SPIRE PFM3

THERMAL BALANCE TEST REPORT

PREPARED BY:	A.S. GOIZEL	RAL	15/12/06	Signature Not Verified Digitally signed by Anne-Sophie Goizel Date: 2006.12.15 14:30:16 Z
CHECKED BY:	B. SHAUGHNESSY	RAL	Signature Not Verified	Digitally signed by Bryan Shaughnessy Date: 2006.12.15 14:22:47 Z
APPROVED BY:	E. SAWYER	RAL		

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CHANGE RECORD

Issue	Date	Section	Change
Draft A	04/07/06	-	New Document.
Draft B	12/09/06	All	Additional information added to complete various sections.
Draft C	13/12/06	All	Add missing information to various sections.
Issue 1	15/12/06	-	First Issue.

ACRONYMS

Acronym	***Definition***
AD	Applicable Document
BDA	Bolometer Detector Arrays
BSM	Beam Steering Mechanism
CBB	Cold Black Body
CQM	Cryogenic Qualification Model
DRCU	Digital Readout Control Unit
DTMM	Detailed Thermal Mathematical Model
EGSE	Electronic Ground Support Equipment
FM	Flight Model
FPU	Focal Plane Unit
FS	Flight Spare
HCSS	Herschel Common Science System
HeI	Helium I
HeII	Helium II
HOB	Herschel Optical Bench
I/F	Interface
IIDB	Instrument Interface Document Part B
IRD	Instrument Requirement Document
ILT	Instrument Level Testing
JFET	Junction Field Effect Transistor
L0	Level-0
L1	Level-1
L2	Level-2
L3	Level-3
LN2	Liquid Nitrogen
MGSE	Mechanical Ground Support Equipment
PFM	Proto Flight Model
RD	Reference Document
SMEC	Spectrometer Mechanism
SCU	Subsystem Control Unit
SOB	SPIRE Optical Bench
SPIRE	Spectral and Photometric Imaging Receiver
SVR	Science Verification Review
TBT	Thermal Balance Test
VM	Virtual Machine

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1 INTRODUCTION

This document summarises the thermal performance of the SPIRE Proto-Flight Model (PFM3) measured during the third thermal balance test campaign which took place at RAL in May/June 2006.

2 DOCUMENTS

2.1 Applicable Documents [AD]

ID	Title	Number
AD1	Instrument Interface Document Part A	SCI-PT-IIDA-04624 3.3
AD2	Instrument Interface Document Part B - SPIRE Instrument	SCI-PT-IIDB/SPIRE-02124 Issue 3.2
AD3	SPIRE Instrument Requirement Document	SPIRE-RAL-PRJ-000034 Issue 1.3
AD4	SPIRE Cryogenic Thermal Design Requirements	SPIRE-RAL-PRJ-002075 Issue 1

Table 2-1 – Applicable Documents

2.2 Reference Documents [RD]

ID	Title	Number
RD1	SPIRE PFM2 Thermal Balance Test Specification	SPIRE-RAL-DOC-002435 Issue 1
RD2	SPIRE Verification Science Review Thermal Performance	SPIRE-RAL-REP-002557 Issue 1 13/01/06
RD3	PFM3 Thermal Test Inputs	Email from A. Goizel 30/01/06
RD4	SPIRE PFM3 Thermal Balance Test Specification	SPIRE-RAL-MEM-002563 Issue 1 12/05/2006
RD5	PFM3 Cold Test – Master Procedure	SPIRE-RAL-PRC-002582 Issue 1 D. Smith
RD6	PFM3 Thermometers 2 0 - For PFM-3 2nd Run.xls	D. Smith
RD7	PFM3 Thermometer C2T Issue 0.2.xls	Issue 0.2 D. Smith 14/03/06
RD8	As Built Configuration List	SPIRE-RAL-DOC-002326 Issue 2.2 E. Sawyer
RD9	PTC Test Procedure PFM3	D. Griffin
R10	PFM3 Test Results Summary – v5.xls	A. Goizel
RD11	NCR - 370 Lakeshore Scanner Unit	HR-SP-RAL-NCR-154v1 03/08/06
RD12	NCR - Cooler Performance Degradation	HR-SP-RAL-NCR-150v2 09/08/06
RD13	NCR - Flight Temperature DC Offset	HR-SP-RAL-NCR-155 13/07/06
RD14	NCR – PJFET L3 Interface	HR-SP-RAL-NCR-158 24/08/06
RD15	Cooler Performance Degradation Analysis	SPIRE-RAL-MEM-002693 09/08/06
RD16	SPIRE PFM2 Thermal Performance Flight Predictions	SPIRE-RAL-NOT-002588 Issue 1

Table 2-2 - Reference Documents

3 PFM3 TEST CAMPAIGN OVERVIEW

3.1 PFM3 Thermal Balance Test Campaign Objectives

The primary objective of the PFM-3 test campaign was to verify that the performance of the SPIRE flight model had not been degraded following the cold vibration testing carried out at CSL in December 2005. The PFM3 test campaign included repeats of some of the tests performed during the PFM-2 campaign to ensure the instrument was still performing as expected. It was also an opportunity to continue activities that were not successfully completed in earlier test campaigns (because of time, thermal hardware and/or test equipment limitations). Table 3.1 describes the list of thermal tests which have been defined in the PFM3 Thermal Test Specification [RD4] based on the recommendations from the instrument Science Verification Review (SVR) held on January, 27th 2006 at RAL [RD2].

Test Name	Description
Thermal Balance Test - Nominal Case	These tests will ensure that the instrument thermal performance has not degraded following the cold vibration testing done at CSL in December 2005.
Thermal Balance Test - Hot Case	
L1 Strap Characterisation	This test will characterize the change in L1 heat load following the change of the L1 cone support from CFRP to Stainless Steel as well as the L1 glued interface which was not present during the PFM2 test campaign.
PTC Operation	This test will assess the impact of the PTC operation on the cooler total load and detector temperature stability.
Mechanisms/Calibration Sources Operation	This test will assess the impact of mechanisms operation on the instrument FPU temperature and checks for any overall mechanisms temperature increase for all operational modes.
Automated and Optimized Cooler Recycling	This test will allow the tuning of the control parameters that will be used to maintain the pump temperature at ≥ 45K during the cooler recycling condensation phase.

Table 3-1 – PFM3 Campaign - Thermal Test Overview [RD4]

3.2 Changes to the Cryostat Built Standard since PFM2

The following changes have been implemented between the PFM2 and the PFM3 test campaigns:

- The aluminium L1 MGSE strap has been replaced with a 4N purity copper strap.
- The instrument cryo-harnesses were not heat sunk as well as during the PFM2 test campaign in order to limit any risks of electrical shorts.
- Some of the EGSE sensor locations have changed since PFM2 and some additional sensors have been lost. Please refer to [RD6] and section 4.1 of this document for additional information about the sensors configuration.

3.3 Changes to the Instrument Built Standard since PFM2

The following instrument changes have been implemented between the PFM2 and the PFM3 test campaigns:

- The instrument L1 cone isolation support was replaced with the SST version after a failure of the CFRP cone during the cold vibration test in December 2005. Both L1 A-frames were replaced with the spare CFRP supports.
- The L1 electrically isolating joint was implemented on the SOB after the PFM2 test campaign.
- The flight temperature sensor calibration curves have been updated to correct for the inconsistencies detected as part of the PFM2 test campaign.
- The SCAL transfer function calibration has been extended to cover a temperature range up to 80K.

Further details about the instrument standard build can be found in [RD8].

3.4 Summary of Cryostat Operations

Table 3-2 gives an overview of the cryostat operations during the PFM3 test campaign.

Cryostat Warm-up	Start Date	Completed
Cryostat Cooldown to 4K	26/04/06	08/05/06
Cryostat at 1.7K-4K	08/05/06	08/05/06
All cryostat warm-up to 65K	26/05/06	29/05/06
Issue with AC bridge – data should not be used for thermal correlation (see NCR154 in [RD11])	31/05/06 14.00 UTC	05/06/06 08.30 UTC
HOB left operating at 22K over Week-end Period	10/06/06	11/06/06
HOB cooled to 10K	14/06/06	14/06/06
L0 Stage Warmed-up to 4K	19/06/06	20/06/06
HOB cooled to 10K	27/06/06	28/06/06
Cryostat Final Warm-up	28/06/06	03/07/06

Table 3-2 – Summary of Cryostat Operations

3.5 Overview of Thermal Tests Performed

Test Name	**Start Date**	**Completed**	**Issues / Test Limitations**	**Report Section**
Thermal Balance Test - Nominal Case	12/05/06	14/05/06	A suspected degradation of the bolted interface between the cooler heat switches interface and the L0 MGSE straps meant that at the end of the recycling condensation phase, the evaporator could not reach temperatures below 2.3K.	4.4
Thermal Balance Test - Hot Case	19/05/06	21/05/06	Same issue as above. As a result, a slightly different test case was run and will be referenced as Thermal Balance Test Case #2 in the following sections of this report.	4.5
EGSE Temperature Sensors Self-Heating Check	25/05/06	25/05/06	All sensors working fine.	4.1
L1 Strap Characterisation	25/05/06	25/05/06	Test completed successfully.	4.2.1
Pump Characterisation	26/05/06	26/05/06	Additional test performed in order to get a better understanding of the cooler/L0 MGSE straps interface issue.	4.3.2.5
L1 Strap Characterisation	10/06/06	11/06/06	Additional test performed in a different cryostat environment (HOB at 22K) in order to get a better understanding of the measured L1 heat load.	4.2.2.1
L1 Strap Characterisation	27/06/06	27/06/06	Additional test performed in a different cryostat environment (HOB at 10K) in order to get a better understanding of the measured L1 heat load.	4.2.2.2

Table 3-3 –Thermal Balance Tests Performed During PFM3

4 PFM3 THERMAL TEST RESULTS

4.1 Temperature Sensors Functional Tests

4.1.1 Cryostat EGSE Temperature Sensors Verification

Table 4-1 gives an overview of the temperature sensors that were open circuit at the start of the PFM3 test campaign as well as additional sensors lost throughout the test campaign.

Lost Sensors Before Cooldown	**Location**	**Sensor**
	End Cap 2	S2
	Filter Flange	S11
	FSJFP L3 I/F (L3 strap side)	S16
	Support foot 1	S12
	4K Vessel - Flexible	S26
	1.7K Flexible - Evap Strap Interface	S28
	1.7K Flexible - Box Strap Interface	S30
Lost Sensors After Cooldown	**Location**	**Sensor**
	End Cap 1 (77K)	S1
	Support foot 4	S15
	PJFET Chassis (CX)	S18
	HOB - A-frame (Bot -Y)	S21

Table 4-1 - Cryostat EGSE Temperature Sensors Verification

4.1.2 Instrument EGSE Temperature Sensors Self-Heating Characterisation

The instrument EGSE sensors (sensors used for the characterisation of the instrument heat loads) have all been tested for self-heating errors. This test was performed once the instrument had reached its nominal operating temperatures (1.7K-4K) by increasing the AC bridge excitation current from 1uA to 10ua.

Table 4-2 summarises the results from this test. A 1uA excitation current was subsequently used throughout the test campaign.

	Temperature Increase (1)	**Sensors Interface Resistance**	**Sensors Self-Heating**
	[mK]	**[K/W]**	**[mK]**
Evaporator Strap Adaptor (top)	3.6	46841	0.04
Pump Strap Adaptor (top)	36.5	538500	0.37
Detector Strap Adaptor (top)	7.5	55659	0.08
Evaporator Strap Adaptor (bottom)	16	48639	0.16
Pump Strap Adaptor (bottom)	11.5	52373	0.12
Detector Strap Adaptor (bottom)	5.6	44070	0.06
L1 Strap Interface at SOB	1	2340	0.01
L1 Strap Adaptor	-1	-10305	-0.01

Table 4-2 – EGSE Temperature Sensors Self-Heating

(1) For an increase in sensor excitation current from 1uA to 10uA.

Note: The negative temperature increase for the “L1 Strap Adaptor” sensor isn’t consistent but suggests that the sensor has no self-heating as a change in the temperature reading by +/-1mK is likely to be noise in the measurement.

4.1.3 Instrument Flight Temperature Sensors Verification

The discrepancies in the instrument calibration curves and transfer functions have been corrected for since the PFM2 test campaign. The DC offset could not be corrected for and is therefore still present in the data. This should be accounted for when correlating the thermal model with the test data. During the test campaign, the SCAL transfer function calibration has been extended to cover a temperature range up to 80K.

4.1.4 BDA Temperature Predictions

A new algorithm has been used to predict the Photometer Bolometer Detector Arrays temperatures from the dark load curve. The performance data measured during the PFM2 test campaign should be re-evaluated using this new algorithm in order for the comparison to be consistent.

4.2 L1 Strap Characterisation

4.2.1 L1 Characterisation – Nominal Test Case

The aim of this test is to quantify the instrument L1 heat load for the “nominal” thermal environment described in Table 4-3.

Required Cryostat Interface Temperature	Required
L0 Stage	1.7K
L1 Stage	4.3K
L2 Stage	~15K

Table 4-3 – Cryostat Environment during L1 Characterisation Test

The Herschel Optical Bench (HOB) is thermally coupled to the cryostat instrument shield which is also the heat sink for the JFETs. They run more or less at the same temperature which means that the instrument L2 conductive, L2 radiative and L3 conductive interface temperatures are all the same in the RAL calibration cryostat (versus 12K, 16K and 15K respectively in the flight cryostat). The cryostat L2 temperature stage (HOB and instrument shield) has been running at 15K for most of the test campaign for the following reasons:

- This represents a worse case scenario,
- This optimises the use of helium during the test campaign.

A Keithley 236 power supply (on loan) has been used to drive the FPU warm-up heater as it allows accurate 4-wire measurements to be taken for a large range of power dissipations. Additional background about the method used for the characterisation can be found in RD1. Figure 4-1 shows the instrument temperature profiles during the L1 characterisation test. Average “temperature delta T” (described in appendix in
Figure 6-1) have been used for the analysis.

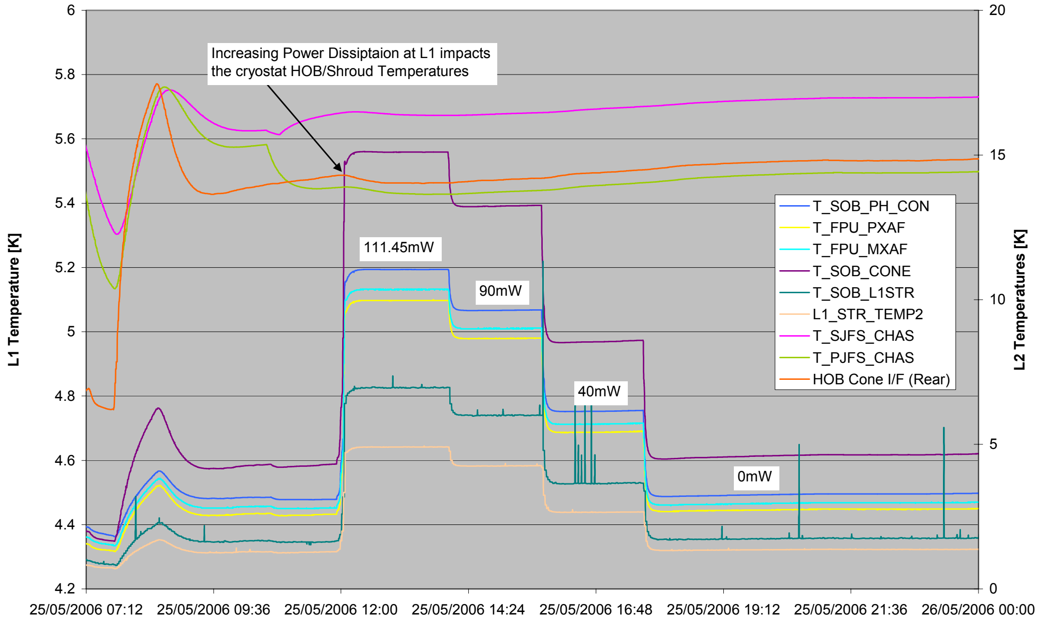


Figure 4-1 – SPIRE Temperatures Profile During L1 Characterisation Test

Table 4-4 and Figure 4-2 summarise the results obtained for the nominal test as well as the resulting test data curve fit and correlation.

m	p
0.00135	**0.03455**

Current	Voltage	Heater Resistance	T_Strap	T_SOB	Heating Power	Temperature Gradient	Strap Conductance
[mA]	[mV]	[ohms]	[K]	[K]	[mW]	[K]	[W/K]
					-25.50	-	-
0	0	-	4.322	4.356	0	0.034	-
33.36	1200	35.97	4.439	4.530	40.03	0.0895	0.7322
50	1800.0	36.00	4.583	4.740	90.00	0.1570	0.7357
55.58	2000.0	35.98	4.642	4.828	111.16	0.1845	0.7407

Table 4-4 – L1 Characterisation Test Results Summary Showing Linear Fit Coefficients

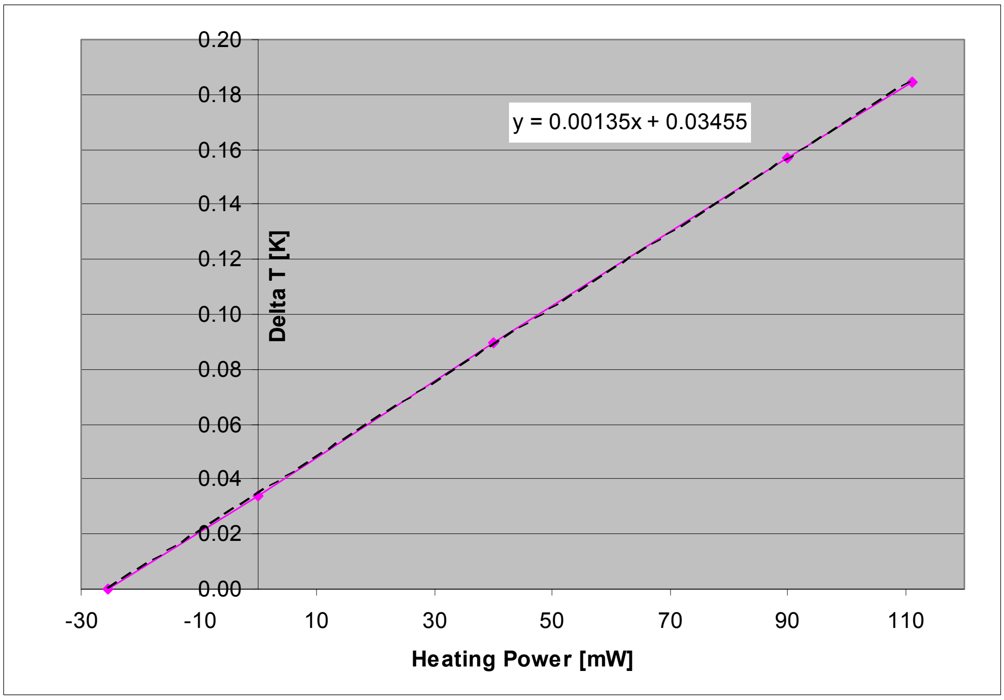


Figure 4-2 – L1 Characterisation Test Results Correlation

Based on this characterisation test, the instrument L1 heat load under a nominal thermal environment have been estimated to 25.5mW. Some of this heat load is coming from the instrument L1 hybrid supports, the cryo-harnesses and radiation load from the environment.

