SPIRE Science Verification Review

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BSM Performance in PFM 2

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Contents

1. Introduction and scope

This note gives the verification status of the BSM. It will focus only on BSM verification and how well it meets requirements, but not on BSM calibration which will be dealt with elsewhere.

2. List of requirements that the test programme was designed to evaluate

IRD-BSMP-R01 - The BSM shall move the imaged field of view of the detectors by a maximum of ± 130 arcsec on the sky in the ± Y axis of the satellite

IRD-BSMP-R02 - The BSM shall move the imaged field of view of the detectors by a maximum of ± 30 arcsec (TBC) in the ± Z axis of the satellite

IRD-BSMP-R03 - The minimum step size in either chop or jiggle axes shall be 2 arcsec

IRD-BSMP-R04 - The chop frequency in either axis shall be continuously variable or selectable in 16 steps from 0 to 2 Hz for nominal operation and power dissipation. The chop frequency should be capable of reaching 5 Hz with increased power dissipation and settling time.

IRD-BSMP-R05 - The BSM shall be capable of moving to and holding indefinitely at any commanded position within its range of movement

IRD-BSMP-R06 - The angle on the sky must not vary by more than 0.1 arcsec over 60 sec at the commanded mirror position. The mirror position shall also have a stability equivalent to 0.2 arcsec rms in the 0.03 to 25 Hz frequency band

IRD-BSMP-R07 - The knowledge of the mirror position shall be equivalent to a stability of 0.2 arcsec rms in the 0.03 to 25 Hz frequency band. The absolute knowledge of the mirror position shall be equivalent to less then 0.01 arcsec.

IRD-BSMP-R08 - The mirror shall settle to within 1 arcsec of its commanded position in less than 20 milliseconds.

IRD-BSMP-R10 - Nominal operating <6 K. The mechanism shall be capable of operating in a temperature range of 4-300 K.

IRD-BSMP-R12 - The power dissipation into level 1 shall be within the specification in RD1 (Note RD1 states: Maximum average power dissipation of the BSM Cryogenic Mechanism (BSMm) and the BSM Support Structure (BSMs) < 4mW)

3. Test results and conclusions

3.1.1 Movement range and angle on the sky (IRD-BSMP-R01, R02, R03)

The BSM movement range was approximately ± 6 PSW pixels in the Y direction. The detector centre-centre spacing is 2.5 mm and the plate scale at the detector focal plane (for *f*/5 final optics) is 12.6 arcsec/mm, so this corresponds to a total range of (12)(2.5)(12.6) = 378 arcsec (± 189 arcsec), exceeding the maximum requirement given by IRD-BSMP-R01. This shows that the requirement can be met by operations.

The BSM proved capable of reaching the centre of pixels on three adjacent rows on the PMW array and with a pixel separation of about 50 arcsec apart, this corresponds to at least 75 arcsec range exceeding the 30 arcsec range requirement given by IRD-BSMP-R02. This shows that the requirement can be met by operations.

A preliminary calibration of the BSM shows that 1 arcsec (again taking a 31.5 arcsec pixel separation for the PSW array) corresponds to 185 position units in the chop axis. As the BSM is commandable to a single position unit, the ability to set a minimum step of 2 arcsec in operations (requirement IRD-BSMP-R03) is met.

3.1.2 Chop Frequency (IRD-BSMP-R04)

The chop frequency has only been exercised at 2 Hz therefore this requirement has not been demonstrated. However the instrument design allows for all required frequencies and these will be demonstrated in the next test campaign.

3.1.3 Holding Ability and Mirror position (IRD-BSMP-R05, R06, R07)

The BSM was stepped over its full range with between 5 and 15 seconds of data taken at each position. The analysis of this data is not complete but preliminary results show that the jitter on the BSM position sensor at mid range are within a few sensor units with the maximum deviation being about 5 units. From the preliminary calibration 0.1 arcsec corresponds to about 30 position units.

No longer duration tests have been done but as 15 seconds is likely to correspond to the longest holding time needed, IRD-BSMP-R05 has been demonstrated (note an indefinite requirement cannot be verified). This also verifies the first part of the requirement IRD-BSMP-R06.

