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SPIRE Beam Steering Mirror Subsystem Development Plan V1.0

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1. Table of contents

2. Table of Figures

3. Scope of the document

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

The development plan is based on the applicable documents cited in paragraph 4.1.

4. Documents

4.1 Applicable documents

	Title	Author	Reference	Date
AD1	SPIRE Beam Steering Mirror Mechanism Subsystem Specification	D.Henry	???	??? May 2000
AD2	SPIRE Development plan	K.King	To be written	

4.2 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	??	??

4.3 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
FIRST	Far InfraRed Space Telescope	UK ATC	United Kingdom Astronomy Technology Centre
FPU	Focal Plane Unit	BSM	Beam Steering Mirror
FS	Flight Spare model	SPIRE	Spectral and Photometric Imaging REceiver
LAM	Laboratoire d'Astrophysique de Marseille	TBC	To Be Confirmed
FTS	Fourier Transform Spectrometer	TBD	To Be Defined
		WE	Warm Electronics

5. Description of the Beam Steering mirror mechanism subsystem

The Beam Steering Mirror mechanism subsystem (BSM) is a major 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 :

The cryogenic mechanism (BSMm).
The structural interface (BSMs).
The warm electronics (BSMe)
Mass dummies as required for SPIRE system level integration, (BSMd)

However, for the purposes of the development plan it is assumed that the BSMs and BSMm will be integrated prior to delivery outside of ATC. Indeed, the actual structural interface may be integral to the BSMm housing, or attached as a distinct entity (TBD). The position of the BSMm & BSMs are indicated in Figure 1.

Beam Steering Mirror Mechanism (BSMm), on Structural Interface (BSMs)