4.2.2 L1 Characterisation – Additional Test Cases

4.2.2.1 HOB and Instrument Shield at 22K

On the 10/06/06, the cryostat L2 stage was warmed-up to 22K and left running at this temperature for the whole week-end. The instrument temperatures were recorded in this specific configuration and will provide an additional test case for the thermal model correlation. The following assumptions have been used for the instrument L1 load analysis:

- No heat was dissipated on the FPU in this specific case as the main purpose of this setup was to save helium,
- The HOB and instrument shield were running between 21.5K and 22.5K,
- The L1 MGSE strap conductance is assumed to be about 0.7322W/K (for the measured L1 strap interface temperature) based on the data correlation obtained with the nominal test case.

Table 4-5 summarises the gradient measured across the L1 strap (taken on the 11/06/2006 at 07:00 UTC) as well as the instrument load predicted for this specific test setup. It is important to note that in this configuration, the instrument L1 heat load is quite sensitive to variations of the cryostat L2 temperature stage as described in Figure 4-3. These data should therefore be used with precautions. Please note that the FPU warm-up heater wasn't used during this test so the instrument total L1 load corresponds to the actual instrument L1 parasitic load.

Strap Conductance	Estimated Total L1 Heat Load	Estimated Parasitic L1 Heat Load
[W/K]	[mW]	[mW]
0.7322	67.4	**67.4**

Table 4-5 – Summary of Instrument L1 Heat load for Cryostat L2 at 22K

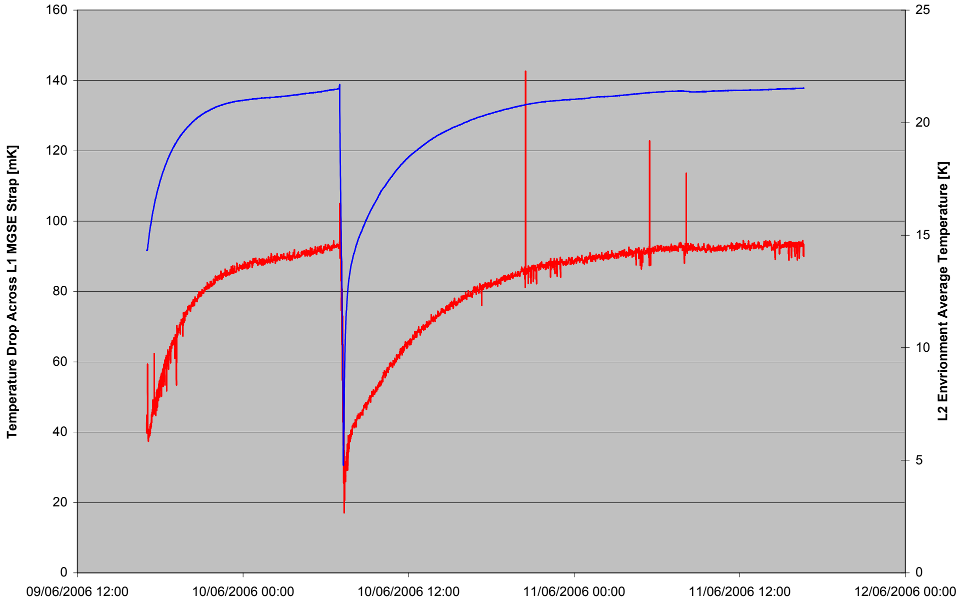


Figure 4-3 - SPIRE L1 Strap Gradient versus Cryostat L2 Temperature Variation

4.2.2.2 HOB and Instrument Shield at 10K

On the 27/06/06, the cryostat L2 stage was cooled down to 10K and left running at this temperature overnight. The instrument temperatures were recorded in this specific configuration and will provide an additional test case for the correlation of the thermal model. The following assumptions have been used for the instrument L1 load analysis:

- 90mW were dissipated in the instrument FPU during the whole test duration to ensure that the delta T across the L1 strap could be measured with enough accuracy,
- The HOB and cryostat instrument shield were running at about 11K,
- The L1 MGSE strap conductance is assumed to be about 0.7357 W/K (for the measured L1 strap interface temperature) based on the data correlation obtained with the nominal test case.

Table 4-6 and Table 4-7 summarise the gradient measured across the L1 strap (taken on the 28/06/2006 at 03:00 UTC) as well as the instrument load predicted for this specific test setup. Again, an average "temperature delta T" (described in appendix in Figure 6-2) has been used for the analysis.

Heating Case	Current	Voltage	Heater Resistance	T_Strap	T_SOB	Heating Power	Temperature Gradient
[mW]	[mA]	[mV]	[ohms]	[K]	[K]	[mW]	[K]
90	50	1799	35.98	4.565	4.711	89.95	0.147

Table 4-6 – Test Setup and Measurement

Strap Conductance	Estimated Total L1 Heat Load	Estimated Parasitic L1 Heat Load
[W/K]	[mW]	[mW]
0.7357	108.1	**18.2**

Table 4-7 – Predicted L1 Parasitic Load

Note: The instrument parasitic load correspond to the total L1 heat load less the FPU warm-up heater dissipation.

4.2.3 L1 Characterisation Summary

Date	**25/05/2006 23:30**	**11/06/2006 07:00**	**28/06/2006 03:00**
Test Case	**Nominal HOB at 15K**	**HOB at 22K**	**HOB at 10K**
Instrument MODE	TBC	TBC	TBC
End Cap 1	14.577	21.626	10.509
End Cap 2	16.236	22.667	12.837
Cylinder End	14.079	21.331	9.801
Cylinder Centre	14.416	21.394	10.327
Cylinder End	14.597	21.728	10.338
Support foot 2	33.197	36.549	32.796
Support foot 3	29.923	33.916	29.880
Support foot 4	36.329	39.372	36.274
Spect JFET L3 I/F Block	16.979	23.019	13.572
HOB Cone I/F (Rear)	14.831	21.692	10.766
HOB +Y A-Frame I/F	15.053	21.828	10.995
Phot JFET L3 I/F Block	14.227	21.687	10.983
T_SOB_PH_CON	4.496	4.808	5.014
T_SJFS_CHAS	16.988	22.740	13.654
T_FPU_PXAF	4.449	4.724	4.927
T_FPU_MXAF	4.470	4.768	4.957
T_SOB_CONE	4.619	5.106	5.288
T_PJFS_CHAS	14.401	22.355	12.857
T_SOB_L1STR	4.358	4.535	4.711
T_L0_DSTR1	1.705	*1.713*	1.708
T_L0_PSTR1	1.738	*1.742*	1.734
T_L0_ESTR1	1.698	*1.704*	1.700
T_PL0_2	1.719	1.729	1.724
T_SL0_2	1.713	1.722	1.717
L0_ESTR_TEMP2	1.696	1.702	1.698
L0_PSTR_TEMP2	1.703	1.709	1.704
L0_DSTR_TEMP2	1.698	1.705	1.700
L1_STR_TEMP2	4.323	4.443	4.565
L1 Strap Conductance [W/K]	-	0.7322	0.7357
L1 Delta T [K]	0.035	0.092	0.147
L1 Total Load [mW]	25.5	67.4	108.1
Q_FPU Heater [mW]	0	0	89.95
L1 Parasitic Load [mW]	**25.5**	**67.4**	**18.2**

Table 4-8 – L1 Characterisation Test Results Summary

4.3 Cooler Recyclings

4.3.1 Overview

At the beginning of the PFM3 test campaign, the cooler recyclings have been carried out using the “manual” PFM2 script to allow direct comparison of the cooler post-vibration performance with the performance measured during the PFM2 test campaign. Some issues were encountered during this phase of testing, this is discussed in more details in section 4.3.2.

Later on in the test campaign, a Virtual Machine (VM) was used to optimise the cooler recycling by controlling the pump temperature to ≥ 45K during the recycling condensation phase and automating the complete recycling process. This is described in more details in section 4.3.3.

4.3.2 Manual Recycling with PFM2 Script

4.3.2.1 Overview

The first cooler recyclings were completed successfully and hold times consistent with those recorded during the PFM2 test campaign were measured (~50 hr for an evaporator condensation temperature of 1.9K [RD16]). However when the cooler recycling was performed for the first time in a controlled environment with the cryostat L0 temperature stage at 1.9K, changes in the cooler performance became apparent as described in Table 4-9: the evaporator temperature at the end of the condensation phase stabilised at 2.3K during the PFM3 test campaign versus 2.1K during the PFM2 test campaign.

	PFM2	**PFM3**
L0 Cryostat Temperature	1.9K	1.9K
Evaporator Temperature At end of condensation phase	2.1K	2.3K
Delta T	0.2K	0.4K

Table 4-9 – Issue with Evaporator Temperature at end of Condensation Phase

A closer inspection of the cooler temperature profiles during the recycling was carried out in order to understand the causes of this unexpected behaviour.

4.3.2.2 Observations

When recycling the cooler during the PFM3 test campaign, a larger temperature drop was observed between the cooler evaporator/shunt and the top of the evaporator MGSE L0 strap. When compared with data from the PFM2 test campaign, differences in the cooler overall temperature and timing profiles were also observed as described in Figure 4-4.

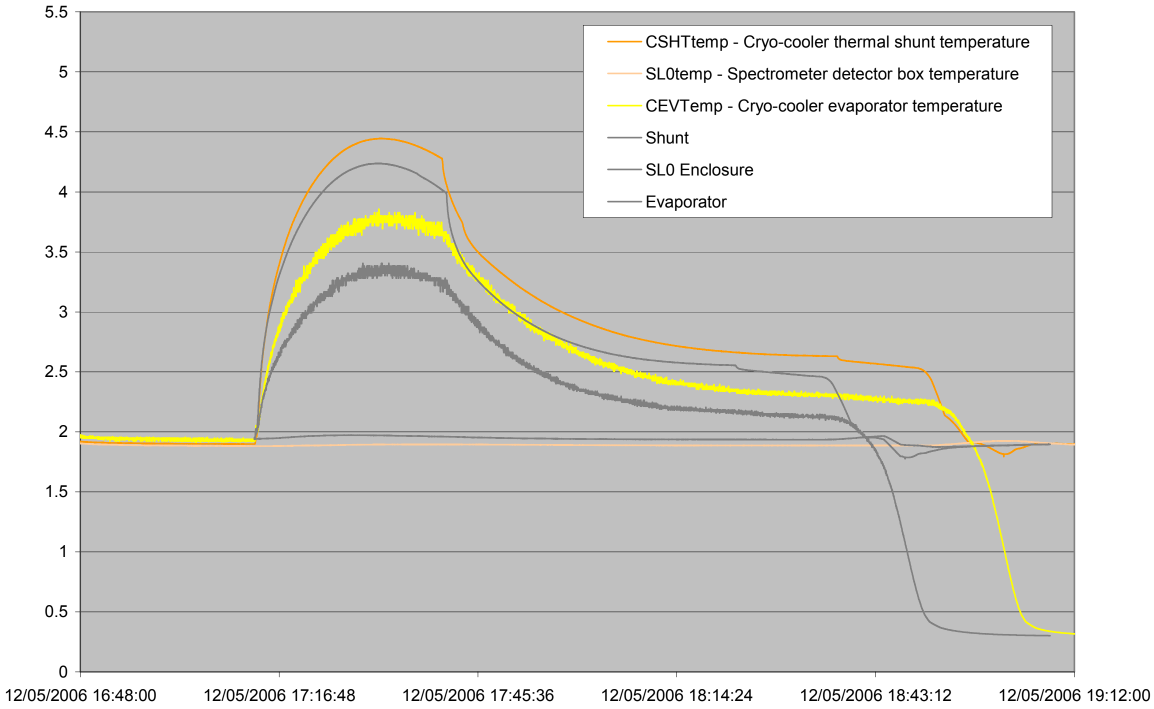


Figure 4-4 – Cooler Recycling PFM2 vs. PFM3 Temperature Profiles [in K]

Notes: The temperatures measured during the PFM3 test campaign are as follow:

- shunt temperature in orange,
- evaporator temperature in yellow
- L0 stage temperature in light orange

- Temperatures measured during the PFM2 test campaign are represented by the grey curves,
- In both cases, the cryostat L0 stage was operating at ~1.9K.

It can be seen that during the PFM3 test campaign, the evaporator and shunt temperatures are getting warmer during the condensation phase and that they take longer to cooldown. This indicates that the cooler is not as well coupled to the L0 stage as it used to be. The graph on the following page describes the temperatures recorded on the L0 MGSE straps (for both the evaporator and the pump strap) during the same recycling. Please note that these MGSE straps are not like the flight straps and that they have been manufactured for the sole purpose of testing SPIRE in the RAL calibration cryostat.

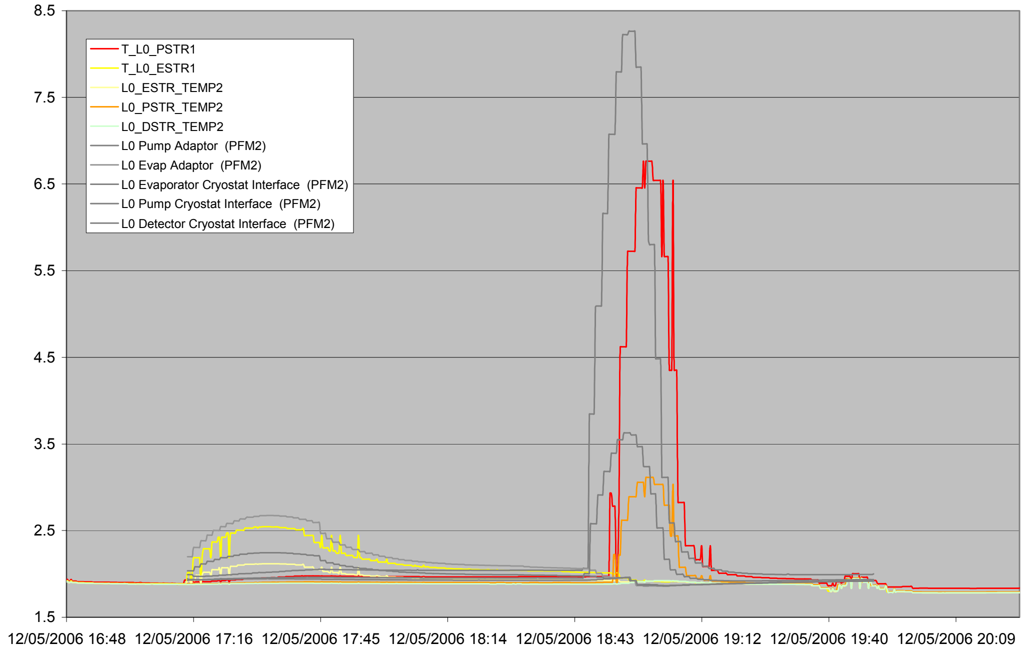


Figure 4-5 – L0 MGSE Straps PFM2 vs. PFM3 Temperature Profiles during Cooler Recycling [in K]

Notes: The temperatures measured during the PFM3 test campaign are as follow:

- The red and orange curves are temperature readings from the sensors at the top and bottom of the MGSE L0 pump strap respectively,
- The dark and light yellow curves are temperature readings from the sensors at the top and bottom of the MGSE L0 evaporator strap respectively.

- Temperatures measured during the PFM2 test campaign are represented by the grey curves,
- In both cases, the cryostat L0 stage was operating at ~1.9K.

Contrary to the cooler temperatures which were warmer, both L0 straps appear to run cooler during the PFM3 test campaign. This suggests that the heat generated during recycling is released more slowly than before which also points towards a poorer thermal coupling between the cooler and the L0 straps.

Figure 4-6 describes the temperature profiles recorded during the cooler recycling completed as part of the PFM2 and PFM3 test campaigns, but this time, with a 1.7K L0 temperature stage (versus 1.9K in the previous figures). Again, the evaporator and shunt run warmer during the condensation phase and it takes them longer to cooldown for the PFM3 recycling. The evaporator manages to reach 2K in this case but only because the cryostat L0 temperature stage is allowed to cool to 1.5K (i.e. as the manostat is opened to prevent any instabilities in the L0 pot).

