SPIRE Science Verification Review

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Photometer Calibrator (PCal) Performance in PFM2 and PFM3

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1. Introduction and scope

This document describes the performance of the Photometer Calibrator source (PCal) as implemented within the SPIRE FPU. The analysis in this updated document refers to data taken during the PFM2 and PFM3 test campaign, with the main data sets noted where relevant. Updates from the PFM2 document are indicated by blue text.

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 < λ < 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 both PFM2 and PFM3 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 during PFM2 (this has not yet been measured for PFM3 but it looks similar), 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 during PFM2 due to the effects of the helium leak, which caused the response of the detectors to vary from test to test. During PFM3 the He leak problem was much reduced and PCal flashes demonstrated consistency throughout most of the campaign. The specific requirement (12 calibration operations equi-spaced over a period of 12 hours, with uniform base temperature and drive current) was not strictly tested but the consistency from test to test was at the few percent level. 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 PFM2 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 ratio (SNR) 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 (δV). 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 δV into an absorbed power δP:

$$\delta P = \frac{\delta V}{S}$$

The following table summarises the results for a PFM3 PCal flash performed with the arrays viewing the CBB, which was switched off (OBSID: 0x3000E279). Absorbed power for the brightest and central pixels is shown due to the high degree of non-uniformity (see appendix for PCal illumination patterns for all three arrays). Also shown are the fraction of detectors that fail to meet the requirements for each array. 'Effective absorbed power' is defined here as absorbed power * 0.7 / (detector optical efficiency), so that non-uniformities in detector optical efficiency are removed.

CBB off	Effective Absorbed power δP (pW)			
	Central pixel	Brightest pixel	Requirement	Fraction of failures
PSW	(E8) 0.106	(J4) 0.213	0.061	26/139
PMW	(D6) 0.092	(G10) 0.143	0.050	21/88
PLW	(C5) 0.095	(A3) 0.163	0.045	9/43

Equivalent analyses on PCal flashes performed under different optical loading gives results for absorbed power that are consistent with to within 5%. This repeatability gives us confidence that the results are robust.

In general, the requirement is met for most (~80%) of the detectors in all three arrays.

As an additional check on this requirement the achieved SNR was calculated for PCal flash sequence OBSID:0x3000E4A5, a flash taken under illumination from the CBB at a temperature of 14 K. This test was approximately representative of the expected in flight background optical loading (although the spectrum is different.) SNR is defined as:

$$SNR = \frac{\delta V}{\sigma} \cdot \sqrt{N_{samp}} \,,$$

where σ is the standard deviation of the data and N_{samp} is the number of data samples in 1 s.

Encouragingly, almost all detectors experienced a SNR in 1 s of over 500, bar a few exceptions. The second set of illumination patterns shown in the appendix illustrate the range of SNR experienced across the arrays.

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.

- **IRD-OPTP-R05 – Throughput**

This requirement is to be verified separately (see document **TBD**), 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.

