SPIRE PFM2

THERMAL BALANCE TEST REPORT

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CHANGE RECORD

Issue	Date	Section	Change
Draft A	08/11/05	-	New Document.
Draft B	16/02/06	All	Complete document.
Issue 1	08/03/06	-	First Issue

ACRONYMS

Acronym	***Definition***
RD	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
TBT	Thermal Balance Test
DTMM	Detailed Thermal Mathematical Model

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This document summarises the measured thermal performances of the SPIRE Proto-Flight Model 2 (PFM2) during a thermal balance test campaign which took place at RAL in September 2005.

2 DOCUMENTS

2.1 Applicable Documents [AD]

ID	Title	Number
AD1	SPIRE Instrument Interface Document Part B (IIDB)	SPIRE-ESA-DOC-000275 01-Mar-04 Issue 3.2
AD2	SPIRE Instrument Requirement Document (IRD)	SPIRE-RAL-PRJ-000034 Issue 1.3, First Release 14/07/05
AD3	SPIRE Thermal Design Requirements	SPIRE-RAL-PJR-002075 Issue 1 13/01/06
AD4	Procedure to perform 4-wire measurement on heaters	Heaters.doc Draft 0.2 10/09/04
AD5	Therm Harness Swap	SPIRE-RAL-PRC-002508 Issue 1 Rev.1
AD6	PFM2 Thermal Balance Test Specification	SPIRE-RAL-DOC-002435 Issue 1 A. Goizel
AD7	PFM1 Performance Test Details DAB-P/S Dark Load Curves or DAL-P/S Optical Load curves Procedure	SPIRE-RAL-NOT-002211 Draft 0.3 23/02/2005

Table 2-1 – Applicable Documents

2.2 Reference Documents [RD]

ID	Title	Number
RD1	SPIRE PFM2 Build Standard	Issue 2.1 D. Smith
RD2	Temperature Sensor Technical Note	Issue 6 D. Griffin 02/06/05
RD3	PFM2 Thermometers 1.2	Issue 1.2 D. Smith 26/08/05
RD4	PFM2 Thermometer C2T Issue 1.0.xls	Issue 1 D. Smith 07/07/05
RD5	Cal Table for TFCS MIB -23-Aug-2005.xls	D. Smith 23/8/05
RD6	CQM2 Thermal Test Results Memo	SPIRE-RAL-MEM-002533 A. Goizel 20/07/05
RD7	SPIRE FM1 Sorption Cooler EIDP	SPIRE-SBT-DOC-002221 Issue 1 L. Duband 07/10/04
RD8	SCU QM2 Test Report	SEDI-SCU-MM-2005-1 Issue 0.2 21/06/05
RD9	SPIRE PFM2 Test Results Summary – v3.xls	A. Goizel 16/02/06

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Table 2-2- Reference Documents

3 PFM2 TEST CAMPAIGN OVERVIEW

3.1 PFM2 Thermal Balance Test Campaign Objectives

The objectives of the SPIRE PFM2 Thermal Balance Test campaign can be summarised as follows:

- **Goal 1** To validate the instrument thermal heat loads at the Herschel Level-0 and Level-1 Cryostat Interfaces as far as possible, as described in Table 3-1,
- **Goal 2** To validate the instrument thermal performances in terms of absolute detector temperature and total cooler heat load (for both a nominal and a warmer environment), as described in Table 3-2,
- **Goal 3** To provide sets of thermal data for the correlation of the SPIRE Detailed Thermal Mathematical Model (DTMM) and hence allow accurate predictions of the future in-flight instrument performances.

SPIRE Thermal Interface	***Maximum Heat Load***	***Herschel Interfaces Temperature***	***Comments***
Level-0 (L0) Detector Box	4 mW	2 K	This load should be verified with a L1 temperature stage stabilised at 5.5K.
Level-0 (L0) Cooler Pump	2 mW	2 K	
Level-0 (L0) Cooler Evaporator	-	-	Heat load requirement on this interface are only applicable during the cooler recycling and has been verified at unit level [RD7].
Level-1 (L1)	15 mW	5.5 K	This load should be verified with a L2 temperature stage stabilised at 12K.
Level-2 (L2)	-	12K	No Heat Load Requirements.
Level-3 (L3) Photometer	50 mW	15 K	These requirements cannot be directly verified at Instrument Level as they depend on the Astrium L3 ventline design and as well as on the Astrium harness heat loads. The verification will be done by analysis with a correlated SPIRE thermal model and the Astrium Herschel Thermal Model.
Level-3 (L3) Spectrometer	25 mW	15 K	

Table 3-1 - Maximum Heat Loads at the various Herschel Cryostat Interfaces [AD1]

SPIRE High-Level Thermal Requirements	
Absolute Temperature at the Bolometer Detector Arrays (BDA) Thermal Interface	< 310 mK
Total Cooler Heat Load	< 30 uW

Table 3-2 - SPIRE High-Level Thermal Requirement [AD3]

3.2 Summary of Thermal Tests Performed

Table 3-3 summarises the thermal tests that have been carried out as part of the PFM2 Thermal balance test campaign.

Test Name	Description	Summary
EGSE Heater Resistance Characterisation	Measure the EGSE heater resistances at operating temperatures using a 4-wire measurement.	This test could not be performed as the EGSE heater was open circuit after cooldown.
Temperature Sensors Characterisation	Characterise the temperature measurement errors (self-heating, calibration and DC offset) of the flight prime and redundant sensors as well as of the EGSE sensors.	Cold functional check performed on 05/09/05. DC offset and self-heating errors checked on 06/09/05 and 07/09/05 for the EGSE and flight temperature sensors respectively.
Cooler Pump Characterisation	Characterise the MGSE L0 pump strap conductance and establish the relation between the pump temperature and its internal power dissipation. The later will be used for future correlation to estimate the total cooler load based on the pump temperature.	Performed on 19/09/05 for 0mW, 5mW and 10mW.
Level-0 Detector Strap Characterisation	Characterise the MGSE L0 detector strap conductance.	This test could not be performed as the EGSE heater was open circuit after cooldown.
Level-1 Characterisation	Characterise the MGSE L1 strap conductance.	Performed on 23/09/05 for 0mW, 10mW and 30mW.
Cooler Recycling	The operation profile of the cooler during recycling is assessed during this test.	Performed on 19/09/05 and 23/09/05 before the thermal balance tests.
Cooler Hold Time Characterisation	This test assesses the instrument hold time performances for two different thermal environment cases (part of thermal balance test case 2 and 3).	See thermal balance test case 1 and 2 below.
Thermal Balance Case 1 OFF Mode	Instrument left in OFF mode to stabilise with the Level-0 and Level-1 of the cryostat is maintained at 1.7K and 4.2K respectively.	Performed on 06/09/05.
Thermal Balance Case 2	Effectively a COLD nominal test case where the Level-0 and Level-1 of the cryostat is maintained at 1.7K and 4.2K respectively.	Test started with cooler recycling on 19/09/05 at 16.30 and completed when cooler ran out of helium on 21/09/05 at 18.30.
Thermal Balance Case 3	Effectively a HOT test case where the Level-0 and Level-1 of the cryostat is maintained at 2K and 5.5K respectively.	Test started with cooler recycling on 23/09/05 at 20.40 and completed when cooler ran out of helium on 25/09/05 at 8.00.

Table 3-3 – Summary of Thermal Tests performed during the PFM2 Test Campaign

3.3 Overview of Thermal Environment in RAL Calibration Cryostat

3.3.1 L3/L2 Temperature Stage

In the RAL calibration cryostat, the Level 2 temperature stage is provided by an instrument shield and a HOB operating at about the same temperature. This temperature can be varied between 10K and 30K depending on the required thermal environment. There is no Level 3 temperature stage in the calibration cryostat as this feature is a late change in the Herschel flight cryostat design. To prevent the JFETs units to become too warm during operation (as they are now isolated from the HOB), they have been thermally coupled to the instrument shield through MGSE straps as well. Finally, the instrument cryo-harnesses was heat sunk on the 77K temperature stage of the cryostat and then again at the L2 stage on the instrument shield and the HOB. The L2 stage of the cryostat was left running at 15K during most of the test campaign as well as during the thermal test cases.

3.3.2 L1 Temperature Stage

The SPIRE PFM2 FPU is connected to the L1 interface of the RAL calibration cryostat with an MGSE strap. The following is also applicable:

- One temperature sensor has been fitted on the SOB at the L1 interface with the strap. This interface corresponds to the Herschel cryostat L1 thermal interface and is therefore used as a reference when comparing the instrument on-ground thermal performances with the predicted flight ones. Please note that the instrument L1 electrically isolating joint was missing during the PFM2 test campaign.

- One temperature sensor was fitted on the L1 MGSE strap.

- The L1 temperature stage of the RAL calibration cryostat is not affected by the instrument heat load and therefore it remains constant for all operating conditions at about 4.2K.

- An EGSE heater fitted to the FPU (i.e. used to warm the instrument up after a test campaign) has been used to vary the temperature gradient across the L1 strap and adapt the instrument SOB interface temperature to the required boundaries.

The L1 stage of the cryostat has been running at 4.2K during the whole test campaign. One specific thermal test case was performed where the L1 EGSE heater was used to warm the FPU at about 5.5K.

3.3.3 L0 Temperature Stage

The flight L0 straps cannot be used during Instrument Level Testing (ILT) at RAL because their new recent design doesn't fit in the calibration cryostat. The SPIRE cooler heat switches interfaces (evaporator and pump) and the spectrometer L0 enclosure interface were instead connected to the cryostat L0 interfaces with three dedicated L0 MGSE straps. The following is applicable:

- The L0 pump strap conductance has been characterised and is about 0.0446 W/K at 1.7K,

- The L0 evaporator strap conductance could not be characterised as part of the instrument level testing as there was no heater available to do this.

- The L0 detector strap conductance could not be characterised as part of the instrument level testing as the EGSE heater fitted on the photometer enclosure was found to be open-circuit after cooldown.

- All three straps have been equipped with two temperature sensors, one on the straps' adaptor to the cooler heat switches and spectrometer box, one on the straps' interface with the calibration cryostat. The Figure 3-1 below provides more details about the sensors locations.

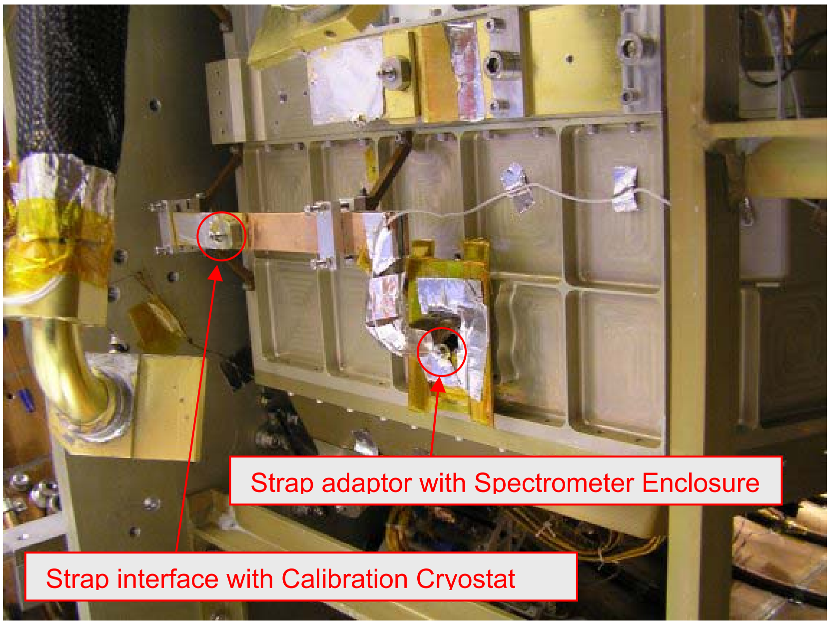

Figure 3-1 – L0 MGSE Strap Temperature Sensors – Spectrometer Strap given as an Example

Given that the flight L0 straps could not be used for the thermal verification at instrument level, the following assumptions were used:

- The instrument hold time performance should be verified with an evaporator temperature at the end of the condensation phase which is representative of the temperature likely to be obtained while in flight i.e. ~ 2K (based on the Herschel "Goal" interface temperatures [AD1] and the SPIRE thermal design document [AD3]),

- The cooler recycling should therefore be operated as a function of the evaporator temperature rather than on a time basis. This however means that the requirement on the cooler recycling duration could not be verified at this stage.

The following is also applicable to the RAL calibration cryostat operation:

- A manostat is used to control the cryostat L0 interface temperatures from 1.4K to 2K. Each interface cannot however be controlled independently.

- During each cooler recycling, the manostat needs to be opened to prevent instabilities (caused by the large amount of heat released during the cooler recycling) in the cryostat L0 He pot.

- Opening the manostat during the cooler recycling means however that the cryostat L0 interfaces temperatures tend to vary during the recycling period.

The L0 stage of the cryostat has been running at 1.7K during the whole test campaign. One specific thermal test case was performed where these interfaces were running at 2K.

4 PFM2 THERMAL TEST RESULTS

4.1 Temperature Sensors Functional Tests

All temperature sensors were checked as part of the warm and cold functional test. All sensors were working correctly at room temperature. The following EGSE temperature sensors were found open circuit after cooldown (see HR-SP-RAL-NCR-086v1):

- FSJFP L3 I/F (L3 strap side) – sensor mounted at the L3 strap interface of the spectrometer JFET,
- FPU -Y Foot I/F (HOB side) – sensor mounted on the HOB near the instrument -A Frame interface.

Temperature sensors on the HOB and the 12K shield will be used to predict the temperature at these interfaces.

Note: All the EGSE temperature sensors at the cryostat L0 clamp interface were rewired before the test campaign and were all working fine.

4.2 EGSE Heaters Functional Tests

Both the FPU and photometer box EGSE heaters were checked as part of the warm and cold functional test. Both heaters were working correctly at room temperature. The photometer box heater however was found open circuit once cold. This meant that the L0 Detector Strap Characterisation test could not be performed (see HR-SP-RAL-NCR-130). .

4.3 Temperature Sensors Characterisation Test

4.3.1 Test Overview

This test investigated any source of errors in the readings of the flight (prime and redundant) temperature sensors and was carried out with the instrument in OFF mode and in the nominal thermal conditions (1.7K-4K).

To check the instrument flight sensors for any DC offset errors, both the prime and redundant temperature sensors were first monitored on the Subsystem Control Unit (SCU) and then with a Lakeshore 370 AC Bridge (whenever possible). This approach allowed to:

- Detect any calibration error,
- Characterise any sensor self-heating errors and thus derive the sensor interface conductances,
- Characterise any DC offset errors (which were first suspected during the instrument CQM test campaign [RD6]).

All EGSE sensors used to characterise the instrument L1 and L0 heat loads are monitored on the AC Bridge at all time (therefore cancelling any DC offset errors). A “self-heating” check of these EGSE sensors was also carried out as part of this test.

Due to hardware limitation, not all flight sensors could be checked and characterised:

- No EGSE harness was available to connect the evaporator heat switch temperature sensors (prime or redundant) to the AC Bridge. As a result, the self-heating and DC offset errors of these two sensors could not be characterised.

- To prevent any instability in the instrument electronics, it was decided that the mechanism harnesses would not be disconnected from the instrument at any time. The self-heating and DC offset errors of these prime/redundant sensors (BSM, SMEC) therefore could not be characterised.

- The redundant side of the instrument electronics was not part of this instrument standard built. The redundant flight temperature sensors present on the instrument had to be connected to the prime channels of the SCU to be checked out. When possible, they were also checked with the AC Bridge.

- The redundant side of the SCAL could not be operated, therefore the SCAL redundant temperature sensors self-heating and DC offset errors could not be characterised.

4.3.2 Test Results

4.3.2.1 Flight Temperature Sensor – Inaccuracies

Before looking at the flight sensors self-heating and DC errors, a comparison of the temperatures obtained with the prime and the redundant sensors (both read out by the SCU) was done. Table 4-1 shows the temperature measured with both sensor at a 40 minutes interval. As the instrument temperatures were very stable during this period (see appendices, section 6.1.1), one would expect both the prime and redundant sensors to read similar temperatures. Most sensors were reading identical temperature to within 5mK with the exception of the “Input Baffle” sensors which had quite a large dispersion of 0.17K.

Name		Prime	Redundant	Measurement Dispersion	Noise Estimation	Interpolation Dispersion
		K	K	mK	mK	mK
Cooler Pump	T_CPHP_1	2.134	2.130	4.0	2.2	3.7
Cooler Shunt	T_CSHT_1	1.705	1.705	0.6	1.5	7.3
Cooler Evap	T_CEV_1	1.819	1.816	2.4	25.0	-1.3
Cooler Pump Heat Switch (sieve)	T_CPHS_1	2.931	2.925	5.7	2.5	0.7
Cooler Evap Heat Switch (sieve)	T_CEHS_1	2.822	2.820	1.5	2	1.0
Photometer Level 0 Enclosure	T_PL0_1	1.715	1.715	-0.2	1.0	6.9
Spectrometer Level 0 Enclosure	T_SL0_1	1.703	1.706	-2.3	1.0	7.5
HSFPU Harness Filter Bracket	EMCFIL_1	4.279	4.288	-8.1	10.0	-0.6
M3,5,7 Optical Sub Bench	T_SUB_1	4.288	4.292	-3.6	3.0	8.2
Input Baffle	T_BAF_1	4.393	4.224	169.1	6.0	13.0
BSM/SOB I/F (SOB side)	T_BSMS_1	4.279	4.277	2.4	4.0	9.2
SCAL Structure	T_SCST_1	5.745				2.0
SCAL 4%	T_SCL4_1	4.192				0.0
SCAL 2%	T_SCL2_1	4.533				10.1

Table 4-1 – Dispersion between the Prime and Redundant Temperature Sensors Readings

<u>Note:</u> Please note that the temperatures described in the table have not been directly taken from the HCSS (Herschel Common Science System). They have been calculated using the raw “count” value from the SCU and the HCSS transfer function defined in [RD8] to convert to resistance first. A final linear interpolation of the resistance data with the sensors calibration curves was carried out to get the temperature.

