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Spectrometer Calibrator (SCal) Performance in PFM 1

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Contents

1. Introduction and scope

This document summarises the performance of the flight model Spectrometer Calibration source (SCal) within the SPIRE PFM FPU. The majority of test results discussed are derived from the PFM1 test campaign.

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

The following tables list SCal requirements in the Instrument Requirements Document [1].

IRD-CALS-R01	Radiated spectrum:	Design Analysis Instrument level performance tests	PFMI	ILT_PERF	IRD-SPEC-R17
IRD-CALS-R03	Adjustability:	Design Analysis Instrument level performance tests	PFMI	ILT_CFT ILT_PERF	
IRD-CALS-R04	Uniformity	Design Analysis Instrument level performance tests	PFMI	ILT_PERF	
IRD-CALS-R05	Repeatability and drift	Design Analysis Instrument level performance tests	PFMI	ILT_PERF	
IRD-CALS-R06	Operation	Design Analysis Instrument level performance tests	PFMI	ILT_OPS	
IRD-CALS-R07	Number of operations	Design Analysis Subsystem acceptance data package	N/A	N/A	IRD-SUBS-R02
IRD-CALS-R09	Power dissipation in the focal plane	Design Analysis Instrument level cold functional test Instrument level operations tests	PFMI	ILT_CFT ILT_OPS	IID-B-SECT5.9.1
IRD-CALS-R13	Operating Temperature	Design Analysis Instrument level cold functional test	CQM PFMI	ILT_CFT	
IRD-CALS-R16	Time response	Design Analysis Instrument level thermal verification Instrument level performance test	PFMI	ILT_THER ILT_PERF	
IRD-CALS-R12	Thermal Isolation	Design Analysis Instrument level thermal verification Instrument level cold functional test	CQM PFMI	ILT_THER ILT_CFT	

Discussion of requirements.

CALS-R01 (radiated spectrum): *Null the central maximum to accuracy of 5% (goal 2%) Replicate the dilute spectrum of the telescope to an accuracy of better than 20% (goal 5%) over 200 - 400 mm.*

The dynamic range is set by the intensity of the central maximum of the interferogram, which is in turn determined by the difference in the total power received from the two ports. The origin of this requirement is that in order to carry out low-resolution spectrophotometry with SPIRE, the central maximum must be nulled to a high level to prevent phase errors associated with inadequate sampling from affecting the spectrum.

Besides reducing the dynamic range, it is also desirable that the spectrum of the calibrator be identical or nearly identical to that of the telescope. Ideally they will be the same, resulting in a null interferogram when viewing blank sky. The requirement covers the range 200-400 μm, which at the time when the requirements were formulated was the prime band for the FTS. Nulling over the 400 - 670 μm range should be as good as possible but is not the subject of a specific requirement.

CALS-R03 (adjustability): *Zero - maximum in 256 step.*

In the design and modelling of the SPIRE instrument, the telescope has been assumed to be at 80 K and to have an effective emissivity of 0.04. These values are both uncertain. The temperature is expected to be in the range 60-80 K. The emissivity is subject to much larger uncertainty - it could easily be a factor of two lower or higher - and the value will not be known for sure until after launch. SCal must therefore be adjustable in order to provide the required nulling and spectral matching over a wide range of conditions.

CALS-R04 (uniformity): *The uniformity of the intensity from the cal. source across the field image at the detector shall be better than 5%*

As the SCal sources are located at a pupil, the detectors should view all parts of SCal with the same angular distribution. This requirement cannot be verified at unit level.

CALS-R05 (repeatability and drift): *The output intensity of the calibration source shall drift by no more than 1% over one hour of continuous operation. The absolute change in the output intensity of the source shall be no more than 15% over the mission lifetime*

A typical long integration with the FTS may comprise a sequence of interferograms (each taking around one minute), repeated for an hour or more. It is important that the power received from the calibrator does not vary significantly on the timescale of an observation.