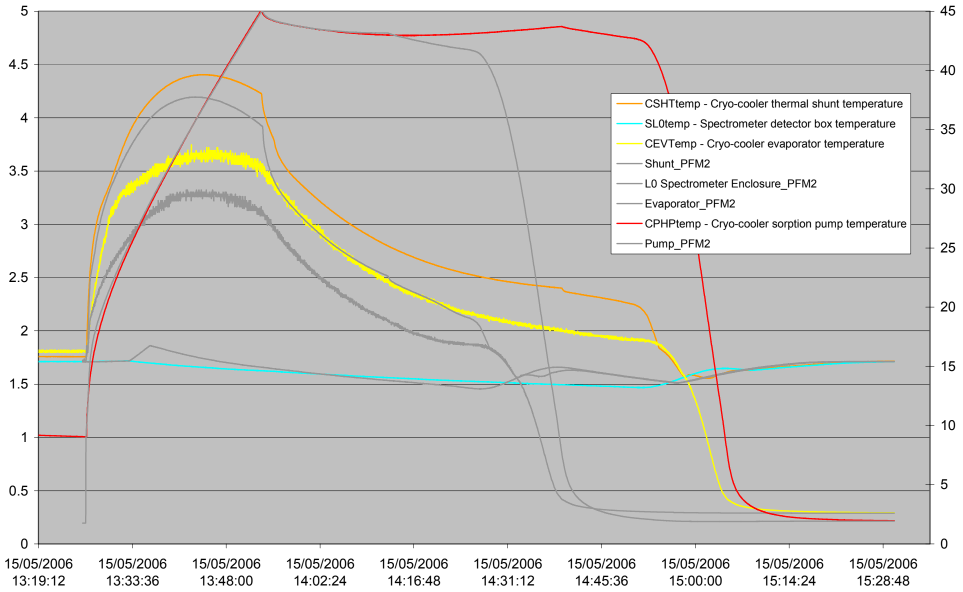


Figure 4-6 - Cooler Recycling Temperature Profiles [in K]

<u>Notes</u>: The temperatures profiles are as follow:

- Coloured curves are the cooler temperature readings during PFM3,
- Grey curves are the cooler temperature readings during PFM2,
- The cryostat L0 stage was operating at ~1.7K at the beginning of the recycling and then cooled down to as low as 1.5K during the operation of the manostat (as indicated by the L0 spectrometer enclosure temperature).

4.3.2.3 Impact of Cooler Performance Degradation

The current cooler behaviour is a problem because it will affect the cooler hold time in the following ways:

- For a nominal recycling, the cooler requires an additional 20 min to complete the condensation phase,

- The temperature drop between the evaporator and the top of the evaporator strap has increased from 0.23K to 0.36K (+0.13K). This means that at the moment, a condensation temperature of 2.1K cannot be achieved if the temperature at the heat switch interface is higher than 1.74K (versus 1.87K in the previous test campaign),

An NCR [RD12] was raised to keep track and record any progress made on this issue. The following options have been considered as possible causes for this abnormal behaviour:

- Thermometry and calibration errors,
- The cooler internal straps and/or heat switches and/or bolted interfaces conductance has degraded during cold vibration,
- The L0 MGSE straps have not been integrated properly,
- The L0 MGSE straps conductances have degraded over time (handling and many integration cycles).

In the current configuration, the only temperature sensors available to help with the diagnostic are as follow:

- Cooler sensors (pump, shunt, evaporator and both heat switches sorption pumps). None have been fitted on the copper base of the heat switch interfaces with the L0 straps.
- L0 straps sensors (one at the top of the strap near the heat switch interface and one at the bottom of the strap near the cryostat interfaces).

4.3.2.4 Discussion

It is critical to understand where these changes might have taken place (strap or cooler) and why in order to anticipate whether they will affect the cooler hold time during flight. The possible causes are considered in more details hereafter.

- Thermometry and calibration errors:

The sensors locations and calibration curves on the L0 MGSE straps and cooler have not changed since the PFM2 test campaign. While a shift in the sensors' calibrations is possible (with time and/or shock), it seems unlikely that it would introduce such large changes in the temperature readings. The electronics reading the sensors have not changed since PFM2.

- The cooler internal straps thermal conductance has degraded during cold vibration:

Vibration testing has been carried by Lionel Duband's team at unit level on braided straps and showed that the straps thermal performance was not degraded by the vibrations. It is therefore unlikely to be the cause of the problem. This was also confirmed following the unit level testing of the instrument flight L0 straps.

- The cooler heat switches ON conductance has degraded during cold vibration:

The temperature profiles described previously showed that the evaporator and the shunt temperatures both shifted by roughly the same amount. This observation goes against a possible degradation of the evaporator heat switch ON conductance i.e. if the evaporator heat switch was the problem, one would expect the evaporator temperature profile to change only. There is no way to check the ON conductance of the pump heat switch as no temperature sensors have been fitted on the copper base of the switch.

- The cooler internal strap bolted interfaces conductance has degraded during cold vibration:

Another possibility could be that the cooler internal bolted interfaces have lost some of their preload following vibration but this again appears unlikely as changes have been observed as much on the pump as on the shunt and the evaporator i.e. it would means that all internal bolted interfaces have been degraded at the same time and in the same way.

- The L0 MGSE straps have not been integrated properly:

The same integration procedure has been used to integrate the MGSE straps during the CQM2, PFM2 and PFM3 test campaigns. In addition, given that the change in performance has been observed on both the pump and the evaporator strap, it makes it unlikely to be a workmanship error.

- The L0 MGSE straps performance has degraded over time (handling and integration cycles):

These MGSE L0 straps (which are different from the flight straps) have been used on numerous occasions to test the instrument CQM and PFM models in the RAL calibration. They have therefore been handled quite a lot and have undergone a certain number of integration/disintegration cycles with the various instrument models. While no major sign of degradation could be observed along the L0 straps body (i.e. similar temperature drops observed between the top and bottom temperature sensors), it has been suggested that work hardening might have taken place at the straps interface with the cooler heat switches i.e. surface flatness and gold plating degrading. This suggestion currently appears to be the most likely cause for the observed degradation in performance. This is also consistent with the fact that degradation in performance has been observed on both the pump and the evaporator/shunt sides.

4.3.2.5 Additional Test - Pump Characterisation

Although the pump characterisation test was not part of the thermal tests planned for the PFM3 test campaign, one case was carried out to provide an additional input to the L0 straps/cooler heat switches interface degradation discussion. This test was performed on the 26/05/06,
Table 4-10 summarises the cooler temperatures measured when steady-state was reached for a 5mW pump heater dissipation test case. The temperatures measured during the PFM2 test campaign for a similar test are also given here for comparison purpose.

Cooler Parameters (UTC)	**PFM2**	**PFM3**	**Delta**
	19/09/05 @ 14.30	**26/05/06 @ 14.15**	
SPHSV [mV]	551.224	562.045	10.821
EVHSV [mV]	-0.029	-0.134	-0.105
SPHTRV [V]	1.428	1.426	-0.002
Pump Heater I [A]	0.004	0.004	0.000
Q Pump Heater [mW]	5.036	5.030	0.006
Pump Heat Switch [K]	19.674	19.386	-0.288
Evaporator Heat Switch [K]	2.911	2.916	0.005
Shunt [K]	1.711	1.709	-0.002
Pump [K]	2.307	2.270	-0.037
Pump Strap Adaptor [K]	1.886	1.832	-0.055
Pump Strap Bottom [K]	1.753	1.725	-0.028
Temperature Gradient [K]	**PFM2**	**PFM3**	**Delta**
Pump to L0 Strap I/F	0.421	0.438	0.017
Across L0 Strap	0.133	0.107	-0.026
Total Temperature Drop	0.554	0.545	-0.009

Table 4-10 – Pump Characterisation Test

This test suggests that the pump is actually performing in a similar way during PFM2 and PFM3 for the applied load i.e. there are no obvious sign that the pump is running warmer in this configuration (the measured temperature gradients are very small and close to the sensor accuracy).

Note: it is important to note however that during the recycling, both the cooler and L0 straps are subjected to much higher heat loads (ranging from 80mW for the evaporator strap to 1W on the pump strap).

4.3.2.6 Preliminary Conclusions

A degradation of the interface conductance between the L0 straps and the cooler heat switches (both at the evaporator and the pump) is likely to be at the origin of the changes in the cooler temperature profiles observed during the PFM3 test campaign recyclings. Multiple strap integration/disintegrations cycles are believed to be the cause for these interfaces degradations (as much on the straps as on the heat switches bases). As no temperature sensor is fitted on the heat switches copper base (on the cooler side), it is currently impossible to discard any other source of degradation at this stage. On this basis however, it is currently assumed that if “non-degraded” thermal straps were used, the cooler performance would return to normal. New L0 MGSE straps will therefore be used as part of the PFM4 test campaign in order to confirm/validate this statement.

4.3.3 Automated and Optimised Cooler Recycling

A Virtual Machine (VM) was created during the PFM3 test campaign with the following objectives:

- Ensure repeatability from of cooler recycling to the other,
- Maintain the pump temperature above 45K for the whole duration of the condensation phase,
- Validate the VM algorithm and script.

As accurate control of the pump absolute temperature isn't needed here, a bang-bang control was implemented to maintain the pump within a +45K/+45.2K temperature range. Details about the VM pseudo-code and control parameters can be found in section 6.4.
Figure 4-7 is an example of temperature profiles recorded during an automated cooler recycling while Figure 4-8 provides a close-up of the pump temperature and heater voltage during the cooler condensation period. The following control was used:

- Apply 400mW to the pump until it reaches 45K,
- Reduce the pump heater output and modulate its power dissipation between 10mW and 70mW to maintain the pump temperature within 45K/45.2K,
- Control loop sampling time is 10 seconds.

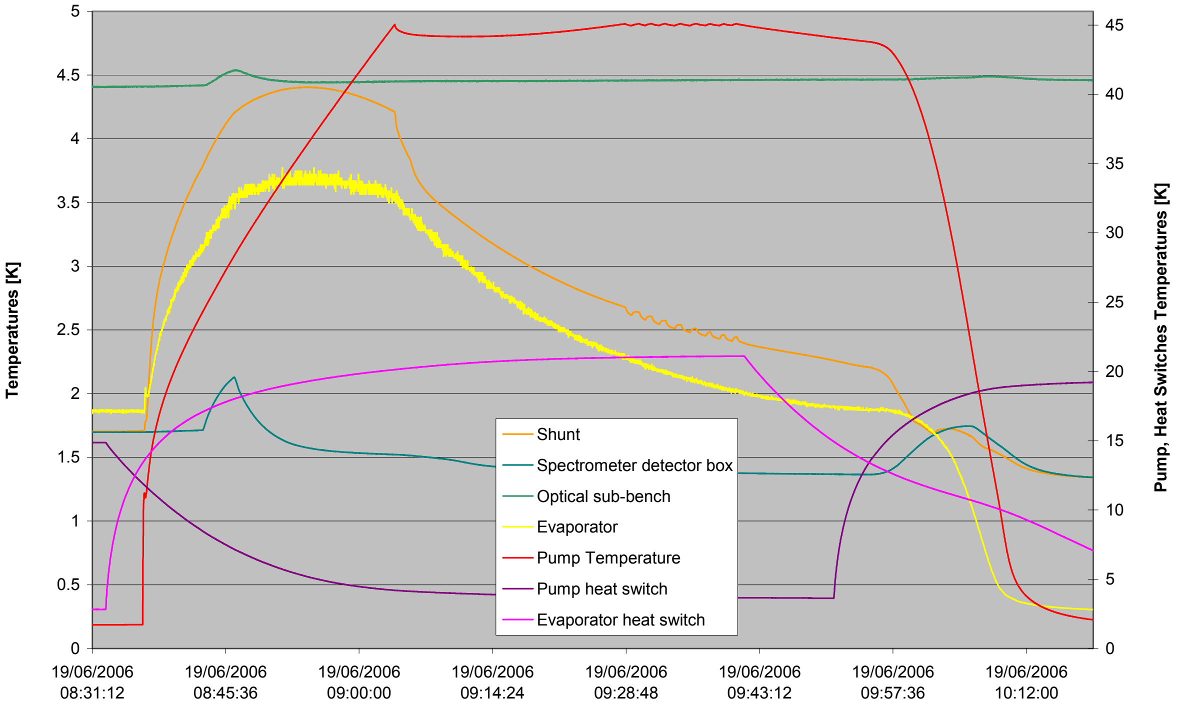


Figure 4-7 – Example of Automated Cooler Recycling

Note: the pump heater voltage modulation can be seen on the shunt temperature profile.

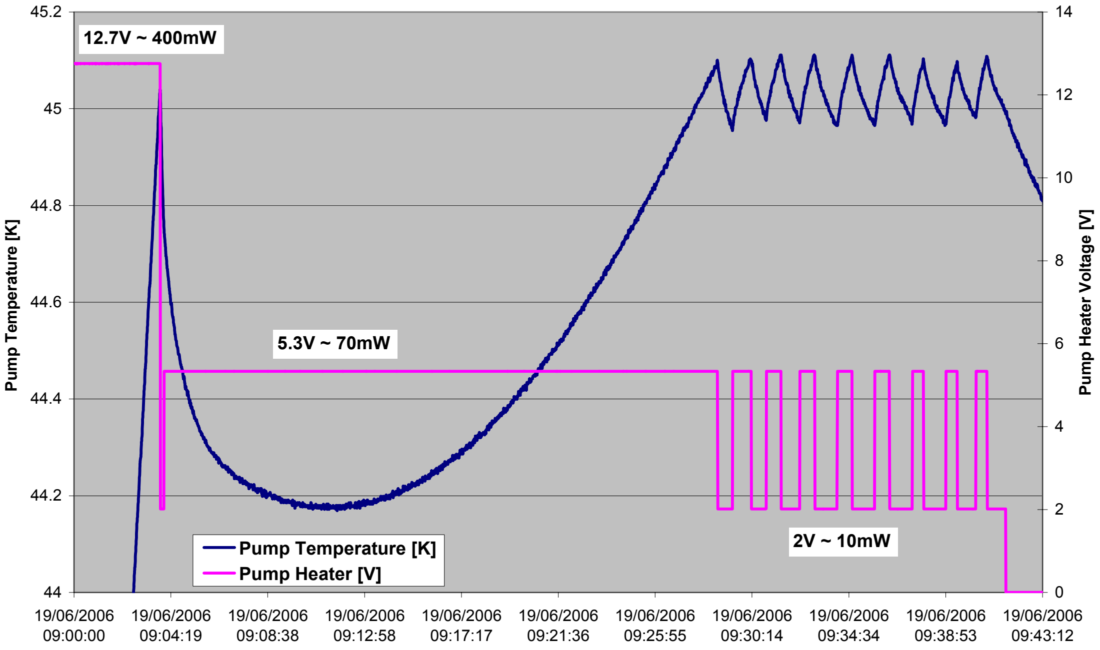


Figure 4-8 – Pump Temperature and Heater Voltage during Condensation Phase of Automated Recycling

In Figure 4-8, it can be seen that after switching the pump heater down and despite the 70mW dissipation, the pump still managed to cool down from 45K to about 44.2K before returning to the setpoint. This means that the control parameters requires more tuning to prevent this from happening:

4.4 Thermal Balance Test – Nominal Case

4.4.1 Cryostat Thermal Environment

The aim of this test was to measure and verify the instrument temperatures and performance for the "nominal" 1.7K/4K thermal environment. Table 4-11 and Figure 4-9 summarise the cryostat L1 and L0 environment required and achieved during the nominal thermal balance test case.

Required Cryostat Interface Temperature	Temperature Sensor	Required	Measured During Test	Limitations
During recycling	T_L0_ESTR1	1.9K	1.886K	-
At end of Condensation Phase	T_CEV_1	2.1K	**2.3K**	**Degraded interface between cooler and L0 MGSE straps (see NCR in [RD12])**
During low-phase operation	T_L0_DSTR1	1.71K	1.707K	-
	T_SOB_L1STR	4.3K	4.325K	-

Table 4-11 – Nominal Thermal Balance Case – Cryostat Setup

Note: The cryostat L2 temperature stage has been running at 15K for most of the test campaign. This does not affect the cooler performance as the cryostat L1 temperature stage is very stable whatever the instrument L1 operating load.