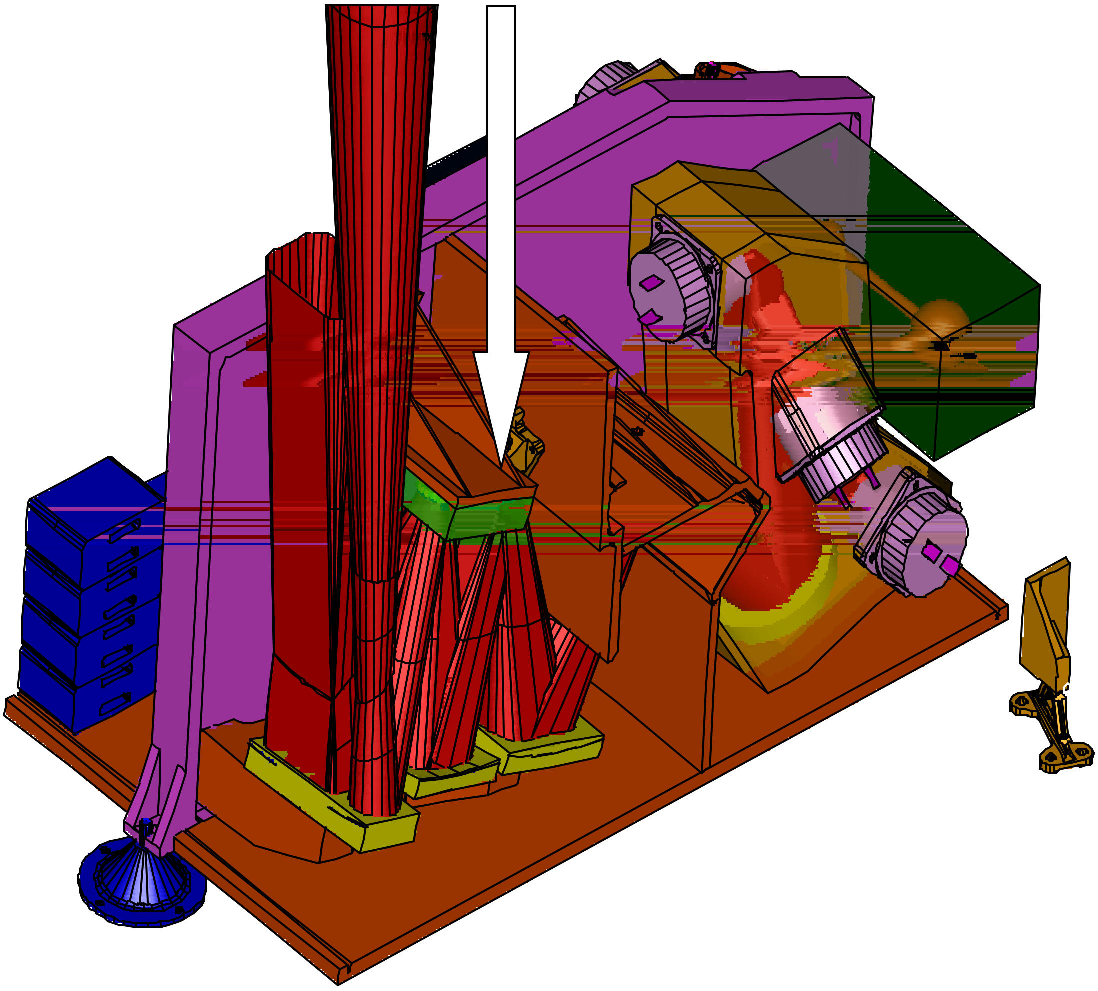

Figure 1: Photometer Layout

Similarly, mass dummies are referred to only as necessary, and not otherwise discussed separately.

5.1 The Cryogenic Mechanism (BSMm)

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

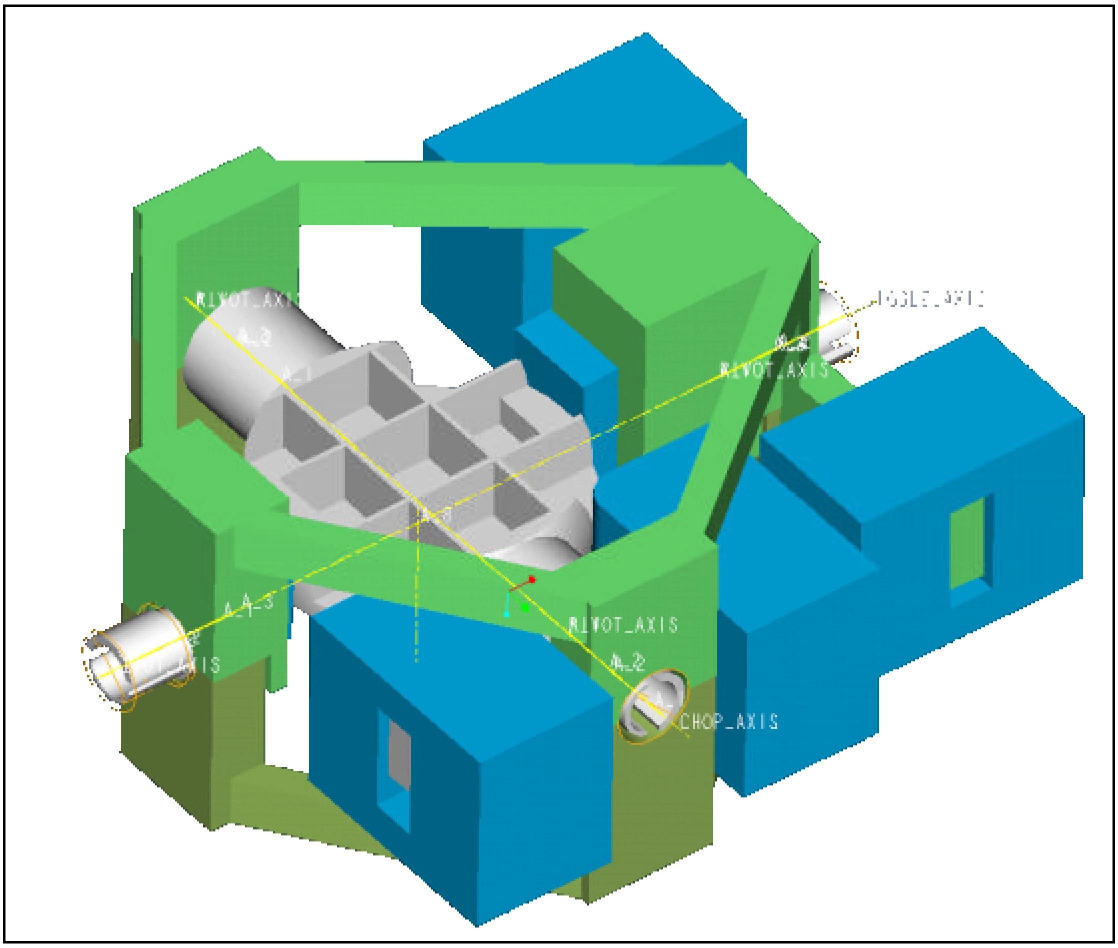

Figure 2: View on underside of mirror - Chop stage grey, jiggle stage green, motors and sensors blue