The in-orbit telescope temperature and emissivity are not expected to change significantly even on timescales of months. It is envisaged that the optimum settings for SCal will be determined empirically early in the mission and should need only occasional checking and adjustment. A calibrator output drift less than 15% over the mission lifetime means that only occasional re-adjustment of the calibrator excitation levels will be needed.

CALS-R06 (operation): *SCal must be capable of operation for periods of up to two hours with no loss of operational performance.*

CALS-R07 (number of operations): *The calibration source shall be capable of up to 12,000 operational cycles.*

The maximum number of cycles envisaged in flight is around 4,300. A waiver was accepted on life testing due to the time required to carry out 12,000 cycles (~20 minutes per cycle), such that the life test model was tested to 4,500 cycles for qualification purposes.

CALS-R08 (transient response): *SCal should take no longer than 30 minutes (15 goal) to heat to operating temperature from 4 K, and no more than 3 hrs (30 min. goal) to cool from operating temperature to 4 K.*

To minimise set-up time, it is desirable that SCal can be warmed up or cooled down as quickly as possible. The envisaged operational scenario for Herschel and SPIRE involves each instrument being operated for substantial periods of time (e.g., one cooler cycle - equivalent to 48 hrs). During such a period when SPIRE is operating, the FTS or photometer are also likely to be used continuously for long periods of time (typically hours). The warm-up and cool-down time should therefore be on the order of minutes or tens of minutes. There is a trade-off here between stability (requiring a long time constant) and short warm-up time (requiring a short time constant).

Note that when SCal is switched off to allow change-over from SPIRE FTS to photometer operation, there will be a settling time of at least 15 minutes associated with the JFETs, and in any case SCal cannot be viewed by the photometer detectors. It should therefore be possible to start photometer operation as soon as the JFETs are warmed up without any delay imposed by SCal cool-down.

CALS-R10 (power dissipation in the focal plane): *Shall be within the specification given in the systems budget document*

SCal will be powered up continuously while the FTS is operating, and its dissipation will load the Level-1 stage, the temperature of which is to a large extent determined by the total FPU dissipation. It is important that this load be as small as possible to avoid the Level-1 temperature being raised too much (and to maximise the Herschel lifetime).

CALS-R12 (thermal isolation): *The temperature of the SCal housing and surrounding structure shall rise by no more than 1 K over the temperature of the FPU structure after one hour of continuous operation. To ensure that this requirement can be met, provision shall be made for a direct thermal strap from the SCal housing to the SPIRE optical bench*

When SCal is switched on, almost all of the electrical power will be conducted to the SCal mounting (only a tiny fraction is actually radiated by the device). The rise in temperature of the environment must be small to avoid changes in the radiated power by the structure affecting the overall sensitivity of the system. The mounting and FPU structure must thus be designed to be able to conduct efficiently this power into the Herschel cryostat 4-K strap. In case it proves necessary, the SCal housing and the SPIRE optical Bench must be equipped with appropriate lugs to allow a direct thermal strap to be fitted.

CALS-R12 (operating temperature): *< 6 K.*

The SOB temperature determines the nominal temperature of the SCal housing. The current SPIRE thermal model predicts that this should be about 5 K. In practice this temperature could rise by one or two degrees depending on the total power dissipation of the SPIRE FPU. This will have no significant impact on the operation of SCal.

3. Test results and conclusions

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

During PFM 1, tests were carried out to evaluate the SCal thermal performance: time constant and achieved equilibrium temperature vs. applied power, and the spectral performance of the system: ability to null the background spectrum with SCal.

3.1.1 SCal thermal performance tests

These tests were specified in [2]. Tests were performed on 9 and 10 March 2005. Note that the procedure was not followed fully due to time constraints, and a sub-set of the tests was performed.

A variety of constant current levels were applied to the SCal 2% source, and the resulting warm-up curves were recorded. This was then repeated for the 4% source, and the results are listed below. A typical warm-up curve is shown in Figure 1.