Only chopping at 2 Hz has so far been done and this has not been done with the BSM tuned therefore the stability requirement in IRD-BSMP-R06 has not yet been demonstrated as there is a large overshoot of the BSM at the start of each chop cycle. However after the settling time the stability of the BSM is within a few BSM sensor units which is well within the requirement, therefore it is likely that once tuned the BSM stability will be well within this requirement.

3.1.4 Setting time (IRD-BSMP-R08)

The required settling time is to be within 1 arcsec within 20 ms. This was not achieved in either the PFM1 or PFM2 test campaigns despite some considerable time being dedicated to the tuning. LAM have achieved 17 ms with flight electronics during a warm test with the flight spare unit. Tuning the BSM is one of the first priority tests for PFM3

3.1.5 Operating temperature and power dissipation (IRD-BSMP-R10, R12)

The BSM has been operated at ambient down to cold (IRD-BSMP-R10). Tests done at subsystem level (RD2) have measured the following values:

Unit	Chop Motor Power (mW)	Chop Sensor Power (mW)	Jiggle Motor Power (mW)	Jiggle Sensor Power (mW)
Prime	0.19	0.51	0.23	0.47
Redundant	0.15	0.48	0.22	0.49

3.2 List of tests carried out and tests still to be done

As delivered, the BSM was uncalibrated, and therefore the test campaign was established to do the following:

1. Set up the initial calibration of the position to which the BSM moves, by peaking up an externally chopped blackbody point source on a pixel with the BSM at its home position, then using the BSM to steer this chopped signal across the FOV.
2. Tune the BSM PID parameters to allow chopping between two pixels found by the FOV test.
3. Chopping between the pixels at the desired frequency.

The FOV test has been carried out for the central spectrometer pixels and for the photometer pixel PSW E6. This rough calibration from this test will need to be refined by offsetting the source using the telescope simulator from the peaked position.

The PID tuning has been attempted several times in both the PFM1 and PFM2 test campaigns. The procedure used has proved difficult to exercise and more knowledge transfer needs to take place before this can be streamlined.

The difficulty in tuning the BSM has impacted the ability to carry out extensive chopping tests. Only nominal pixels at the nominal 2 Hz frequency have so far been tested.

3.3 Subsystem requirements tested at instrument level and their verification status

BSM-SSSD-R16 - The steady state repeatability between successive chop cycles shall be less than 0.004° (rms) on the mirror over 4 hours.

At present it is not planned to test this as it will need 4 hours of continuous chopping. However, a test of this nature could be carried out during PFM3 and it is recommended that this is implemented.

3.4 Instrument-level requirements and their verification status.

All requirements tested (see Section 2) were instrument level requirements.

4. Open issues and anomalies

No clear written procedure yet exists for BSM tuning. Therefore the 20 ms requirement has not yet been verified. A written procedure will be available for the next test campaign.

5. Recommendations for further data analysis and tests

The ability of the BSM to move a requisite distance has been demonstrated. The initial calibration derived from this will need to be refined by further tests with an offset source. Although chopping with the BSM has been demonstrated, the ability of the BSM to act as a chopper with the required settling time has still to be demonstrated. To achieve this a better procedure for tuning the PID is required. The delivery of an updated procedure by LAM has been agreed. Once the tuning has been achieved alternate ranges and frequencies can be tested.

A long duration test on the stability of the BSM chopping should be considered to ensure that deep integrations on faint objects will not be compromised by BSM performance.

6. References

RD1: SPIRE Thermal Design Requirements (SPIRE-RAL-PRJ-002075)
RD2: FSM Test Report v 3.0 090929 (SPI-BSM-REP-0010)

7. Appendices

7.1 Verification matrix for the BSM

Requirement Name	Description	Verification Method	Models	Test ID	Test Type	Upper Links
IRD-BSMP-R01	Maximum throw in chop axis	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	IRD-PHOT-R17 IRD-OPS-R06 IRD-OPS-R07 IRD-OPS-R08