While a 5mK error can be explained by phenomena such as electronic noise or dispersions during the temperature interpolation, the larger error on the baffle sensor was unexpected. A calibration issue was suspected and after inverting the calibration curves between the prime and redundant sensors, consistent data were obtained as described in Table 4-2:

	Temperature [K]	Inverted Cal Curve
Input Baffle (Prime) [K]	4.393	4.303
Input Baffle (Redundant) [K]	4.224	4.312
Dispersion [K]	0.169	-0.009

Table 4-2 – Input Baffle Sensor Calibration Curve Error

Another large dispersion has also been observed between the two prime temperature sensors “SCAL2” and “SCAL4”. One would expect them to sit at a similar temperature when the instrument is OFF and a calibration issue was again suspected. After inverting the calibration curves of these two prime sensors, consistent data were obtained as described in Table 4-3:

	Temperature [K]	Inverted Cal Curve
SCAL 4% (Prime)	4.192	4.365
SCAL 2% (Prime)	4.523	4.364
Dispersion [K]	0.331	-0.001

Table 4-3 – Additional Temperature Dispersion – SCAL Sources

Finally, the “SCAL Structure” prime temperature sensor was reading a higher temperature than expected, i.e. 5.75K versus ~4.3K average on the SOB as described in Table 4-4.

Name	Prime	Temperature
		K
HSFPU Harness Filter Bracket	EMCFIL_1	4.279
M3,5,7 Optical Sub Bench	T_SUB_1	4.288
Input Baffle	T_BAF_1	4.303
BSM/SOB I/F (SOB side)	T_BSMS_1	4.279
SCAL Structure	T_SCST_1	5.745
SCAL 4%	T_SCL4_1	4.367
SCAL 2%	T_SCL2_1	4.364

Table 4-4 - Additional Temperature Dispersion – SCAL Structure

After looking in more details at the SCU/HCSS data, the following observations could be made:

- The calibration curve used to convert the resistance value into temperature is correct and the temperature reading is right for the measured resistance.
- The SCU/HCSS resistance value differs from the resistance measured with the AC bridge by ~191 ohms (747 ohms for DRCU versus 938 ohms for the AC bridge).
- When looking at the HCSS transfer functions in more details [RD4], it appears that the function used for the “SCAL Structure” temperature sensor was identical to the one used for the “SCAL4” temperature sensor. This transfer function was checked against the SCU QM2 Test Report [RD8] and this confirmed that the function used during the test campaign was wrong.

- The “SCAL Structure” temperature has been estimated to be 4.299K with the new transfer function, which is now well within the average SOB temperatures described in Table 4-4.

4.3.2.2 Flight Temperature Sensors - Self-Heating Errors

In this section, the self-heating of both the prime and redundant flight temperature sensors is investigated in more detail. This test was carried out by reading these sensors through the Lakeshore 370 AC bridge, and taking temperature measurements with excitation currents set at 1uA and 10uA. Table 4-5 and Table 4-6 summarise the results obtained during this test. . The full data is contained in the appendix in section 6.1.2.

Name		Prime		
		Self-Heating	**Sensors Interface Resistance**	**AC Bridge Temperature**
		mK	**K/W**	**K**
Cooler Pump	T_CPHP_1	5.0	42107	2.13
Cooler Shunt	T_CSHT_1	3.3	58306	1.70
Cooler Evap	T_CEV_1	N/A	43819	1.80
Cooler Pump Heat Switch (sieve)	T_CPHS_1	2.3	20846	2.91
Photometer Level 0 Enclosure	T_PL0_1	2.9	54135	1.71
Spectrometer Level 0 Enclosure	T_SL0_1	3.2	54275	1.71
HSFPU Harness Filter Bracket	EMCFIL_1	7.5	33550	4.36
M3,5,7 Optical Sub Bench	T_SUB_1	4.2	21880	4.35
Input Baffle	T_BAF_1	1.9	12903	4.35
BSM/SOB I/F (SOB side)	T_BSMS_1	44.8	286506	4.31
Cooler Evap Heat Switch (sieve)	T_CEHS_1			
SCAL Structure	T_SCST_1	1.1	10402	4.34
SCAL 4%	T_SCL4_1	13.9	60206	4.35
SCAL 2%	T_SCL2_1	17.9	75575	4.35

Table 4-5 – Flight Prime Temperature Sensors Self-Heating Error

Name		Redundant		
		Self-Heating	**Sensors Interface Resistance**	**AC Bridge Temperature**
		mK	**K/W**	**K**
Cooler Pump	T_CPHP_1	4.1	31437	2.13
Cooler Shunt	T_CSHT_1	4.5	73999	1.70
Cooler Evap	T_CEV_1	N/A	53588	1.79
Cooler Pump Heat Switch (sieve)	T_CPHS_1	1.2	10641	2.92
Photometer Level 0 Enclosure	T_PL0_1	2.5	49884	1.71
Spectrometer Level 0 Enclosure	T_SL0_1	3.3	56654	1.71
HSFPU Harness Filter Bracket	EMCFIL_1	Error	Error	4.38
M3,5,7 Optical Sub Bench	T_SUB_1	Error	Error	4.35
Input Baffle	T_BAF_1	0.4	2595	4.36
BSM/SOB I/F (SOB side)	T_BSMS_1	43.0	275444	4.31
Cooler Evap Heat Switch (sieve)	T_CEHS_1			
SCAL Structure	T_SCST_1			
SCAL 4%	T_SCL4_1			
SCAL 2%	T_SCL2_1			

Table 4-6 - Flight Redundant Temperature Sensors Self-Heating Error

As one can see, most sensors have a predicted self-heating error more or less equal to 5mK. In addition, no self-heating was detected on the "evaporator" temperature sensors (prime and redundant) because they are driven with a different excitation source which uses a very low excitation current.

Some anomalies were found for the following sensors however:

- Post analysis of the data measured for the "Filter Bracket" and the "Optical Sub Bench" redundant temperature sensors gave inconsistent results (i.e. negative self-heating). A typographic error when logging the test data is a likely cause for these inconsistencies. These data have been discarded.
- A large but consistent self-heating error was found for both the prime and redundant "BSM/SOB IF" sensors. This indicates that the sensors are not well fitted to the surface and will need to be checked before the next test campaign.
- The "SCAL2" and "SCAL4" prime sensors appear to have a larger self-heating error than others. Again, their integration procedure should be checked before the next test campaign. The redundant side could not be checked as part of this test.

Note: All sensors mounted on the L1 of the instrument should have low self-heating as their interface conductance increases at these higher temperatures (4K versus 1.7K for temperature sensors at L0).

4.3.2.3 Flight Temperature Sensors - DC Offset Errors

Any DC offset present on the flight temperature sensors was characterised with the EGSE AC Bridge. The results of this test are summarised in
Table 4-7. For each sensor, the DC offset is calculated as follows:

DC_Offset = (Temp_SCU – SH_SCU) - (Temp_AC – SH_AC)

Where:

- Temp_SCU is the sensor temperature in K when measured with the SCU,
- SH_SCU is the sensor self-heating when driven by the SCU,
- Temp_AC is the sensor temperature in K when measured with the AC bridge,
- SH_AC is the sensor self-heating when driven by the AC bridge.

Name		Prime DC Offset	Redundant DC Offset
		mK	mK
Cooler Pump	T_CPHP_1	-3.4	-4.5
Cooler Shunt	T_CSHT_1	0.5	0.4
Cooler Evap	T_CEV_1	N/A	N/A
Cooler Pump Heat Switch (sieve)	T_CPHS_1	14.2	3.7
Photometer Level 0 Enclosure	T_PL0_1	0.5	0.8
Spectrometer Level 0 Enclosure	T_SL0_1	-7.0	-7.3
HSFPU Harness Filter Bracket	EMCFIL_1	-90.4	-80.9
M3,5,7 Optical Sub Bench	T_SUB_1	-67.4	-62.2
Input Baffle	T_BAF_1	-49.4	-49.8
BSM/SOB I/F (SOB side)	T_BSMS_1	-75.0	-76.5
SCAL Structure	T_SCST_1	-44.3	
SCAL 4%	T_SCL4_1	4.1	
SCAL 2%	T_SCL2_1	-5.2	
Cooler Evap Heat Switch (sieve)	T_CEHS_1		

Table 4-7 – Flight Temperature Sensor - Temperature DC Offsets

Note: There is no DC offset on the evaporator sensors as these use an AC excitation current source in order to obtain a high accuracy when operating in the 300mK range.

The following observations can be made:

- The DC offsets measured for the flight sensors look consistent for the prime and redundant sensors. This confirms that the harnesses are of similar design on the prime and redundant side. The only exception is the “Cooler Pump Heat Switch” sensor where different offsets have been obtained for the prime and redundant sensors.
- All DC offsets ranging within +/- 5mK should be interpreted with care as they fall within or are really close to the range of the sensors noise and calibration errors.
- An important DC offset (between 50 up to 90mK) has been confirmed on five flight temperature sensors at L1 as suspected in [RD6]. A 7mK offset has also been measured on the “Spectrometer L0 Enclosure” which ties in well with some of the discrepancies observed also during the CQM2 test campaign.
- The DC offsets described for the “Filter Bracket” and the “Optical Sub Bench” redundant temperature sensors are only given as an indication as the self-heating errors could not be removed because of inconsistent test data (i.e. negative self-heating).

The measured DC offsets are effectively a fixed error in the resistance measurement of these temperature sensors. The actual resistance offset needs to be known for each sensor, so that the temperatures readings used for the thermal model correlation can be corrected for it. Table 4-8 describes the calculated resistance DC offsets for the sensors tested.

Name		Prime DC Offset	Redumdant DC Offset
		ohms	ohms
Cooler Pump	T_CPHP_1	1.2	1.4
Cooler Shunt	T_CSHT_1	-0.6	-0.4
Cooler Evap	T_CEV_1	N/A	N/A
Cooler Pump Heat Switch (sieve)	T_CPHS_1	-4.1	-1.0
Cooler Evap Heat Switch (sieve)	T_CEHS_1		
Photometer Level 0 Enclosure	T_PL0_1	-0.7	-1.1
Spectrometer Level 0 Enclosure	T_SL0_1	8.1	8.6
HSFPU Harness Filter Bracket	EMCFIL_1	6.1	5.6
M3,5,7 Optical Sub Bench	T_SUB_1	5.4	5.3
Input Baffle	T_BAF_1	5.7	5.7
BSM/SOB I/F (SOB side)	T_BSMS_1	8.3	8.0
SCAL Structure	T_SCST_1	7.8	
SCAL 4%	T_SCL4_1	-0.3	
SCAL 2%	T_SCL2_1	0.3	

Table 4-8 – Flight Temperature Sensors - Resistance DC Offsets

Note: The DC offsets described for the “Filter Bracket” and the “Optical Sub Bench” redundant temperature sensors are only given here as an indication.

4.3.2.4 Cryostat Temperature Sensor Calibration Errors

During the PFM2 test campaign, the temperature sensors at the cryostat clamp interfaces (L1 and L0) were reading warmer temperatures than the ones on the instrument's own interfaces as described in Table 4-9. A similar behaviour had been observed during the CQM2 test campaign and hence, additional EGSE sensors were fitted to the L0 and L1 straps for trouble-shooting and redundancy. These additional sensors allowed confirmation that the sensors at the cryostat clamp interfaces are currently providing erroneous data and that calibration is likely to be the cause for these measurement errors.

	At Heat Switch/Box/FPU Interfaces	Bottom of L0/L1 Straps	Cryostat Clamp Interface
Cooler Pump	1.688	1.681	1.821
Cooler Evaporator	1.682	1.681	1.712
L0 Spectrometer Enclosure	1.687	1.682	1.779
Level-1 FPU	4.254	4.226	4.387

Table 4-9 - Cryostat Temperature Sensors Calibration Errors

These sensors should be recalibrated before the next campaign if time allows. Their readings will not be used in the future analyses or correlation with the thermal model.

4.3.2.5 EGSE Temperature Sensor Self-Heating Errors

The EGSE sensors fitted on all three L0 MGSE straps and on the L1 MGSE strap have been tested for self-heating errors as shown in Figure 4-1. During this test, the AC bridge excitation current was changed from 1uA to 10uA. Table 4-10 summarises the results from the test.

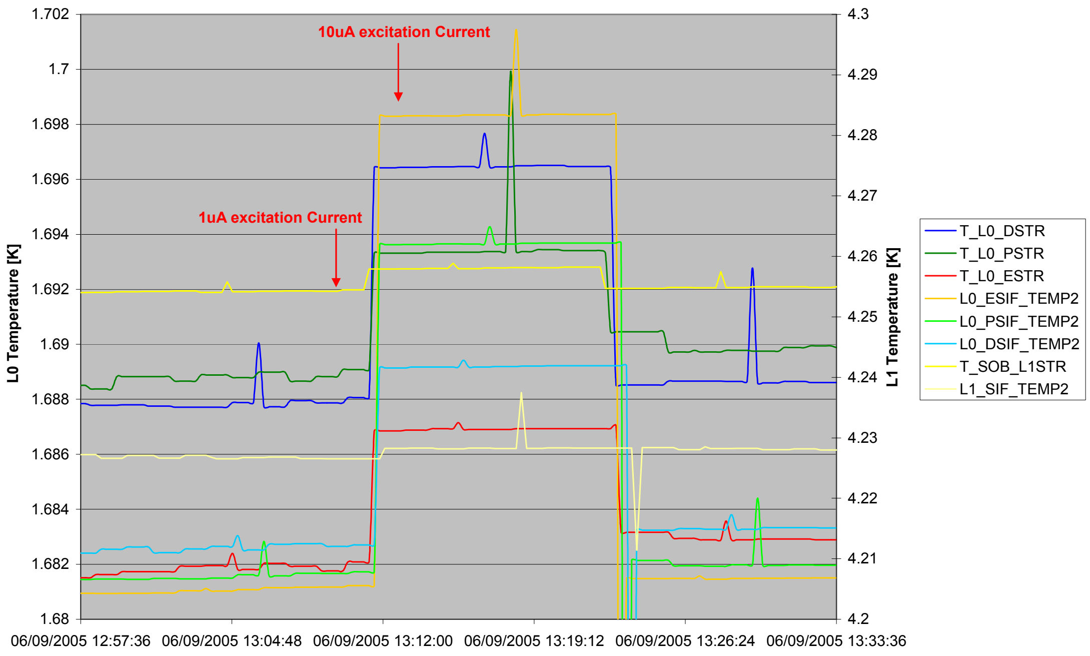

Figure 4-1 - EGSE Temperature Sensor Self-Heating Test

	Sensors Temperature Increase (*)	Sensors Interface Resistance	Sensors Self-Heating (**)
	[mK]	[K/W]	[mK]
Evaporator Strap Adaptor (top)	4.8	62046	0.05
Pump Strap Adaptor (top)	4	57758	0.04
Detector Strap Adaptor (top)	8	58849	0.08
Evaporator Strap Adaptor (bottom)	17	51040	0.17
Pump Strap Adaptor (bottom)	11.9	53343	0.12
Detector Strap Adaptor (bottom)	6.3	49113	0.06
L1 Strap Interface at SOB	4	9212	0.04
L1 Strap	1.7	17215	0.02

(*) Following a change in excitation current from 1uA to 10uA.
(**) For the nominal AC bridge setup (1uA excitation current).

Table 4-10 - EGSE Temperature Sensor Self-Heating Errors

This test demonstrated that the EGSE sensors have been well integrated.

4.3.3 Temperature Sensors Characterisation – Conclusion

All flight and EGSE temperature sensors characterisation testing was completed successfully. The following conclusions and suggestions for improvement can be made:

- The “Evaporator” temperature sensor reading is noisy (~25mK amplitude) in the 1.7K temperature range. This must be accounted for when using the evaporator temperature during the condensation phase of the recycling.
- It appears that the “Input Baffle” prime and redundant temperature sensor calibration curves are inverted. This will need to be corrected for the next test campaign and also when using the PFM2 test data for the thermal model correlation.
- It appears that the “SCAL2” and “SCAL4” prime temperature sensor calibration curves are inverted. This will need to be corrected for the next test campaign and also when using the PFM2 test data for the thermal model correlation.
- The HCSS transfer function used to calculate the “SCAL Structure” temperature sensor resistance during the PFM2 test campaign was incorrect. This will need to be corrected for the next test campaign and also when using the PFM2 test data for the thermal model correlation.
- Despite being integrated on the L1 temperature stage, both the prime and redundant “BSM/SOB IF” temperature sensors have an excessive self-heating indicating that they are not fitted properly on the surface and/or that the bolted interface has relaxed. They will need to be checked before the next test campaign. The same applies to the prime sensors on SCAL2 and SCAL4.
- Important DC offsets have been measured on five of the L1 temperature sensors as well as on one of the L0 sensors. While this error cannot be corrected for at this stage, it needs to be corrected for when using the PFM2 test data for the thermal model correlation and for any future analyses.
- The EGSE sensors at the cryostat clamp interfaces (L1 and L0) are still providing erroneous data caused by inaccurate calibration curves. These sensors should be recalibrated before the next test campaign.
- The new EGSE sensors fitted to the L1 and L0 straps are working well and provided consistent measurements to within 10mK or better.

In the following sections of this report, all temperature readings from the flight temperature sensors have been corrected for any error in DC offset, self-heating and/or calibration curve as applicable.

4.4 L1 Strap Characterisation

4.4.1 *Test Overview*

For this test, the FPU warm-up heater and EGSE temperature sensors on the SOB L1 interface and on the L1 thermal strap were used to characterise the instrument L1 heat load. Please refer to the PFM2 Thermal Balance Test Specification [AD6] for pictures of the sensors and heater locations. Both sensors were monitored on the Lakeshore AC Bridge to minimise errors in temperature measurement. No mechanisms were used for the whole test duration therefore the only FPU dissipation was coming from the heater and the instrument own L1 parasitic loads. The temperature profiles of the instrument during the period of test are presented in Figure 4-2.