2% source			
Drive current (mA)	Power dissipation (mW)	Equilibrium temperature (K)	Stabilisation time (minutes)
0.22	0.024	12.98	12
0.451	0.102	24.01	27.2*
0.702	0.246	32.7	35.2*

4% source			
Drive current (mA)	Power dissipation (mW)	Equilibrium temperature (K)	Stabilisation time (minutes)
0.22	0.024	12.42	20
0.75	0.283	38.04	54.4*
1.1	0.607	56.3	60**

* Time to stabilise, starting from previous temperature level in the list.
** A "first guess" attempt at a rapid warm-up was attempted - see Figure 2. At time 16.40, 2.5 mA was applied for 30 seconds, after which point the current was reduced to 1.1 mA. The temperature overshot the equilibrium level and took around an hour to stabilise passively.

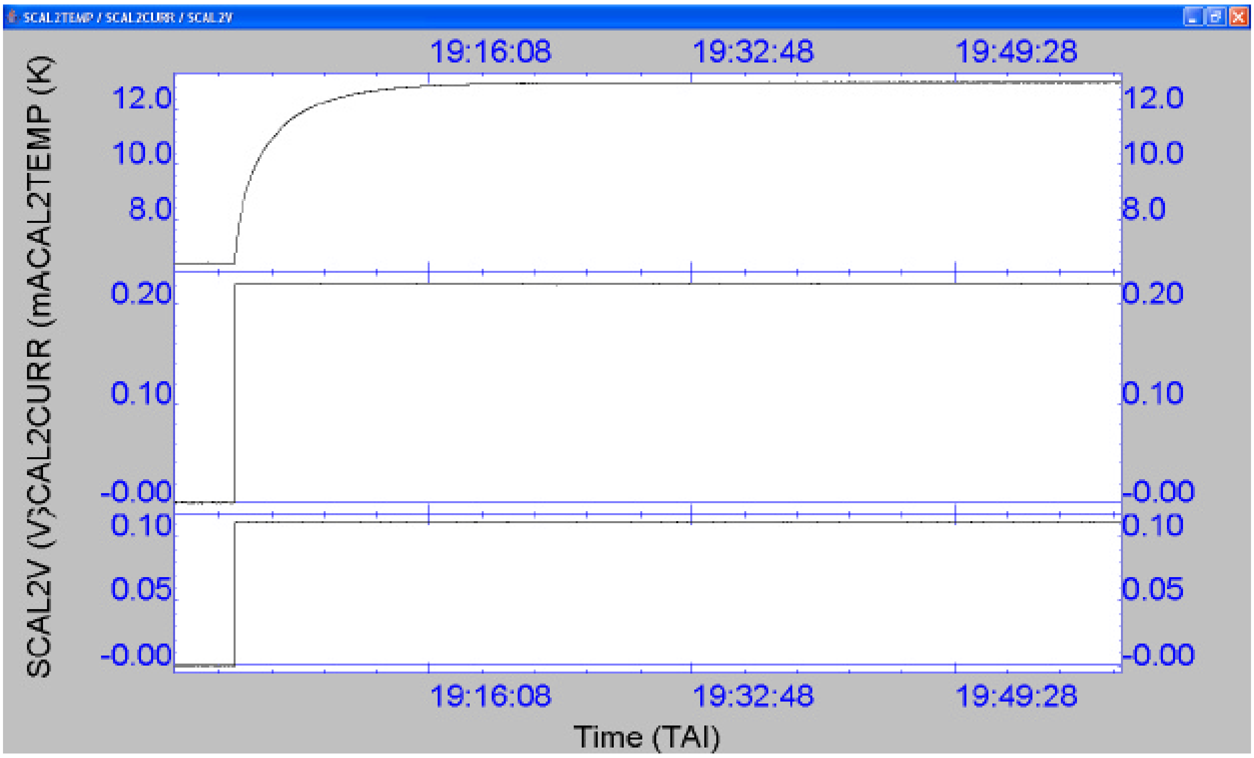


Figure 1 Warm-up curve for SCal 2% source, 0.22 mA applied.