IRD-BSMP-R02	Maximum throw in jiggle axis	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	IRD-OPS-R06 IRD-OPS-R07 IRD-OPS-R08
IRD-BSMP-R03	Minimum step in both axis	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	IRD-PHOT-R17
IRD-BSMP-R04	Frequency of chop	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BCT	
IRD-BSMP-R05	Holding Position	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	
IRD-BSMP-R06	Stability	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	IRD-SPEC-R17
IRD-BSMP-R07	Position Measurement	Design analysis Instrument level performance tests	PFMI	ILT_PERF	ILT-PERF-BSM	IRD-SPEC-R17
IRD-BSMP-R08	Duty Cycle	Design analysis Instrument level performance tests	PFMI	ILT_PERF	PID Tuning Tests	
IRD-BSMP-R10	Operating temperature	Design analysis Instrument level warm functional test Instrument level cold functional tests	PFMI	ILT_WFT ILT_CFT	FUNC-BSM-01	
IRD-BSMP-R12	Cold power dissipation	Design analysis Instrument level cold functional test	PFMI	ILT_CFT		IID-B-SECT-5.9.1

7.2 BSM PID tuning

The process of optimising PID parameters search on both chop and jiggle axis aims to achieve a dynamical behaviour that meets the following performance requirements on the BSM:

a) settling time on the correspondent axis of ? t_{settle} < 20ms;
b) stability of 0.2 arcsec rms in the 0.03 to 25 Hz frequency band on the commanded position.

OPERATIONS:

In order to achieve this, the BSM is operated in a close loop where the current chop/jiggle position of the mirror (magneto-resistive sensor readout) is read by the MCU software. This then computes the error between the original commanded position and the actual position and adjusts the current on the motor coil accordingly. The goal of this feedback loop is to completely cancel out the error. Three parameters, Proportional (Kp), Integral (Ki) and Derivative (Kd), feed into this iterative loop and have to be manually adjusted in real time until the performance required is achieved.

Each axis requires its own set of PID parameters due to the different extent of the travel in the two axis and the different mechanical components.

The process explained above which may seem a priori reasonably simple is actually complicated by two facts:

- The dynamical behaviour of the BSM is mainly driven by a scaling factor between the operator input which is a target position between 0 and 65535 and the actual commanded current (DAC input). This scaling factor FFGAIN is non-linear, i.e., different chop throws require different gain factors to achieve a correct end position.
- The circuitry that drives the mirror imposes and offset current which means that the BSM rest position (position where the chop/jiggle motorcurrents are zero) does not correspond to the zero chop/jiggle target positions (0x8000).

These two factors have to be adjusted/corrected respectively before the PID optimization is attempted.

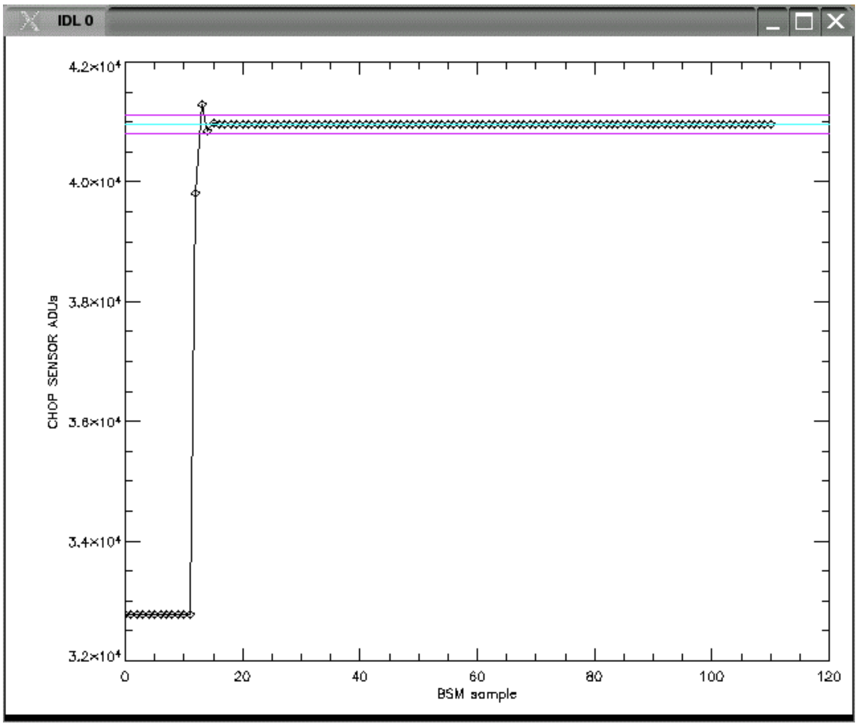
RESULTS:

In order to search for the 'best' set of PID parameter the BSM was operated using its own test mode were the mechanism chops continuously between the target position 0x8000(32768) and a given target position either side at a frequency of 0.5 Hz.