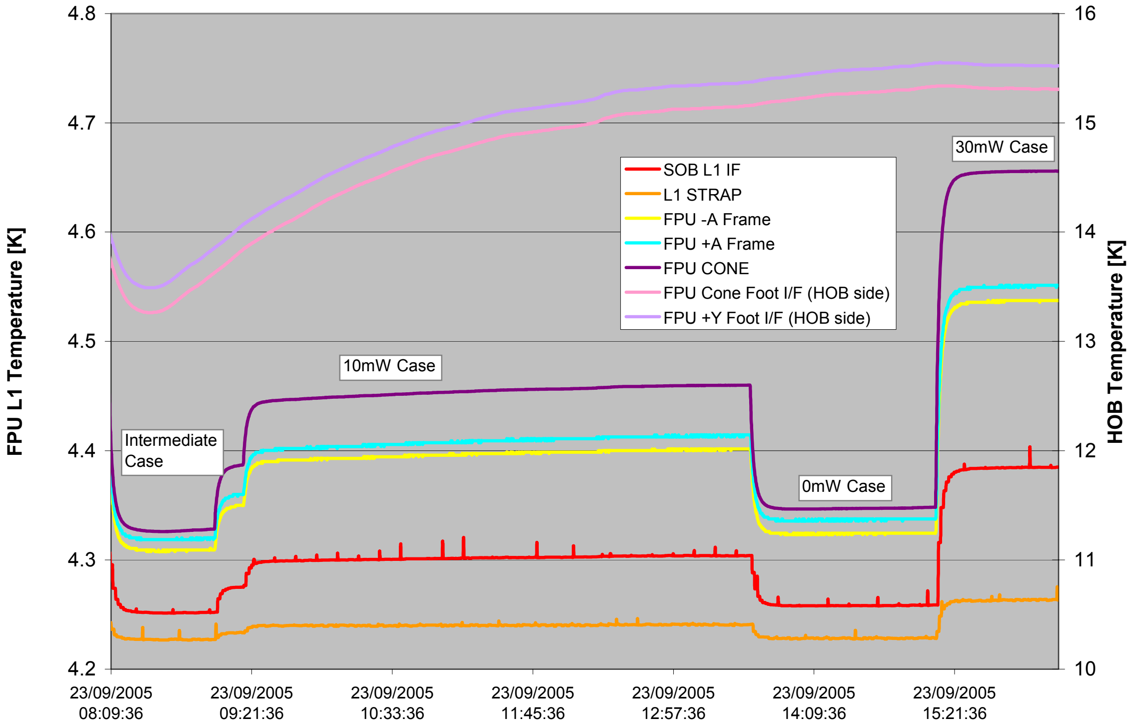

Figure 4-2 - L1 Characterisation Test – Temperature Profiles

Additional details about the instrument and HOB temperature stability during the various test cases can be found in appendices, section 6.2.1.

The following limitations are applicable for this test:

- The cryostat takes a long time to stabilise which means that the HOB temperature has been slightly varying during the test period.
- The power supply that was used for the 4-wire measurement could only draw a maximum current of 17mA (~10mW) so a different power supply had to be used for the higher heating power. A 4-wire measurement however was not possible in this case.

- The FPU heater resistance was measured as part of the 10mW case and has then been used to estimate the power dissipated during the 30mW case. An intermediate heating power case was used to estimate the heater change in resistance for a changing L1 temperature. The maximum change in heater resistance was estimated to be 0.063 ohms (see section 6.2.2 in appendices for more information).

4.4.2 Test Results

Time of Stability	Current	Voltage	Heater Resistance	T_Strap	T_SOB	Heating Power	Temperature Gradient	Strap Conductance
[UT]	[mA]	[mV]	[ohms]	[K]	[K]	[mW]	[K]	[W/K]
						-9.06	0	
14:35:00	0	0	-	4.229	4.258	0	0.030	0.3062
13:25:00	17	591.8	34.81	4.240	4.304	10.06	0.064	0.3001
16:10:00	-	983.1	-	4.263	4.385	27.76	0.121	0.3032

Table 4-11 – L1 Characterisation Test Results Summary

Note: the blue value in Table 4-11 is the intercept of the curve fit with the x axis and corresponds to the instrument parasitic load that was present on the L1 strap in addition to the heater dissipation.

A curve fit (Figure 4-3) has been used through the three test cases and extrapolated to a 0 K “temperature gradient” case, which corresponds to the instrument own L1 parasitic loads with the FPU heater OFF. The L1 strap conductance (measured between the two temperature sensors) has been estimated from the measured temperature gradient and heat loads for all three cases. It appears that the strap conductance obtained with the 0mW case is inconsistent i.e. slightly larger than the other two sets of data. This is not surprising as the temperature gradient measured for this case is quite small and therefore less accurate.

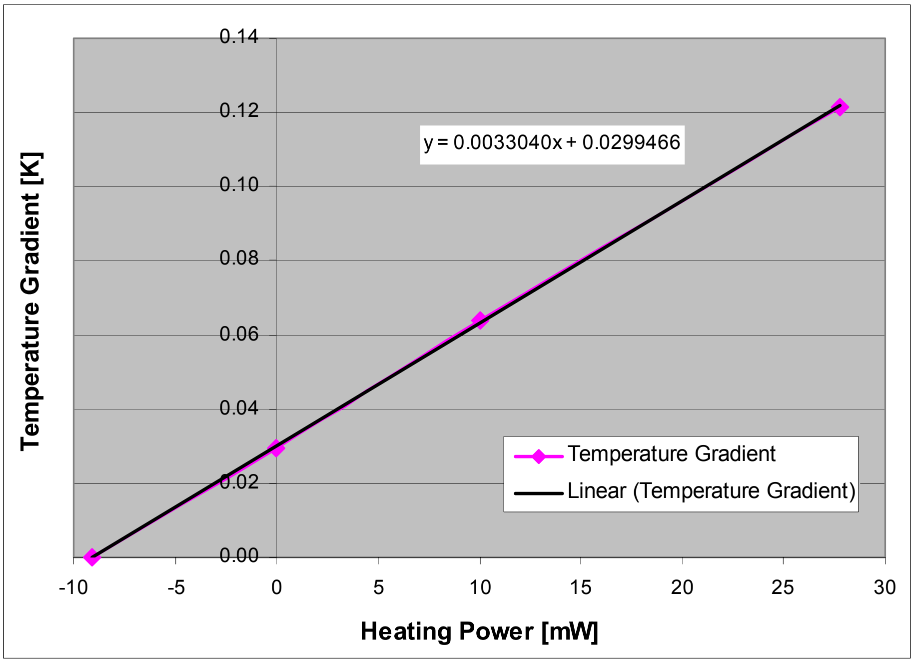

Figure 4-3 - L1 Characterisation Test Results

The curve fit has therefore been carried out again without the 0mW case result, as described in Table 4-12. The results showed that this didn't have much effect on the extrapolated instrument L1 parasitic load.

Heating Power	**Temperature Gradient**	**Strap Conductance**
[mW]	**[K]**	**[W/K]**
-9.22	0	**-**
10.060	0.063	0.306
27.760	0.121	0.306

Table 4-12 - L1 Characterisation Test Results Summary 2

Note 1: As larger heater dissipations were used, the instrument FPU slightly warmed up thus reducing its temperature gradient with the HOB environment by a maximum of 0.33K. Quick hand calculations showed however that this would have a negligible impact on the overall heat load measurement [RD9].

Note 2: The temperatures used to characterize the L1 strap conductance and instrument L1 parasitic loads are thought to be quite accurate with no self-heating and/or DC offsets. The only source of error would relate to the sensors calibration resolution, interpolation error and noise. A 5mK overall calibration error on the measured gradients would have the following impact on the L1 parasitic load and strap conductance estimations:

"0.063K" Gradient Error	"0.121K" Gradient Error	L1 Parasitic Load		L1 Strap Conductance	
[mK]	[mK]	[mW]	[%]	[W/K]	[%]
0	0	9.22	100	0.306	100
0	5	7.69	83	0.282	92
5	0	12.72	138	0.335	109
5	5	10.75	117	0.306	100

Table 4-13 - L1 parasitic load and strap conductance estimations errors

This analysis shows that a 5mK error in the temperature gradient measurements can introduce up to:

- -17%/+38% error in the L1 parasitic load estimation,
- -8/+9% error in the L1 strap conductance estimation.

4.4.3 L1 Characterisation – Conclusion

The instrument L1 MGSE strap and parasitic heat loads have been characterized for the following thermal environment:

- HOB and JFETs temperatures ranging between 15K and 15.5K, with the SJFET ON,
- All SOB temperatures were less than 4.7K,
- L0 enclosures temperature were about 1.71K,
- The measured instrument heat load for these conditions has been estimated to be about 9.2mW -17%/+38%,
- The MGSE L1 strap conductance has been estimated to be about 0.306 W/K -8/+9% at 4.26K.

Please note that the measured L1 heat load accounts for the following instrument parasitic loads:

- L1 CFRP Supports (minus heat loss through the L0 CFRP supports),
- Radiation from cryostat (not flight representative),
- EGSE Housekeeping harness (not flight representative),
- Cryo-harness from the JFETs (minus heat loss through cryo-harness to the L0 stage).

It is therefore not possible at this stage to confirm whether the instrument total L1 parasitic load will be within the 15mW requirement. Further correlation of the test data with the thermal model will help validating the instrument parasitic load through the supports and JFET cryo-harnesses. The radiation and housekeeping harnesses heat loads will be validated as part of the Herschel cryostat STM test campaign.

4.5 Cooler Pump Characterisation

4.5.1 Test Overview

The pump characterisation test aims to dissipate a known heat load in the pump using its heater and to measure the pump change in temperature versus heat load. During the whole test duration, the cooler was in a “discharged” state with the evaporator heat switch OFF and pump heat switch ON. This test has been carried out for the following heat load on the pump - 0mW, 5mW and 10mW. The test data will be used to characterise the adsorption heat load present on the pump when the cooler is ON and operating at 300mK. This test also allows characterisation of the MGSE L0 pump strap conductance. The Table 4-14 summarises the main test parameters and results while the various temperature profiles obtained during the test are presented in Figure 4-4.

Pump Characterisation Test Summary				
Stability Time	-	16:32	14:35	15:32
Stability Reached	-	Y	Y	N
Pump Heater				
Pump Command	Hex	0	124	19C
Pump Current	A	0	0.004	0.005
Pump Voltage	V	0	1.427	2.017
Pump Power	mW	0	5.034	10.058
Pump Heat Switch				
Pump HS Command	Hex	DEB	DEB	DEB
Pump HS Current	mA	1.400	1.400	1.400
Pump HS Voltage	mV	551.2	551.2	551.2
Pump HS Power	mW	0.772	0.772	0.772
T Pump HS	K	19.671	19.667	19.684
Cryostat L0 Bath				
T Evaporator Adaptor 2	K	1.702	1.703	1.704
Pump/Pump L0 Strap				
T Pump	K	1.731	2.306	2.783
T Pump Corrected (DC+SH)	K	1.730	2.304	2.780
T Pump Strap Adaptor Top	K	1.727	1.886	2.035
T Pump Strap Adaptor Bottom	K	1.707	1.753	1.797
Characterisation				
T Pump Increase	K	0.00	0.573	1.048
Q_pump	mW	0.000	5.034	10.058

Table 4-14 – Cooler Pump Characterisation Result Summary

The following limitations are applicable for this test:

- Post-processing of the test data indicates that the temperatures for the 10mW test case had not yet reached stability as originally though. The pump temperature was still decreasing at twice the required rate for steady-state when the test case was stopped (see temperature stability profiles in appendices section 6.3.1). The data from the 10mW test case have therefore not been used for the analysis.

- This characterisation test is only applicable when the cooler is operating with a 0.77mW power dissipation of the pump heat switch.

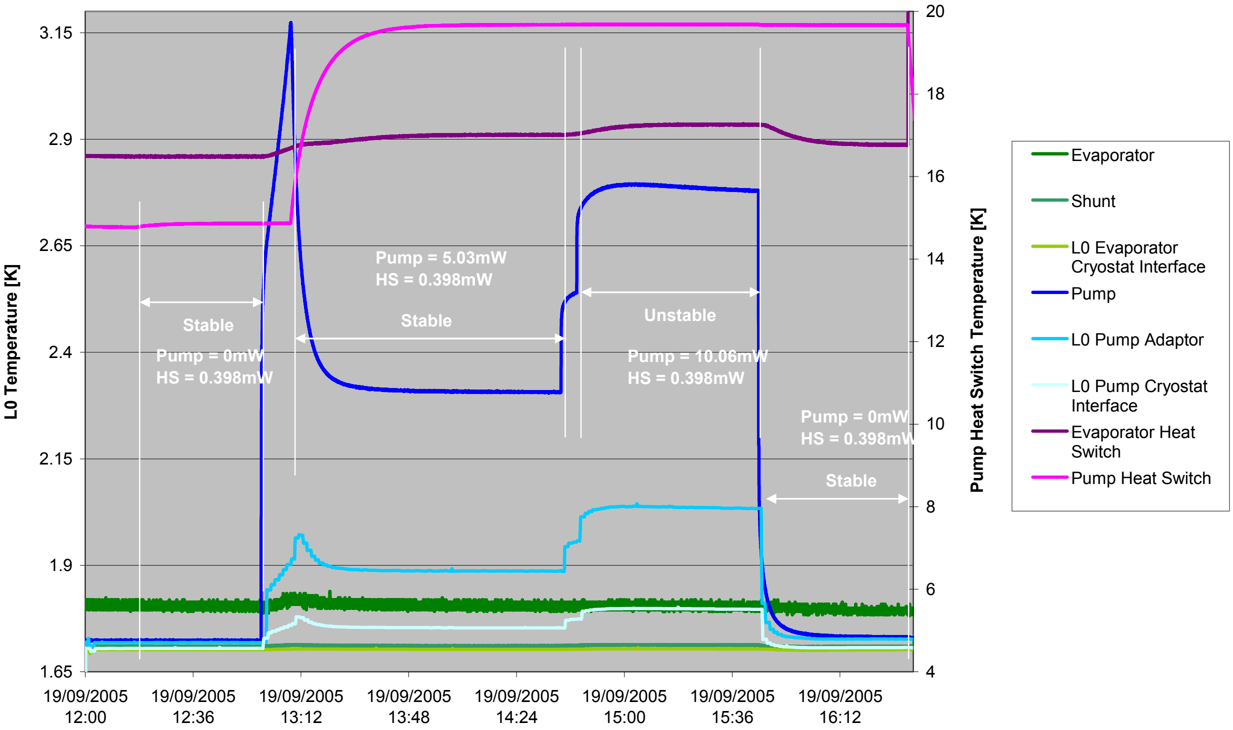

Figure 4-4 - Pump Characterisation Test – Cooler Temperature Profiles

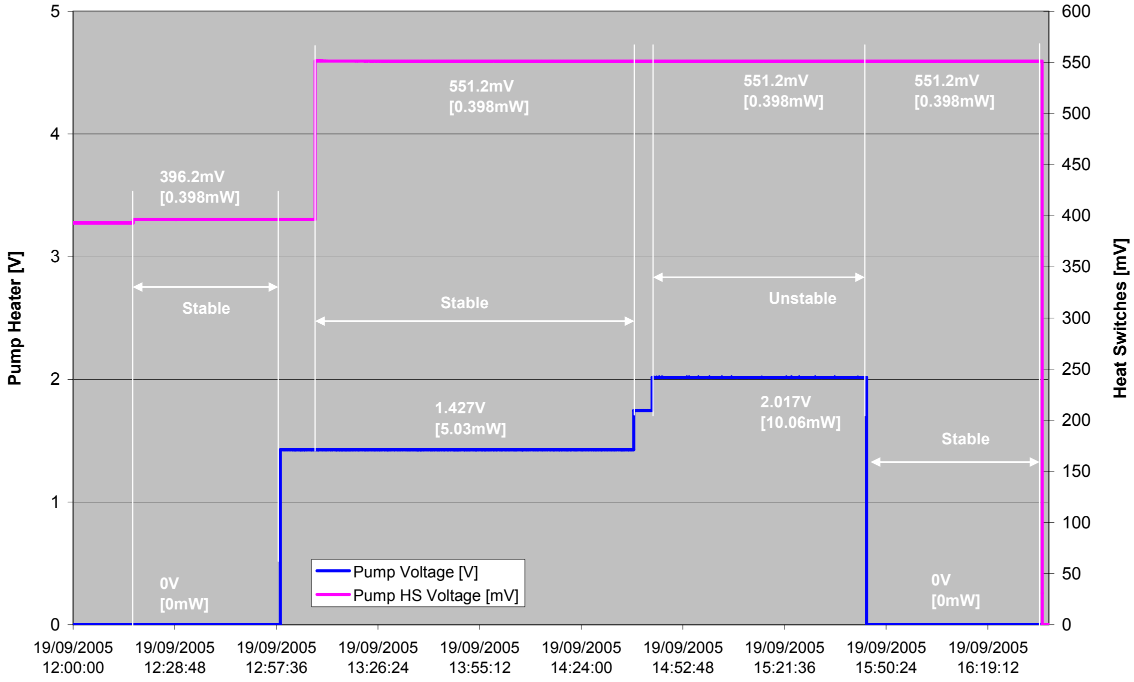

Figure 4-5 - Pump Characterisation Test – Cooler Heater Dissipation Profiles

4.5.2 Test Results

4.5.2.1 Cooler Pump Characterisation

The cooler pump characterisation test is used to quantify the adsorption heat load present on the pump when the cooler is operating at 300mK. From this, the evaporator total heat load can be estimated [AD6]. This characterisation is only valid however for pump heat switch setup used during the test i.e. 0.77mW used on the pump heat switch.

Note: The pump heat switch has been optimised to operate with 0.4mW in flight so this value was initially used for the pump characterisation test in order to be “flight” representative. It was found however that this heat switch setup was not appropriate for the test because it prevented the pump to stabilise during the 5mW test case. The test was therefore carried out with a higher pump heat switch power dissipation i.e. 0.77mW and this setup was then used consistently throughout the thermal test cases.

Table 4-15 describes the increase in pump temperature after a 5mW heat load was applied and Figure 4-6 shows the pump temperature rate of change versus applied power.

Pump Temperature Increase	**Pump Heater Dissipation**
[K]	**[mW]**
0	0
0.573	5.034

Table 4-15 – Pump Characterisation Summary

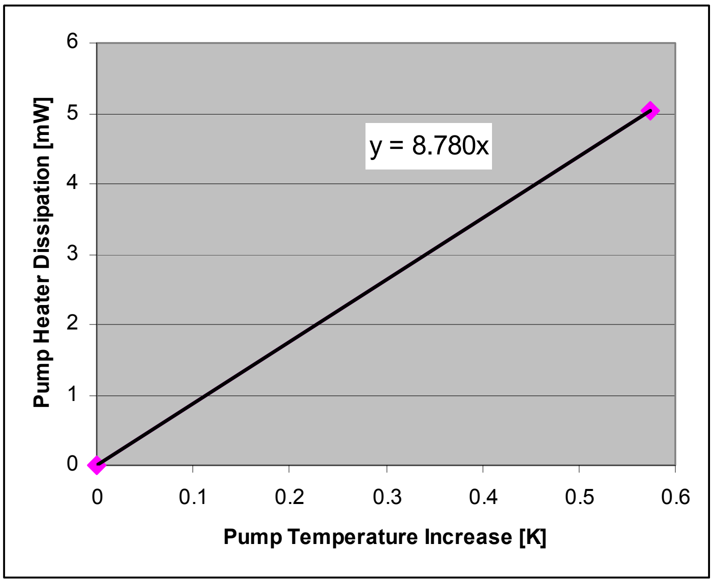

Figure 4-6 – Pump Characterisation Summary

The measured pump temperature has been adjusted for the following errors and variations in the thermal environment:

- DC and self-heating errors characterized as part of the previous thermal test,
- The slight change in L0 bath temperature.
- The changes in L1 and shunt temperatures were negligible and have been ignored.