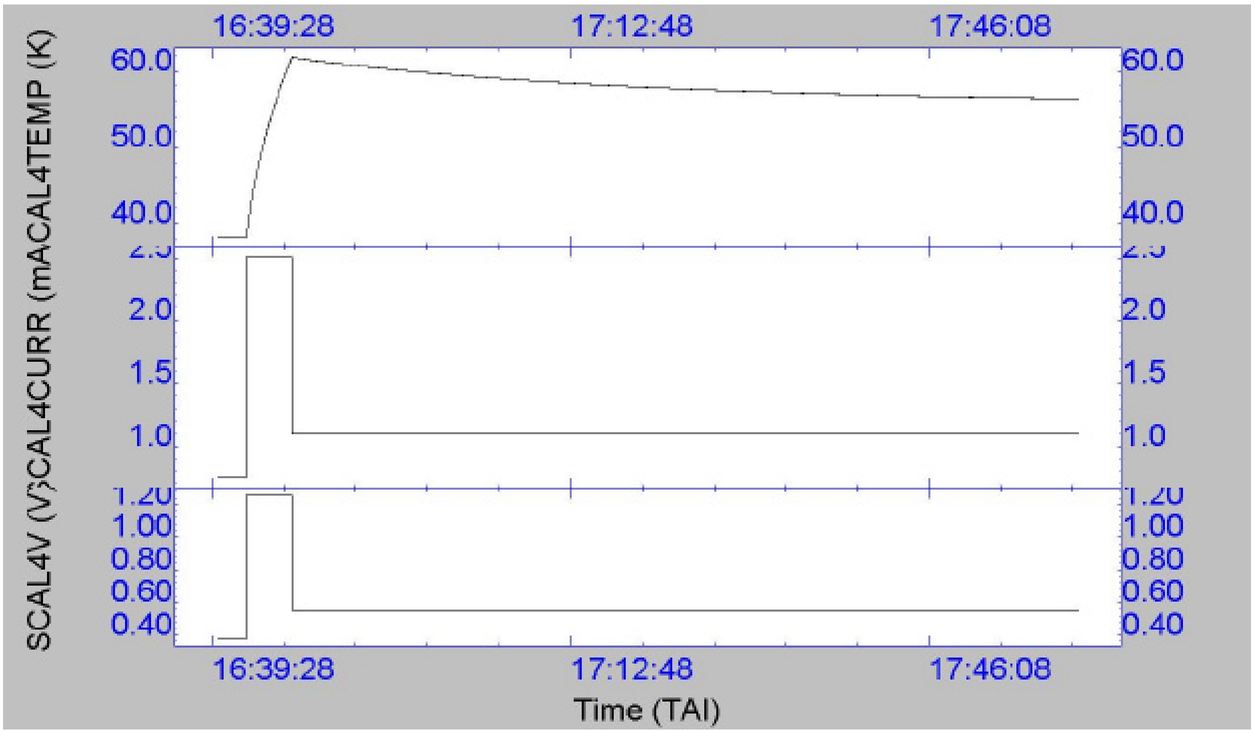


Figure 2 Manual attempt at rapid warm-up.

Conclusions

There is good consistency between the SCal instrument-level tests and the unit-level tests. There is a small difference in the temperature vs. applied power calibration due to the different base temperature in the instrument, compared to the unit-level test cryostat, as expected.

It will be important to obtain a good set of warming/cooling transients for each source early in the PFM3 campaign in order that we can implement and test software PID control parameters.

3.1.2 SCal nulling tests

Tests were performed on 24 and 31 March 2005. For test details, see SPIRE-RAL-NOT-002211 *PFM1 performance test details*.

