SPIRE Science Verification Review

RAL

January 26, 27 2005

Photometer Calibrator (PCal) Performance in PFM2

Document Number: SPIRE-UCF-REP-002567

Tim Waskett
Pete Hargrave

16 Jan 2006

Contents

1. Introduction and scope

This document describes the performance of the Photometer Calibrator source (PCal) as implemented within the SPIRE FPU.

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

The following tables list PCal requirements in the Instrument Requirements Document [1]. Requirements investigated in this document are indicated in **boldface** in the table

Requirement Name	Description	Verification Method	Model	Test ID	Upper Links
IRD-CALP-R01	Nominal operating output	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	
IRD-CALP-R02	Operating range	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	
IRD-CALP-R03	Equivalent obscuration of aperture through BSM mirror	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	
IRD-CALP-R04	Speed of response	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	
IRD-CALP-R05	Repeatability	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_PERF	
IRD-CALP-R06	Operation	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_OPS	
IRD-CALP-R07	Frequency	Design Analysis Instrument level performance tests	CQM PFMI PFMII	ILT_OPS	
IRD-CALP-R11	Operating temperature	Design Analysis Instrument level cold functional test	CQM PFMI PFMII	ILT_CFT	
IRD-CALP-R12	Cold power dissipation	Design Analysis Instrument level cold functional test Instrument level operations tests	CQM PFMI PFMII	ILT_CFT ILT_OPS	IID-B-SECT5.9.1
IRD-CALP-R16	Lifetime	Sub-system verification programme	N/A		IRD-SUBS-R02

Additional instrument requirements tested by PCal, also listed in [1].

Requirement Name	Description	Verification Method	Model	Test ID	Upper Links
IRD-OPTP-R05	Throughput	Design Analysis Instrument level performance tests	AM CQM PFMI PFMII	ILT_ALIGN ILT_PERF	IRD-PHOT-R04 IRD-PHOT-R05

- **IRD-CALP-R01:** The area:surface brightness product of the calibrator aperture shall be ≥ 1% of the area:surface brightness product of the telescope image at the position of M4 (with an assumed telescope temperature of 80 K and emissivity of 4%) for $200 < \lambda < 700$ μm.
    - This is defined by requiring that the signal to noise of PCal is 500 in 1 s integration (with nominal detector sensitivity). This can then be converted into an absorbed power at the arrays (PSW: 0.061, PMW: 0.05, PLW: 0.045 pW) by assuming nominal detector parameters. See [2] for a full derivation.

- **IRD-CALP-R04:** In response to a step change in applied electrical power, the 90% settling time of the radiant power output shall be less than 350 ms (requirement); 70 ms (goal).

- **IRD-CALP-R05 a:** RMS of output signal better than 1% over 20 cycles on to off during a calibration operation of less than 2 minutes.

- **IRD-CALP-R05 b:** Repeatability of signal 1% for 12 calibration operations equi-spaced over a period of 12 hours, with uniform base temperature and drive current.

- **IRD-CALP-R012:** Photometer Calibrator maximum power dissipation in the FPU when operating continuously at nominal radiant output: 4 mW (requirement), 2 mW (goal).

- **IRD-OPTP-R05:** The throughput of the photometer mirrors, filters, dichroics and baffles shall be greater than 0.27 over the instrument waveband. This includes losses due to manufacturing defects; surface finish and alignment tolerances.

- Uniformity of the illumination of the three photometer arrays provided by PCal. Illumination should be as uniform as possible.

All other requirements are met at subsystem level and either do not require verification, or are not appropriate for verification in this document.

3. Test results and conclusions

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

For PFM2 the standard PCal flash sequence consisted of 15 cycles performed at 0.25 Hz (i.e., 2 s off, 2 s on etc.), with low-high levels of 0 - 3.8 mA applied current (equating to 0 - 2.9 mW). When viewing the room, rather than the CBB, the high level was increased to 4.8 mA (4.6 mW) due to under-biasing of the detectors under the higher optical loading.

Full photometer data were acquired during the flash sequence under nominal detector settings.

No further tests are required.

3.2 Subsystem requirements tested at instrument level and their verification status

- **IRD-CALP-R04**

The detectors measure a 90% rise time of ~130 ms, which is a combination of the PCal response with the detector response. The detector response was affected during the PFM2 campaign by a He leak causing build-up of superfluid helium on the detectors, affecting the heat capacity. In any event, the PCal response is faster than this upper limit. The requirement of 350 ms is thus comfortably met while the 70 ms goal is not far off once the detector response is taken into consideration.