The chop and jiggle stages are shown in Figure 1. The chop stage is monolithic with the mirror machined integrally. The underside of the mirror is light-weighted and has pockets for the iron plates for the magneto-resistive position sensors. The chop direction is along the long axis of the array (the spacecraft y-axis). A 2mm diameter (TBC) hole in the centre provides an optical path for the calibrator mounted behind the BSMm

The jiggle stage is in the form of a split frame split and clamps together around the flex pivots. To balance the jiggle stage the framework in the opposite corner to the coils has been made solid. This also increases the stiffness of the structure. Both stages are designed to be stiff, so that the first resonant frequencies are high enough that the system modelling can regard them as rigid bodies.

Space envelopes for the coils and sensors are shown in blue. There are four coils for each of the two motors. (The outer rings of the flex-pivots, and the housing are not shown for clarity.) Position sensors for the chop axis are mounted on the jiggle stage, which means flexible cable connections are required, unlike the jiggle stage position sensors, which mount directly on the non-moving housing.

5.2 *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.

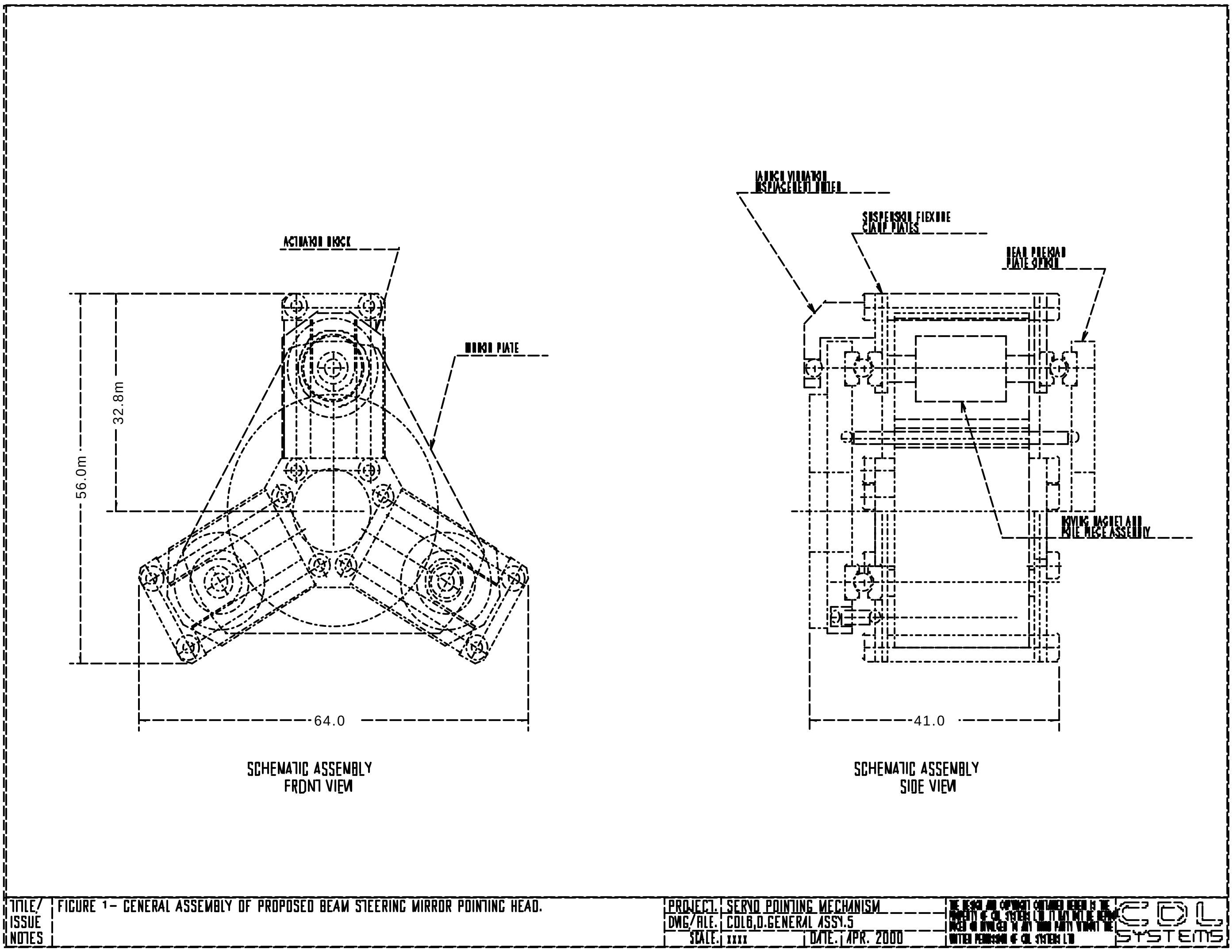

Figure 3: Alternative 3 axis mechanism

An overall assembly of the proposed two axis pointing mechanism for the SPIRE beam steering subsystem is shown in Figure 1 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 Figure 1, 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.

