SPIRE Science Verification Review - 3

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SPIRE ILT Report: PCAL performance

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Contents

1. Introduction and scope

This document describes the performance of the PFM Photometer Calibrator source (PCal) as implemented within the SPIRE FPU. The analyses in this updated document refers to data taken during flight-model test campaigns 2 through 5, with the main data sets noted where relevant.

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 PFM I-5	ILT_PERF	
IRD-CALP-R02	Operating range	Design Analysis Instrument level performance tests	CQM PFM I-5	ILT_PERF	
IRD-CALP-R03	Equivalent obscuration of aperture through BSM mirror	Design Analysis Instrument level performance tests	CQM PFM I-5	ILT_PERF	
IRD-CALP-R04	Speed of response	Design Analysis Instrument level performance tests	CQM PFM 1-5	ILT_PERF	
IRD-CALP-R05	Repeatability	Design Analysis Instrument level performance tests	CQM PFM I-5	ILT_PERF	
IRD-CALP-R06	Operation	Design Analysis Instrument level performance tests	CQM PFM I-5	ILT_OPS	
IRD-CALP-R07	Frequency	Design Analysis Instrument level performance tests	CQM PFM I-5	ILT_OPS	
IRD-CALP-R11	Operating temperature	Design Analysis Instrument level cold functional test	CQM PFM I-5	ILT_CFT	
IRD-CALP-R12	Cold power dissipation	Design Analysis Instrument level cold functional test Instrument level operations tests	CQM PFM 1-5	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 PFM I-5	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, although this is not explicitly stated in the IRD.

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. The standard flash sequence adopted for PFM4 and PFM5 consisted of 15 cycles at 0.25Hz, 0-3.8mA, followed by 15 cycles at 0.25Hz, 0-4.8mA.
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 – Time Response**

In response to a PCal flash, the detectors measure a 90% rise time of ~130 ms during all test campaigns, 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 96 ms, and a fall time of 52 ms, as shown in Figure 1.

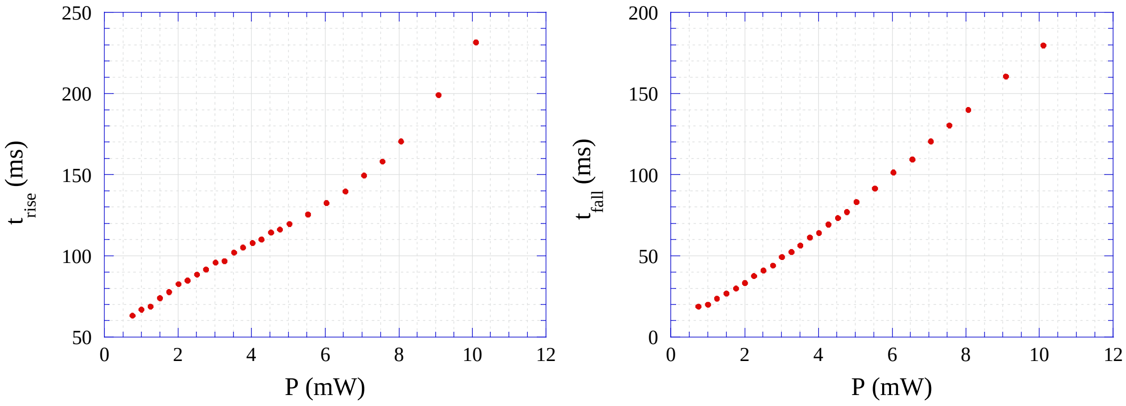


Figure 1 Rise and fall time (90%) for the PFM prime source, as a function of applied power, measured at unit level with a photoconductor detector.

- **IRD-CALP-R05 a – Flash to flash repeatability**

The RMS variation of 15 flash cycles (lasting 60 s in total) is always < 0.1 % for all PCal flash sequences, measured over PFM test campaigns 2-5. This requirement is easily met.