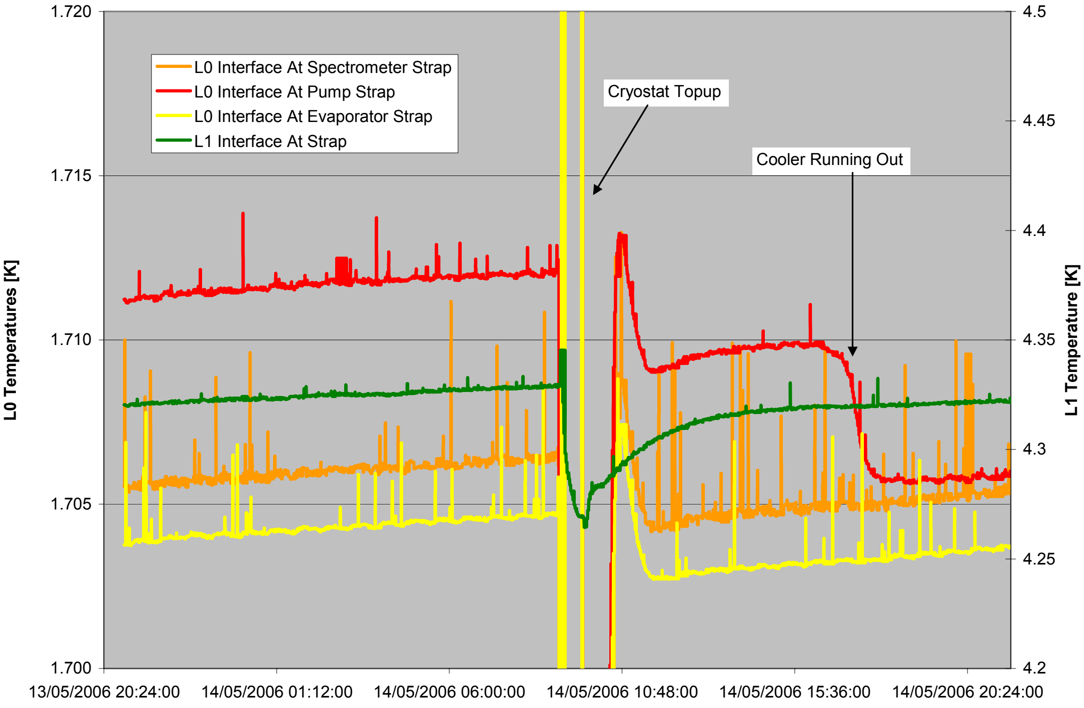


Figure 4-9 – Cryostat Thermal Environment during Nominal Thermal Case

4.4.2 Cooler Recycling and Hold Time

Before recycling, the cooler had been fully discharged to ensure nominal operating conditions. The cryostat L0 stage was setup to operate at 1.9K to ensure that one wouldn't have to open the manostat (as is needed during a recycling at 1.7K) and therefore ensures stable L0 interface temperatures throughout the recycling. This approach has been successfully used during the PFM2 test campaign and an evaporator temperature as low as 2.1K had been achieved at the end of the condensation phase. Figure 4-10 and Figure 4-11 describe the instrument and cryostat temperature profiles obtained during the cooler recycling. After the recycling, the cryostat L0 stage was set back to 1.7K in order to provide a flight representative thermal environment.

On Figure 4-10, one can see that the evaporator only managed to reach 2.3K at the end of the condensation phase. Reasons for this behaviour have been discussed in the previous section. Because of this however, the original test case could not be fully carried out. This test will still provide a set of data for the correlation of the thermal model.

Figure 4-12 on the following page shows the time at which the cooler ran out of helium for this specific test case.

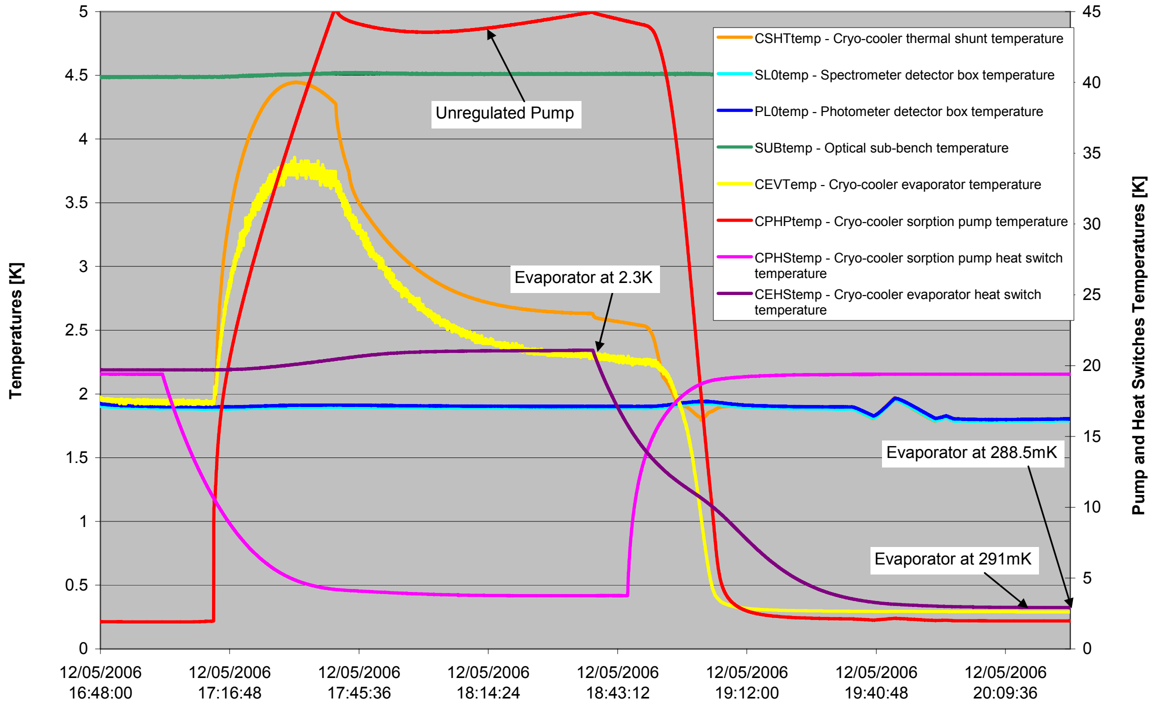


Figure 4-10 – Cooler Recycling During Nominal Thermal Balance Test Case

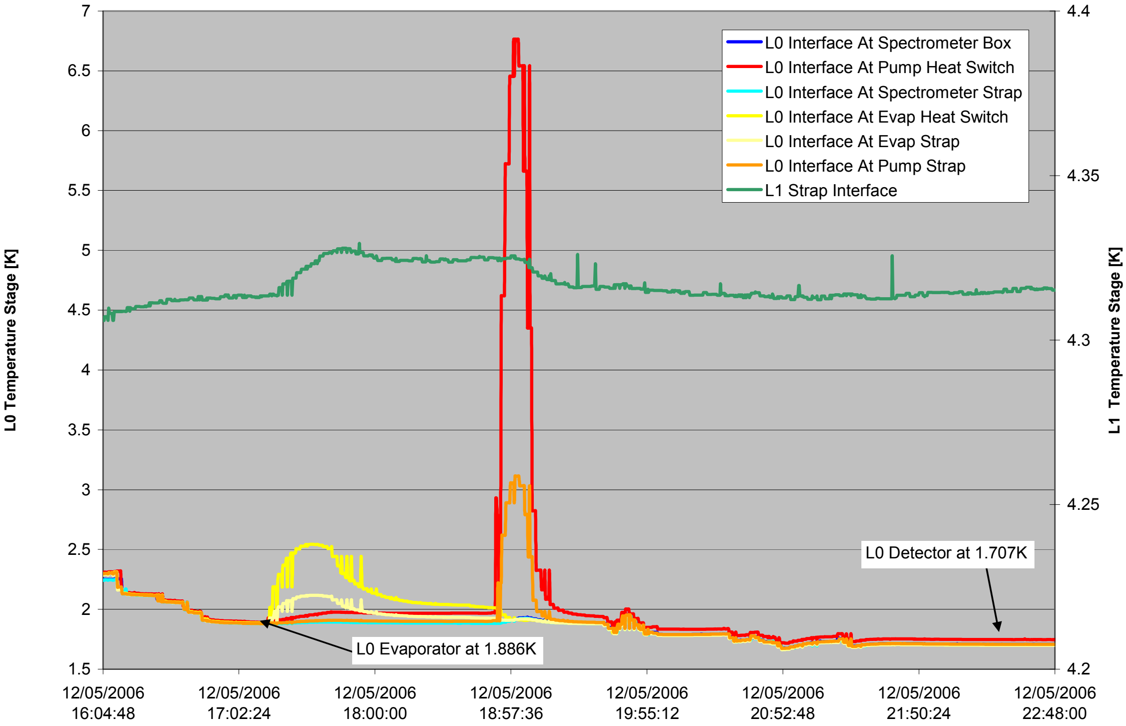


Figure 4-11 - Cryostat Setup during Nominal Thermal Case Cooler Recycling

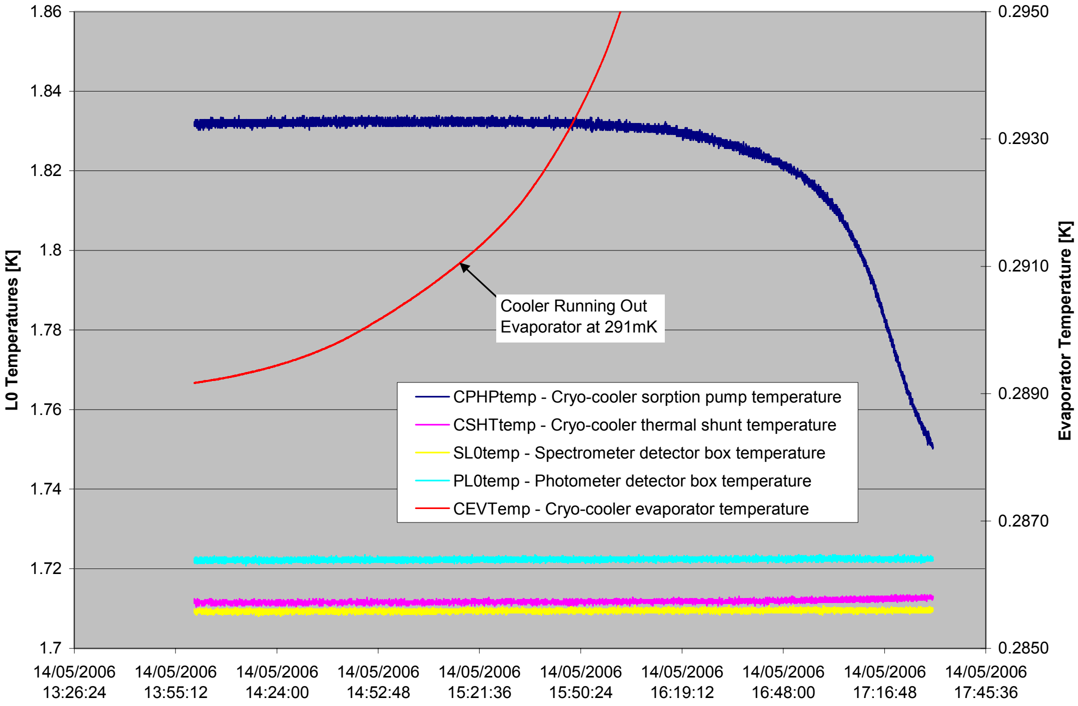


Figure 4-12 – Cooler Running Out during Nominal Thermal Balance Case

4.4.3 Nominal Thermal Balance Test Case - Summary

Parameters	**Value**	**Comments**
Recycling Start Date Time (UTC)	12/05/06 17.00	-
Recycling End Date Time (UTC)	12/05/06 19.53	-
L0 Temperature	1.886K	During Recycling.
Recycling Duration	~ 3 hr	The cooler recycling duration was affected by the degraded interfaces conductance too. See RD12
Pump Temperature	Unregulated	@ 44.4K at start of cryo-pumping
Evaporator Condensation Temperature	2.3K	See RD12 and section 4.3.2 of this document.
L0 Temperature	1.707K	During Operation.
L1 Temperature	4.31K	During Operation.
Hold Time Start	12/05/06 20:15:20	Based on evaporator temperature of 291mK (+1% of cold base temperature).
Hold Time End	14/05/06 15:16:19	Based on evaporator temperature of 291mK (+1% of cold base temperature).
Cooler Hold Time	~ 43hr 49 sec	Below the 46-hr required but the evaporator end of condensation temperature was 2.3K versus 2.1K required.
Evaporator Cold Base Temperature	288.5mK	As during PFM2.

Table 4-12 – Nominal Thermal Balance Test – Instrument Performance Summary

4.5 Thermal Balance Test – Test Case #2

4.5.1 Cryostat Thermal Environment

As the issue with the cooler was preventing any flight representative thermal testing, the hot case was redefined with a different purpose: assess the impact of the L0 enclosure temperatures on the cooler hold time. The following new interface temperatures were therefore defined for second thermal balance test case:

Required Cryostat Interface Temperature	Temperature Sensor	Required	New Reqt	Measured During Test	Notes
During recycling	T_L0_ESTR1	1.9K	1.8K	1.785K	[1]
At end of Condensation Phase	T_CEV_1	2.2K	2.3K	2.3K	[2]
During low-phase operation	T_L0_DSTR1	1.78K	1.78K	1.79K	[3]
	T_SOB_L1STR	5.5K	4.3K	4.275K	[3]

Table 4-13 – Thermal Balance Test Case #2 – Cryostat Setup

[1] - 1.8K was used instead of 1.9K in this case to see whether this manostat setting could also prevent instabilities in the L0 pot during recycling. If it did, it would have saved time by not having to reset the manostat after recycling (which is quite a lengthy process).

[2] – 2.3K should be used to account for issue experienced with cooler and allow a direct comparison with the performance measured as part of the Nominal thermal test case.

[3] - As for Nominal thermal case with a slightly warmer L0 enclosure temperatures in order to assess the impact of the L0 stage on the cooler hold time.

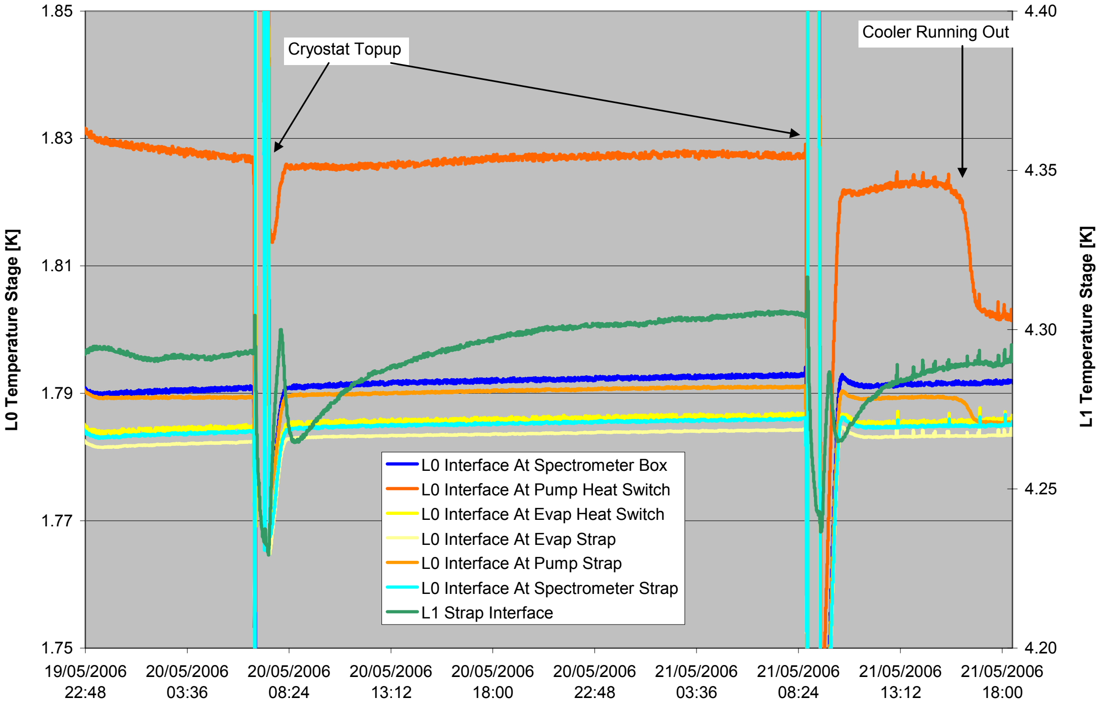


Figure 4-13 - Cryostat Thermal Environment during Thermal Test Case #2

4.5.2 Cooler Recycling and Hold Time

Before recycling, the cooler had been fully discharged to ensure nominal operating conditions. The cryostat L0 stage was setup to operate at 1.8K. Figure 4-14 and Figure 4-15 describe the instrument and cryostat temperature profiles obtained during the cooler recycling. After the recycling, the cryostat L0 stage was left to 1.8K in order to provide a second test case with a slightly different L0 thermal environment. Figure 4-16 on the following page shows the time at which the cooler ran out of helium for this specific test case.