Again, due to time constraints, the test procedure listed above was not carried out in full (the SCal sources have long time constants). So instead, the actual procedure followed was as follows:

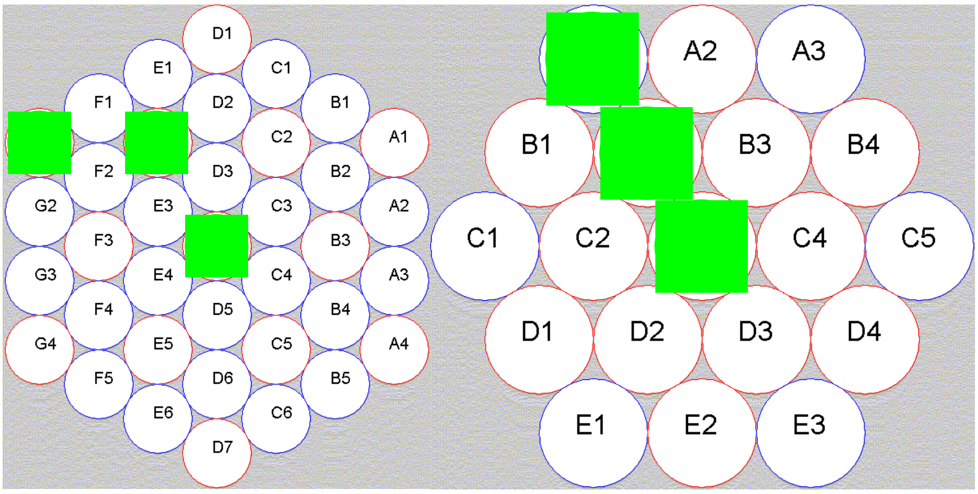
- Detectors set to nominal bias parameters, and operating temperature.
- SPIRE viewing cold black-body source
- SCal 4% source temperature stable at 24.5 K, 2% source at 5 K
- Medium resolution FTS scans carried out for a variety of CBB plate temperatures in the range 6.4 K to 17 K
- This procedure was repeated for the 2% source, with a 2% source temperature of 27.4 K

The data analysed for SCal 4% nulling using the CBB were taken on 24 March between the times of 17:15-22:30 (UTC), p144-150 of the log. SCal 4 @ 24.5 K, SCal 2 @ 5 K.

The data analysed for SCal 2% nulling using the CBB were taken on 31 March between the times of 18:40-21:30 (UTC), p188-192 of the log. SCal 2 @ 27.44 K, SCal 4 @ 5 K.

Data from three pixels in each array were analysed, as shown in the table and diagram below.

Array	SSW	SLW
Central pixel	D4	C3
Mid-way pixel	E2	B2
Peripheral pixel	G1	A1



For each CBB temperature, the baseline and the value of the central maximum peak were measured for a series of 10 medium-resolution scans (where available) to obtain good averages. The response was characterised as baseline – peak. Typical scans are shown in Fig. 3.

Typical measurement errors were: $\Delta T_{CBB} = 0.05$ K; $\Delta V_{Resopnse} = 0.003$ mV