5.3 The Warm Electronics (BSMe)

We describe the warm electronics for the primary BSM design. Clearly, the back-up design would differ in that it has three axes to control, and the position sensors are AC excited LVDT coils, which require synchronous demodulation.

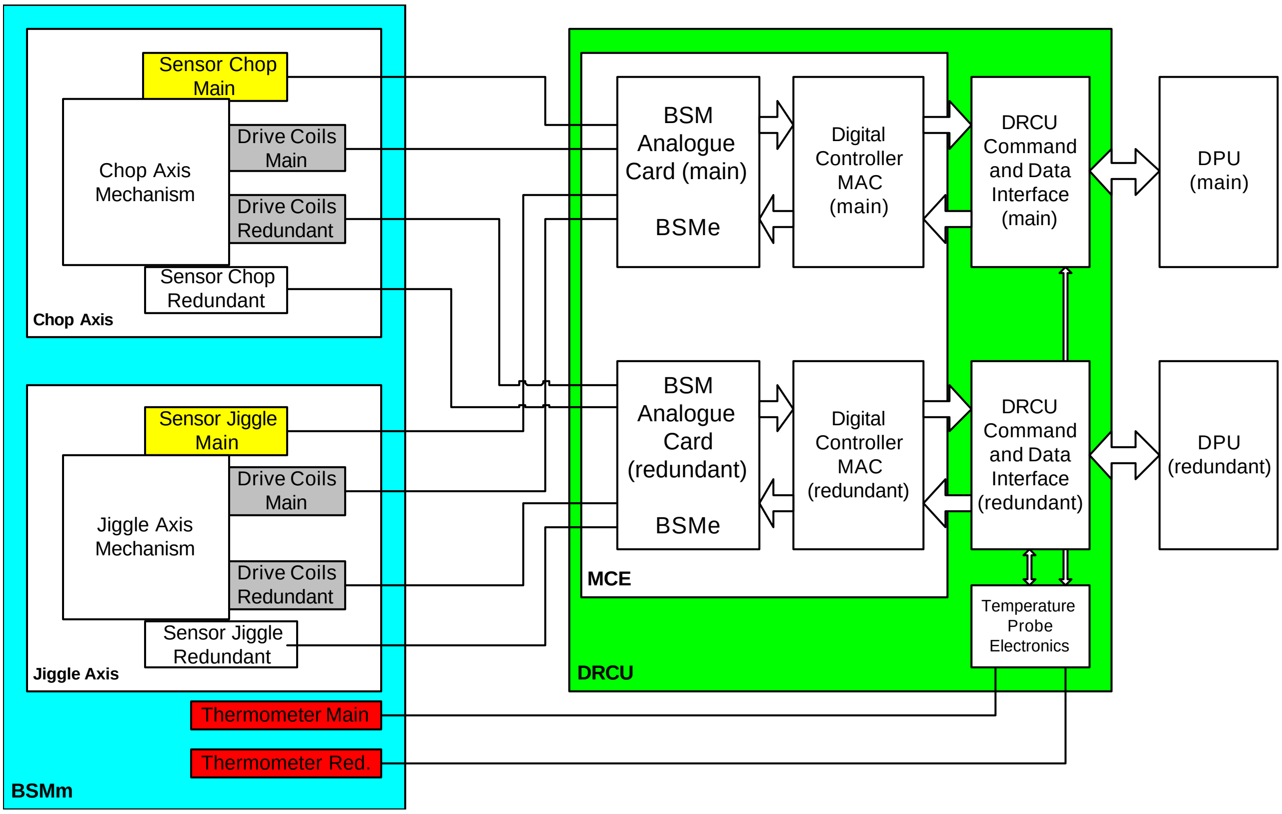

Figure 4: BSM Control : Parallel Redundant Option

The BSMe provides analogue signals for motor power and position control. The warm electronics (WE) are integrated with the digital controller (MAC) and spectrometer electronics (SMECe) to form the MCE (mechanism Control Electronics). A cable harness connects to the cold electronics, and also provides provision for the connectors through to thermometers. This cable harness is also used to serve the photometer calibration source.