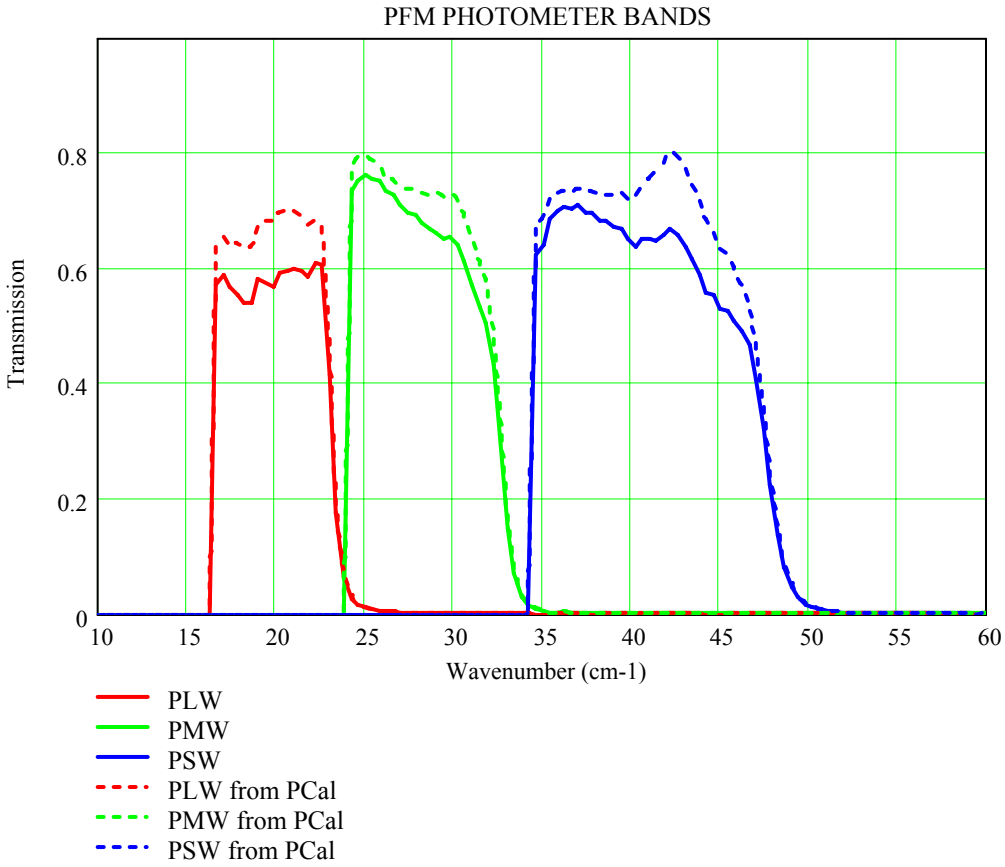


Figure 1 Photometer bands as defined by instrument filters and dichroics. Dashed lines indicate overall instrument transmission, and solid lines indicate transmission from PCal to the detectors.

The model has been used to estimate the incident power in each band for a PCal "Standard flash" (2.9 mW pulse), and then converted into absorbed power assuming a detector optical efficiency of 0.7. The resultant predicted absorbed 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 PCal flashes and 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
PSW	52%	104%
PMW	47%	73%
PLW	55%	95%

With this brief analysis, there is reasonable agreement with the model – assuming the most brightly illuminated detector corresponds to what we expect from PCal. The PMW array demonstrated a lower than expected absorbed power in PFM2 data, a factor of 2 lower than the other two arrays. Although the PMW array in this PFM3 data still shows a discrepancy it is much closer to the other arrays than during PFM2.

- **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 results in ~20% of the detectors falling below the required level. The same PCal flash illumination pattern is demonstrated under all conditions (e.g. 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 4 testing. PCal measurements will be a useful diagnostic for this purpose.