Due to the several problems encountered on the process of tuning the chop axis (related to the two facts explained above) the tuning of jiggle axis was never actually attempted.

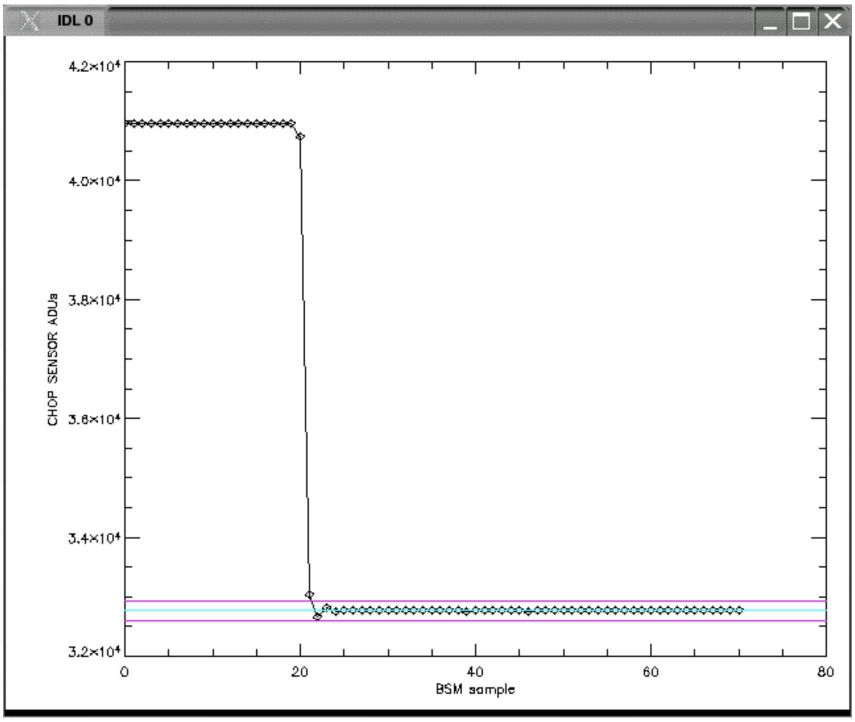
Settling time (chop axis): During the PFM2 test campaign several attempts were carried out to try to find a set of PID parameters that meet the requirement on settling time but none of them actually achieved the settling time specified ? t_{settle} < 20ms. The best settling time achieved in chop axis was ~24ms (during a test carried out on the 15th September 2005).

The following pictures show close ups on the 'step up/down' while the BSM is chopping.



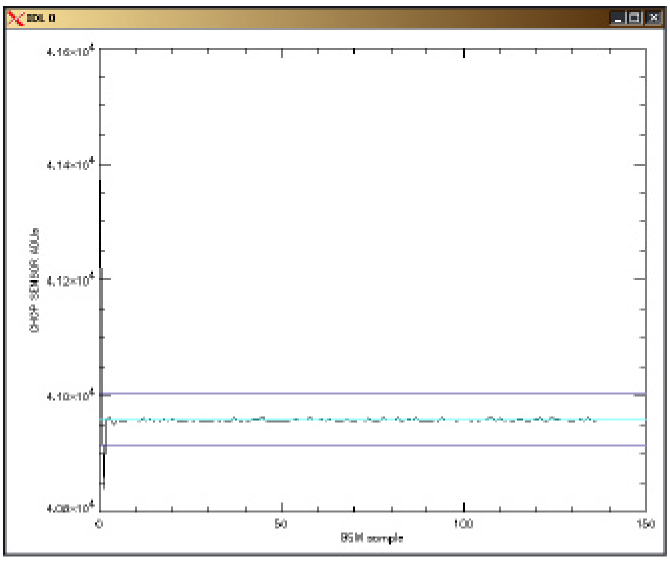
This figure shows the chop magneto resistive sensor signal on a 'step up' where the target position is shown in cian and a 1 arcsec band is also included to check the settling time. The BSM samples (diamonds) are 8 ms apart (125 Hz BSM sampling).

It can be seen that we require at least three samples (= 24 ms) to be within the 1" band.