Based of this characterisation, the following relationship has been derived and will be used as part of the thermal test balance cases to estimate the adsorption load on the pump:

Q_pump_ads = [(Tpump – 1.730) – (T_L0_bath – 1.702)] x 8.78

Where:

- Q_pump_ads is the pump adsorption load in mW,
- Tpump is the pump temperature during the cooler operation in K,
- 1.73 and 1.702 are the pump and L0 bath reference temperature respectively in K.

Note: A quick hand calculation showed that a 5mK error on the measured pump temperature gradient would only introduce a +/-1% error in the pump adsorption load estimation, as described in Table 4-16.

"0.573K" Gradient Error	Pump Rate	
[mK]	[mW/K]	[%]
0	8.780	100
5	8.704	99
-5	8.857	101

Table 4-16 – Pump Characterisation Errors [RD9]

4.5.2.2 L0 MGSE Pump Strap Conductance Characterisation

During the pump characterisation test, the temperature drop along the MGSE L0 pump strap was also monitored. Please refer to the PFM2 Thermal Balance Test Specification [AD6] for pictures of the sensors locations on the strap. The heat load flowing along this strap consists of:

- The pump heater power dissipation, Qp
- The pump heat switch power dissipation, Qhs
- The pump heat switch support parasitic loads from the L1, Qhsp
- The pump L0 strap support parasitic load from the L1, QL0p

While Qp and Qhs are well known in each case (both heaters dissipations are measured with 4-wire), the Qhsp and QL0p parasitic loads aren't. They can be "estimated" however from the measured temperature gradient along the L0 pump strap. Table 4-17 and Figure 4-7 summarise the results from the test where:

- Q is the total dissipated heat from the cooler (Qp + Qhs) in mW
- Delta T is the temperature gradient along the L0 pump strap in mK
- Qtot is the total power flowing along the strap Q + (QL0p + Qhsp) in mW
- G is the estimated L0 pump strap conductance in W/K

Time of Stability	Pump HS Power	Pump Heater Power	T Strap Top	T Strap Bottom	Q	Gradient	Qtot	G	Tavr [K]
[UT]	[mW]	[mW]	[K]	[K]	[mW]	[mK]	[mW]	[W/K]	
-	0	0	-	-	-0.129	0.0	-	-	
16:32	0.772	0.000	1.727	1.707	0.772	20.2	0.901	0.0446	1.717
14:35	0.772	5.034	1.886	1.753	5.806	133.0	5.935	0.0446	1.820

Table 4-17 – L0 Pump Strap Conductance Characterisation

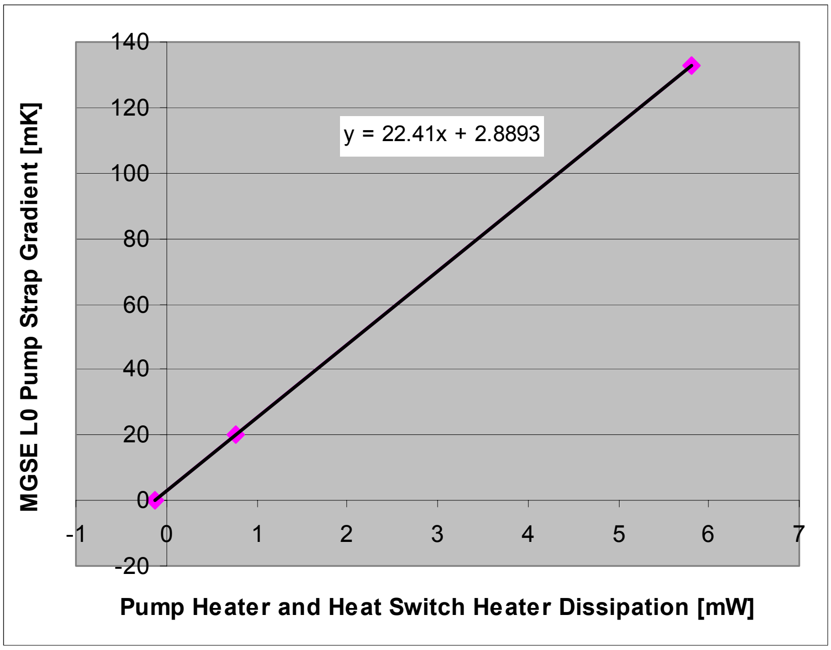

Figure 4-7 - L0 Pump Strap Characterisation

This extrapolation greatly depends on the accuracy of the two temperature gradients measured. The temperatures sensors used for this test are thought to be quite accurate with no self-heating and/or DC offsets. The only source of error would relate to the sensors calibration resolution, interpolation error and noise. A 5mK overall calibration error on the measured gradients would have the following impact on the L0 pump strap parasitic load and strap conductance estimations:

"20.2mK" Gradient Error	"133mK" Gradient Error	L0 Pump Parasitic Load		L0 Pump Strap Conductance	
[mK]	[mK]	[mW]	[%]	[W/K]	[%]
0	0	0.129	100	0.0446	100
0	5	0.091	71	0.0427	96
5	0	0.404	313	0.0467	105
5	5	0.352	273	0.0446	100

Table 4-18 - Pump Characterisation Errors 2

This analysis shows that the 5mK error in the temperature gradient measurements can introduce error of:

- Up to 313% in the L0 pump parasitic load estimation,
- -4/+5% in the L0 pump strap conductance estimation.

4.5.3 Pump Heat Switch Characterisation

The pump heat switch conductance is highly dependent on the power dissipated on the heat switch. This test assesses the impact of reducing the pump heat switch power from 0.8W to 0.4mW on the pump and evaporator temperatures. Table 4-19 summarises the test results and the temperature profiles of the cooler are described Figure 4-8and Figure 4-9.

Pump Heat switch Command	[Hex]	DEB	A2A
Pump HS Dissipation	[mW]	0.77	0.41
Pump Temperature	[K]	1.908	1.991
Pump Heat Switch Temperature	[K]	19.67	15.14
Evaporator Temperature	[m]	288.8	288.8

Table 4-19 – Pump Heat Switch Characterisation

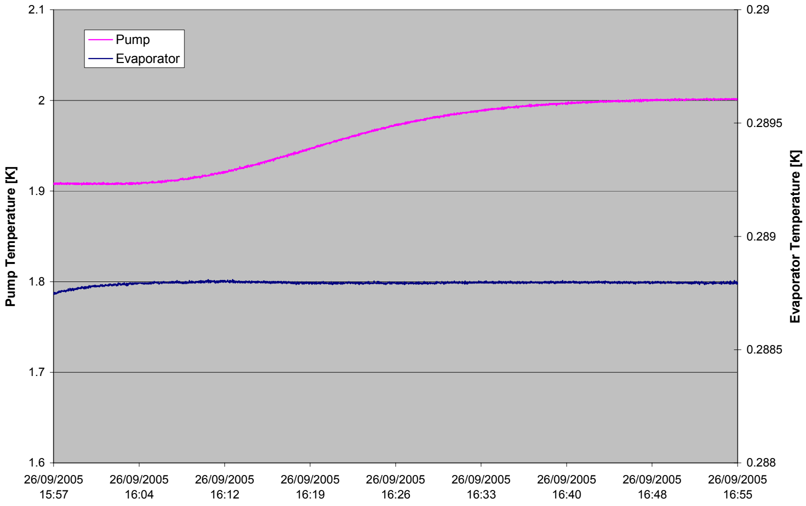

Figure 4-8 – Pump Heat Switch Characterisation

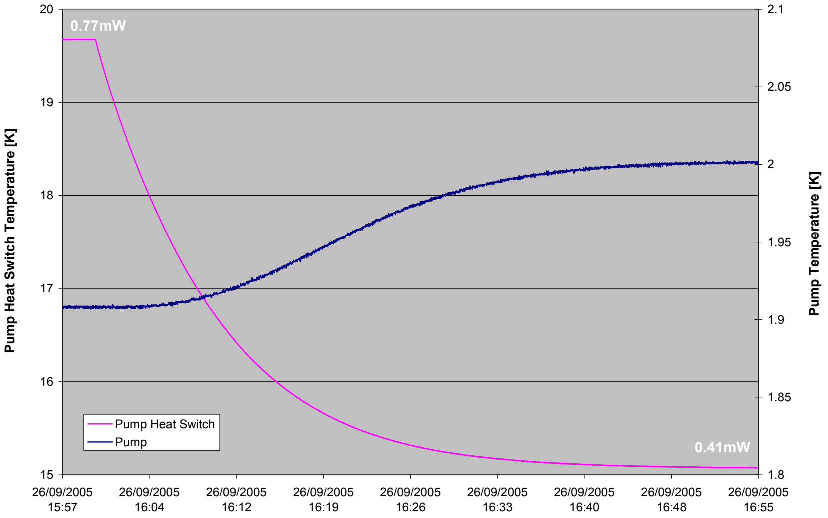

Figure 4-9 – Pump Heat Switch Characterisation

4.5.4 Cooler Pump Characterisation - Conclusion

- When the cooler is in operation, the pump adsorption heat load can be estimated to +/-1% with the following expression : Q_pump_ads = [(Tpump – 1.730) – (T_L0_bath – 1.702)] x 8.78
- The MGSE L0 Pump Strap conductance has been estimated to 0.0446W/K +/-5% at 1.7K,
- The total parasitic load flowing on the pump strap has been estimated to 0.129mW. There is a certain amount of uncertainty with this data however as it relies on a small temperature gradient measurement which is quite close to the sensors accuracy.
- The pump heat switch power dissipation can be reduced to 0.4mW when the cooler is in operation without affecting the evaporator absolute temperature performances.

4.6 Thermal Balance Tests

4.6.1 Test Overview

Two Thermal Balance Test (TBT) cases have been performed during the PFM2 test campaign:

- One with a so call "nominal thermal environment" where the L0 and the L1 are held at ~1.7K and ~4.2K respectively,
- One with a "warmer thermal environment" where the L0 and the L1 are held at ~2K and ~5K respectively.

While the warmer case is not fully flight representative[1], it provided a second set of data (sufficiently different from the first case) for the correlation of the instrument "measured" hold time with the one "predicted" with the thermal model.

In both cases, the L2 stage of the cryostat was held at ~15K. The reason for keeping the L2 so warm is that in this configuration, the radiation load from the instrument shield and the parasitic load from the JFETs cryo-harnesses should be a good representation of the flight environment. It would mean that the parasitic loads from the L1 isolation supports will be higher than in flight (where the HOB will be at about 12K) but this is somewhat favourable as the loads we are trying to measure are very small.

During both thermal test cases, none of the instrument mechanisms and/or calibration sources was used as this presented no real advantage at the time:

- It would not affect the thermal stability of the L1 in any way,
- The way the mechanisms will be operated in flight had not yet been clearly defined and therefore might not have been flight representative.

Mechanisms power dissipation will be characterised in details as part of the PFM3 test campaign where all flight components will be fine tuned and calibrated, therefore providing a better idea of the power dissipation profiles that we are likely to be experienced once in flight for the various instrument operating modes.

As a result of the thermal balance test cases and in addition to providing two sets of temperatures that will be used for the correlation of the SPIRE detailed thermal model, the following instrument thermal performances have been measured and are described in more details in the following sections:

- Cooler recycling temperature profiles,
- Cooler measured hold time,
- Estimated total evaporator load,
- Detector absolute temperature,
- 300mK busbar bar temperature drop,
- L0 interbox strap bar temperature drop.

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[1] *While the 2K L0 interface temperature is representative for the pump interface in flight, it is unlikely that the L0 detector enclosure interface would be this warm. As the L0 interfaces of the calibration cryostat cannot be controlled independently however, this provides a worst case scenario.*

4.6.2 Tests Results

4.6.2.1 Cooler Recycling in 1.7K/4K Nominal Environment

Figure 4-10 describes the temperature profiles of the SPIRE FM cooler during the thermal test case in the nominal thermal environment of 1.7K/4K.

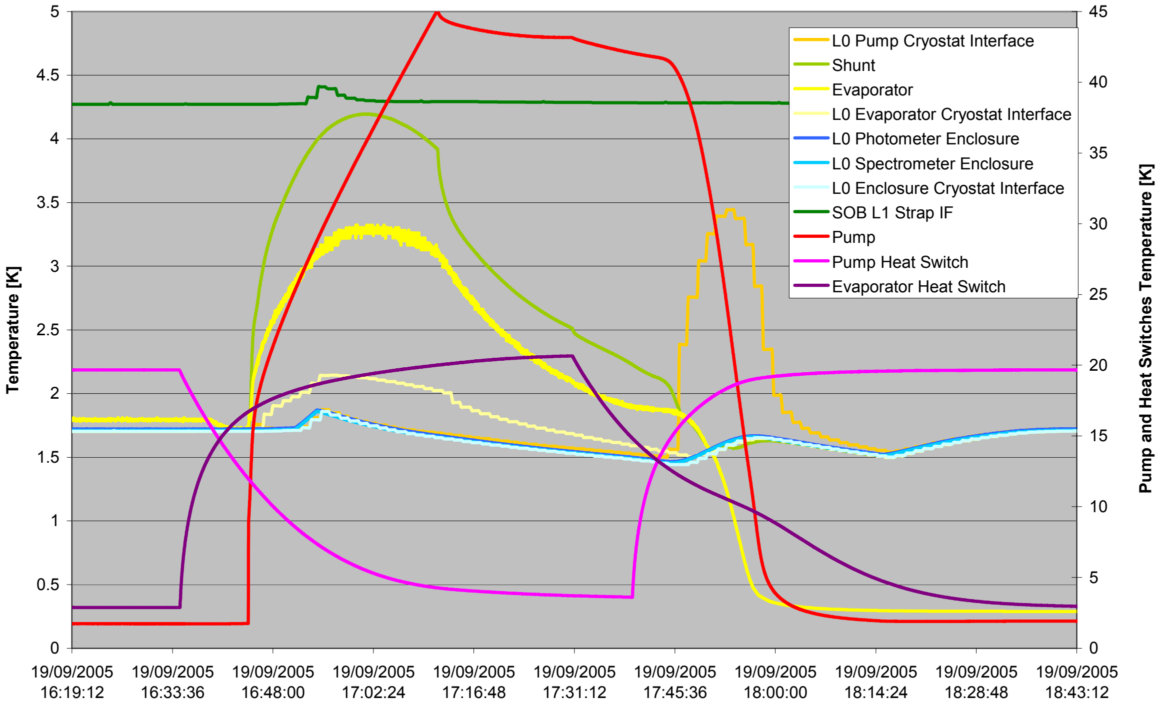

Figure 4-10 - FM Cooler Recycling – 1.7K/4K Nominal Environment

The cooler recycling started and ended at 16:34 and 18:20 respectively on the 19/09/05. The evaporator reached a cold "base" temperature of 288.5mK following recycling and for the nominal 1.7K/4K thermal environment.

Note: The start of the cooler low-temperature operation phase (and criteria for end of cooler recycling) has been defined as the time at which the evaporator temperature is within 1% of its base temperature (i.e. in this case, 1% of 288.5mK which gives 291.4mK). This approach allows a direct comparison of the cooler performances measured during ILT with the performances obtained by CEA at unit level [RD7]. It is important to note however that while this approach is acceptable from a thermal verification point of view, it doesn't account for any of the thermal stability requirements (applicable to the evaporator and detectors) defined for some of the scientific observation modes[2].

The cryo-pumping phase was initiated as soon as the evaporator reached 2.1K, by turning the evaporator heat switch OFF and turning the pump heat switch ON. The reason for switching at 2.1K rather than 2K was to account for the slight cooldown of the cryostat L0 temperature stage during the time required for the evaporator heat switch to turn OFF and the pump heat switch to reach its ON state and start cryo-pumping (which is about 15min after sending the first command). Please note that the cryostat L0 cools down as the manostat is opened to prevent any instability in the cryostat L0 pot during recycling.

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[2] *As mentioned previously, the dynamic behaviour of the RAL calibration cryostat is completely different and non representative of the Herschel flight cryostat.*

When looking at the evaporator temperature profile more closely however (Figure 4-11), one can see that the evaporator was allowed to cool further than the originally planned 2K i.e. the evaporator temperature had reached 1.86K when evidence of cryo-pumping appeared at the pump L0 interface temperature sensor (orange curve). Figure 4-10 shows that the cryostat L0 interface temperatures (described by the light blue/orange/yellow curves for the spectrometer enclosure, the pump and the evaporator respectively) has decreased from 1.7K to 1.45K between the start of the recycling and the start of the cryo-pumping phase, which was 0.15K more than expected based on past experience.

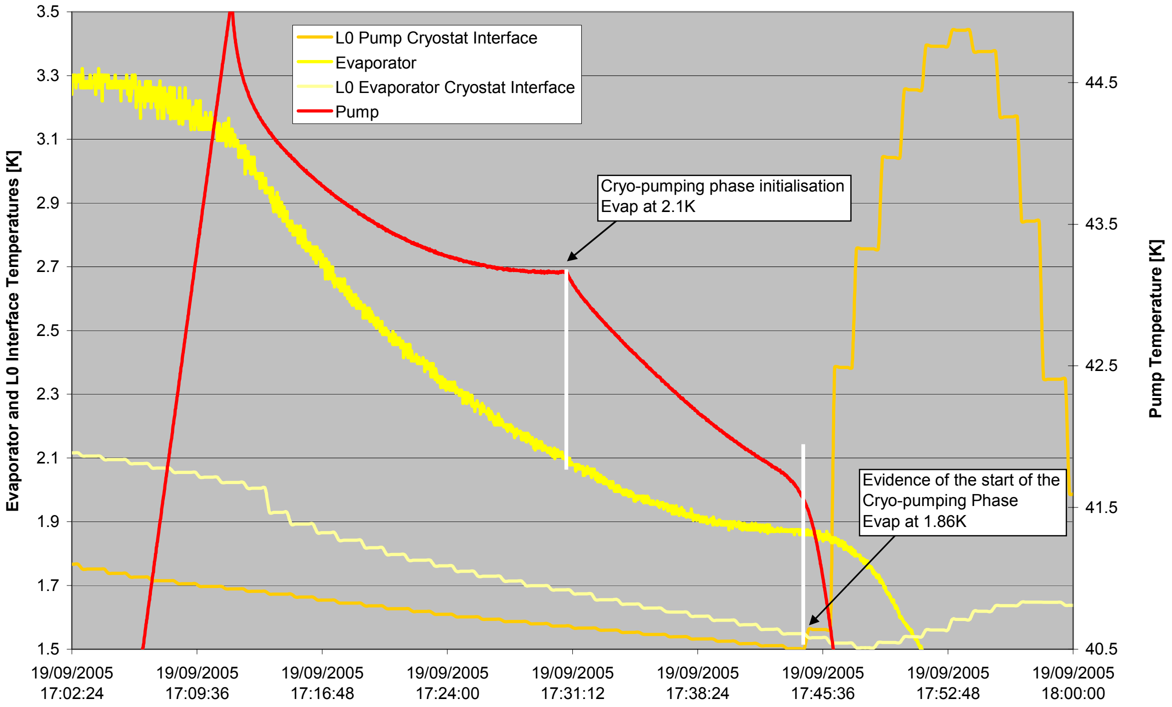


Figure 4-11 – Cooler Recycling close-up - 1.7K/4K Nominal Environment

Based on this observation, one can assume that the evaporator temperature at the end of the condensation phase was somewhere between 1.86K and 2.1K. An average of the two values (1.98K) has been used as a starting point.