The BSM & SMEC architecture have a consistent design philosophy regarding parallel redundancy. The main BSM analogue electronics powers one motor, and reads out from one position sensor, on each BSMm axis. The other part of the electronics (which may be a separate board) and associated motors and sensors is cold redundant.

This architecture is adopted, as the alternative of attempting to power all components from either of the MAC boards would imply additional switching to ensure that only one MAC board provides instruction and power. This switching is undesirable for reasons of complexity, reduced reliability and the linking of the two otherwise independent DPU/MAC/SMEC sets to a common part.

Concerns remain in that this architecture requires the ability to provide two separate pairs motor coils. This may be challenging in terms of torque delivery or manufacturing constraints. Several options exist, including

to double wind the motor coils, which would result in reduced torque provision (nominally 50%, possibly worse) and would be more difficult to manufacture (and hence more prone to unreliability from manufacturing defects).
to use only one par of coils on each axis. This generates an unbalanced force set and would also result in a 50% torque provision. However, the mechanism remains physically balance for launch, and the single-winding design would not degrade reliability. This option is the baseline.

Further investigation is required to optimise motor design, and to quantify the torque, force and reliability issues for each option.

The ½ BSM & ½ SMEC cards may be physically combined or separate as appropriate - depending on size and detailed layout, and the preferred solution will be selected with the agreement of ATC and LAM following detailed design.

The baseline is that the MAC will provide power for BMS analogue board.

We have an alternative proposal which we regard as a back-up in case it proves not to be possible to meet the specification using parallel redundant motors. Only one BSM analogue card is controlled by either the main or redundant MAC. This card has on-board logic and switching circuits to select which controller, which causes some problems in dealing with main & redundant power sources. In this case all four motor coils for each axis will be wired in series, and latching relays used to select which coils are driven. Thus a failed coil or connection is bypassed, and the system continues to operate, with lower performance. The same relays can be used for shorting coils during launch to provide damping. As on board switching is provided, it is then possible to also select which position sensors to power up, providing more flexibility than the parallel redundant solution. However, the added complexity of this solution must be accounted for in failure modes analysis.