- **IRD-CALP-R05 b – Long-term repeatability**

Although no test was performed to specifically address this requirement (i.e. 12 calibration operations, equi-spaced over a 12 hour period) this requirement has been verified with the observations described in Table 1 below, where we compare flash sequence pairs taken under similar conditions.

Table 1 Summary of PCal observations used to determine repeatability. “RMS difference” is the difference in the RMS signal level on the detectors between each test pair.

ObsID	Date / time Date, time diff.	Bias (mV)	Phase (deg)	SubK_Temp (K)	RMS difference (%)		
					PSW	PMW	PLW
30012170	15/02/07, 15.51	31.076	179.294	0.297	0.2	0.2	0.7
30012172	15/02/07, 34m	31.076	179.294	0.297			
300121FC	16/02/07, 14.40	31.076	179.294	0.284	0.4	0.5	0.5
300121FE	16/02/07, 33m	31.076	179.294	0.284			
30012252	19/02/07, 12.55	31.076	179.294	0.282	0.2	0.2	0.5
30012254	19/02/07, 36m	31.076	179.294	0.282			
30012254	19/02/07, 13.31	31.076	179.294	0.282	0.3	0.4	0.4
30012274	20/02/07, 20h 26m	31.076	180.706	0.282			
30011303 PFM4	17/11/06	31.076	182.118	0.285	0.5	1.5	5.0
3001234F PFM5	26/02/07	31.076	182.118	0.285			
Note: This last flash sequence pair were taken from two different test campaigns. Test 30011303 was from the PFM4 campaign, and 3001234F was from the PFM5 campaign. Between these two campaigns, SPIRE was warmed, removed from the cryostat, the aperture blanked, and the system re-cooled, with a time interval between the tests of 3.5 months. The agreement in the PSW channel is remarkable. The disagreement at longer wavelengths is due to the fact that in the PFM4 campaign, SPIRE was looking at a 6.7K black body, whereas the aperture was blanked at 4.2K for PFM5.							

Examination of Table 1 draws us to the following conclusions:-

- For two calibration observations under the same conditions, separated by approximately 30 minutes, the RMS repeatability is better than 0.7% (worst case).
- The same is true for observations separated in time by ~20Hrs
- There is excellent agreement in the two datasets that we compare from PFM4 and PFM5. These were separated in time by 3.5 months, and involved an instrument thermal cycle to 300K and back, and a re-configuration of the experiment. Agreement in the PSW channel is of the order 0.5%, whilst the discrepancy at longer wavelengths is due to the different background loading on the detectors.

- **IRD-CALP-R012 – Power dissipation**

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 – Photometric output**

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 (*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 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 *dP* (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:

$$SNR = \frac{dV}{s} \cdot \sqrt{N_{samp}} ,$$

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

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 (section 7.2) illustrate the range of SNR measured 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.

- **Uniformity of illumination**

PCal is centrally located at a pupil in the BSM and so should illuminate the arrays uniformly if the aperture acts as a Lambertian emitter. This is not the case, as can be seen from the illumination patterns in the appendix (section 7.1). The illumination is brightest towards one of the long edges of the arrays resulting in a variation of incident power across the array. The same PCal flash illumination pattern is demonstrated under all conditions (e.g. viewing the CBB or the room).
Preliminary electromagnetic modelling with HFSS (Ansoft inc) shows that the antenna pattern from the PCal structure is highly forward-peaked, and at an angle to the PCal symmetry axis (boresight) dependant upon which source (prime or redundant) is illuminated. This correlates well with ILT observations, as illustrated in Figure 2 below.