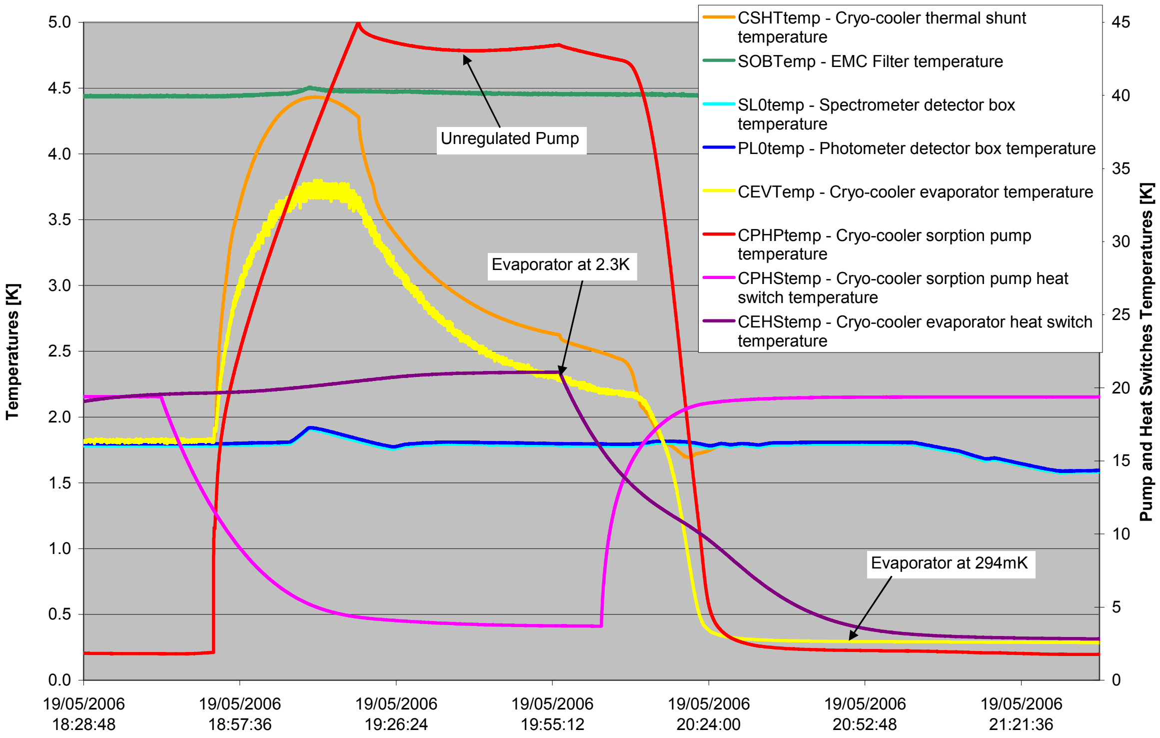


Figure 4-14 - Cooler Recycling During Thermal Balance Test Case #2

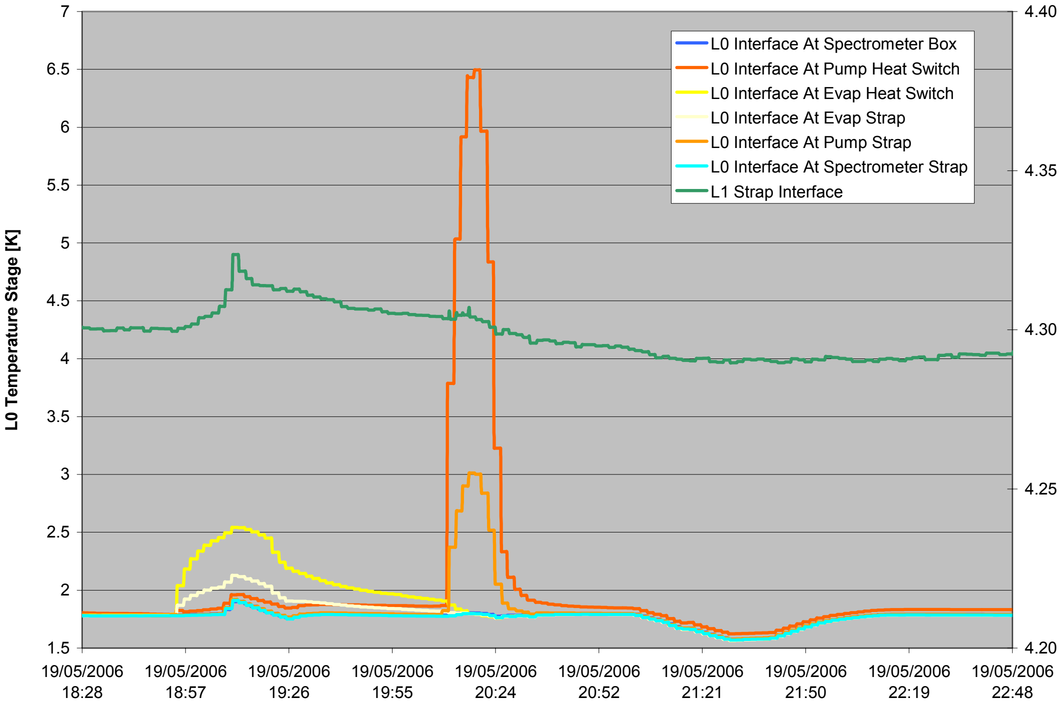


Figure 4-15 - Cryostat Setup during Thermal Case #2 Cooler Recycling

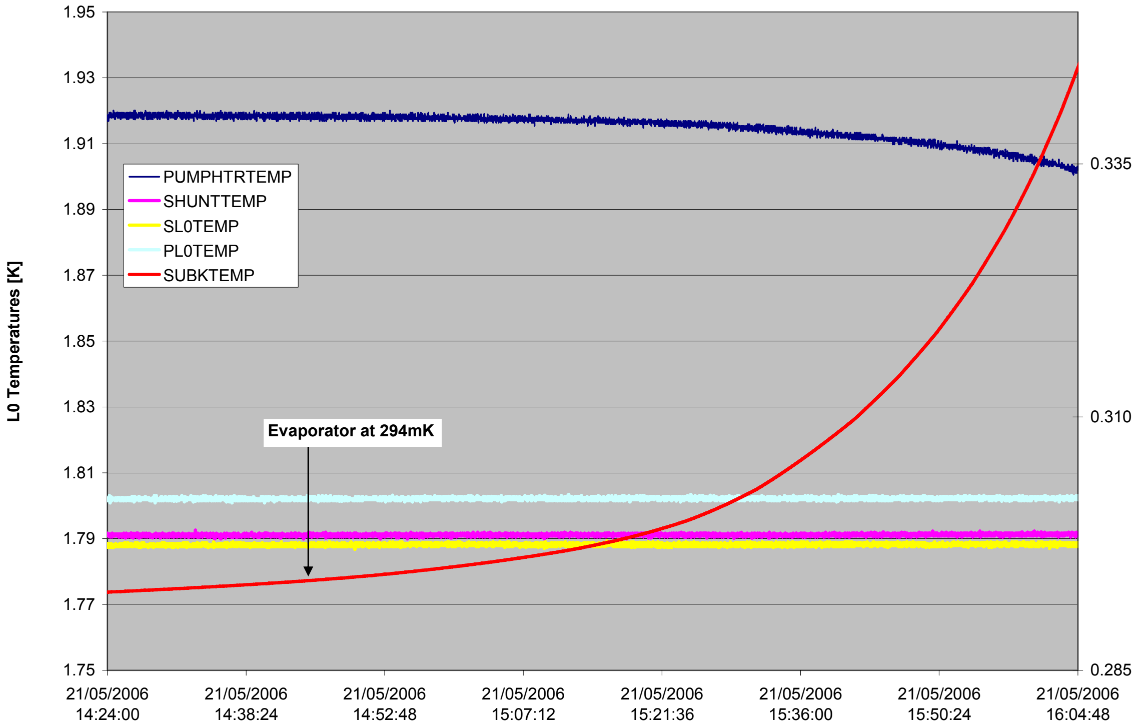


Figure 4-16 - Cooler Running Out during Thermal Balance Case #2

4.5.3 Thermal Balance Test Case #2 – Summary

Parameters	**Value**	**Comments**
Recycling Start Date Time (UTC)	19/05/06 18.44	-
Recycling End Date Time (UTC)	19/05/06 20.44	-
L0 Temperature	~1.8K	During Recycling.
Recycling Duration	2hr	-
Pump Temperature	Unregulated	@ 43.4K at start of cryo-pumping
Evaporator Condensation Temperature	2.3K	See RD12 and section 4.3.2 of this document.
L0 Temperature	1.79K	During Operation.
L1 Temperature	4.275K	During Operation.
Hold Time Start	19/05/06 20:51:30	Based on evaporator temperature of 294mK (+1% of cold base temperature).
Hold Time End	21/05/06 14:47:00	Based on evaporator temperature of 294mK (+1% of cold base temperature).
Cooler Hold Time	~ 42 hr	Below the 46-hr required but the evaporator end of condensation temperature was 2.3K versus 2.1K required.
Evaporator Cold Base Temperature	291mK	-

Table 4-14 –Thermal Balance Test Case #2– Instrument Performance Summary

4.6 BDA Absolute Temperature Performance

4.6.1 Photometer BDAs performance

Table 4-15 gives a summary of the updated photometer BDA temperatures recorded as part of the PFM2 test campaign for the 1.7K/4K environment (measured on 19/09/05 at 20:04). These measurements have been carried out again as part of the PFM3 test campaign for similar conditions (on the 22/05/06), as described in
Table 4-16.

	PFM2 Before	**PFM2 Corrected**	**Max Accuracy**	**Temp. Drop between BDA and Cold Tip**
Temperature	**mK**	**mK**	**mK**	**mK**
Cooler Cold Tip	288.5	288.5	-	-
PLW Detector	283	293	+/- 0.5	4.5
PMW Detector	303.7	298	+2	9.5
PSW Detector	293.3	300	+0.5	11.5

Table 4-15 – Summary of the Photometer BDA temperature during PFM2

	PFM3	**Max Accuracy**	**Temp. Drop between BDA and Cold Tip**
Temperature	**mK**	**mK**	**mK**
Cooler Cold Tip	288.5	-	-
PLW Detector	292.3	+/- 0.5	3.8
PMW Detector	291	+/-2	2.5
PSW Detector	294	+/-1	5.5

Table 4-16 - Summary of the Photometer BDA temperature during PFM3

- At first sight, the data appear consistent i.e. all detector temperatures are warmer than the cooler cold tip,

- The measured delta T however consists of the temperature drop along the 300mK busbar (designed to be 20mK maximum) as well as the temperature drop internal to the BDAs (designed to be 10mK maximum),

- According to the BDA EIDP, the detector internal temperature drops range from 7mK to 10mK, suggesting in this case a negative or next to null temperature drop along the 300-mK busbar, which is inconsistent,

- Some self-heating of the cooler cold tip temperature sensor might be at the origin of this discrepancies and/or the algorithm used to estimate the BDA temperature is not properly calibrated,

- While the temperature of the cold tip hasn’t changed from PFM2 to PFM3, the PMW and PSW detector temperatures now appear to be colder (the predicted PLW temperature has also slightly changed but delta remains close to the measurement maximum accuracy) . Calibration error and/or presence of an helium film on the BDA are two possible explanations for this discrepancy.

4.6.2 Spectrometer BDAs performance

Table 4-17 gives a summary of the spectrometer BDA temperatures recorded as part of the PFM2 test campaign for the 1.7K/4K environment (measured on 22/09/05 at 19.28). These measurements have been carried out again as part of the PFM3 test campaign for similar conditions (on the 06/06/06 at 10.09), as described in Table 4-18.

	PFM2	**Temp. Drop between BDA and Cold Tip**
Temperature	**mK**	**mK**
Cooler Cold Tip	288.5	-
SLW Detector	299.9	11.4
SSW Detector	299.5	11

Table 4-17 – Summary of the Spectrometer BDA temperature during PFM2

	PFM3	**Temp. Drop between BDA and Cold Tip**
Temperature	**mK**	**mK**
Cooler Cold Tip	288.5	-
SLW Detector	283	-5.5
SSW Detector	302	13.5

Table 4-18 - Summary of the Spectrometer BDA temperature during PFM3

- The temperature measured during PFM3 for SLW is inconsistent, its temperature is currently predicted colder than the cooler cold tip,
- The measured delta T also consists of the temperature drop along the 300mK busbar (designed to be 20mK maximum) as well as the temperature drop internal to the BDAs (designed to be 10mK maximum),
- According to the BDA EIDP, the detector internal temperature drops range from 7mK to 12mK, suggesting in this case a negative or next to null temperature drop along the 300-mK busbar, which is again inconsistent,
- Some self-heating of the cooler cold tip temperature sensor might be at the origin of this discrepancies and/or the algorithm used to estimate the BDA temperature is not properly calibrated,
- Calibration error and/or presence of an helium film on the BDA are two possible explanations for the detector temperature discrepancies.

4.7 PTC Thermal Performance

The temperature increase of the 300mK subsystem versus PTC power dissipation has been characterised as part of the PFM3 test campaign [RD9]. The evaporator drift over 46hr has also been characterised and preliminary analysis shows that the thermal stability required at the 300mK stage can be achieved within the 1µW power budget allocated to the PTC.

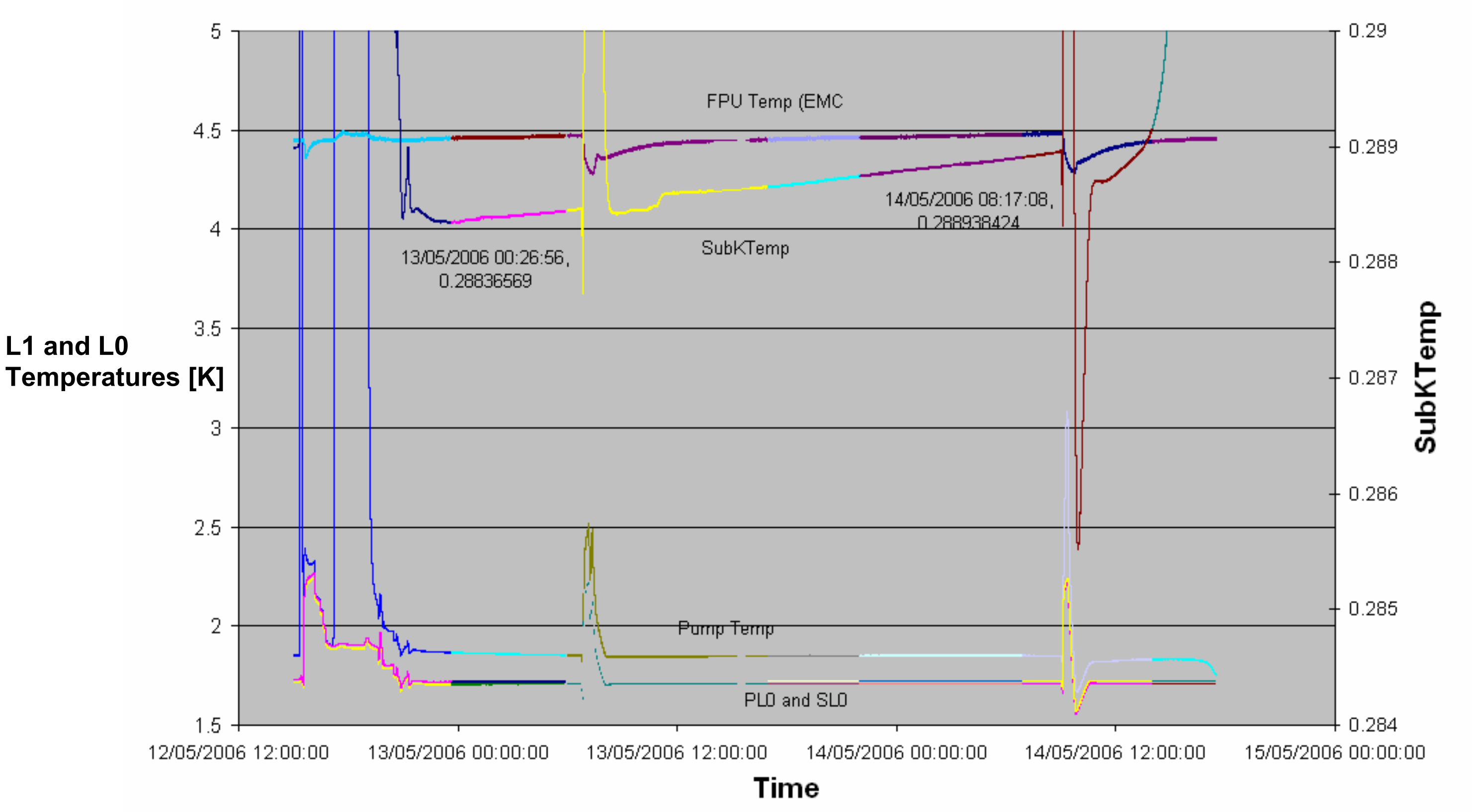


Figure 4-17 – Evaporator Temperature Profile during a 46hr timeline (without PTC)

Observations:

- An approximate linear drift of 0.018mK/hr has been measured for the evaporator over a 46hr period without any PTC control (as described in Figure 4-17),
- This corresponds to a total temperature drift of 0.828mK over the 46 hours period,
- The following performance has been measured during the PTC characterisation test:
  - dT/dQ = 0.62mK/µW,
- To stabilise the evaporator temperature over 46hr thus requires an average PTC power dissipation of 0.67uW,
- The 1 µW budget allocated to the PTC should therefore be enough to stabilise the temperature of 300-mK system and also leaves some “Headroom” for further control.

It is important to note however that the RAL calibration cryostat provides a more stable environment than Herschel.

4.8 Mechanisms/Calibration Source Operations

4.8.1 Observations

The following figures describe the impact of the operation of various mechanisms and calibration sources on the SPIRE FPU temperatures.