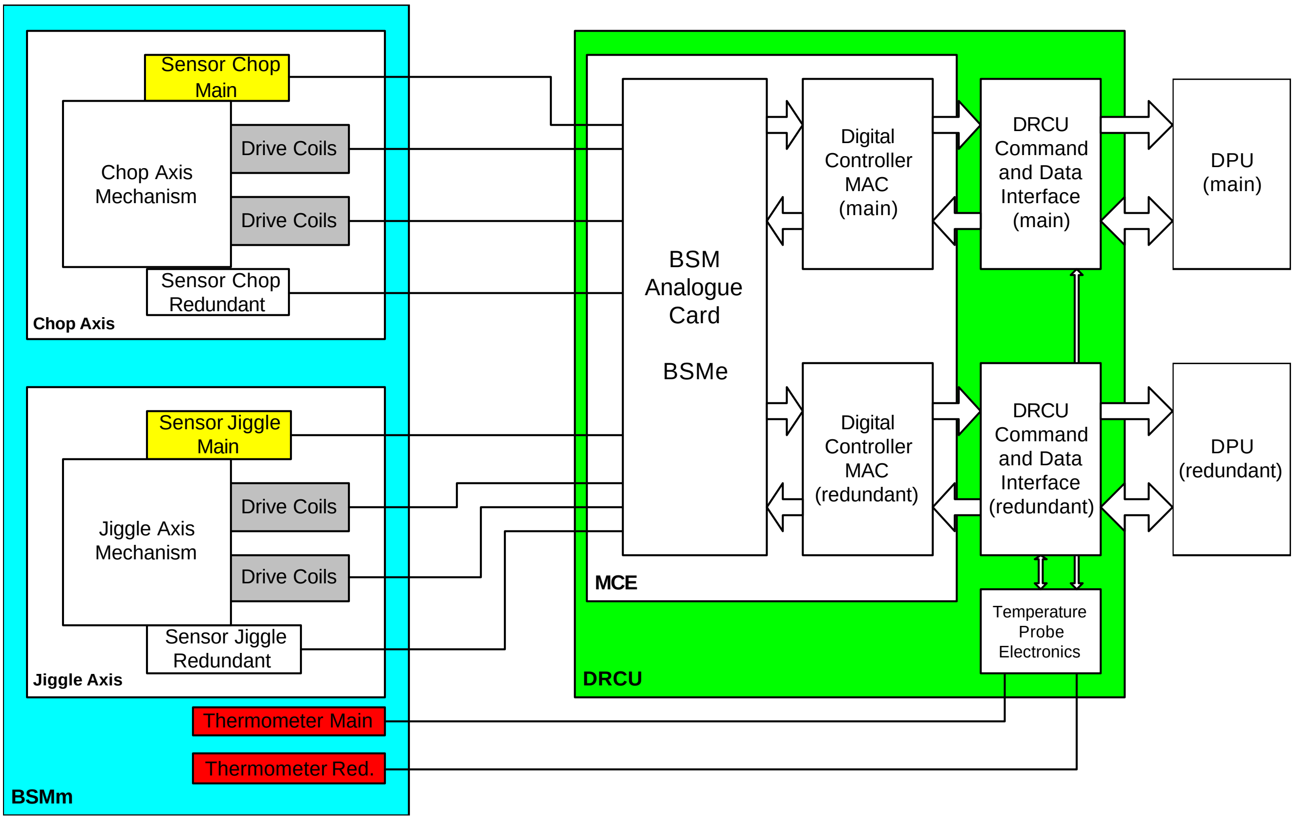

Figure 5: BSMe Control : Switched rebdundancy option (Single BSMe with switched motor windings)

6. Constraints

6.1 Development constraints

6.1.1 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: ± 2.4°
maximum frequency: 2Hz
settling time: 25 ms
stability: 0.02° rms

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

6.1.2 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

6.1.3 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 if required.
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 FIRST 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.

6.1.4 Work Flow

The work flow between ATC, 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 .