5. Recommendations for further data analysis and test

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

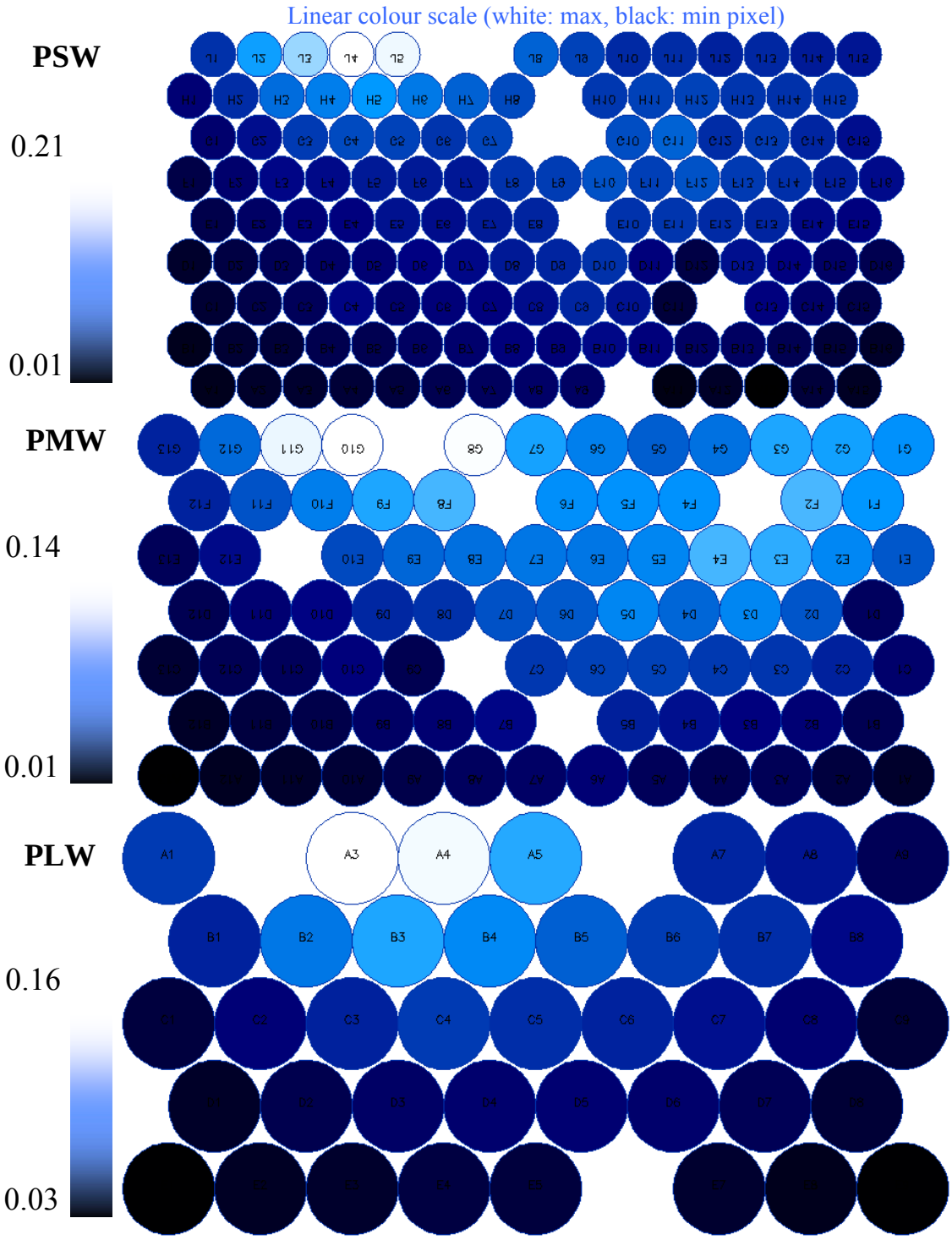
6. References

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

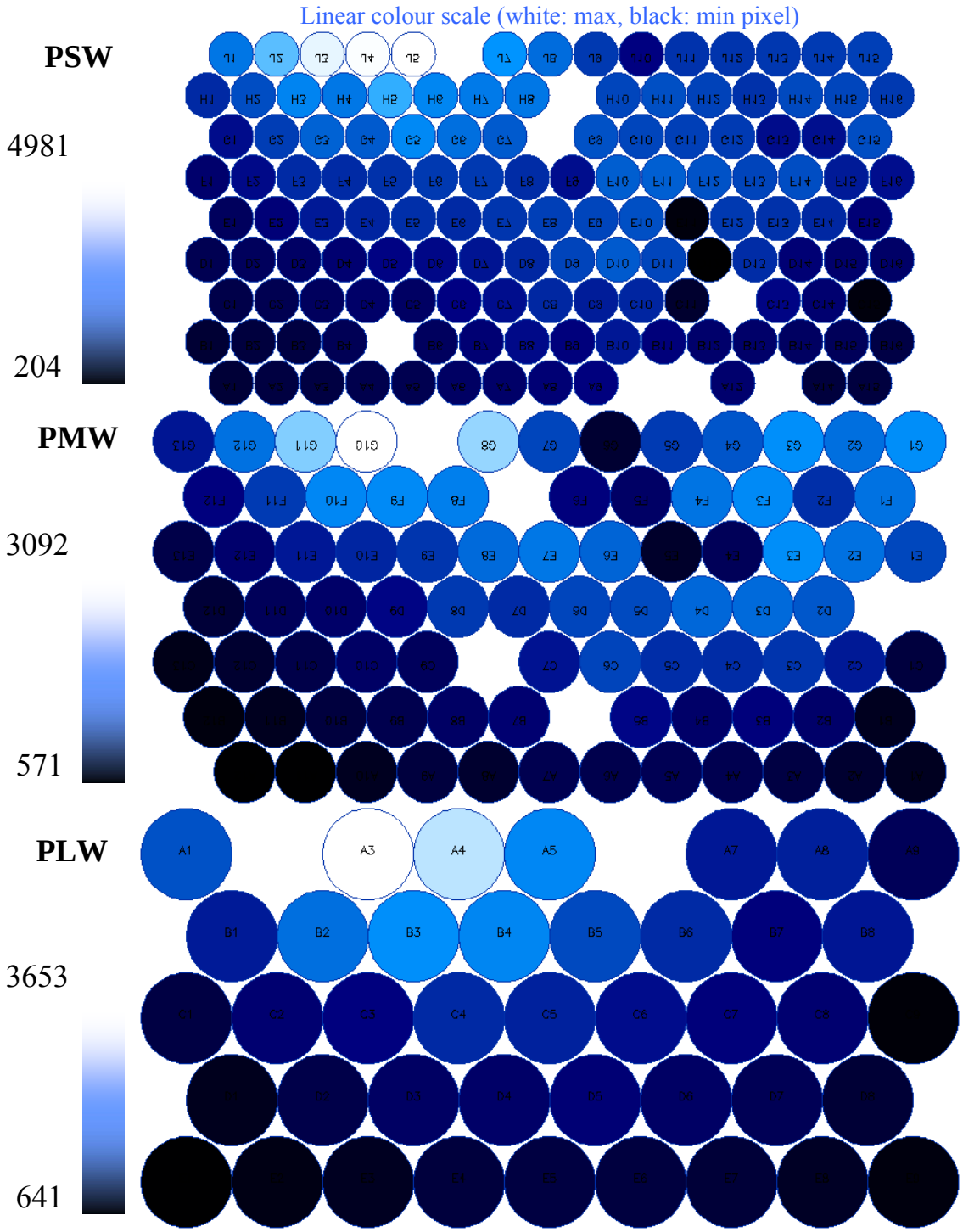
[2] Redefinition of the requirement on PCAL photometric output (HSO-CDF-ECR-116)

7. Appendix

7.1 Array illumination patterns, effective absorbed power (pW)



7.2 Array illumination patterns, Signal-to-Noise Ratio (SNR)



7.3 BSM temperature changes in response to PCal operation