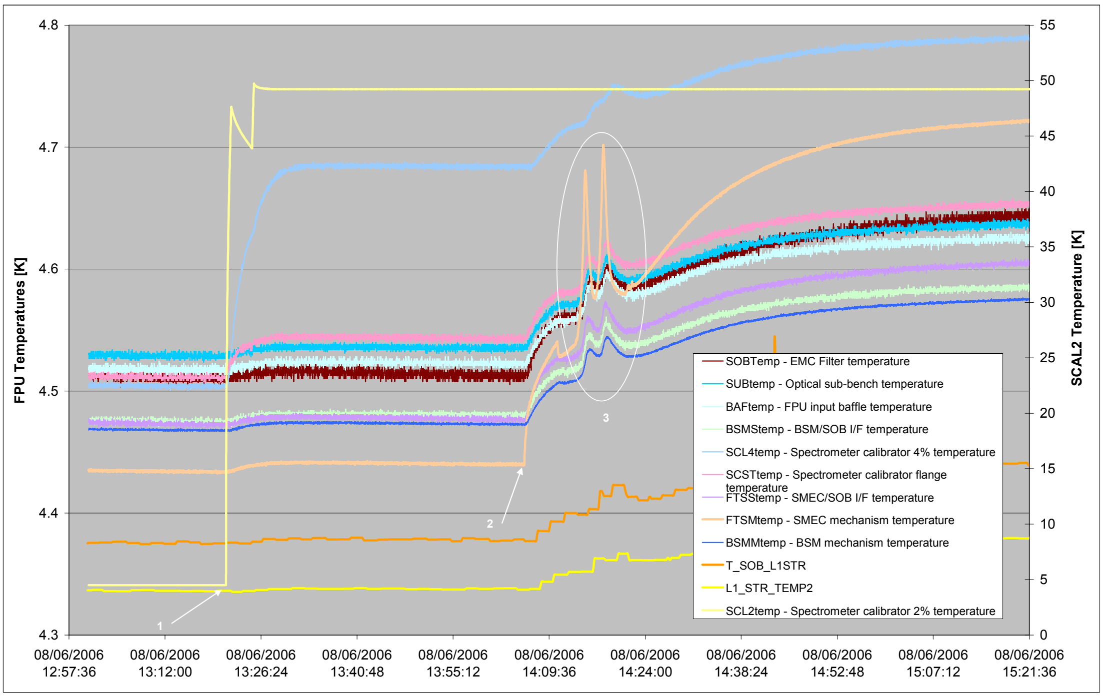


Figure 4-18 – FPU Temperatures during SCAL and SMEC Operations

Step	Time	Action	Bias
1	13.21	SCAL2 Manual Warm-up to ~49K	4.47mA => 1.26mA
2	14.06	SMEC ON	
3	14.14	SMEC Scans: 4	High Resolution Scan 1-39.5mm, 0.5mm/s

Table 4-19 – Details about SCAL and SMEC Operations

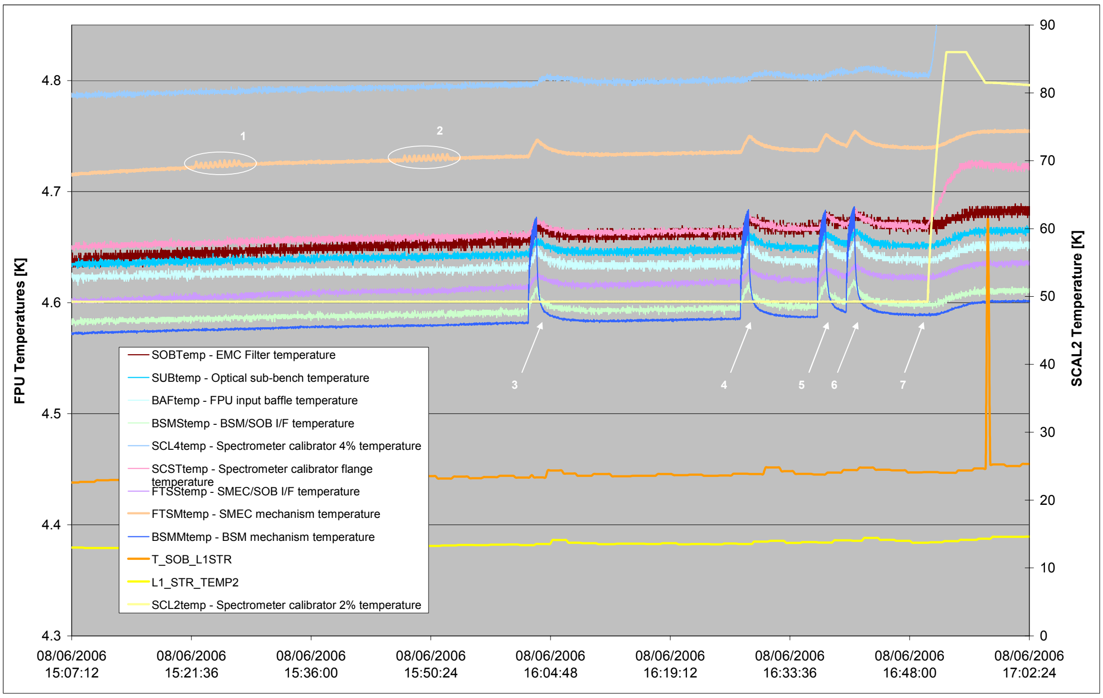


Figure 4-19 - FPU Temperatures during SCAL, PCAL and SMEC Operations

Step	Time	Action	Bias
1	15.21	SMEC Scans: 20	Low Resolution Scan 4-12mm, 0.5mm/s
2	15.47	SMEC Scans: 20	Low Resolution Scan 4-12mm, 0.5mm/s
3	16.03	PCAL Flash (looking at the lab)	6mA
4	16.03	PCAL Flash (looking at the lab)	6mA
5	16.28	PCAL Flash (looking at the lab)	6mA
6	16.41	PCAL Flash (looking at the lab)	6mA
7	16.49	SCAL2 Manual Warm-up to ~82K	5.4998mA => 2.025mA

Table 4-20 – Details about SCAL, PCAL and SMEC Operations

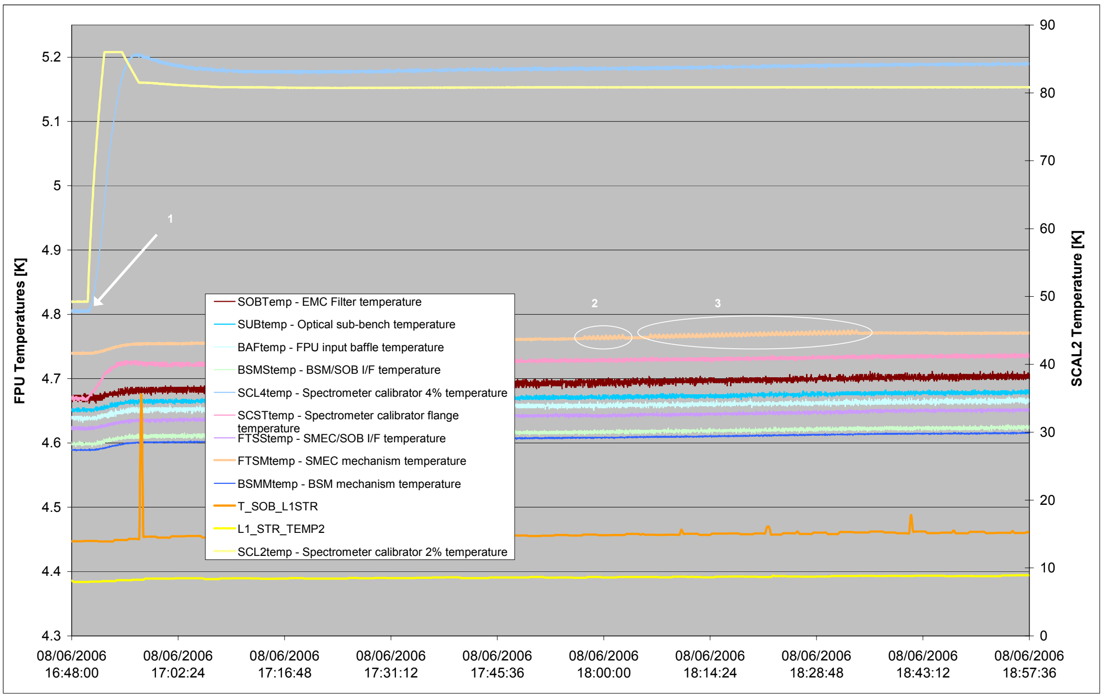


Figure 4-20 - FPU Temperatures during SCAL and SMEC Operations

Step	Time	Action	Bias
1	16.49	SCAL2 Manual Warm-up to ~82K	5.4998mA => 2.025mA
2	17.57	SMEC Scans: 10	Low Resolution Scan 4-12mm, 0.5mm/s
3	18.00	SMEC Scans: 100	Low Resolution Scan 4-12mm, 0.5mm/s

Table 4-21 – Details about SCAL and SMEC Operations

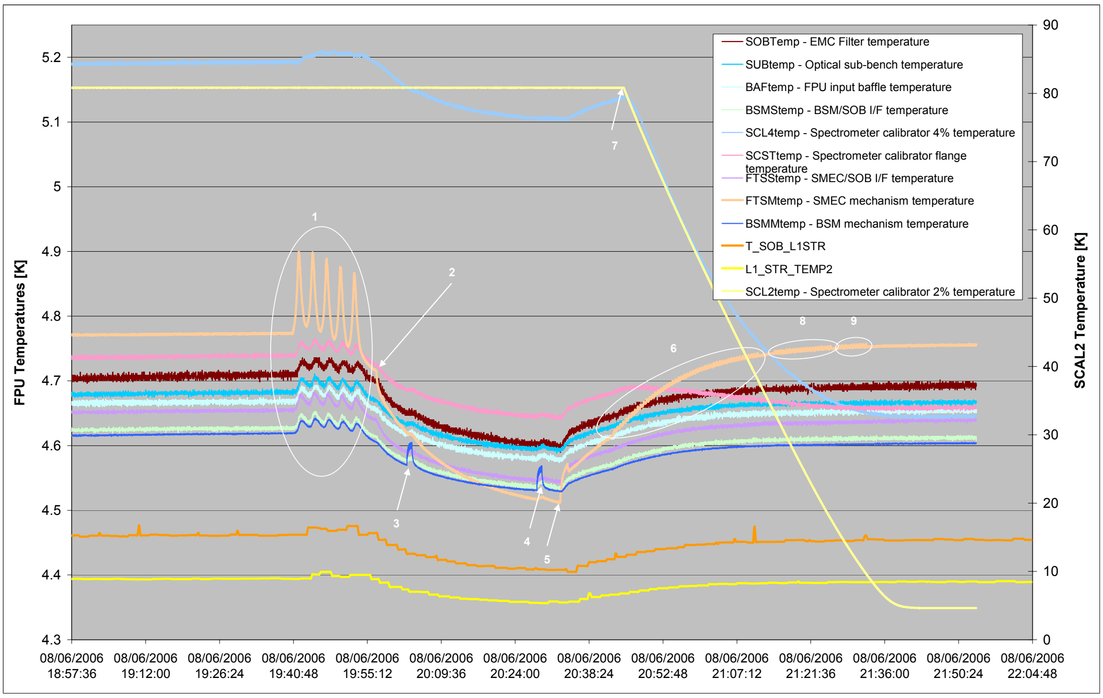


Figure 4-21 - FPU Temperatures during SCAL, PCAL and SMEC Operations

Step	Time	Action	Bias
1	19.41	SMEC Scans: 10	High Resolution Scan 1-39.5mm, 0.5mm/s
2	20.00	SMEC OFF	-
3	20.03	PCAL Flash (Standard)	3.8mA
4	20.30	PCAL Flash (Standard)	3.8mA
5	20.33	SMEC ON	-
6	20.43	SMEC Scans: 100	Low Resolution Scan 4-12mm, 0.5mm/s
7	20.46	SCAL2 OFF	-
8	21.14	SMEC Scans: 40	Low Resolution Scan 4-12mm, 0.5mm/s
9	21.27	SMEC Scans: 20	Low Resolution Scan 4-12mm, 0.5mm/s

Table 4-22 – Details about SCAL, PCAL and SMEC Operations

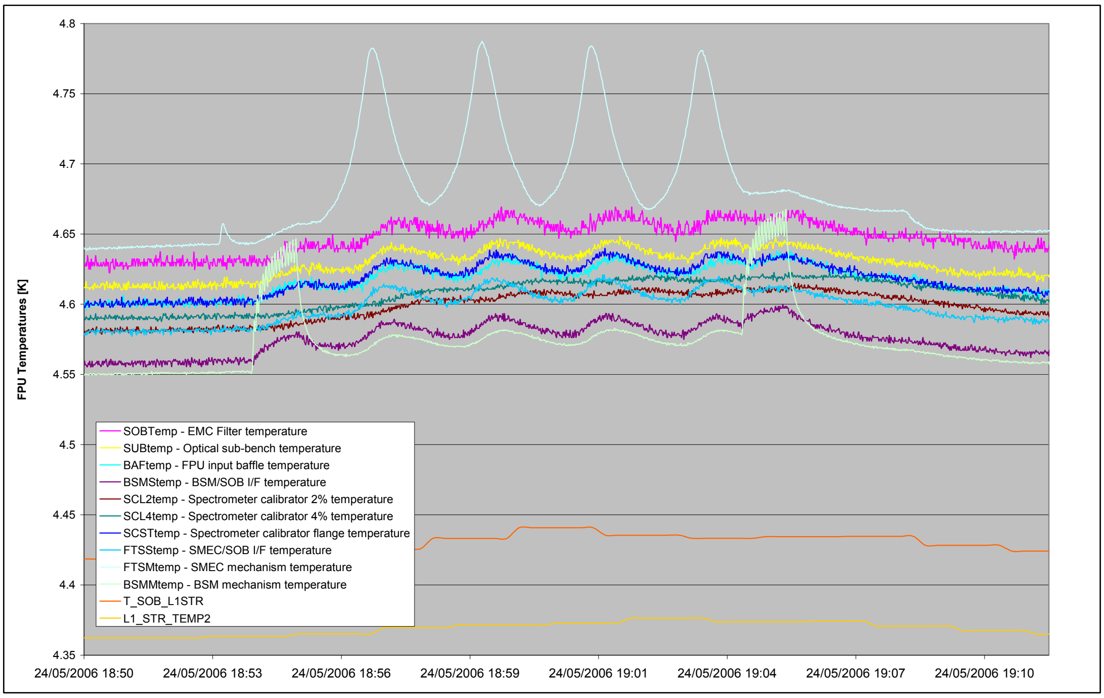


Figure 4-22 - FPU Temperatures during Spectrometer Point AOT

SPIRE Spectro Point	Parameters
SMEC Sampling	250Hz
Spatial Sampling	Sparse
Spectral Sampling	High
Total number of H/M scan at each pointing and jiggle position	8
Total number of L scan at each pointing and jiggle position	0
PCAL Flashes	1 at start of scan 1 at end of scan

Table 4-23 - Details about Instrument Operations during Spectrometer Point AOT

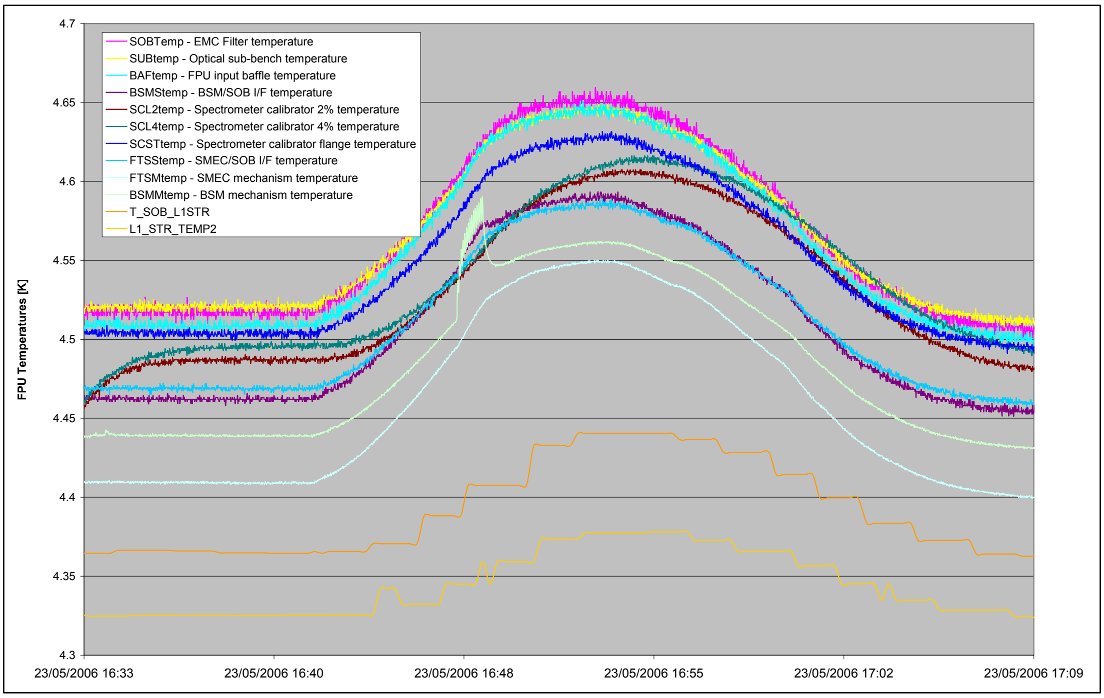


Figure 4-23 - FPU Temperatures during Large Photometer Scan AOT

SPIRE Photo Large scan	Parameters
Scan Length	60
Number of times to repeat map	1
Number of scan lines in map	4
Number of lines between PCAL Flashes	999999

Table 4-24 - Details about Instrument Operations during Large Photometer Scan AOT

Notes:

- The observed L1 stage warm-up is the result of a manostat operation as the cryostat L0 stage was getting instable.
- The first PCAL flash gives an indication of the start of the AOT test.
- The test was aborted at 17.00 because of some problem with the telemetry.