Another point to consider is that as the pump temperature was not regulated during this recycling; its temperature was therefore allowed to slightly cool down from 45K to 41.6K at the start of the cryo-pumping phase. Additional analysis will be required to look at the adsorption state of both the evaporator and the pump during this period, to try and estimate when exactly the evaporator stopped condensing.

4.6.2.2 Cooler Hold Time in 1.7K/4K Nominal Environment

An evaporator base temperature of 291.4mK (see section 6.4.2.1) was used to determine the cooler hold time for the nominal thermal environment, as described in Figure 4-12 and Figure 4-13.

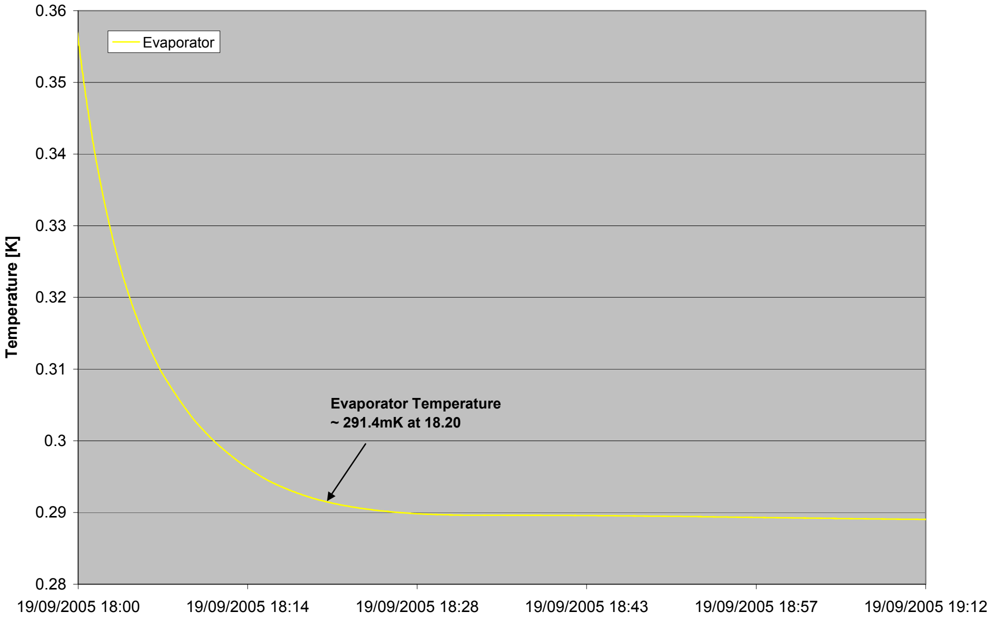


Figure 4-12 – Start of Cooler Hold Time for 1.7K/4K Thermal Environment

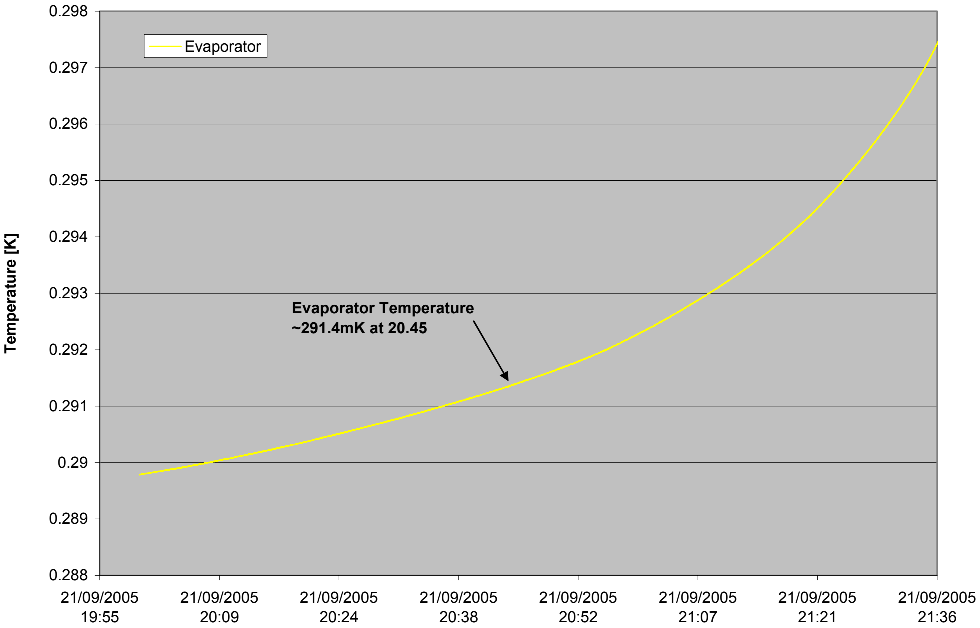


Figure 4-13 – End of Cooler Hold Time for 1.7K/4K Thermal Environment

A 50 hr 25 min cooler hold time was measured between 18.20 (on 19/09/05) and 20.45 (on 21/09/05).

4.6.2.3 Instrument Temperatures during the Nominal 1.7K/4K Test

		00:00-08:00	**@ 03:00 on 20/09/05**	**Corrected**
		Stability Criteria	**Temperature**	**Temperature**
Subsystems	**Sensor Name**	**K/hr**	**K**	**K**
Instrument	Pump	-3.31E-03	1.879	1.877
	Pump Heat Switch	-4.46E-03	19.677	19.044
	Evaporator Heat Switch	-9.59E-04	2.892	2.892
	Shunt	-8.83E-04	1.708	1.704
	SOBtemp	-2.92E-04	4.309	4.393
	Spectrometer L0 Enclosure	-8.38E-04	1.707	1.711
	Photometer L0 Enclosure	-8.60E-04	1.719	1.715
	SUBtemp	1.84E-04	4.312	4.375
	BAFtemp	4.70E-04	4.408	4.365
	BSMtemp	4.71E-04	4.300	4.330
	SCL2temp	4.45E-04	4.548	4.365
	SCL4temp	1.11E-04	4.217	4.375
	SCSTtemp	0.00E+00	5.776	4.368
	FTSStemp	-2.74E-04	4.293	4.293
	FTSMtemp	2.21E-04	4.228	4.228
	BSMMtemp	1.45E-04	4.267	4.267
	Evaporator	-1.82E-05	0.288	0.288
EGSE	T_PJFS_CHAS	-4.89E-02	16.742	16.742
	T_SJFS_CHAS	6.16E-02	15.583	15.583
	T_FPU_MYAF	3.54E-04	4.344	4.344
	T_FPU_PYAF	0.00E+00	4.362	4.362
	T_SOB_CONE	6.28E-04	4.369	4.369
	T_SOB_L1CON	-6.33E-04	4.303	4.303
	SOB L1 Strap IF	1.40E-04	4.275	4.275
	L0 Enclosure Adaptor	-9.03E-04	1.707	1.707
	L0 Pump Adaptor	-1.55E-03	1.764	1.764
	L0 Evaporator Adaptor	-9.35E-04	1.702	1.702
	T_PL0_2	0.00E+00	1.723	1.723
	T_SL0_2	0.00E+00	1.719	1.719
	L0 Evaporator Adaptor 2	-9.15E-04	1.701	1.701
	L0 Pump Adaptor 2	-1.06E-03	1.717	1.717
	L0 Enclosure Adaptor 2	-8.73E-04	1.702	1.702
	L1 Strap IF	2.43E-04	4.242	4.242
Cryostat	End Cap 1	-9.72E-02	80.750	80.750
	End Cap 2	-9.03E-02	81.679	81.679
	Filter Mount	-6.53E-03	77.684	77.684
	End Cap 1	1.23E-01	15.360	15.360
	End Cap 2	1.06E-01	17.152	17.152
	Cylinder End	1.45E-01	14.826	14.826
	Cylinder Centre	1.15E-01	15.276	15.276
	Cylinder End	1.21E-01	15.539	15.539
	FSJFP L3 I/F (L3 strap side)	1.37E-01	23.058	23.058
	FSJFS L3 I/F (L3 strap side)	9.00E-02	15.597	15.597
	FSJFP-HOB I/F (HOB side)	1.16E-01	15.376	15.376
	FPU Cone Foot I/F (HOB side)	1.12E-01	15.805	15.805
	FPU +Y Foot I/F (HOB side)	1.11E-01	16.015	16.015
	FPU -Y Foot I/F (HOB side)	N/A	N/A	N/A
	FSJFS-HOB I/F (HOB side)	1.13E-01	15.423	15.423
	Harness Sink WE-Ph JFET (L2 Shield Side)	-2.64E-02	20.119	20.119

Table 4-20 – Instrument Temperatures during the Nominal 1.7K/4K Test

4.6.2.4 Thermal Environment during the nominal 1.7K/4K Thermal Test Case

Figure 4-14 and Figure 4-15 describe the temperature profiles of the cryostat L0/L1 temperature stages during the cooler cold phase operation.

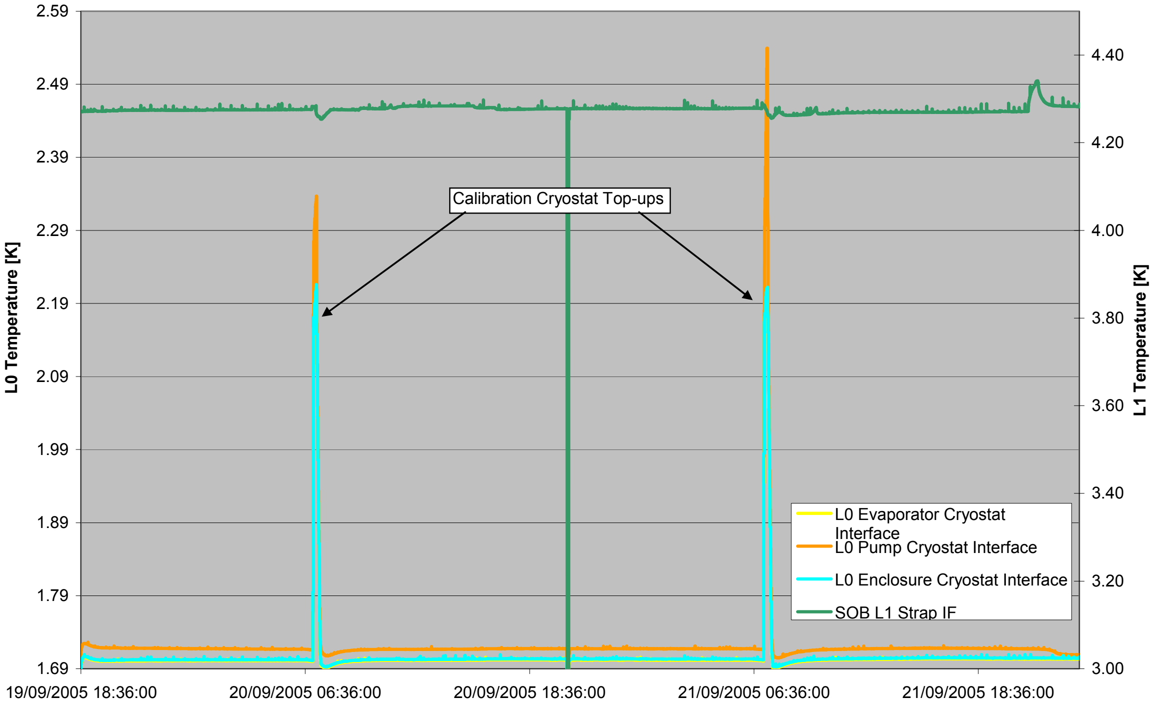


Figure 4-14 – Cryostat L0/L1 Thermal Environment during Cold Operation for the nominal 1.7K/4K environment

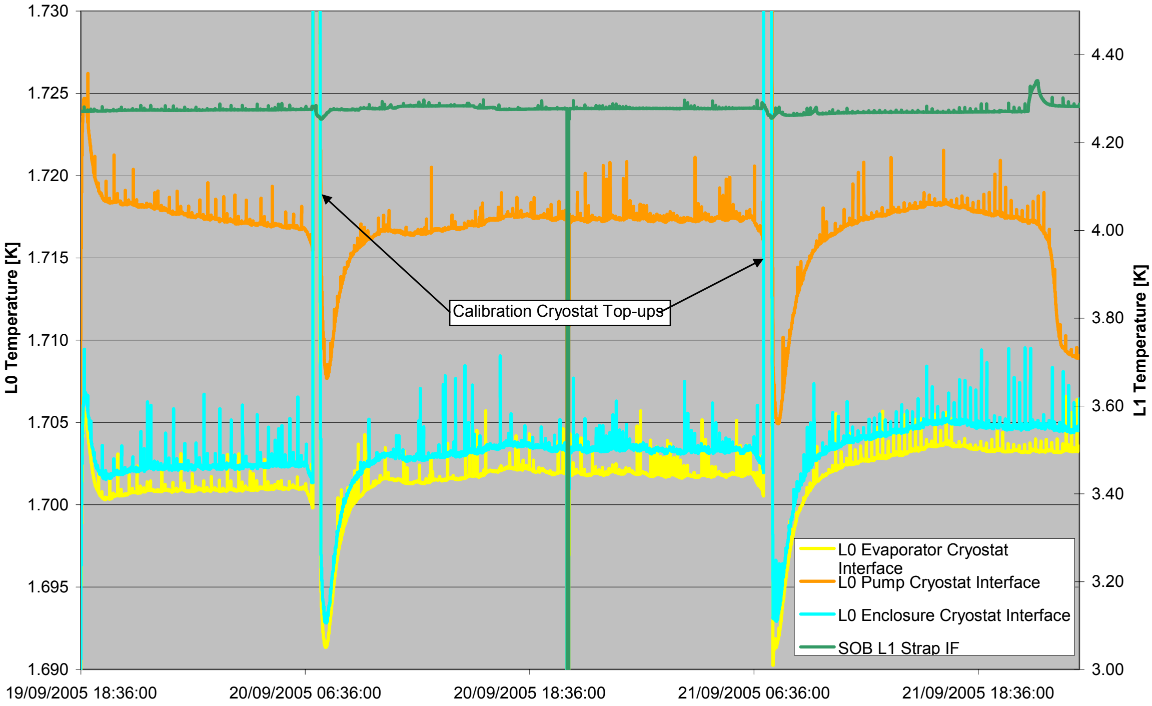


Figure 4-15 – Cryostat L0/L1 Thermal Environment during Cold Operation for the nominal 1.7K/4K environment

Figure 4-16 describes the temperature profiles of the cryostat L2 temperature stage during the cooler cold phase operation.

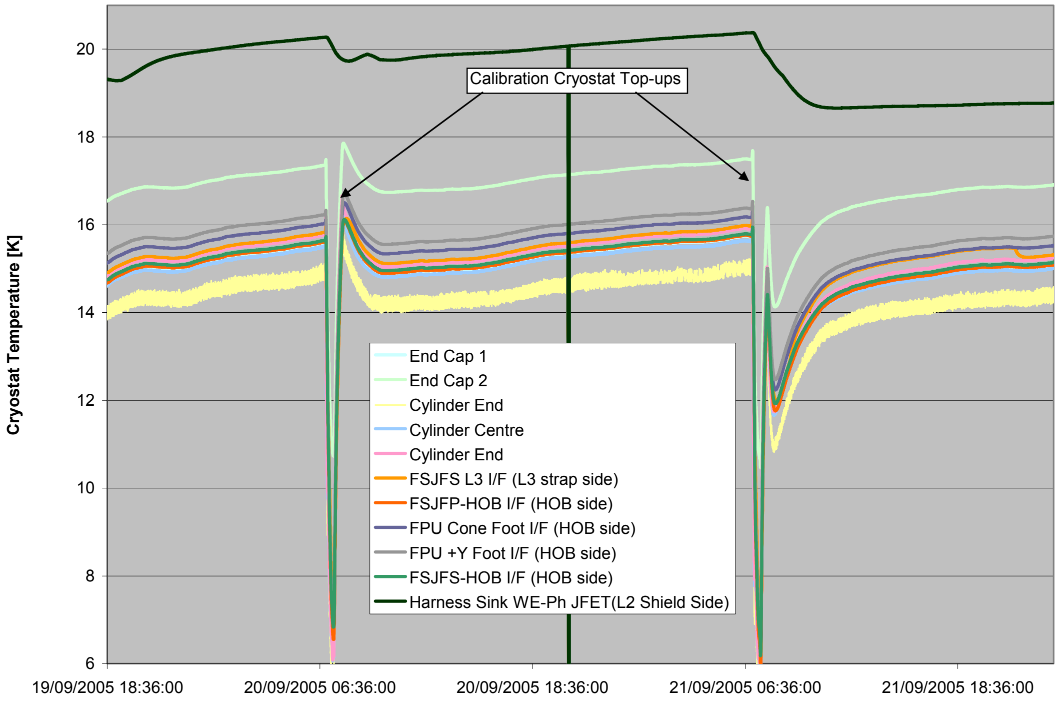


Figure 4-16– Cryostat L2 Thermal Environment during Cold Operation for the nominal 1.7K/4K environment

4.6.2.5 Instrument Thermal Performance- Summary

Table 4-21 through Table 4-25 summarise the SPIRE PFM2 thermal performances for the nominal 1.7K/4K thermal environment test case.