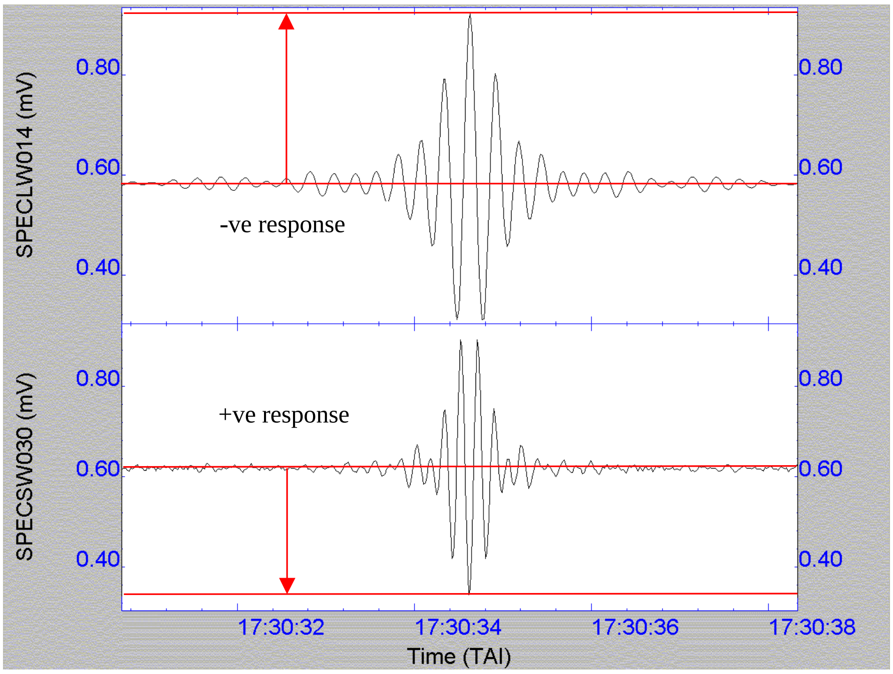


Figure 3 Typical medium-resolution scan from SCal/CBB nulling test.

The central maximum height for each detector was plotted as a function of CBB temperature, and the CBB temperature at which the central maximum reduces to zero was derived. An example is shown in Figure 4 and the results are summarised in Table 1.

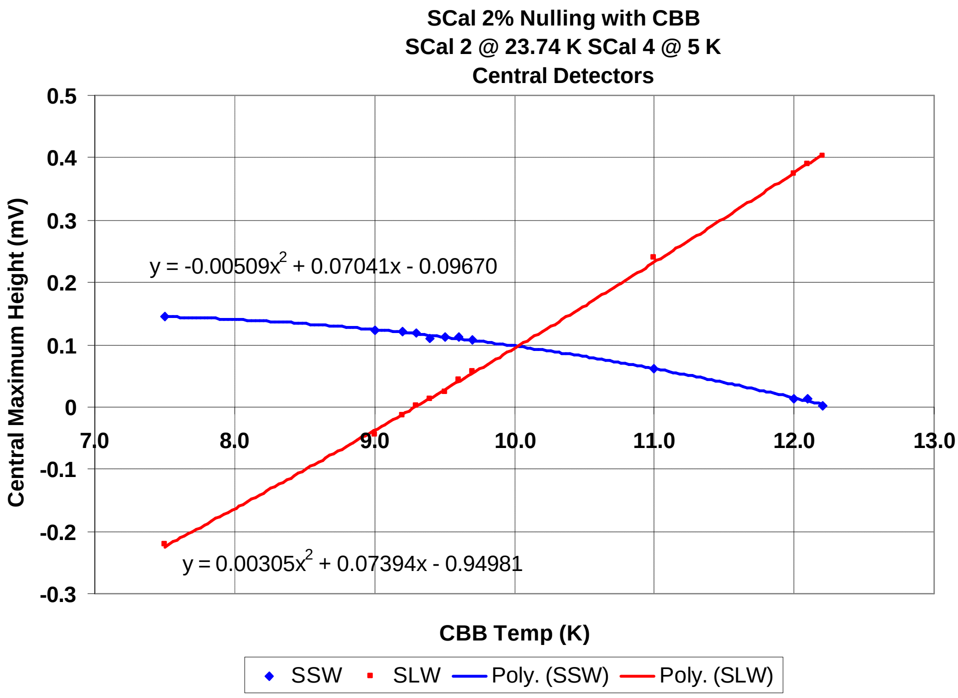


Figure 4 Central maximum height vs CBB temperature for 2% source at 23.74K. Pixels D4 (SSW) and C3 (SLW) shown.

Table 1 CBB temperatures needed to achieve nulling.