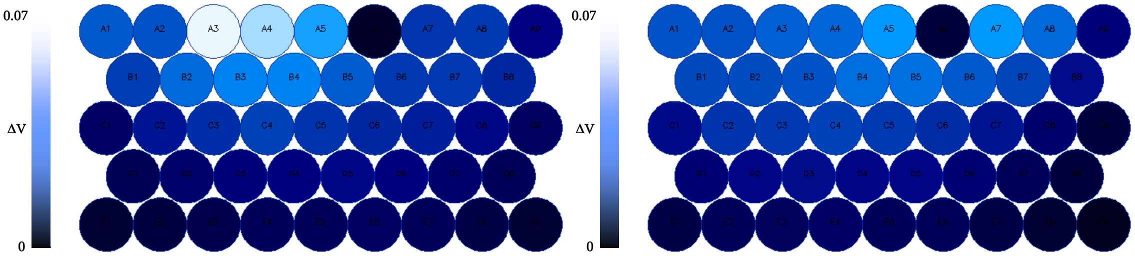


Figure 2 PLW illumination pattern from the prime (left) and redundant (right) source.

The non-uniform illumination across the short edge of the arrays needs to be investigated further, using a combination of the modelled PCal antenna pattern and the SPIRE optical model.
The non-uniform illumination is not an issue for SPIRE. The only requirement is that all detectors can be illuminated with the required signal-noise, and that the illumination from PCal is repeatable.

- **Illumination pattern vs. BSM position**

The illumination pattern has been found to be sensitive to BSM position. This is due to the fact that the PCal aperture sits slightly behind the edge of the hole in the centre of the BSM. This edge is reflective, and will modify the radiation pattern from the PCal aperture according to the BSM chop or jiggle position.
There is a maximum of 25% change in the illumination of an individual pixel at the extremes of the chop axis throw, as shown in Figure 3.

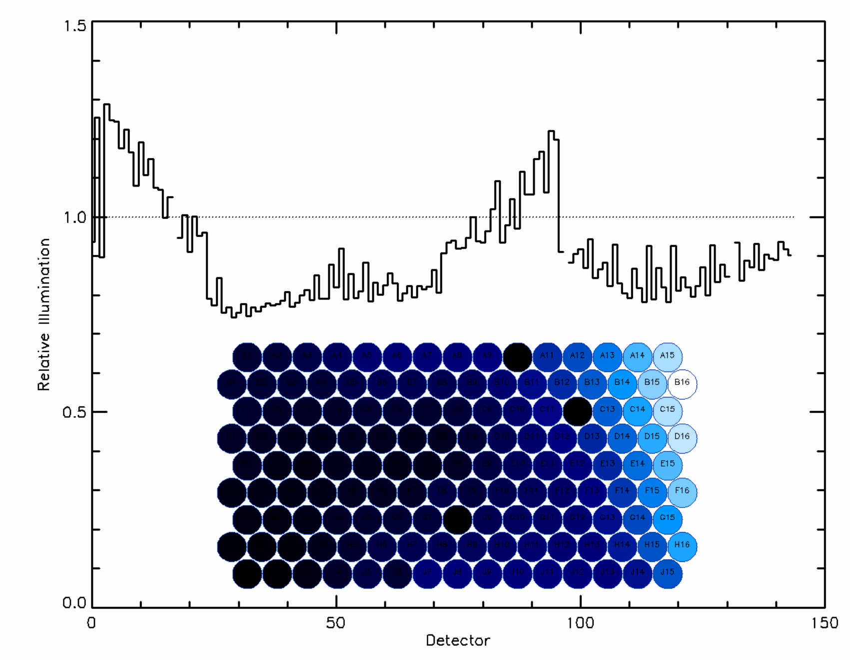


Figure 3 Difference in detector signal at the extremes of the BSM chop axis throw.

There is also a very small dependence on the jiggle axis position.

Therefore, critical PCal observations should always be made with the BSM in it’s “home” position.

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 will be investigated using the modelled PCal antenna pattern in combination with the SPIRE optical model.

5. Recommendations for further data analysis and test

From the last day of PFM5 testing, we have a series of PCal flashes performed under increasing SubK_temp conditions, from ~280mK up to ~800mK. These data will be analysed to check that the detector response to PCal flashes correlates to the responsivity derived from loadcurves at these temperatures.
Standard flash sequences will be performed as a matter of course in the IST campaign pre-flight.