	Parameters	**Comments**
Start of Recycling	16:34	On 19/09/05.
End of Recycling	18:20	On 19/09/05.
Total Recycling Duration	1 hr 46 min	-
Evaporator End of Condensation Temperature	1.86K / 2.1K	Average of 1.98K.
Pump temperature at end of condensation	41.6K	Versus 45K at Unit Level Testing.
Start of Cold Phase Operation	18:20	On 19/09/05.
End of Cold Phase Operation	20:45	On 21/09/05.
Measured Hold Time	50 hr 25 min	-
Cooler Cold Base Temperature	288.5mK	-

Table 4-21 - Cooler Recycling Performances Summary

	Parameters	**Comments**
Pump Heat Switch Heater Setting during Cold Operation Phase	0.77mW	This allows the use of the pump characterisation test results.
Pump Temperature	1.868 K	-
Estimated Pump Adsorption Load	~ 1.21mW	(1.868-1.73) x 8.78
Estimated Total Evaporator Load	26.9uW	Using a 45 amplification factor. [RD7]

Table 4-22 - Cooler Total Load Performance Summary

	Temperature	**Temperature Drops**	**Comments**
Cooler Cold Base Temperature	288.5mK	-	-
PLW Detector	283mK	-5.5mK	Measured on 19/09/05 at 20:04. This data looks inconsistent.
PMW Detector	303.7mK	15.2mK	Measured on 19/09/05 at 20:04.
PSW Detector	293.3mK	4.8mK	Measured on 19/09/05 at 20:04.
SLW Detector	299.9mK	11.4mK	Measured on 22/09/05 at 19:28.
SSW Detector	299.5mK	11mK	Measured on 22/09/05 at 19:28.

Table 4-23 - Detectors and 300mK Busbar Performances Summary

Note 1: The temperature drops described in the above table are taking place between the evaporator cold tip and the detectors so these temperature drops include the temperature drop along the 300mK busbar as well as the temperature drop internal to the BDA.

When looking at the data obtained for the “evaporator cold tip temperature versus applied load” at unit level (see Table 4-24), it appears that the evaporator temperature measured during PFM2 is inconsistent with the estimated total load on the evaporator.

Applied Power (*) [uW]	Cold Tip Temperature [mK]
0	257.6
10	271
20	280.2
30	288
40	294.5
50	299.9
100	319.8

(*) In addition to the 6.9uW cooler internal parasitic load measured for the 1.6K/1.8K for the L0 and L1 thermal environment respectively.

Table 4-24 – FM Cooler Evaporator Temperature versus applied power [RD7]

Based on this assumption and assuming that the 26.9uW estimated for the evaporator load is not too far from reality, the cold tip temperature could be expected to be about ~ 280mK. In this case, the temperature drop with the PLW detector would become consistent again (within the uncertainties). The pump temperature was most likely running at a temperatures lower than 1.7K during the unit level testing (versus 1.887K during the PFM2 test), but it is unlikely that it would affect the evaporator temperature unless the pump temperature was above 2.5K [RD7]. A calibration error or self-heating are therefore the most likely causes for this evaporator temperature inconsistency.

Table 4-25 and Figure 4-17 below describe the thermal performances of the instrument L0 enclosures.

	Sensors	Temperatures
Photometer L0 Enclosure – Far End	T1’	1.720
Photometer L0 Enclosure – Strap Interface	T1	1.715
Spectrometer L0 Enclosure – Far End	T2’	1.723
Spectrometer L0 Enclosure – Strap Interface	T2	1.711
L0 Detector Strap - Adaptor	T3’	1.707
L0 Detector Strap – Cryostat Interface	T3	1.702

Table 4-25 - L0 Enclosures Performances Summary

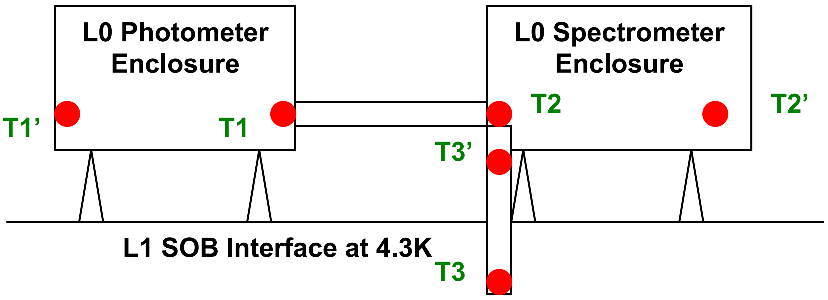


Figure 4-17 - L0 Enclosures Performances Summary

4.6.2.6 Cooler Recycling in 2K/5K Thermal Environment

Figure 4-18 describes the temperature profiles of the SPIRE FM cooler during the thermal test case in the 2K/5K thermal environment.

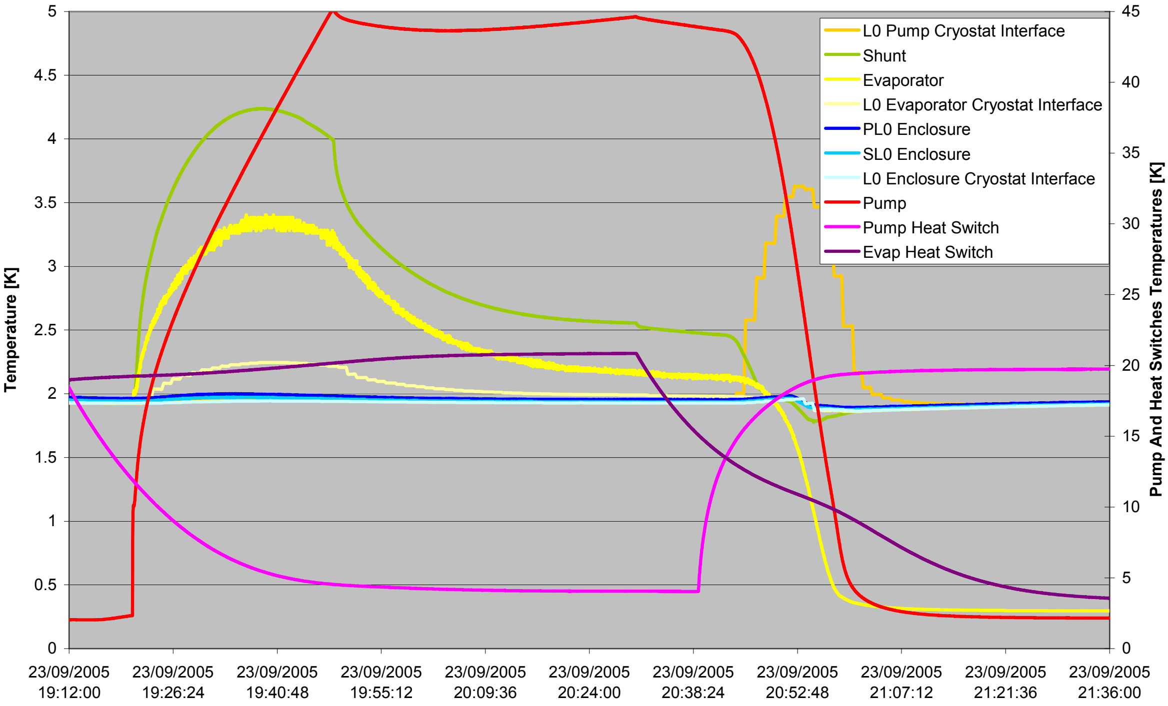


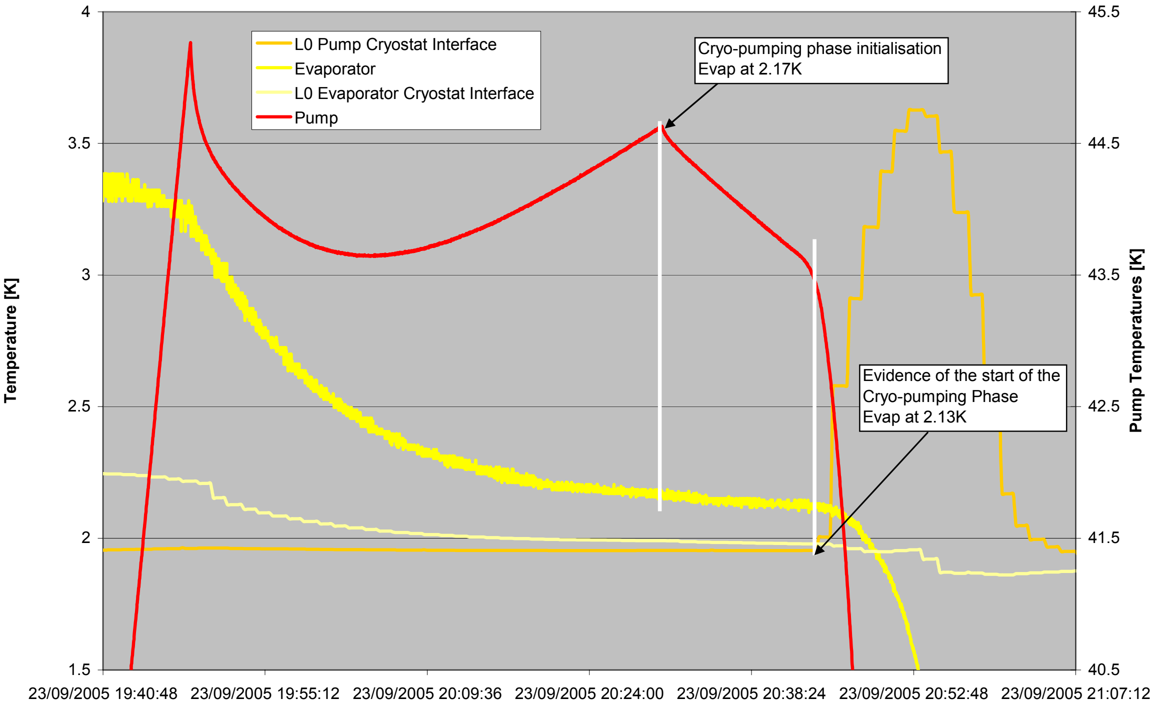
Figure 4-18 – Cooler Recycling for the 2K/5K Thermal Environment

The cooler recycling started and ended at 19:17 and 21:24 respectively on the 23/09/05. The evaporator reached a cold "base" temperature of 295mK following recycling for the 2K/5K thermal environment.

The start of the cooler low-temperature operation phase (and criteria for end of cooler recycling) has been defined as the time at which the evaporator temperature is within 1% of its base temperature i.e. in this case, 1% of 295mK which gives ~298mK.

Because the cryostat L0 interfaces were running at 2K (versus 1.7K in the previous test), it took longer for the evaporator to cool down and its end of condensation temperature was slightly higher: the cryo-pumping phase was initiated with the evaporator at 2.17K. The evaporator had cool down to 2.13K when the first sign of the cryo-pumping phase appeared on the pump cryostat interface, as described in Figure 4-19.

It is interesting to note that in this case, the cryostat manostat has remained closed for most of the cooler recycling period and that little disturbances were experienced at the L0 in comparison with the 1.7K test case.



Cryo-pumping phase initialisation
Evap at 2.17K

Evidence of the start of the
Cryo-pumping Phase
Evap at 2.13K

Figure 4-19 - Cooler Recycling Close-up for the 2K/5K Thermal Environment

In this case, the pump was also unregulated and had been allowed to slightly cool down from 45K to 43.5K at the start of the cryo-pumping phase. Additional analysis will be required to look at the adsorption state of both the evaporator and the pump during this period, to try and estimate when exactly the evaporator stopped condensing. As before, an average condensation temperature of 2.15K will be assumed to start with.

4.6.2.7 Cooler Hold Time in 2K/5K Thermal Environment

An evaporator base temperature of 298mK (see section 6.6.2.1) was used to determine the cooler hold time for the 2K/5K thermal environment, as described in Figure 4-20 and Figure 4-21.

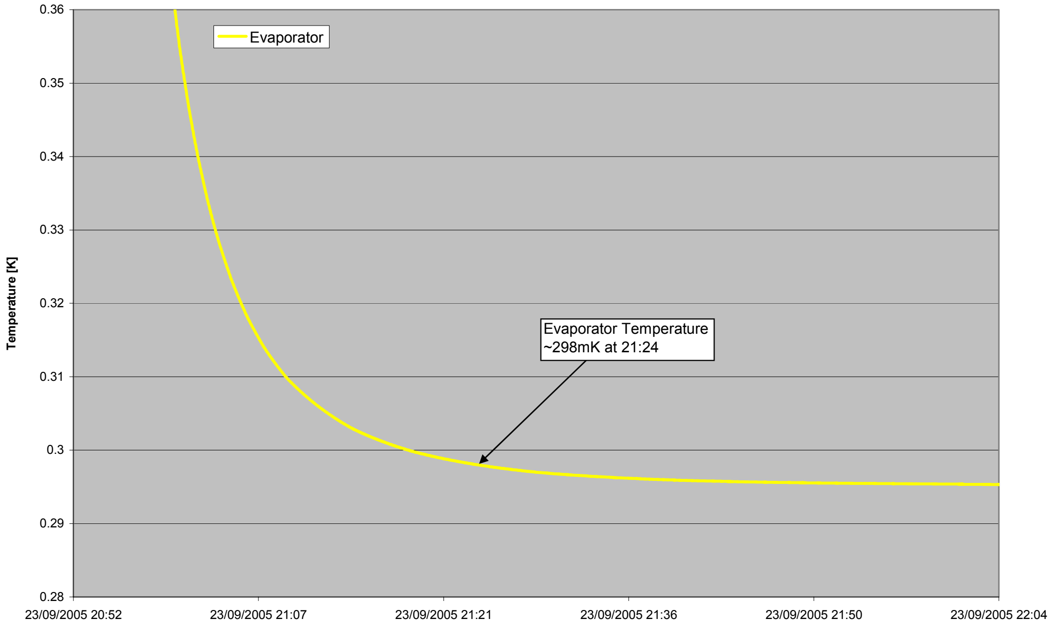


Figure 4-20 – Start of Cooler Hold Time for the 2K/5K Environment

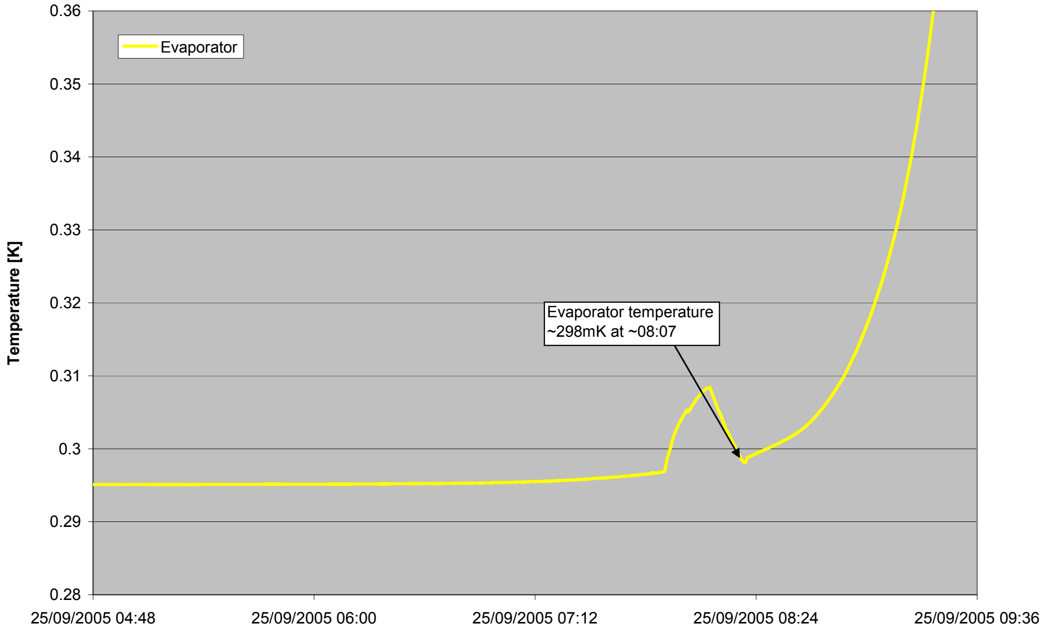


Figure 4-21 - End of Cooler Hold Time for the 2K/5K Environment

A 34 hr 43 min cooler hold time was measured between 21:24 (on 23/09/05) and 08:07 (on 25/09/05). The bump in the evaporator data at the end of the cooler hold time corresponds to a cryostat top up.

4.6.2.8 Instrument Temperatures during the Nominal 2K/5K Test

		21:00-02:00	**@ 02:00 on 25/09**	**Corrected**
		Stability Criteria	**Temperature**	**Temperature**
Subsystems	**Sensor Name**	**K/hr**	**K**	**K**
Instrument	Pump	-4.29E-04	2.108	2.106
	Pump Heat Switch	0.00E+00	19.745	19.112
	Evaporator Heat Switch	-4.71E-04	3.373	3.373
	Shunt	1.22E-04	1.934	1.929
	SOBtemp	-1.05E-03	5.431	5.550
	Spectrometer L0 Enclosure	-6.06E-05	1.936	1.941
	Photometer L0 Enclosure	1.30E-04	1.954	1.949
	SUBtemp	-1.33E-03	5.523	5.615
	BAFtemp	4.44E-04	5.872	6.312
	BSMtemp	5.90E-04	5.561	5.614
	SCL2temp	-2.13E-04	5.727	5.501
	SCL4temp	-7.96E-04	5.323	5.491
	SCSTtemp	0.00E+00	7.433	5.552
	FTSStemp	-4.91E-04	5.349	5.349
	FTSMtemp	-2.99E-04	5.390	5.390
	BSMMtemp	-3.78E-04	5.516	5.516
	Evaporator	-2.60E-06	0.295	0.295
EGSE	T_PJFS_CHAS	2.87E-02	14.298	14.298
	T_SJFS_CHAS	3.09E-02	14.494	14.494
	T_FPU_MYAF	-3.99E-04	5.230	5.230
	T_FPU_PYAF	-4.84E-04	5.244	5.244
	T_SOB_CONE	-2.17E-04	5.642	5.642
	T_SOB_L1CON	-1.73E-04	5.185	5.185
	SOB L1 Strap IF	-4.85E-04	4.798	4.798
	L0 Enclosure Adaptor	9.44E-05	1.939	1.939
	L0 Pump Adaptor	-1.08E-04	1.992	1.992
	L0 Evaporator Adaptor	-5.85E-05	1.932	1.932
	T_PL0_2	0.00E+00	1.723	1.723
	T_SL0_2	0.00E+00	1.719	1.719
	L0 Evaporator Adaptor 2	7.75E-05	1.931	1.931
	L0 Pump Adaptor 2	1.64E-05	1.945	1.945
	L0 Enclosure Adaptor 2	7.72E-05	1.932	1.932
	L1 Strap IF	-7.70E-04	4.358	4.358
Cryostat	End Cap 1	7.24E-02	80.595	80.595
	End Cap 2	5.16E-02	81.576	81.576
	Filter Mount	-2.09E-02	77.528	77.528
	End Cap 1	3.45E-02	14.232	14.232
	End Cap 2	3.03E-02	16.171	16.171
	Cylinder End	-2.91E-02	6.124	6.124
	Cylinder Centre	3.34E-02	14.183	14.183
	Cylinder End	3.58E-02	14.376	14.376
	FSJFP L3 I/F (L3 strap side)	8.06E-02	20.562	20.562
	FSJFS L3 I/F (L3 strap side)	3.29E-02	14.451	14.451
	FSJFP-HOB I/F (HOB side)	3.25E-02	14.222	14.222
	FPU Cone Foot I/F (HOB side)	3.34E-02	14.694	14.694
	FPU +Y Foot I/F (HOB side)	3.17E-02	14.908	14.908
	FPU -Y Foot I/F (HOB side)	dead	dead	dead
	FSJFS-HOB I/F (HOB side)	3.17E-02	14.311	14.311
	Harness Sink WE-Ph JFET (L2 Shield Side)	1.03E-02	18.016	18.016

Table 4-26 – Instrument Temperatures during the 2K/5K Test

Note: The temperatures in red are inconsistent and have been ignored for this specific test.

