RAL	ATC	01/07/02	01/07/02	15 days	
CQM BSMm Harness Delivery to RAL	ATC	01/07/02	01/07/02	15 days	
STM Interim Review			**09/10/02**		
Cold Vibration Campaign Starts	**ESA**		**28/11/02**		
STM Review			**14/02/03**		
CQM Structure and FTBs available			**17/02/03**		

CQM Programme Milestone	Responsible	Need Date	Planned Date	Margin	Comments
CQM PCAL Delivery to ATC	QMW	01/07/02	22/03/02	3 months	Delivery date may be reviewed
CQM BSMm Delivery to LAM	ATC	01/09/02	23/07/02	1 days	Need date needs review
CQM BSMm Delivery to RAL	LAM		10/01/03		Need date/ Margin/ LAM plan needs review
QM1 MCU delivery to SAp	LAM	12/06/02	12/06/02	2 months	Needs update by LAM
DRCU-FPU Test Harness Delivery to SAp	RAL	12/06/02			Needs update by SAp
AVM DPU Delivery to RAL	IFSI	01/06/02	02/04/02	2 months	Needs update by SAp
DRCU Simulator#2 Delivery to RAL	SO	01/06/02	01/06/02		Needs update by SAp
CQM Test Readiness Review			**21/03/03**		
CQM Interim Review			**22/04/03**		
Critical Design Review			**27/06/03**		
CQM Delivery to ESA	**RAL**	**01/04/03**	**15/07/03**		**Needs update by RAL**

QM Warm Electronics Programme Milestone	Responsible	Required Date	Planned Date	Revised Need Date	Comments
QM2 MCU Delivery to SAp	LAM	01/11/02	10/09/02	1.5 months	(Needs update by LAM
WE Critical Design Review			**02/07/03**		

PFM Programme Milestone	Responsible	Need Date	Planned Date	Margin	Comments
PFM PCAL Delivery to ATC	QMW	21/05/03	14/05/03	7 days	(Delivery date may be reviewed
PFM BSMm Delivery to LAM	ATC	15/07/03	03/06/03		Need date needs review
PFM BSMm Delivery to RAL	LAM	01/10/03	18/07/03	2.5 month	Need date and LAM schedule needs review
Delivery of PFM FPU to Cold Vibration Facility	**RAL**		**27/01/04**		
Delivery of Cold-Vibrated PFM FPU to RAL	**RAL**		**24/02/04**		
PFM Test Readiness Review			**09/12/03**		
PFM Delivery to ESA	**RAL**	**01/06/04**	**15/06/04**		**Needs update by RAL**

FS Programme Milestone	Responsible	Need Date	Planned Date	Margin	Comments
FS PCAL Delivery to ATC	QMW	16/01/04	03/09/03	4 months	Delivery date may be reviewed
FS BSMm Delivery to LAM	ATC	01/03/04	22/01/04	5 weeks	Need date needs review
Return of CQM from ESA	**ESA**	**01/06/04**			**9 months after delivery to ESA …**
FS Structure Available for Integration	MSSL	10/01/05	10/01/05	1 month	Need update from RAL
FS BSMm Delivery to RAL	LAM	10/01/05	10/11/04	8 months	LAM schedule update required
Delivery of FS FPU to Cold Vibration Facility	**RAL**		**10/07/05**		
Delivery of Cold-Vibrated FS FPU to RAL	**RAL**		**10/08/05**		
FS Test Readiness Review			**06/06/05**		
FS Available to ESA	**RAL**	**01/07/05**	**29/11/05**		**Realistic Date 1st Jan 06**

Detailed planning is contained in the latest version of the BSM project plan, BSM_mmm_ver.mpp

7. Description of deliverables

7.1 Deliverable models

7.1.1 BSMe models

The FTS warm electronics cards are delivered to CEA by LAM.

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

7.1.2 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

7.2 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 by LAM
BSMm SIM	Simulates the electrical interfaces of the BSMm during WE integration	Any deliverable BSMe	1 to CEA by LAM
BSMm EGSE	BSMm control and monitor during integration and before and after transportation	Any deliverable BSMm	1 to RAL
BSMm OGSE	BSMm alignment after integration in SPIRE structure	Any deliverable BSMm	1 to MSSL

7.3 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, RD 9 . The PFM ADP is described in RD9.