These results are consistent with the unit level tests using a photoconductive detector which demonstrated a 90% rise time of 90 ms, and a fall time of 50 ms.

- **IRD-CALP-R05 a**

The RMS variation of 15 flash cycles (lasting 60 s in total) is ~ 0.1 %, so this requirement is easily met.

- **IRD-CALP-R05 b**

This requirement was impossible to verify under the test conditions due to the effects of the helium leak, which caused the response of the detectors to vary from test to test. However, this requirement was met at unit level.

- **IRD-CALP-R012**

For an applied current of 3.8 mA, which meets the signal/noise requirement (see below), the power dissipated is 2.90 mW, giving an average of 1.45 mW over the flash sequence, and much lower average dissipation over the mission. This level easily satisfies the requirement IRD-CALP-R01.

The BSM temperatures increased slightly during a sequence of PCal flashes (see appendix for plots of BSM temperatures). However, even at the higher flash power of 4.64 mW the average increase was only 60 mK, which will have a negligible effect on the background optical loading from the BSM.

3.3 Instrument-level requirements and their verification status

- **IRD-CALP-R01**

The requirement for a PCal signal to noise of 500 in 1 s integration depends not only on the output of PCal but also on the performance of the detectors themselves and the throughput of the optical chain. To limit the number of variables in this analysis we assume that the detectors have nominal performance and that the optical chain behaves as expected (see IRD-OPTP-R05). This reduces the requirement to just the absorbed power measured at the photometer arrays.

A standard PCal flash sequence was analysed to obtain the voltage difference between the on and off PCal illumination levels (*dV*). A corresponding load curve – taken immediately prior to the PCal flash sequence – provided the responsivities (*S*) of the detectors under the relevant conditions, which is used to convert the *dV* into an absorbed power *dP*:

$$dP = \frac{dV}{S}$$

The following table summarises the results for a PCal flash performed with the arrays viewing the CBB, which was switched off (OBSID: 0x3000C194). Absorbed power for several pixels is shown due to the high degree of non-uniformity (see appendix for PCal illumination patterns for all three arrays). **Boldface** indicates failure to meet the requirements.

CBB off	Absorbed power *dP* (pW)			
	Central pixel	Brightest pixel	Faintest pixel	Requirement
PSW	0.106	0.193	**0.057**	0.061
PMW	0.067	0.079	**0.017**	0.050
PLW	0.088	0.166	**0.025**	0.045

The average power dissipation of 1.45 mW is well below the maximum allowed, so if higher signal to noise were required over a larger fraction of the detectors then PCal could be run at a higher power if necessary.

The next table shows results for a PCal flash performed with the arrays viewing the CBB switched on and running at 13.2 K (OBSID: 0x3000C19E).

CBB @ 13.2 K	Absorbed power *dP* (pW)			
	Central pixel	Brightest pixel	Faintest pixel	Requirement
PSW	0.117	0.215	0.063	0.061
PMW	0.073	0.087	**0.019**	0.050
PLW	0.095	0.180	**0.027**	0.045

The absorbed power step is similar under both conditions, although with the CBB at 13.2 K it is systematically higher by ~10%. This is likely due to uncertainties in the calculation of the responsivities used to convert the voltage difference into absorbed power: the load curves showed anomalous behaviour – possibly due to the He leak – and so modelling of the bolometers may not be accurate. In general, the requirement is met for most of the detectors in all three arrays.

- **IRD-OPTP-R05 – Throughput**

This requirement is to be verified separately (see document SVR9), but an independent check can be derived using PCAL data, using PCAL as an absolute standard source.

A photometric model has been used to predict the incident power in each band. This model incorporates the real instrument filter transmissions, as indicated in Figure 1, and the PCal unit level photometric calibration data.