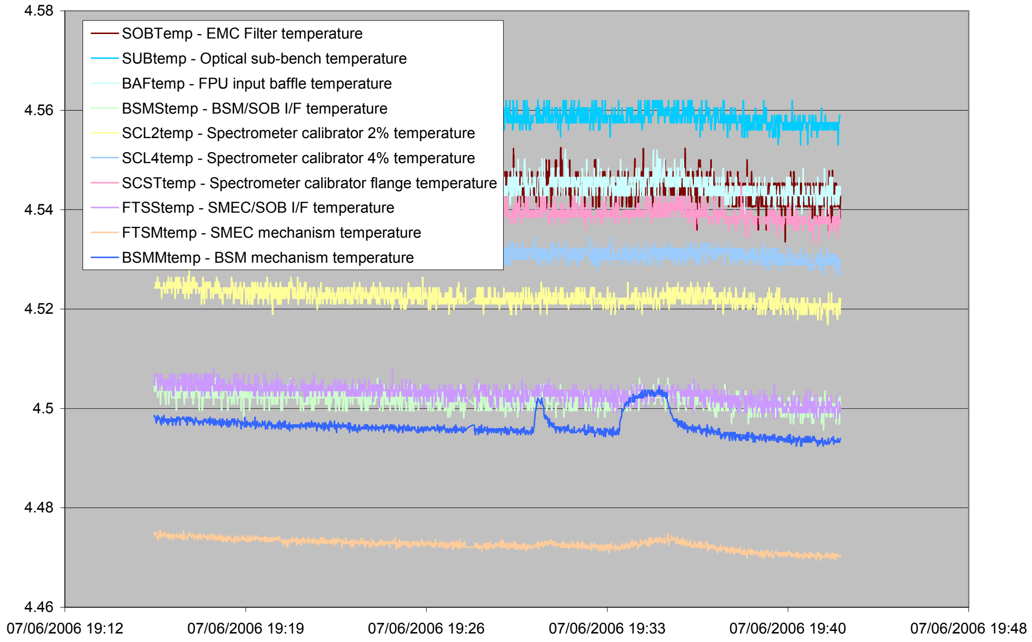


Figure 4-24 – FPU Temperature Profiles during BSM Chopping at 5Hz

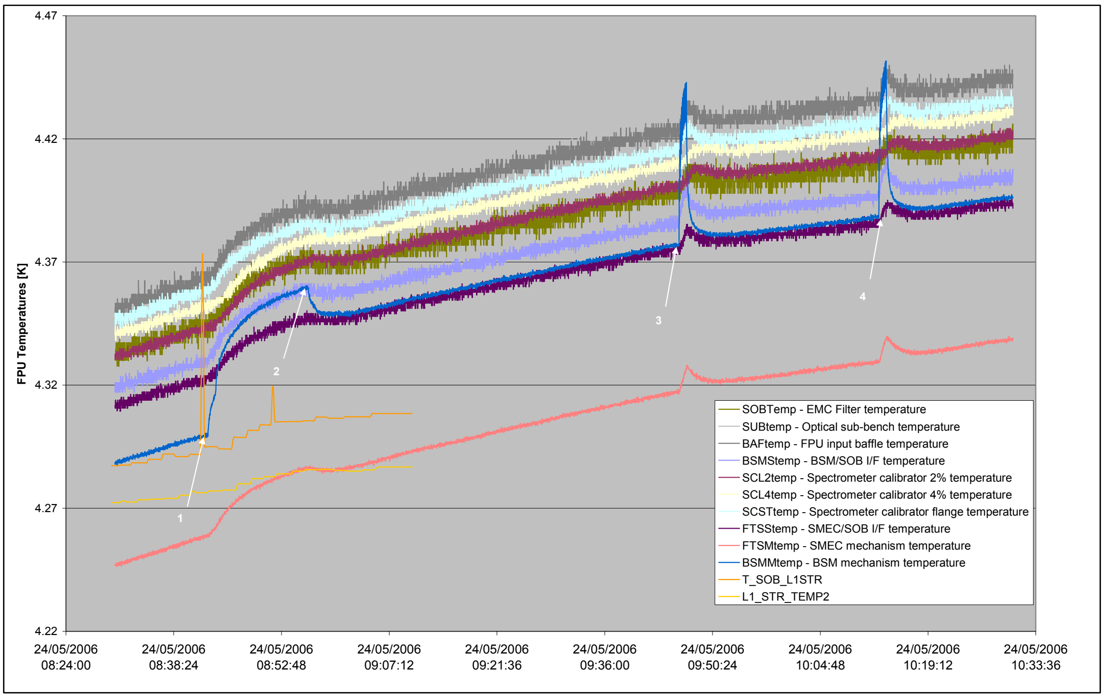


Figure 4-25 - FPU Temperatures during Large Photometer Scan AOT

Step	Time	Action	Comment
1	8.43	BSM ON	
2	8.55	Attempt to find BSM zero current position	
3	9.45	PCAL Flash - Start of SPIRE Photo Large Scan (AOT)	
4	10.14	PCAL Flash - End of SPIRE Photo Large Scan (AOT)	Test Successful

Table 4-25 – Details about BSM and PCAL operation

SPIRE Photo Large scan	Parameters
Scan Length	60
Number of times to repeat map	1
Number of scan lines in map	10
Number of lines between PCAL Flashes	11

Table 4-26 - Details about instrument Operations during Large Photometer Scan AOT

Notes:

- The cryostat L1 temperature stage appeared to be warming up slightly (this test was done shortly after the cryostat morning top-up).
- No data was recorded by the TFCS after 9.00am.

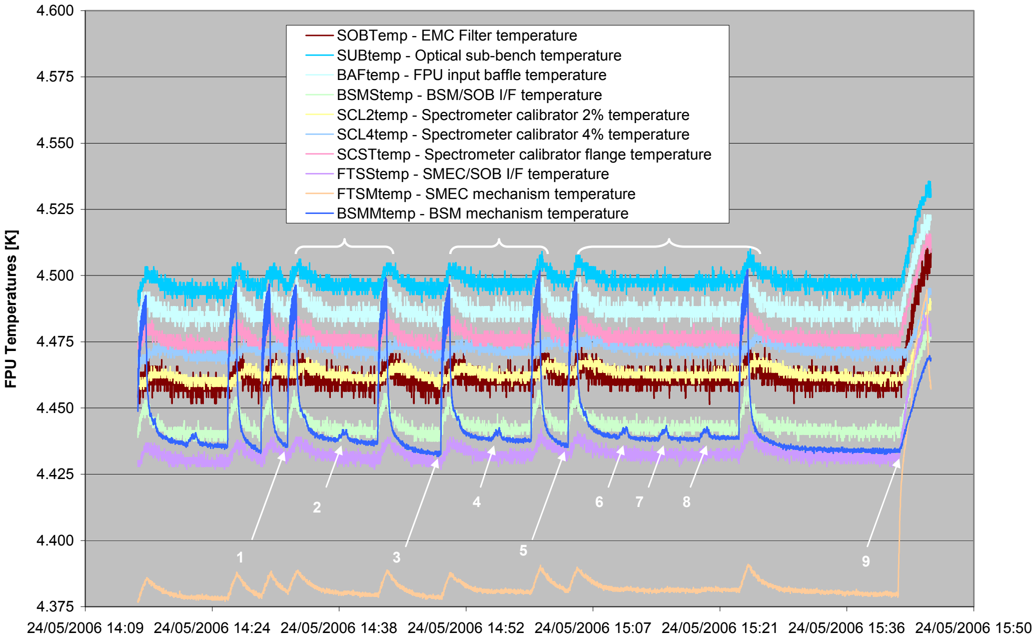


Figure 4-26 - FPU Temperatures during Photometer 7 Point Jiggle AOT

Step	Time	Action
1	14.32	Start of PHOTOMETER 7 POINT JIGGLE (AOT)
		Node Cycle: 1 Jiggle per node: 1 Node cycle per PCAL Flash: 2
2	-	PCAL Flash
3	14.49	Start of PHOTOMETER 7 POINT JIGGLE (AOT)
		Node Cycle: 1 Jiggle per node: 1 Node cycle per PCAL Flash: 2
4	-	PCAL Flash
5	15.03	Start of PHOTOMETER 7 POINT JIGGLE (AOT)
		Node Cycle: 2 Jiggle per node: 1 Node cycle per PCAL Flash: 3
6-7-8	-	PCAL Flashes
9	15.41	SMEC ON

Table 4-27 – Details about Instrument operation during Photometer 7 Point Jiggle AOT

4.8.2 Summary

Delta T	**SCAL2 Warm-up 1**	**SCAL2 Warm-up 2**	**SCAL2 Max**	**SMEC ON**	**SMEC HI Res Scan**	**SMEC LO Res Scan**	**SMEC Max**	**BSM ON**	**PCAL 6mA**	**PCAL 4.8mA**	**BSM Max**
FPU Overall	5 mK	20 mK	25 mK	40 mK	15 mK	2 mK	55 mK	16 mK	15-25 mK	6 mK	41 mK
SCAL2	44.7K [4K-49K]	31.5 K [49K-80.8K]	76.2 K [4K-80.8K]	-	-	-	-	-	-	-	-
SCAL4	0.177 K	0.376 K	0.553 K	-	-	-	-	-	-	-	-
SCALS	31 mK	53 mK	84 mK	50 mK	21 mK	-	-	-	-	-	-
SMEC Mechs	-	-	-	0.18 K	0.39 K	5 mK	0.57 K	-	-	-	-
SMEC SOB IF	-	-	-	64 mK	29 mK	2 mK	93 mK	-	-	-	-
BSM Mechs	-	-	-	-	-	-		37 mK	85 mK	28 mK	122 mK
BSM SOB IF	-	-	-	-	-	-		17 mK	25 mK	12 mK	42 mK

Table 4-28 – Summary of FPU Temperature Gradient during Operation

4.9 JFETS Thermal Performance

During operation, when SPIRE is in spectrometer mode, the spectrometer JFET (SJFET) L3 interface temperature increases by less than 0.5K and it can be seen in Figure 4-27 that the JFET Chassis temperature is closely following (for a dissipation about 2/3 x 15mW +/- 5% during PFM3).

Note: Figure 4-27 below shows that when the SJFET is OFF, its chassis temperature is actually below the L3 interface (by 0.06K). Given that the temperature sensors have an accuracy of +/-0.25K, this doesn't appear unreasonable. It means that when ON, the SJFET is likely to run 0.06K warmer than the L3 interface.

When SPIRE is in photometer mode, the Photometer JFET (PJFET) L3 interface temperature increases by 0.75K (see figure below) but it can be seen that the PJFET temperature is increasing by a further 1.4K (for a dissipation of 57mW +/-5%), a delta which is much higher than expected.

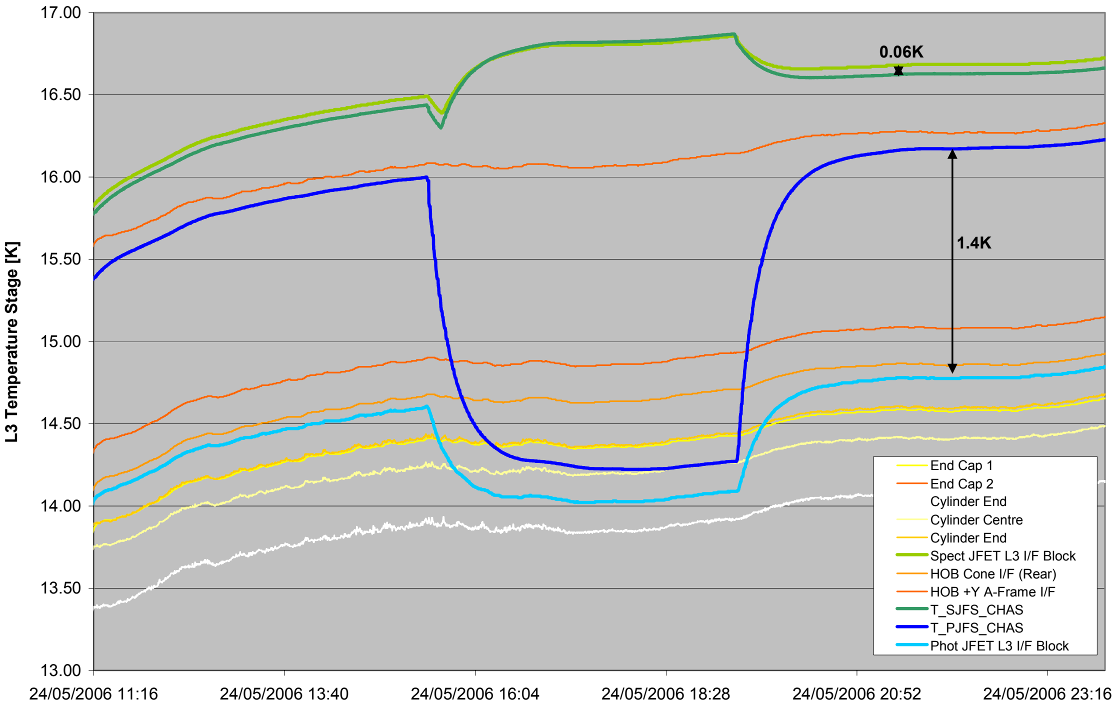


Figure 4-27 – JFETS Thermal Performance during PFM3 Test Campaign

After checking the PFM2 test data (described in Figure 4-28 and Figure 4-29 hereafter), at first sight it seems that this PJFET behaviour was more or less present during the PFM2 test campaign. However, as there was no working sensor at the PJFET L3 interface, it is impossible to tell whether this temperature increase was taking place along the L3 strap or at the interface between the PJFET and the strap. During PFM2, the SJFET temperature increase was about 0.17K for the full power dissipation (would give 0.11K for 2/3 of the power experienced during PFM3 which isn't far of the 0.06K predicted).

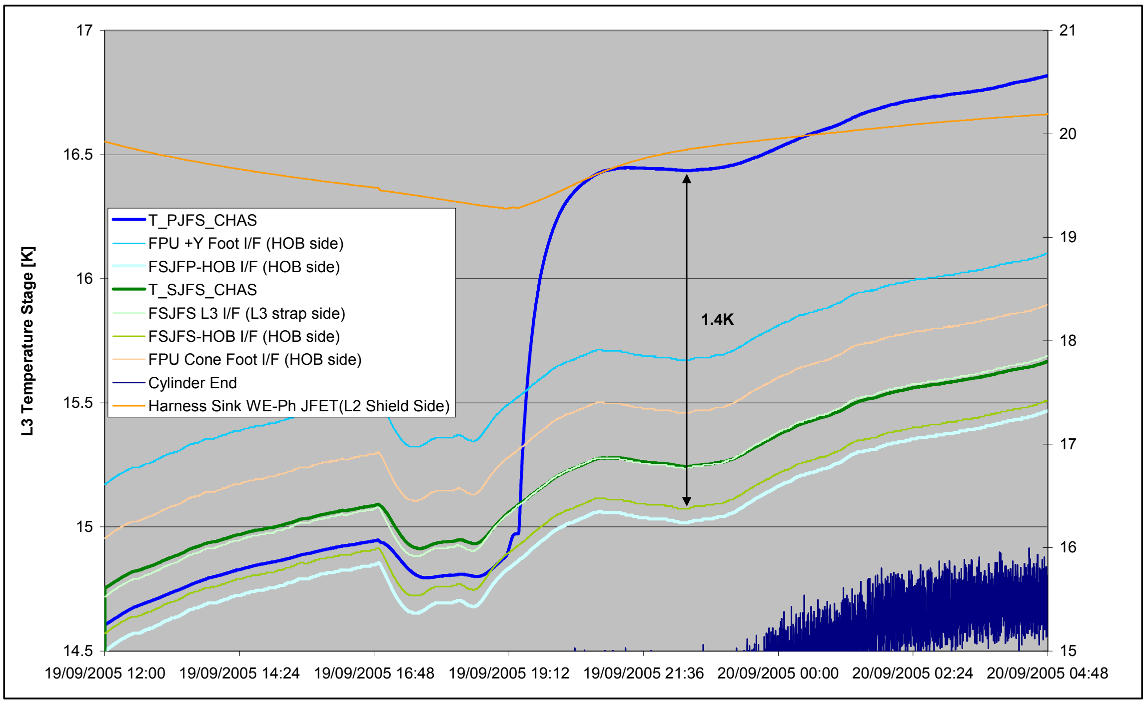


Figure 4-28 – PJFET Thermal Performance during PFM2 (Full Power ~ 57mW +/-5%)

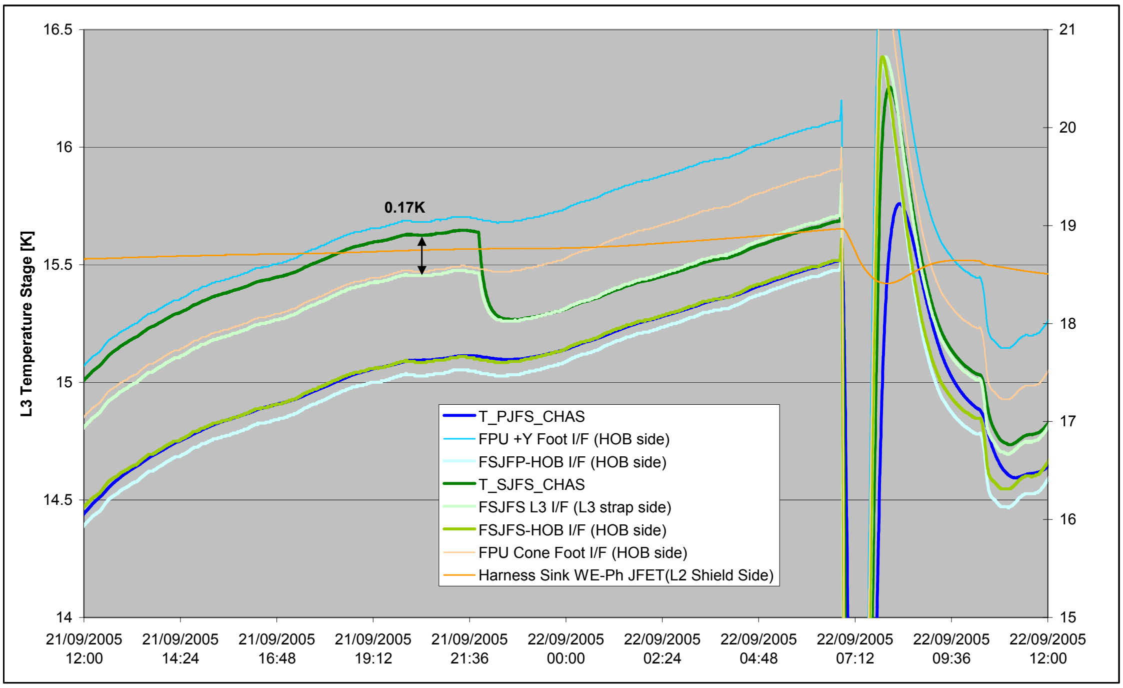


Figure 4-29 – SJFET Thermal Performance during PFM2 (Full Power ~ 15mW +/-5%)

The data from the PFM3 test campaign confirms that most of the PJFET temperature gradient is taking place between the PJFET and the L3 interface. There are several possible causes for this:

- Sensor inaccuracies,
- The contact conductance between the strap and the PJFET Chassis is under-performing,
- The glue joint implemented on the PJFET chassis is underperforming,
- The gradient along the PJFET chassis is higher than expected,
- A combination of all the above.