	SSW			SLW		
	Central D4	Mid-way E2	Peripheral G1	Central C3	Mid-way B2	Peripheral A1
SCal 4% @ 24.5 K	14.7	15.5	13.8	11.2	11.0	8.9
SCal 2% @ 27.44 K	12.3	12.2	11.0	9.3	9.3	9.6

The estimated nulling temperature error is 0.1 K

A photometric model has been produced which produces good agreement with these observations, as shown in Table 2 and Figure 5.

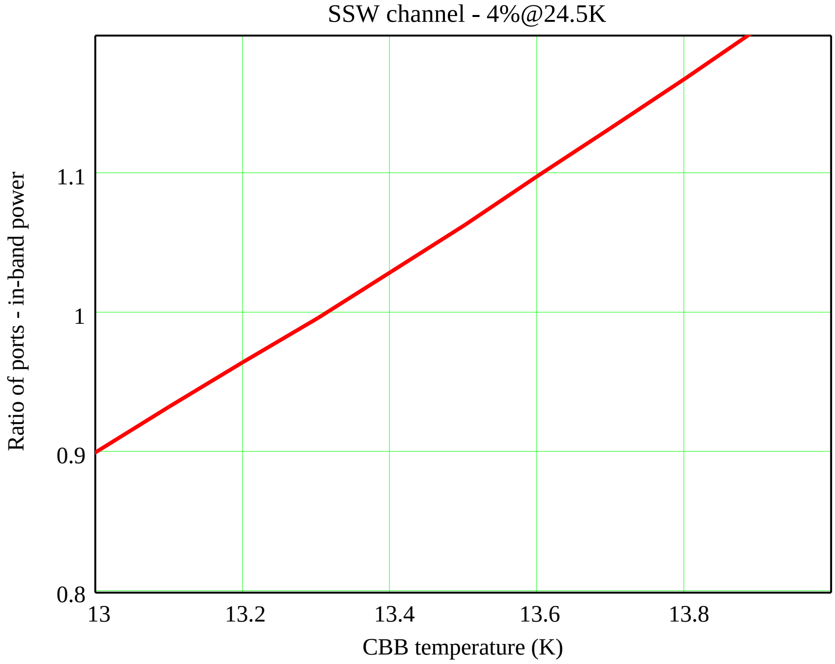


Figure 5 Example output from photometric model showing the ratio of in-band power at each spectrometer port as a function of CBB temperature, for a certain source temperature.

Table 2 Comparison of results in Table 1 with photometric model.

	Band	CBB temperature for power match (K)	
		Experiment (+/- 0.1) (central / peripheral)	Model
4% source @ 24.5K	SSW	14.7 / 13.8	13.31
	SLW	11.2 / 8.9	10.72
2% source @ 23.77K	SSW	12.3	10.61
	SLW	9.3	8.24

3.2 Subsystem requirements tested at instrument level and their verification status

CALS-R03 (adjustability): The SCal drive has been implemented as a current source with 12-bit resolution, giving a total of 4096 steps between zero and the maximum designed level. This gives at least 3000 steps over the maximum envisaged working range, and easily meets the requirement.

CALS-R04 (uniformity): Load curves were taken for all detectors under different conditions (CBB and source temperatures, FTS mechanism in “home” position, away from ZPD). Analysis of these data is in progress. Phase corrections etc. will need to be taken into account, but should be a small correction.

CALS-R05 (repeatability and drift): The temperature of each source is very stable once operating temperature is reached. This requirement is also on the warm electronics drive. No change in source temperature was noted (to within 2 mK) for each source held at operating temperature for several periods of eight hours or more, with the instrument in a stable temperature condition. The requirement on the lifetime change in intensity could only be verified at unit level. This requirement was verified at unit level: the life test model of SCal displayed no change in temperature at the conclusion of 4500 full-power cycles. It is assumed that the emissivity of the black coating does not change significantly over the lifetime of the mission.