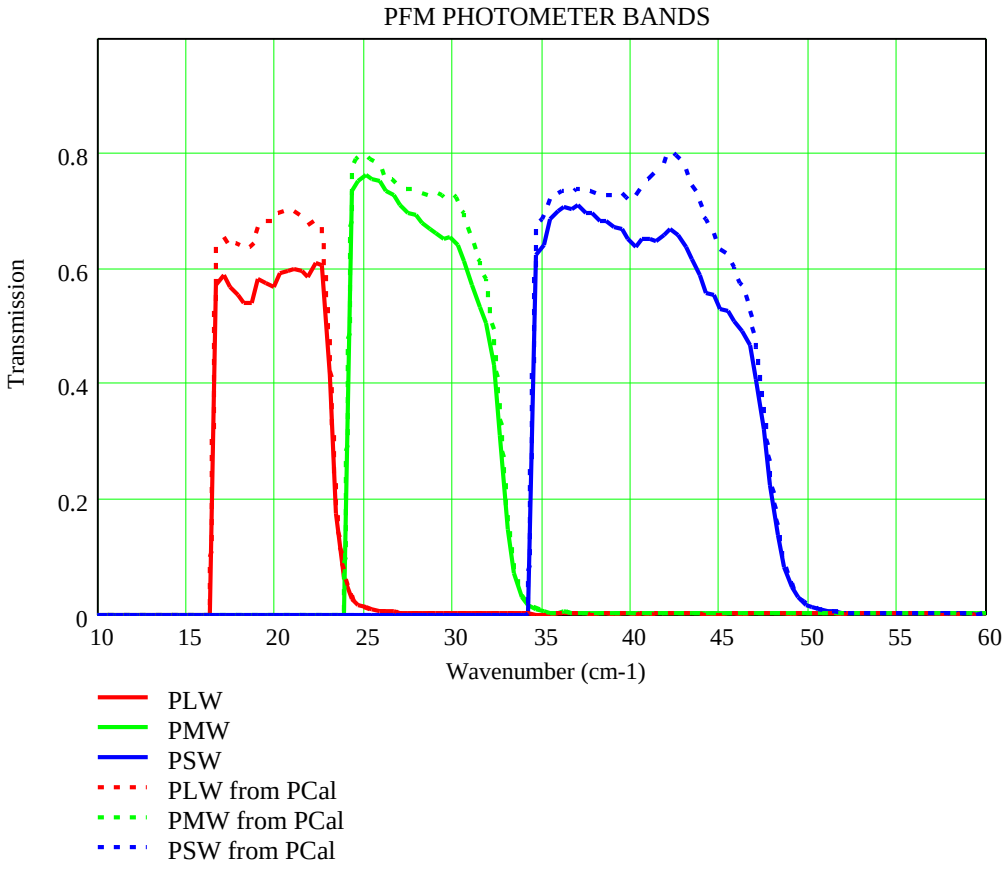


Figure 1 Photometer bands as defined by instrument filters and dichroics. Dashed lines indicate overall instrument transmission, and solid lines indicate transmission from PCal to the detectors.

The model has been used to estimate the incident power in each band for a PCal "Standard flash" (2.9 mW pulse). The resultant predicted powers in each band are:

- PSW – 0.205 pW
- PMW – 0.197 pW
- PLW – 0.172 pW

When compared to the absorbed power estimates, measured from the load curves, the derived overall optical efficiencies are as shown below:-

CBB off	Optical efficiency from PCal data and Cardiff model			
	Central pixel	Brightest pixel	Faintest pixel	
PSW	51.7%	94.1%	27.8%	
PMW	34%	40.1%	8.6%	
PLW	51.2%	84.3%	14.5%	

The optical efficiencies of the above bolometers as measured by JPL are:

	Optical efficiencies		
	Central pixel	Brightest pixel	Faintest pixel
PSW	0.68	0.70	0.70
PMW	0.70	0.74	0.78
PLW	0.78	0.80	0.78

However, it should be noted that there are obvious problems with the load curves used in the above analysis due to the suspected helium contamination. The anomaly is greatest with the PMW data (possibly associated with the known anomalous behaviour of the interim dichroic). The analysis needs refinement and should be repeated in PFM3. But even with this brief analysis, there is reasonable agreement with the model.

- **Uniformity of illumination**

PCal is centrally located at a pupil in the BSM and so should illuminate the arrays uniformly. However, this is not the case, as can be seen from the illumination patterns in the appendix. The illumination is brightest towards one of the long edges of the arrays and the variation of incident power is more than a factor of six in the case of the PMW array. The same PCal flash illumination pattern is demonstrated under all conditions (background viewing the CBB or the room).

4. Open issues and anomalies

The illumination of the photometer arrays by PCal is not uniform and is not central. This anomaly of the optics should be investigated in PFM 3 testing. PCal measurements will be a useful diagnostic for this purpose.

The load curves analysed so far exhibit strange behaviour, and it is difficult to fit the bolometer model parameters reliably to these curves, even at the low bias end. This should also be addressed in the PFM3 test campaign.

Some aspects of PCal verification must be repeated in FM3 since the dichroics have been changed. This can be done by analysing the standard PCal flashes.