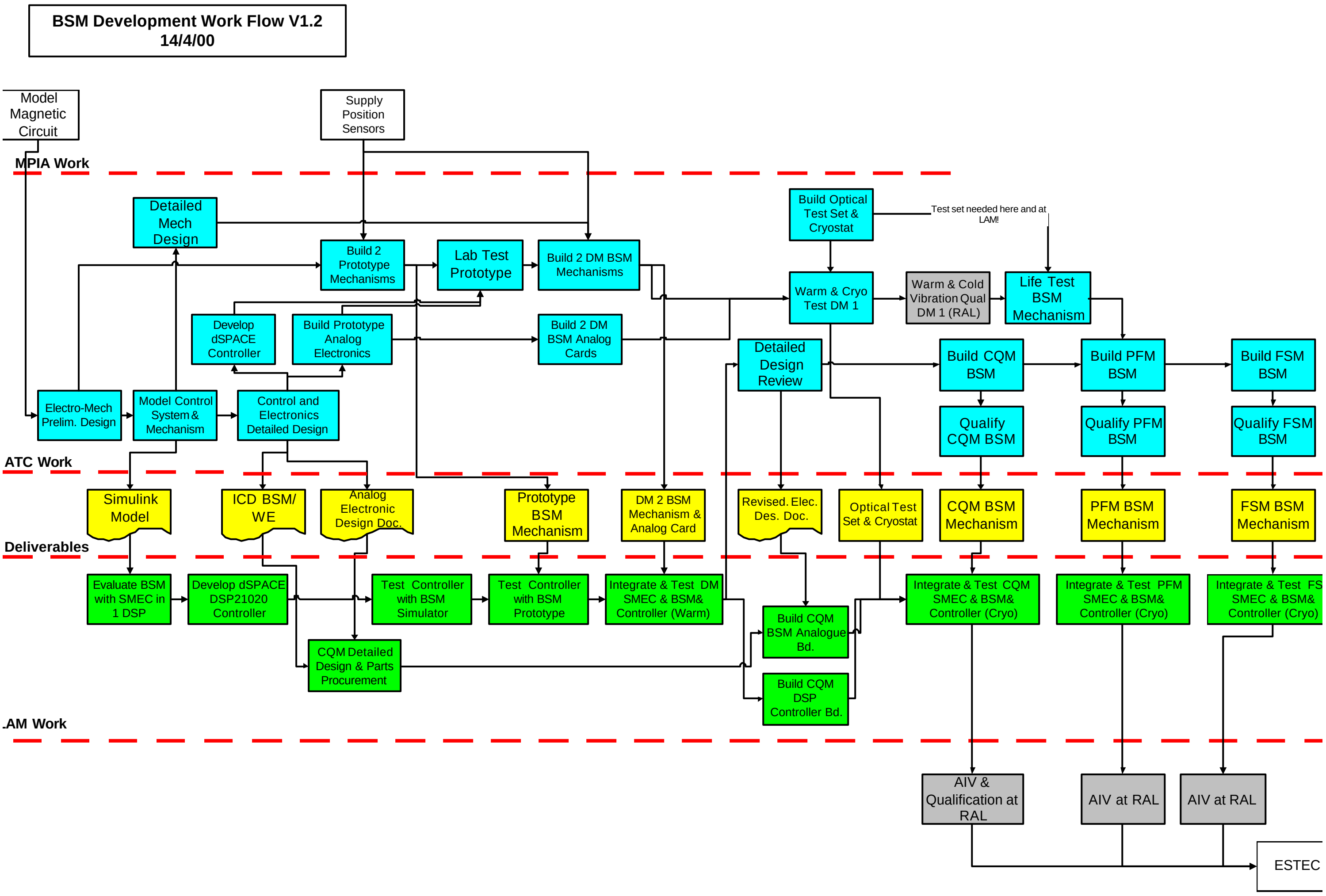

Figure 6: BSM Development Work Flow and Deliverables

6.1.5 Organisation

ATC is responsible for the BSM, i.e. BSMm 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.

6.1.6 Calendar constraints

The main SPIRE project dates are [RD2]:

PDR	26/27 Jun 2000
DDR – Interface Review	9/10th Oct 2000
DDR – BSM & SMEC	Jan 2001 (TBC)
BSM CQM delivery to LAM	Jan 2002
BSM CQM from LAM to RAL	Mar 2002
CDR	1 Dec 2002
SPIRE CQM delivery to ESA	Apr 2003
BSM PFM delivery to SPIRE	Mar 2004
SPIRE PFM delivery to ESA	Nov 2004
BSM FS delivery to SPIRE	May 2005
SPIRE FS delivery to ESA	Dec 2005
FIRST launch	2007

6.2 *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.
ISOPHOT 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
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) Contingency design of full launch lock Alternate design scheme in parallel	Sub-contract of an alternate rugged design is another fall back.
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

6.3 Redundancy

6.3.1 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 5.3. 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.

6.3.2 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.

6.3.3 Launch lock

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.

7. Work description

7.1 Development and model philosophy

The model philosophy is compliant with the SPIRE project requirements and meets the ATC development needs.

7.2 Preliminary Design (Phase B)

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).

Two preliminary prototype mechanisms will be built to verify design assumptions

and gain experience of motor, position sensors and flexures.

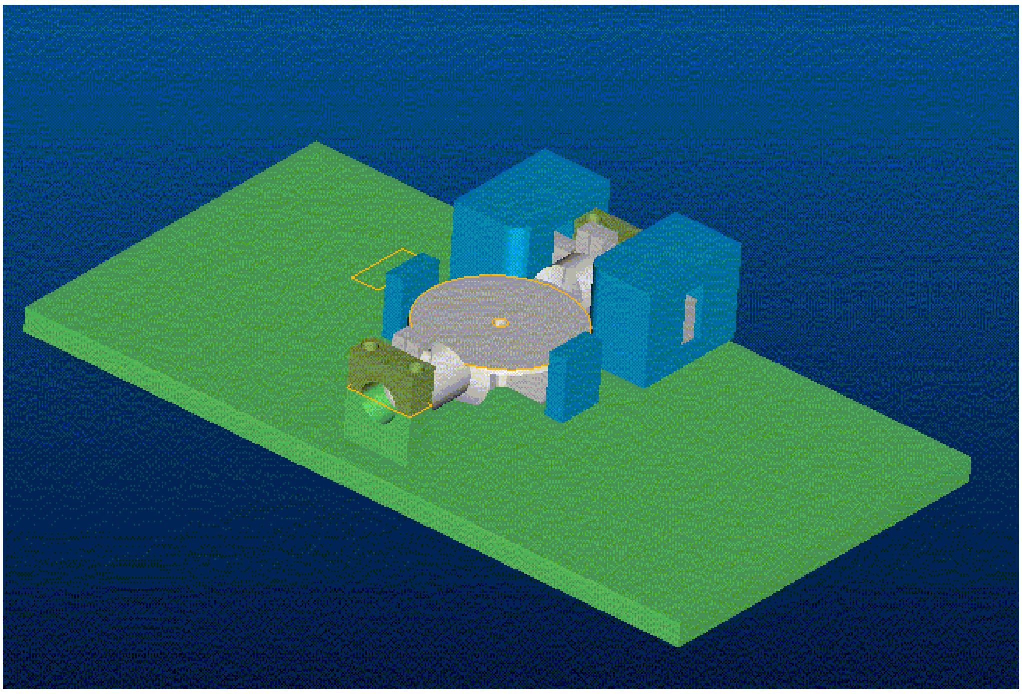

Figure 7: Single axis prototype design

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

7.2.1 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 CQM, PFM and FS.