CALS-R06 (operation): This requirement is easily met, as noted above.

CALS-R07 (number of operations): This requirement was verified at unit level.

CALS-R08 (transient response): The time responses listed in section 3.1.1 are in response to a constant current drive level. For this situation, the warm-up transient requirements are met for source temperatures below ~30 K. However, nominal telescope parameters (80 K, 4% emissivity) imply a required 2% source temperature of 88 K (from the photometric model), and unit-level tests indicate a warm-up transient (for constant current level) of around 45 minutes. Software PID control of the SCal sources will be implemented to reduce the warm-up times, and this will be tested during the next test campaign.

CALS-R10 (power dissipation in the focal plane): Instrument-level temperature vs. applied power results for SCal are in good agreement with unit level testing. Unit-level tests indicate a power dissipation of 2.4 mW while the 2% is at 88 K, in order to null the nominal telescope. This meets the requirement.

CALS-R12 (thermal isolation): Over a period on 90 minutes with the 4% source at 57 K, the SCal structure and interface temperature rose by only 8 mK. This meets the requirement.

CALS-R12 (operating temperature): SCal is compatible with operation below 6 K by design.

3.3 Instrument-level requirements and their verification status.

CALS-R01 (radiated spectrum): Ability to null the central maximum for a variety of CBB temperatures was demonstrated at instrument level. This gave a different CBB temperature for optimal nulling for each spectrometer channel. This is to be expected due to the disparity in the spectral shapes of the sources used in each of the input ports, and was easily modeled. The ability to null the nominal telescope has only been demonstrated thus far by analysis. This analysis also shows the ability to match the dilute spectrum of the telescope to within 5% over 200-400 μm.

However, difficulty was experienced in nulling the spectrum from the room (i.e. when SPIRE was viewing the test lab. through the filters and cryostat window. This could point to problems with the test facility ND filtering, and/or problems with extra modes coupling into the spectrometer detectors. See document SVR9 for an assessment of this issue.

4. Open issues and anomalies

- Investigation of test facility background levels and ND filtering.
- Investigation of mode coupling into spectrometer detectors (see SVR9 and 11).

5. Recommendations for further data analysis and test

- Instrument-level calibration of SCal warming & cooling curves.
    - Verification of temperature vs. power calibration
    - Verification of cooling transients
    - Refinement of PID parameters
- Testing of PID loop
- Nulling test for representative telescope spectrum at sky port.
- Analysis of spectrometer detector load curves to verify uniformity requirement.

6. Summary

Requirement		Verification status
IRD-CALS-R01	Radiated spectrum:	Power matching verified for limited range of conditions. Spectral matching difficult to verify at instrument level, but demonstrated for nominal telescope parameters by analysis
IRD-CALS-R03	Adjustability:	By design, and verified in instrument.
IRD-CALS-R04	Uniformity	Analysis of test data in progress.
IRD-CALS-R05	Repeatability and drift	Verified by instrument and unit level tests.
IRD-CALS-R06	Operation	Verified by instrument and unit level tests.
IRD-CALS-R07	Number of operations	Verified by instrument and unit level tests.
IRD-CALS-R09	Power dissipation in the focal plane	Verified by instrument and unit level tests.
IRD-CALS-R13	Operating Temperature	Verified by instrument and unit level tests.
IRD-CALS-R16	Time response	Verified for non-optimal drive sequence up to 30K. PID control will be implemented and verified in the next test campaign. Cooling transients need to be verified.
IRD-CALS-R12	Thermal Isolation	Verified by instrument and unit level tests.

7. References

[1] SCal B calibration report - HSO-CDF-RP-080
[2] SCal operating procedure – PFM1 test campaign - HSO-CDF-PR-115
[3] PFM1 performance test details - SPIRE-RAL-NOT-002211
[4] “Assembly, integration and test record – PFM1”. RAL electronic log-book.
[5] Instrument Requirements Document - SPIRE-RAL-PRJ-000034