4.6.2.9 Thermal Environment during the 2K/5K Thermal Test Case

Figure 4-22 and Figure 4-23 describe the temperature profiles of the cryostat L0/L1 temperature stages during the cooler cold phase operation.

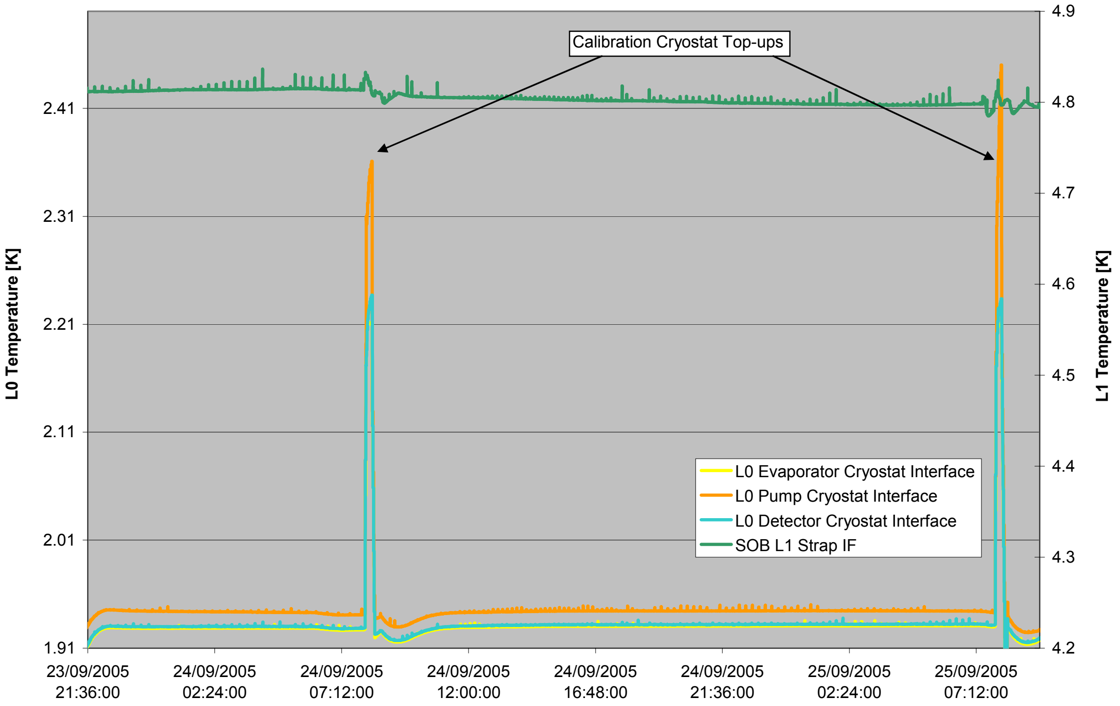


Figure 4-22 - Cryostat L0/L1 Thermal Environment during Cold Operation for the 2K/5K environment

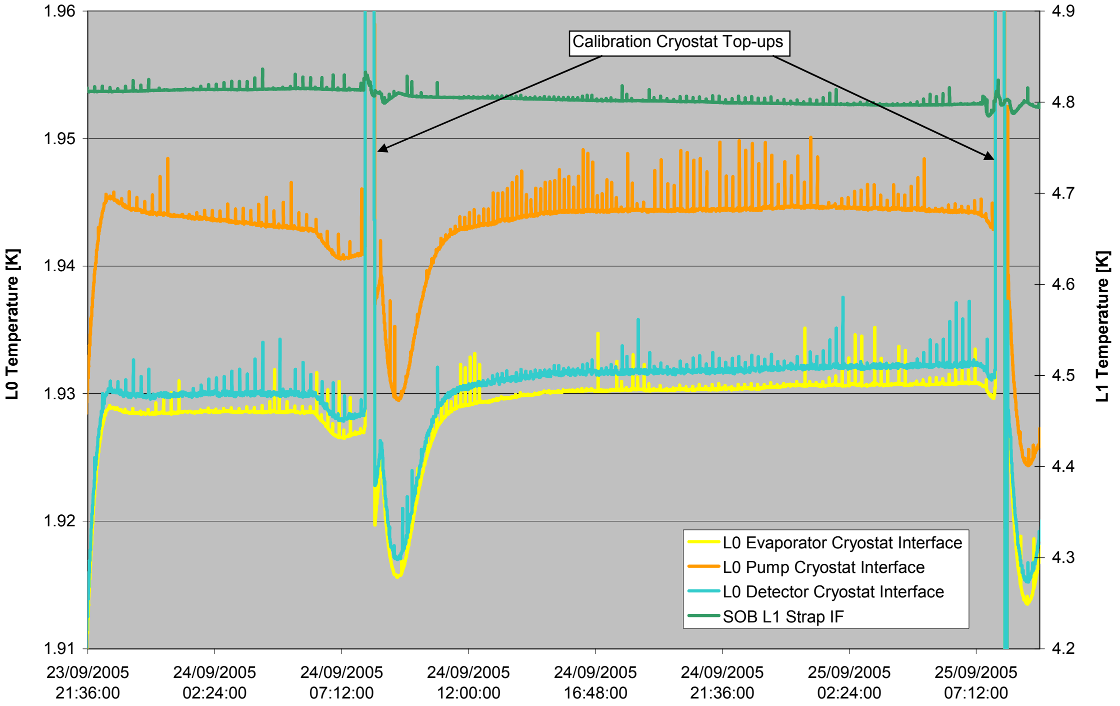


Figure 4-23 - Cryostat L0/L1 Thermal Environment during Cold Operation for the 2K/5K environment

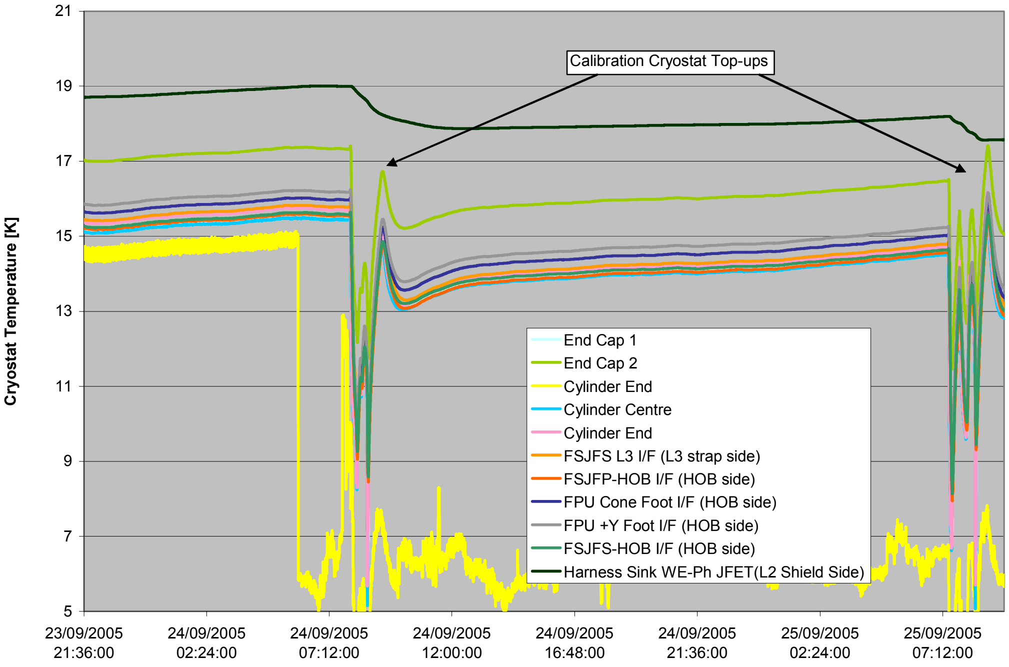


Figure 4-24- Cryostat L2 Thermal Environment during Cold Operation for the 2K/5K environment

Note: It looks like the sensor on the cryostat cylinder end began to malfunction in the early morning on 24/09/05.

4.6.2.10 Instrument Thermal Performance- Summary

Table 4-27 through Table 4-29 summarise the SPIRE PFM2 thermal performances for the 2K/5K thermal environment test case.

	Parameters	**Comments**
Start of Recycling	19:17	On 23/09/05.
End of Recycling	21:24	On 23/09/05.
Total Recycling Duration	02:07	-
Evaporator End of Condensation Temperature	2.13K / 2.17K	Average of 2.15K.
Pump temperature at end of condensation	43.5K	Versus 45K at Unit Level Testing.
Start of Cold Phase Operation	21:24	On 23/09/05.
End of Cold Phase Operation	08:07	On 25/09/05.
Measured Hold Time	34:43	-
Cooler Cold Base Temperature	295mK	-

Table 4-27 - Cooler Recycling Performances Summary

	Temperature	**Temperature Drops**	**Comments**
Cooler Cold Base Temperature	301.9mK	-	-
SLW Detector	340mK	38.1mK	Measured on 23/09/05 at 18:08.
SSW Detector	341.4mK	39.5mK	Measured on 23/09/05 at 18:08.

Table 4-28 - Detectors and 300mK Busbar Performances Summary

Note: The photometer detectors temperatures have not been measured in this specific configuration.

	Sensors	**Temperatures**
Photometer L0 Enclosure – Strap Interface	T1	1.949
Spectrometer L0 Enclosure – Strap Interface	T2	1.941
L0 Detector Strap - Adaptor	T3’	1.939
L0 Detector Strap – Cryostat Interface	T3	1.932

Table 4-29 - L0 Enclosures Performances Summary

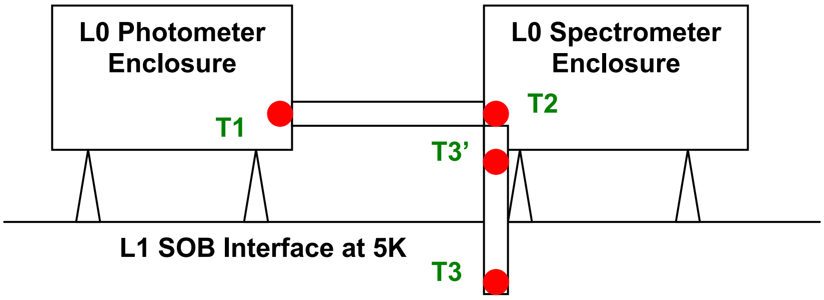


Figure 4-25 - L0 Enclosures Performances Summary

5 CONCLUSION

5.1 Summary

- All the thermal tests planned for the PFM2 test campaign have been completed with the exception of the Level-0 Detector Strap Characterisation as the EGSE heater on the photometer enclosure was open circuit after cooldown.
- One of the pump characterisation test cases was stopped before reaching the required stability.
- A 50 hr 25 min cooler hold time has been measured for the nominal 1.7K/4K environment, an unregulated pump and an evaporator condensation temperature of ~1.9K.
- All five instrument detectors absolute temperatures are below 310mK for the nominal 1.7K/4K environment.

5.2 Area of Possible Improvements

The following suggestions should be taken into account for the next PFM3 test campaign:

- The errors in the calibration curves should be corrected before the next test campaign.
- A graphical interface should be developed to improve the monitoring of the temperature rate of change during the thermal test cases, especially when assessing whether steady-state has been achieved.
- The method used to recycle the cooler should be re-evaluated to ensure that:
    - The evaporator temperature does not fall below 2K at the end of a condensation phase,
    - The pump temperature is regulated to 45K during the whole recycling duration.
- All flight temperature sensors should be measured on an AC bridge when the thermal test cases have reached stability.
- A new power supply should be used for the L1 characterisation test that will provide a 4-wire measurement for all the thermal test cases.

6 APPENDICES

6.1 Temperature Sensors Characterisation Test

6.1.1 Temperature Profiles and Stability

	Period (UTC)		**Temperature Change**	**Rate of Change**
Time	**12.00**	**16.00**	**4**	
Prime Flight on DRCU			**[mK]**	**[mK/hr]**
PUMPHTRTEMP	2.131	2.114	-17	-4.29
PUMPHSTEMP	2.928	2.931	3	0.68
EVAPHSTEMP	2.821	2.823	2	0.55
SHUNTTEMP	1.698	1.701	3	0.74
SOBTEMP	4.279	4.286	7	1.75
SL0TEMP	1.696	1.700	3	0.87
PL0TEMP	1.708	1.711	3	0.86
OPTTEMP	4.283	4.292	9	2.20
BAFTEMP	4.378	4.392	13	3.29
BSMIFTEMP	4.273	4.274	1	0.31
SCAL2TEMP	4.521	4.528	7	1.78
SCAL4TEMP	4.192	4.196	4	1.05
SCALTEMP	5.745	5.745	0	0.00
SMECIFTEMP	4.267	4.270	3	0.82
SMECTEMP	4.200	4.205	5	1.24
BSMTEMP	4.242	4.247	5	1.26
SUBKTEMP	1.819	1.795	-23	-5.80
Instrument EGSE			**[mK]**	**[mK/hr]**
T_PJFS_CHAS	14.541	14.931	390	97.55
T_SJFS_CHAS	14.710	15.102	392	97.98
T_FPU_MYAF	4.320	4.323	3	0.70
T_FPU_PYAF	4.332	4.337	5	1.29
T_SOB_CONE	4.341	4.347	5	1.35
T_SOB_L1CON	4.273	4.278	5	1.22
T_SOB_L1STR	4.256	4.258	2	0.46
T_L0_DSTR	1.697	1.700	3	0.86
T_L0_PSTR	1.698	1.701	3	0.87
T_L0_ESTR	1.691	1.694	4	0.92
T_PL0_2	1.709	1.715	6	1.55
T_SL0_2	1.705	1.711	6	1.53
L0_ESIF_TEMP2	1.690	1.693	4	0.88
L0_PSIF_TEMP2	1.690	1.694	3	0.86
L0_DSIF_TEMP2	1.691	1.695	4	0.88
L1_SIF_TEMP2	4.229	4.229	0	0.01
Cryostat EGSE			**[mK]**	**[mK/hr]**
End Cap 1	14.486	14.883	396	99.04
End Cap 2	16.373	16.713	340	85.08
Cylinder End	13.639	14.045	406	101.47
Cylinder Centre	14.426	14.816	390	97.43
Cylinder End	14.643	15.053	410	102.46
FSJFP L3 I/F (L3 strap side)	21.152	21.833	681	170.29
FSJFS L3 I/F (L3 strap side)	14.683	15.094	411	102.67
FSJFP-HOB I/F (HOB side)	14.466	14.872	406	101.49
FPU Cone Foot I/F (HOB side)	14.924	15.318	394	98.60
FPU +Y Foot I/F (HOB side)	15.141	15.534	393	98.26
FSJFS-HOB I/F (HOB side)	14.542	14.934	392	98.05
Harness Sink	18.062	18.410	348	87.12

Table 6-1 - Temperature Sensors Characterisation – Stability

Figure 6-1 and Figure 6-2 give an overview of the instrument L1 and L0 temperatures during the test.