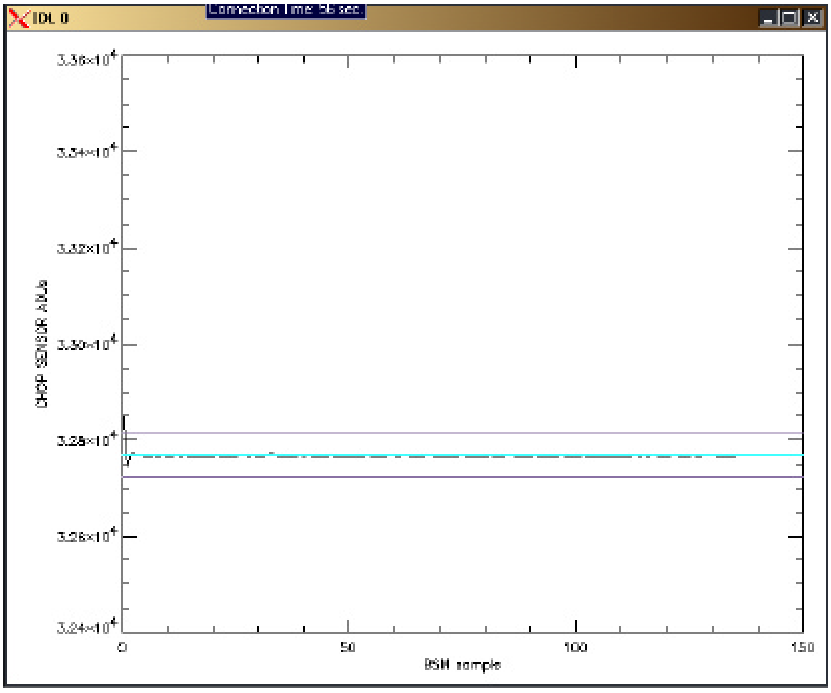


This figure shows the chop magneto resistive sensor signal on a 'step down' where the target position is shown in cian and a 1 arcsec band is also included to check the settling time. The BSM samples (diamonds) are 8 ms apart (125 Hz BSM sampling). It can be seen that we require at least three samples (=24 ms) to be within the 1" band.

Stability (chop axis): A close up on the different target positions to check the stability requirement. In both graphs, the band is the 0.2 rms arcsec stability band:



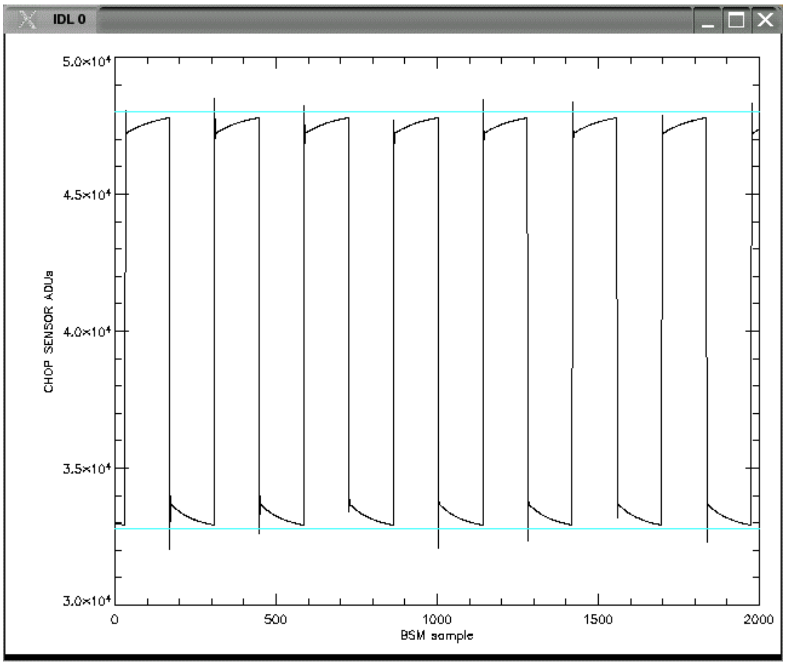
Close up on the target position 40960



Close up on the target position 32768

The stability requirement was achieved on the chop axis although the settling time requirement was not met.

A different chop throw: The effect of changing the chop throw can be clearly seen in the next picture where the position to be reached was incremented:



Here the previous feed forward gain we do not event reach the target position and the integral effect is dragging the mechanism to reach the desired position. Therefore a change in FFGAIN is required.