5. Recommendations for further data analysis and test

Standard PCal flashes will be performed regularly in any future test campaign.

6. References

[1] Instrument Requirements Document (SPIRE-RAL-PRJ-000034)

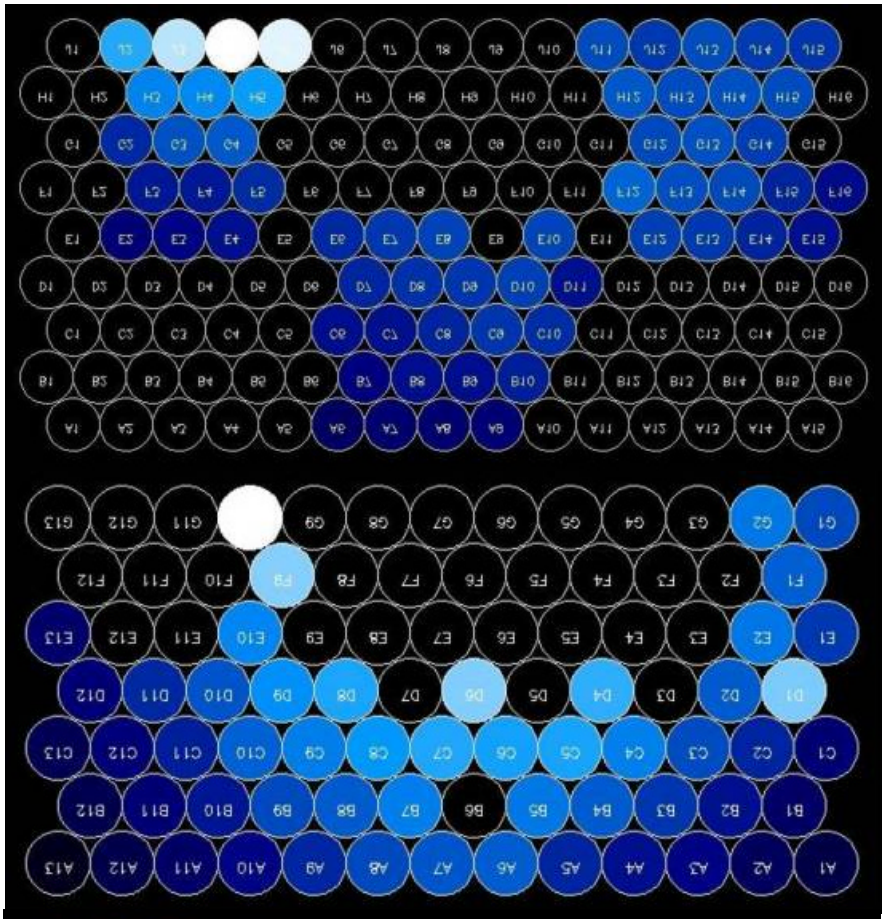
[2] Redefinition of the requirement on PCAL photometric output (HSO-CDF-ECR-116)

7. Appendix

7.1 Array illumination patterns

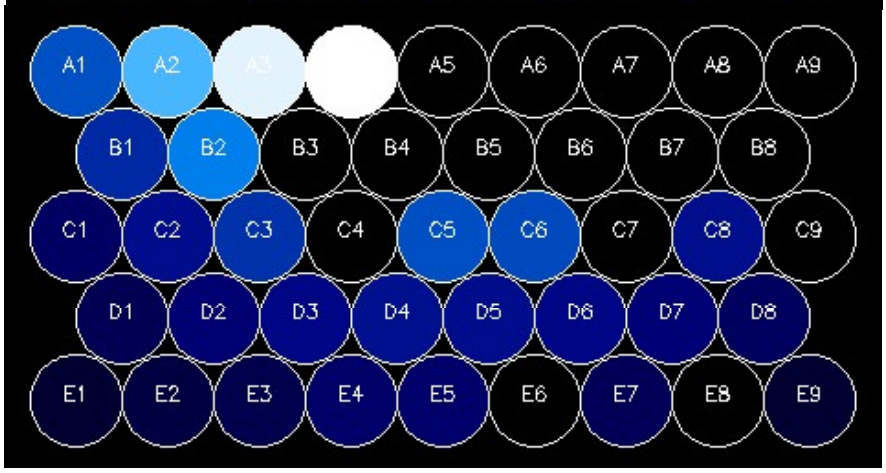
Linear colour scale (white: max, black: zero/unplugged pixel)

PSW



PMW

PLW



7.2 BSM temperature changes in response to PCal operation