An NCR has been raised to trace this issue [RD14] which will be investigated further as part of the PFM4 test campaign.

5 PFM3 TEST CAMPAIGN CONCLUSIONS AND TEST LIMITATIONS

The L1 characterisation test has been completed successfully and two additional cases were run with a different L2 cryostat environment to help the correlation of the thermal model. The following limitations are applicable:

- Radiation and harnesses heat loads in the RAL calibration cryostat are not flight representative,
- The cryo-harnesses heat sinking on the cryostat L2 shield and onto the HOB might have been compromised during this test campaign to reduce the risk of electrical shorts in the cryo-harnesses.
- As the cryostat environment changes, the instrument harnesses, supports and radiation heat loads are all changing as well.

Please refer to section 4.2 for more details.

Some issue were encountered with the cooler during the PFM3 test campaign and analysis [RD15] has been performed to identify the most likely cause for the degraded cooler performance during recycling. It is currently believed that a degradation of the bolted interface conductance between the cooler heat switches and the L0 GSE straps is most likely causing the cooler to run warmer during recycling. New L0 MGSE straps (with non degraded interfaces) will be fitted during the PFM4 test campaign to validate this statement.
A new VM was implemented that help the automation and optimisation of the cooler recycling. This VM was tested and used successfully on several occasions during the PFM3 test campaign. Fine-tuning of the control parameters is still required to ensure that the pump remains above 45K at all time; this activity should be completed as part of the PFM4 test campaign. Please refer to section 4.3 for more details.

Two thermal balance test cases were carried out successfully although the second test case used a thermal environment slightly different from the one originally planned in the test specification. Please refer to sections 4.4 and 4.5 for more details.

The BDAs temperature has been measured on several occasions during the PFM3 test campaign and the predicted temperatures appeared somehow inconsistent with the temperature measured at the cooler cold tip. The temperature sensors on the evaporator will be checked at 0.3K for self-heating errors as part of the PFM4 test campaign. Please refer to section 4.6 for more details.

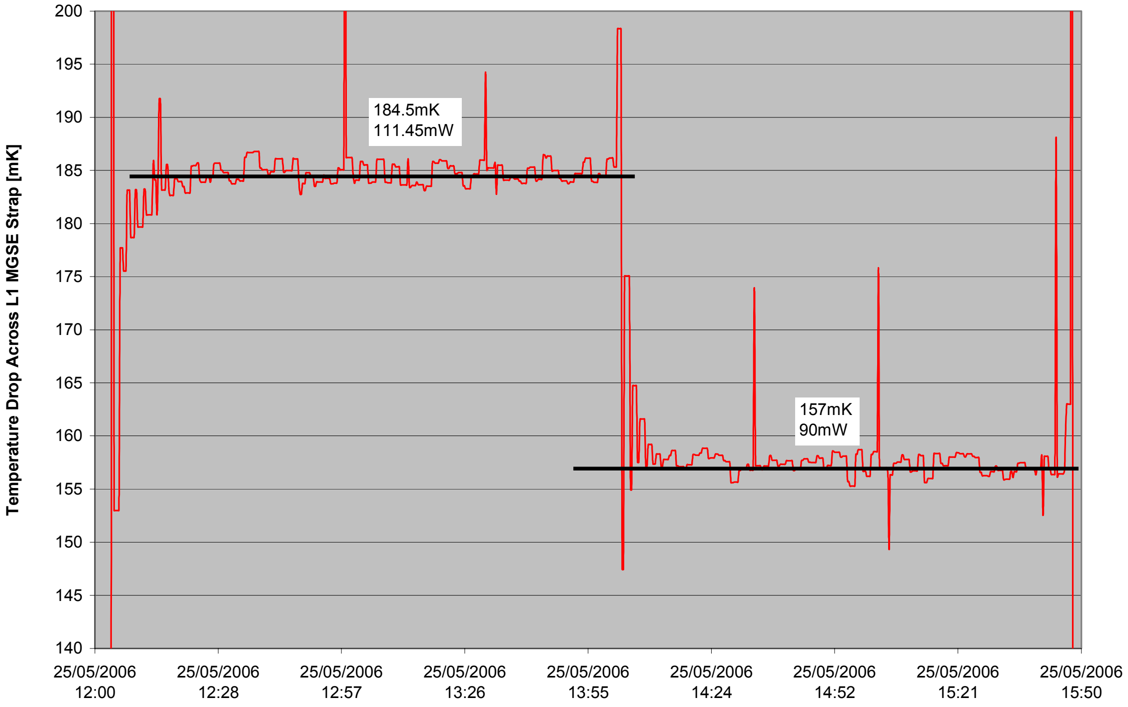
The PTC thermal performance and its impact on the 300-mK subsystem thermal stability has been fully characterised and allowed to confirm that the heat required to control of the BDAs is within the 1uW allocated budget. Please refer to section 4.7 for more details.

All mechanisms and calibration sources have been exerted during the PFM3 test campaign in configurations matching flight operations as far as possible. Overall, the worse case FPU bulk temperature increase during the mechanism operation (independent from L1 interface variations) has been estimated to be about 0.1K and has for effect to increase the L0 stage temperature (L0 detector enclosures) by 1mK only. It is important to note that the CQM SMEC was still in use during this test campaign and that the performance of the flight SMEC remains to be verified as part of the PFM4 test campaign. Please refer to section 4.8 for more details about the mechanisms operations.

During operation, it was detected that the Photometer JFET chassis temperature was running warmer than expected. This discrepancy will be analysed further as part of the PFM4 test campaign. Please refer to section 4.9 for more details.

6 APPENDICES

6.1 L1 Characterisation Test – Nominal Test Case Results



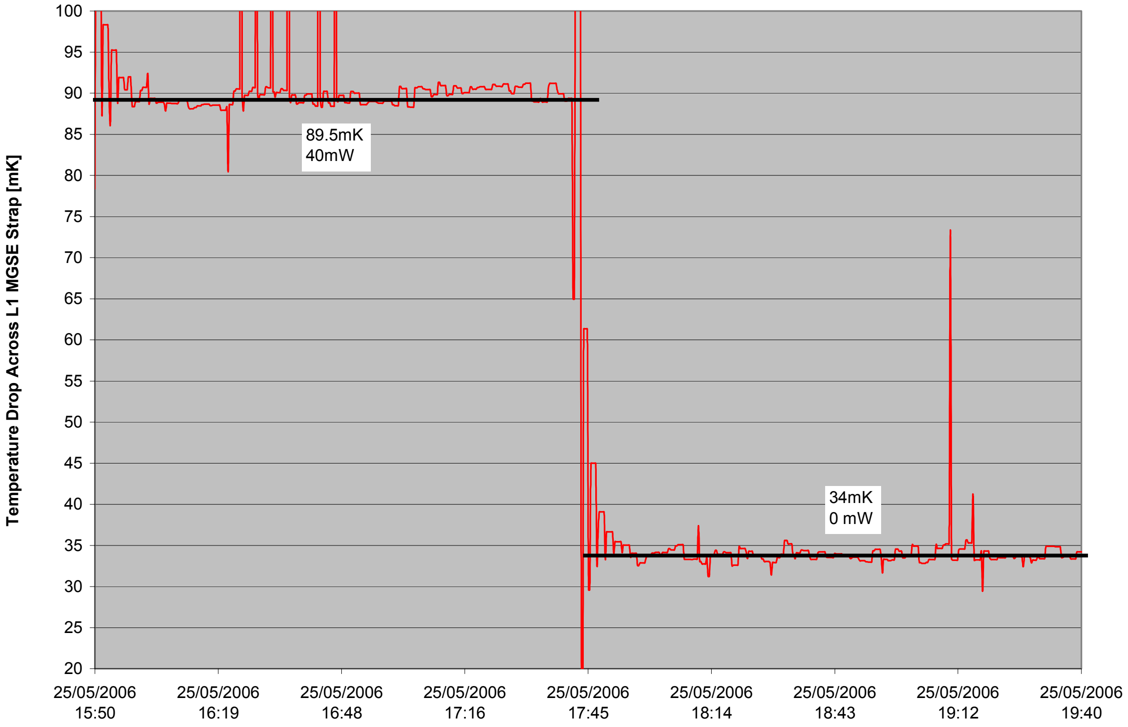


Figure 6-1 – Average L1 Strap Temperature Drop during Characterisation Test

6.2 L1 Characterisation Test – 10K Test Case Result

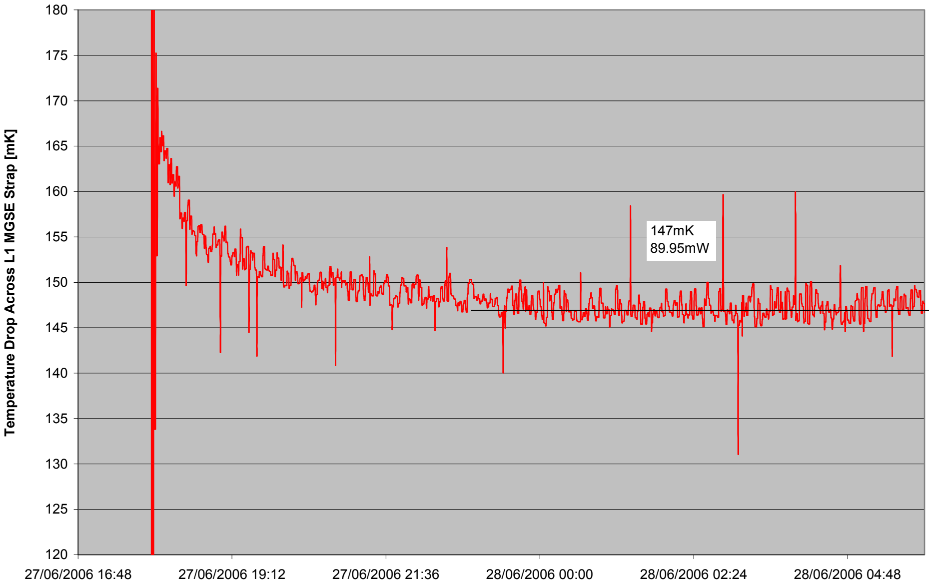


Figure 6-2 - Average L1 Strap Temperature Drop during Characterisation Test

6.3 Cooler Recycling Summary

Cooler Recycling	**ID**	**Date**	**Time (UTC)**	**Comments**
Manual Scripts	1	08/05/06	15.30-18.00	L0 at 1.7K manostat opened
	2	10/05/06	19.55-22.30	L0 at 1.7K manostat opened
Thermal Case	#1	12/05/06	17.00-19.30	L0 at 1.9K manostat remained closed
	3	15/05/06	13.20-14.47	L0 at 1.7K manostat opened
	4	17/05/06	17.00-19.15	L0 at 1.7K manostat opened
Thermal Case	#2	19/05/06	18.42-20.44	L0 at 1.8K manostat opened
	5	21/05/06	19.30-21.30	L0 at 1.7K manostat opened
	6	23/05/06	17.04-19.30	Manostat left opened overnight
Automated Scripts	7	01/06/06	15.58-19.40	Issue with manostat and recycling procedure – L0 pot ran out during cooler recycling
	8	02/06/06	16.18-19.00	
	9	05/06/06	8.12-10.53	
	10	07/06/06	8.55-11.00	
	11	09/06/06	11.04-13.14	
	12	12/06/06	9.34-11.25	
	13	14/06/06	9.15-14.00	Issues with VM recycling procedure – cryostat instable. Manostat was not fully closed
	14	16/06/06	16.33-18.42	L0 at 1.7K Latest version VM HOB at 20K
	15	19/06/06	8.35-10.45	L0 at 1.7K manostat opened Latest version VM Cooler discharged Cryostat L0 Warm-up to 4K
	16	20/06/06	15.39-18.00	L0 at 1.7K manostat opened Latest version VM Manostat left opened after recycling
	17	23/06/06	8.20-10.45	L0 at 1.7K manostat opened Latest version VM
	18	26/06/06	8.00-11.03	L0 at 1.7K manostat opened Latest version VM Manostat left opened after recycling

Table 6-1 – Overview of all Cooler Recycling Performed during the PFM3 Test Campaign

6.4 Automated Cooler Recycling Algorithm and Parameters

The algorithm used for the cooler automated recycling VM (version 4.4) is described in Figure 6-3 on the following page. The applicable parameters are listed in Table 6-2 below.

Parameters	Description	Setting	Current	Voltage	Hex
A	Heater Heat Switch ON (during Recycling)	0.8 mW	1.4 mA	0.56V	0x0DEB
B	Heaters OFF	0 mW	0.0 mA	0V	0x0000
C	Pump Heat Switch – Actuation Temperature	12 K	-	-	0xBF9B
D	Heater Pump Dissipation 1	400 mW	31.54 mA	12.7V	0x0A25
E	Pump Temperature Condensation	45 K	-	-	0x8E76
F	Heater Pump Dissipation 2	10mW	4.987mA	2V	0x019C
G	Heater Pump Dissipation 3	70mW	13.197mA	5.3V	0x043F
H	Pump Temperature Condensation Threshold	45.1K	-	-	0x8E49
I	Evap Temperature Condensation	2 K	-	-	0x7EBE
J	Pump Temperature Threshold	2 K	-	-	0xEFAE
K	Heater Heat Switch ON (during Recycling)	~ 0.4 mW	1.022 mA	0.41V	0x0A2A
L	Loop Sampling (microsecs)	10 sec	-	-	10000000
M	General Timeout (# of loops)	½ hr	-	-	180
N	Evaporator Timeout (# of loops)	1 hr	-	-	360
P	Evaporator Heat Switch Actuation Temperature	15K	-	-	0xB764
Q	Initial Pump Heating Timeout (# of loops)	1hr	-	-	360
R	Pump Cooling Timeout	1hr	-	-	360

Table 6-2 – List of Parameters used during the Cooler Automated Recyclings

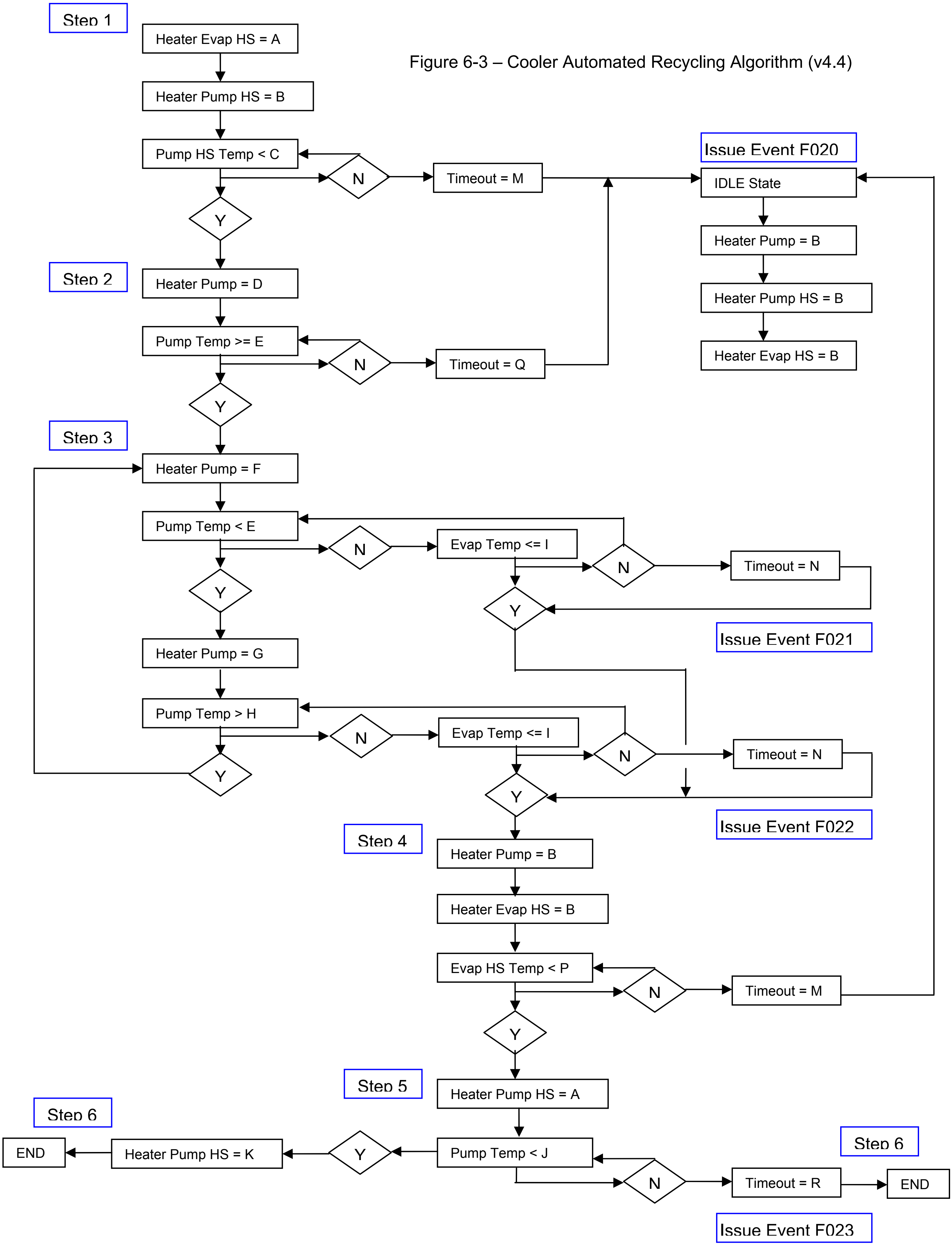


Figure 6-3 – Cooler Automated Recycling Algorithm (v4.4)