*7.3 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 (mid October 2000). The DDR must have happened before CQM manufacture can begin. The typical tests are now frozen.

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

Two models are necessary because the life tests last 6 months and would lead to a delivery date too late in the planning would only one model be built.

The two models are the development model (DM) and the cryogenic qualification model (CQM). The BSM-DM is not deliverable and the BSM-CQM is deliverable.

The DM model is used to qualify the design and conduct the life tests on the BSMm, the DM will be manufactured using fully representative hardware, engineering drawings and appropriate documentation.

The DM will be subjected to full warm and cold tests at the ATC. Performance will be verified cold at the ATC using a test cryostat and measurement equipment developed for the purpose. Details of any cryogenic control parameter changes as compared to warm behaviour will be passed to LAM for incorporation in the control simulation. Subsequently, cold life tests will be performed at RAL. The development model will then be retained in the event that further prototyping is required as a result of late stage problems with the CQM or PFM.

The CQM is to be qualified but does not undergo the life tests. The DM and the CQM include all the functions of the flight design, except redundancies.

In the BSMm-DM and BSMm-CQM, the redundancies are simulated by dummy masses when necessary. The components are of flight grade as BSMm-DM is to be tested at cryogenic temperature.

In the BSMe-DM, no redundancy is implemented. Only commercial components are used in the BSMe-DM and military grade in the BSMe-CQM (ESA's request TBC). Both models are to be used at room temperature only and not under vacuum. 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.

The design verifications by tests 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 FIRST FPU.

7.3.1 Flight design modifications and PFM/FS manufacture

Following the BSM 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.

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. For the moment, it is planned to manufacture a full new BSM-FS.

7.4 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.
Cryo 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.

7.4.1 BSMm

Mechanism **Test**	BSMm-DM	BSMm-CQM	BSMm-PFM	BSMm-FS
Nominal and backup stiffness check	X	X	X	X
Mass measurement	X	X	X	X
CoG measurement	X			
Launch latch test	X	X	X	X
Nominal and backup travel	X	X	X	X
Consumption measurement	X	X	X	X
Vibrations 300K	X	X	X	X
Vibrations 4K	X	X	X	X
Thermal/Vacuum cycle	X	X	X	X
Lifetime	X			
Radiation tolerance	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.

7.4.2 BSMe

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

7.4.3 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-CQM	BSM-PFM	BSM-FS
Travel range	X	X	X	X
Settling time	X	X	X	X
Minimum step increment	X	X	X	X
Stability	X	X	X	X
Repeatability	X	X	X	X
Power consumption	X	X	X	X

7.5 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.

7.5.1 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

7.5.2 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.

8. Development calendar

Detailed design		Apr - Sep 2000
DM & CQM	Manufacture	Sep 2000 - Jan 2001
DM	Qualification, Calibration	Feb - Jun 2001
DM	Life tests	Aug 2001 - Mar 2002
CQM	Modify, qualification & calibration	Aug - Dec 2001
CQM delivery	to RAL, CEA, MSSL	Jan 2002
PFM & FS	Manufacture	Jan 2002 -Jun 2003
PFM	Acceptance & calibration	Jun - Dec 2003
PFM delivery	to RAL, CEA, MSSL	Dec 2003
FS	Acceptance & calibration	Dec 2003 - May 2004
FS delivery	to RAL, CEA, MSSL	May 2004

Detailed planning in file BSM_devplan.mpp

9. Description of deliverables

9.1 Deliverable models

9.1.1 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

9.1.2 BSMm models

The BSMm models are delivered to RAL

Model	Flight representativity	Difference with flight	Deliverables
CQM	100%	No functional redundancy (unless non-parallel redundant option), only mass dummies.	1
PFM	100%	None	1
FS	100%	None	1

9.2 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

9.3 Associated documentation

The documentation is TBD.