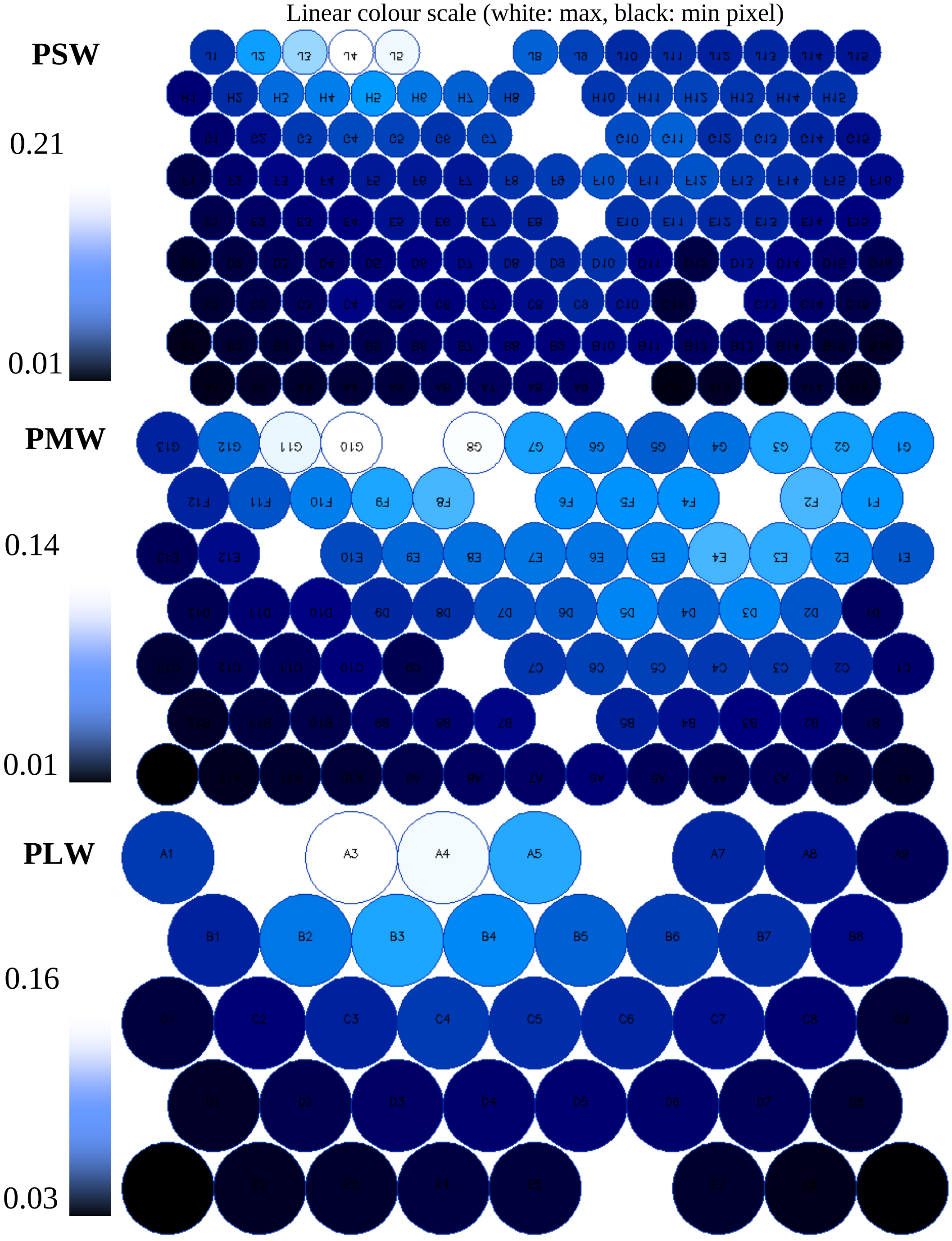
6. References

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

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

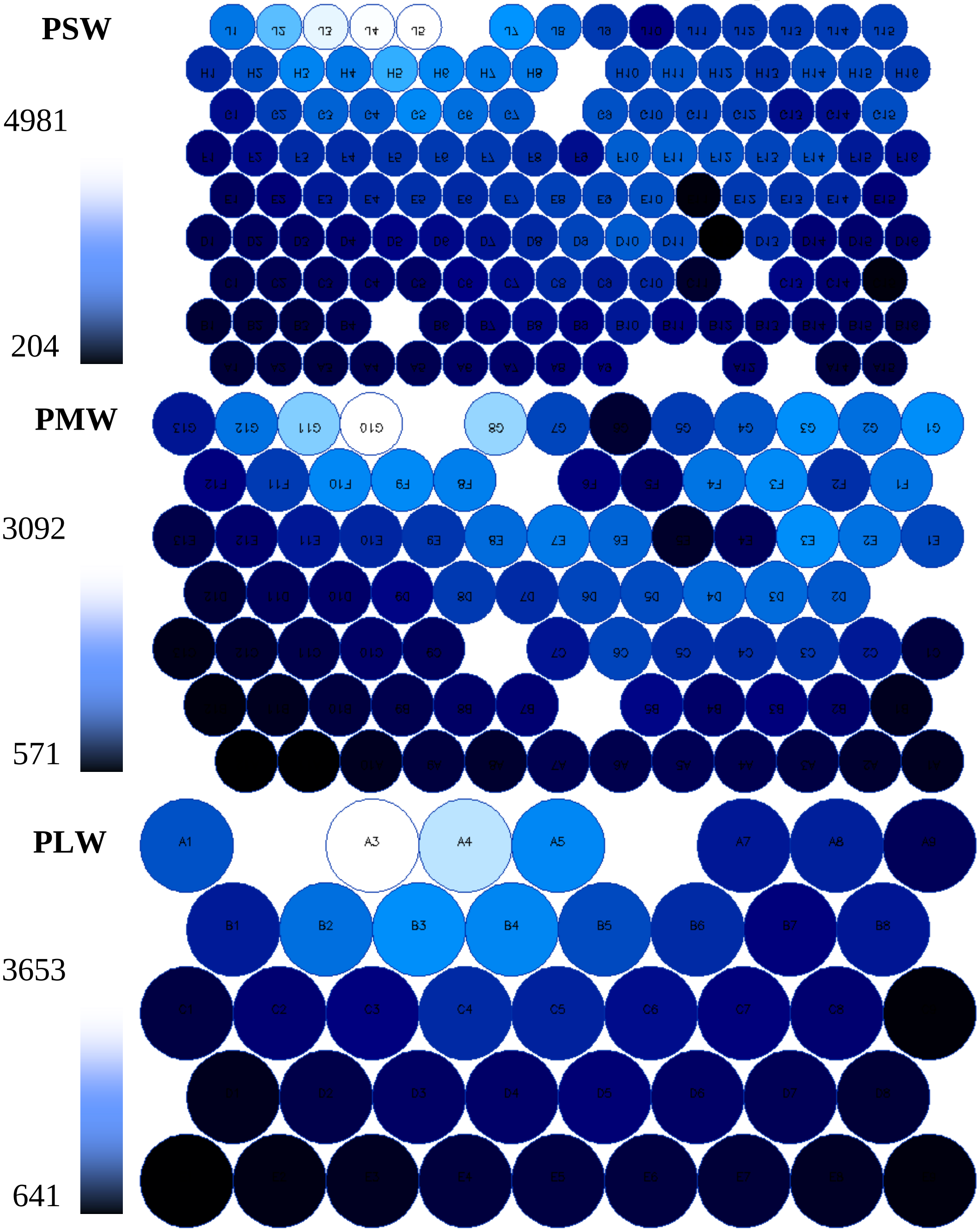
7. Appendix

7.1 Array illumination patterns, effective absorbed power (pW)



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

Linear colour scale (white: max, black: min pixel)



7.3 BSM temperature changes in response to PCal operation