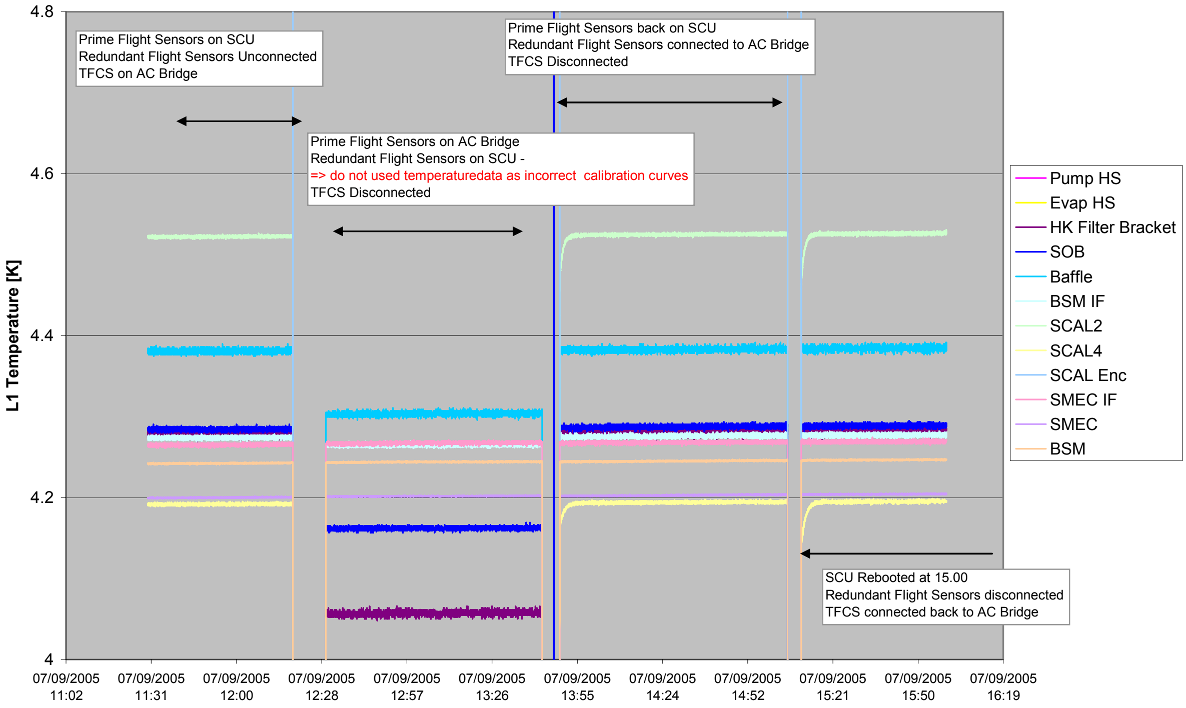


Figure 6-1 – Flight L1 Temperature Sensors Characterisation

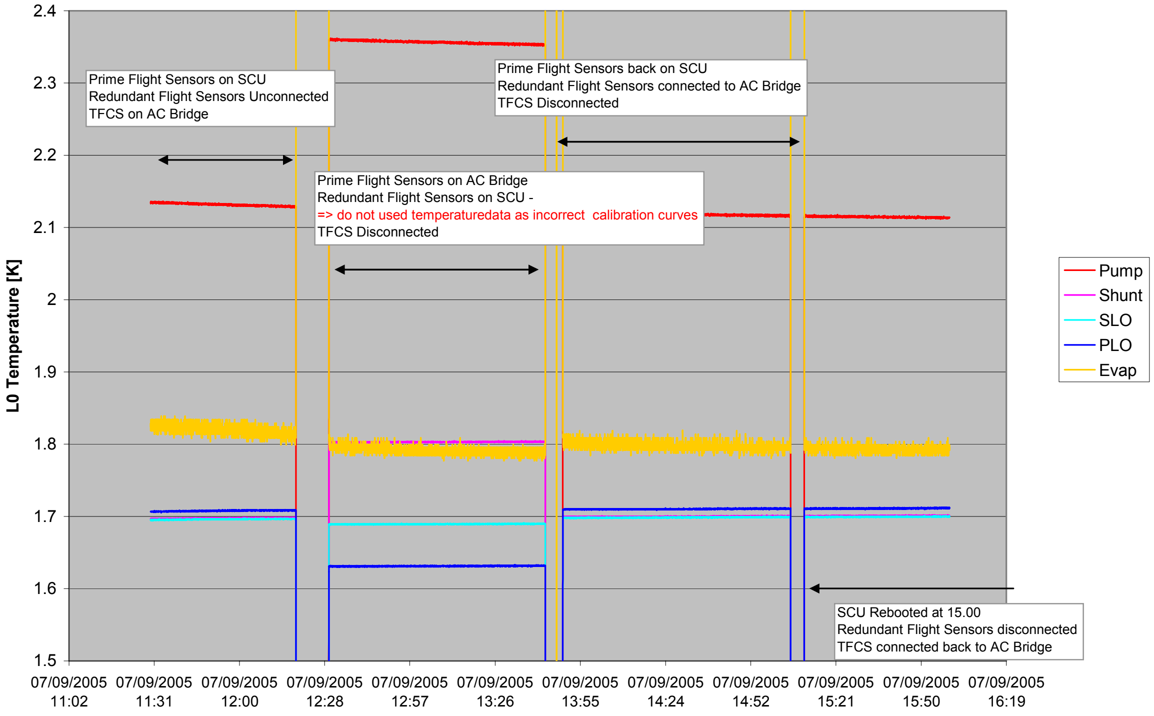


Figure 6-2 - Flight L0 Temperature Sensors Characterisation

6.1.2 Summary of Flight Sensors Performances

6.1.2.1 Prime Temperature Sensors

	Prime	DRCU Transfer Function		DRCU		Calculated Resistance	Calculated Excitation	Calculated Dissipation	Temp Vs Resistance Calibration Curves							
Sensor ID	Sensor Name	P0	P1	Temperature	Raw Value	Based on Transfer Function	Current for 10mV Signal	Q	Temperature 1	Temperature 2	Resistance 1	Resistance 2	Linear Interpolation		DRCU Temperature Check	Calibration Dispersion Errors
		-	-	K	Count	Ohms	uA	W	K	K	Ohms	Ohms	m	p	K	mK
T_CPHP_1	Cooler Pump	5.00E+00	-3.69E+06	2.13	-4412	835.9	11.96	1.20E-07	2.005	2.200	882.609	811.822	-2.76E-03	4.44	2.134	3.7
T_CSHT_1	Cooler Shunt	8.30E+01	-8.54E+06	1.698	-4792	1751.2	5.71	5.71E-08	1.600	1.804	1879.930	1630.390	-8.20E-04	3.14	1.705	7.3
T_CEV_1	Cooler Evap	3.27E+04	-1.71E-01	1.82	32410	1946.2	0.04	3.11E-12	1.801	2.001	1966.690	1734.160	-8.61E-04	3.50	1.819	-1.3
T_CPHS_1	Cooler Pump Heat Switch (sieve)	4.80E+00	-5.48E+06	2.93	-6010	911.6	10.97	1.10E-07	2.806	2.994	947.162	893.421	-3.50E-03	6.12	2.931	0.7
T_CEHS_1	Cooler Evap Heat Switch (sieve)	-8.00E+00	-5.46E+06	2.8208	-5816	939.9	10.64	1.06E-07	2.807	2.995	944.080	891.215	-3.55E-03	6.16	2.822	1.0
T_PL0_1	Photometer Level 0 Enclosure	-2.40E+01	-8.42E+06	1.708	-4531	1867.1	5.36	5.36E-08	1.601	1.800	2019.690	1752.307	-7.44E-04	3.10	1.715	6.9
T_SL0_1	Spectrometer Level 0 Enclosure	2.00E+01	-8.48E+06	1.696	-4974	1698.8	5.89	5.89E-08	1.603	1.801	1816.260	1585.280	-8.58E-04	3.16	1.703	7.5
EMCFIL_1	HSFPU Harness Filter Bracket	7.00E+00	-1.27E+06	4.28	-2776	455.3	21.97	2.20E-07	4.218	4.626	459.355	432.053	-1.49E-02	11.08	4.279	-0.6
T_SUB_1	M3,5,7 Optical Sub Bench	3.90E+01	-2.20E+06	4.28	-4176	521.9	19.16	1.92E-07	4.201	4.674	528.930	490.927	-1.24E-02	10.78	4.288	8.2
T_BAF_1	Input Baffle	-1.60E+01	-2.09E+06	4.38	-3088	680.7	14.69	1.47E-07	4.198	4.781	702.877	636.481	-8.79E-03	10.38	4.393	13.0
T_BAF_1	Input Baffle	-1.60E+01	-2.09E+06	4.38	-3088	680.7	14.69	1.47E-07	4.224	4.642	689.791	641.373	-8.62E-03	10.17	4.303	N/A
T_BSMS_1	BSM/SOB I/F (SOB side)	3.80E+01	-2.93E+06	4.27	-4515	643.1	15.55	1.55E-07	4.206	4.452	651.202	623.975	-9.04E-03	10.10	4.279	9.2
T_SCST_1	SCAL Structure	1.10E+02	-2.91E+06	5.743	-3785	747.1	13.38	1.34E-07	5.714	6.250	750.000	700.000	-1.07E-02	13.75	5.745	2.0
T_SCST_1	SCAL Structure	4.80E+00	-3.58E+06	N/A	-3785	945.4	10.58	1.06E-07	4.273	4.557	950.000	900.000	-5.68E-03	9.67	4.299	N/A
T_SCL4_1	SCAL 4%	1.10E+02	-2.91E+06	4.192	-6606	433.3	23.08	2.31E-07	4.007	4.204	447.968	432.381	-1.26E-02	9.65	4.192	0.0
T_SCL2_1	SCAL 2%	9.00E+01	-2.94E+06	4.523	-6874	421.7	23.71	2.37E-07	4.202	4.724	444.764	408.437	-1.44E-02	10.60	4.533	10.1
T_SCL4_1	SCAL 4%	1.10E+02	-2.91E+06	4.192	-6606	433.3	23.08	2.31E-07	4.202	4.724	444.764	408.437	-1.44E-02	10.60	4.367	N/A
T_SCL2_1	SCAL 2%	9.00E+01	-2.94E+06	4.523	-6874	421.7	23.71	2.37E-07	4.204	4.724	432.381	397.784	-1.50E-02	10.71	4.364	N/A

	Prime	Measured Resistance with 370							**OFFICIAL RESULTS**			
Sensor ID	Sensor Name	R_1uA	Power Dissipated For 1uA	Estimated Temperature	Estimated Self Heating Error	R_10uA	Power Dissipated for 10uA	Estimated Temperature	**DRCU Temperature Sensor Self-Heating**	**DRCU Temperature Sensor Self-Heating**	**DRCU Temperature Sensor DC Offset**	**DRCU Temperature Sensor DC Offset**
		Ohms	W	K	mK	Ohms	W	K	**mK**	**ohms**	**ohms**	**mK**
T_CPHP_1	Cooler Pump	836.44	8.36E-10	2.132	0.035	835.18	8.3518E-08	2.136	5.0	-1.82	1.2	-3.4
T_CSHT_1	Cooler Shunt	1755.85	1.76E-09	1.701	0.102	1743.58	1.74358E-07	1.712	3.3	-4.05	-0.6	0.5
T_CEV_1	Cooler Evap	1967.74	1.97E-09	1.800	0.086	1957.88	1.95788E-07	1.809	N/A	N/A	N/A	N/A
T_CPHS_1	Cooler Pump Heat Switch (sieve)	916.29	9.16E-10	2.914	0.019	915.75	9.1575E-08	2.916	2.3	-0.65	-4.1	14.2
T_CEHS_1	Cooler Evap Heat Switch (sieve)											
T_PL0_1	Photometer Level 0 Enclosure	1871.69	1.87E-09	1.711	0.101	1858.3	1.8583E-07	1.721	2.9	-3.89	-0.7	0.5
T_SL0_1	Spectrometer Level 0 Enclosure	1694.43	1.69E-09	1.707	0.092	1683.89	1.68389E-07	1.716	3.2	-3.73	8.1	-7.0
EMCFIL_1	HSFPU Harness Filter Bracket	449.71	4.50E-10	4.362	0.015	449.61	4.4961E-08	4.364	7.5	-0.50	6.1	-90.4
T_SUB_1	M3,5,7 Optical Sub Bench	516.87	5.17E-10	4.351	0.011	516.78	5.1678E-08	4.352	4.2	-0.34	5.4	-67.4
T_BAF_1	Input Baffle	675.16	6.75E-10	4.441	0.009	675.06	6.7506E-08	4.442				
T_BAF_1	Input Baffle	675.16	6.75E-10	4.350	0.009	675.06	6.7506E-08	4.351	1.9	-0.22	5.7	-49.4
T_BSMS_1	BSM/SOB I/F (SOB side)	639.75	6.40E-10	4.309	0.183	637.75	6.3775E-08	4.327	44.8	-4.95	8.3	-75.0
T_SCST_1	SCAL Structure	937.82	9.38E-10	3.701	0.018	937.65	9.3765E-08	3.702				
		937.82	9.3782E-10	4.342	0.018	937.65	9.3765E-08	4.343	1.1	-0.20	7.8	-44.3
T_SCL4_1	SCAL 4%	434.54	4.35E-10	4.176	0.023	434.36	4.3436E-08	4.179				
T_SCL2_1	SCAL 2%	422.58	4.23E-10	4.521	0.031	422.37	4.2237E-08	4.524				
T_SCL4_1	SCAL 4%	434.54	4.35E-10	4.349	0.026	434.36	4.3436E-08	4.352	13.9	-0.96	-0.3	4.1
T_SCL2_1	SCAL 2%	422.58	4.23E-10	4.351	0.032	422.37	4.2237E-08	4.354	17.9	-1.19	0.3	-5.2

6.1.2.2 *Redundant Temperature Sensors*

	Redundant	DRCU Transfer Function		DRCU	DRCU	Calculated Resistance	Calculated Excitation	Calculated Dissipation	Temp Vs Resistance Calibration Curves							@13.40	
Sensor ID	Sensor Name	P0	P1	Temperature	Raw Value	Based on Transfer Function	Current for 10mV Signal	Q	Calibration Curve	Temperature 1	Temperature 2	Resistance 1	Resistance 2	Linear Interpolation		DRCU Temperature Check	Calibration Dispersion Errors
		-	-	K	Count	Ohms	uA	W	-	K	K	Ohms	Ohms	m	p	K	mK
T_CPHP_1	Cooler Pump	5.000E+00	-3.692E+06	N/A	-4815	765.98	13.06	1.31E-07	29580	2.00023	2.20476	805.473	741.051	-3.17E-03	4.56	2.126	N/A
T_CSHT_1	Cooler Shunt	8.300E+01	-8.537E+06	N/A	-5150	1631.38	6.13	6.13E-08	29571	1.60140	1.80301	1745.87	1521.77	-9.00E-04	3.17	1.704	N/A
T_CEV_1	Cooler Evap	3.274E+04	-1.711E-01	N/A	32404	1981.30	0.04	3.17E-12	29548	1.80206	2.00221	1986.39	1750.68	-8.49E-04	3.49	1.806	N/A
T_CPHS_1	Cooler Pump Heat Switch (sieve)	4.800E+00	-5.483E+06	N/A	-6014	910.98	10.98	1.10E-07	29549	2.80845	2.99472	943.58	891.24	-3.56E-03	6.17	2.924	N/A
T_CEHS_1	Cooler Evap Heat Switch (sieve)	-8.000E+00	-5.459E+06	N/A	-5808	941.21	10.62	1.06E-07	29578	2.80328	3.03686	946.18	882.68	-3.68E-03	6.28	2.822	
T_PL0_1	Photometer Level 0 Enclosure	-2.400E+01	-8.415E+06	N/A	-4287	1973.96	5.07	5.07E-08	29603	1.60277	1.80092	2135.64	1851.15	-6.97E-04	3.09	1.715	N/A
T_SL0_1	Spectrometer Level 0 Enclosure	2.000E+01	-8.484E+06	N/A	-4950	1707.04	5.86	5.86E-08	29592	1.60105	1.80010	1830.35	1595.94	-8.49E-04	3.16	1.706	N/A
EMCFIL_1	HSFPU Harness Filter Bracket	7.000E+00	-1.267E+06	N/A	-2681	471.35	21.22	2.12E-07	31056	4.22465	4.64189	476.40	447.55	-1.45E-02	11.11	4.298	N/A
T_SUB_1	M3,5,7 Optical Sub Bench	3.900E+01	-2.200E+06	N/A	-4091	532.69	18.77	1.88E-07	29602	4.20637	4.45228	539.95	519.03	-1.18E-02	10.56	4.292	N/A
T_BAF_1	Input Baffle	-1.600E+01	-2.091E+06	N/A	-3047	689.87	14.50	1.45E-07	31033	4.00606	4.22443	719.71	689.79	-7.30E-03	9.26	4.224	N/A
T_BAF_1	Input Baffle	-1.600E+01	-2.091E+06	N/A	-3047	689.87	14.50	1.45E-07	31033	4.19770	4.78136	702.88	636.48	-8.79E-03	10.38	4.312	N/A
T_BSMS_1	BSM/SOB I/F (SOB side)	3.800E+01	-2.928E+06	N/A	-4506	644.37	15.52	1.55E-07	31036	4.22433	4.64150	650.15	606.34	-9.52E-03	10.41	4.279	N/A

	Redundant	Measured Resistance with 370							OFFICIAL RESULTS			
Sensor ID	Sensor Name	R_1uA	Power Dissipated For 1uA	Estimated Temperature	Estimated Self-Heating Error	R_10uA	Power Dissipated for 10uA	Estimated Temperature	**DRCU Temperature Sensor Self-Heating**	**DRCU Temperature Sensor Self-Heating**	**DRCU Temperature Sensor DC Offset**	**DRCU Temperature Sensor DC Offset**
		Ohms	W	K	mK	Ohms	W	K	**mK**	**ohms**	**ohms**	**mK**
T_CPHP_1	Cooler Pump	765.85	7.66E-10	2.126	0.024	765.10	7.65E-08	2.128	4.1	-1.3	1.4	-4.5
T_CSHT_1	Cooler Shunt	1636.80	1.64E-09	1.700	0.121	1623.58	1.62E-07	1.711	4.5	-5.0	-0.4	0.4
T_CEV_1	Cooler Evap	2003.68	2.00E-09	1.787	0.107	1991.24	1.99E-07	1.798	N/A	N/A	N/A	N/A
T_CPHS_1	Cooler Pump Heat Switch (sieve)	912.35	9.12E-10	2.920	0.010	912.08	9.12E-08	2.921	1.2	-0.3	-1.0	3.7
T_CEHS_1	Cooler Evap Heat Switch (sieve)											
T_PL0_1	Photometer Level 0 Enclosure	1978.70	1.98E-09	1.712	0.099	1964.77	1.96E-07	1.722	2.5	-3.6	-1.1	0.8
T_SL0_1	Spectrometer Level 0 Enclosure	1702.39	1.70E-09	1.710	0.096	1691.22	1.69E-07	1.719	3.3	-3.9	8.6	-7.3
EMCFIL_1	HSFPU Harness Filter Bracket	465.76	4.66E-10	4.379	-0.174	466.95	4.67E-08	4.361	-80.1	5.5	5.6	-80.9
T_SUB_1	M3,5,7 Optical Sub Bench	527.40	5.27E-10	4.354	-0.013	527.51	5.28E-08	4.353	-4.7	0.4	5.3	-62.2
T_BAF_1	Input Baffle	684.25	6.84E-10	4.265	0.001	684.23	6.84E-08	4.265				
T_BAF_1	Input Baffle	684.25	6.84E-10	4.361	0.002	684.23	6.84E-08	4.362	0.4	0.0	5.7	-49.8
T_BSMS_1	BSM/SOB I/F (SOB side)	640.85	6.41E-10	4.313	0.177	639.02	6.39E-08	4.330	43.0	-4.5	8.0	-76.5

6.1.3 EGSE Sensor Self-Heating Characterisation

Temperature Sensor	Calibration Curve	Temperature	Resistance	m	p	Temperature	Resistance	Sensor Dissipated Power	Temperature	Resistance	Sensor Dissipated Power	Self-Heating	Sensor Interface Resistance	Sensor Self-Heating at 1uA
		K	Ohms			K at 1uA	Ohms at 1uA	W	K at 10uA	Ohms at 1uA	W	mK	K/W	mK
Pump Adaptor	X24411	1.597	729.41	-311.30	-1226.60	1.689	700.80	7.01E-10	1.693	699.56	7.00E-08	4	57757.60405	0.04
		1.799	666.71											
Pump Adaptor 2	X38319	1.601	2418.93	-1779.85	-5267.93	1.6817	2274.76	2.27E-09	1.694	2253.58	2.25E-07	11.9	53343.31348	0.12
		1.800	2064.49											
Evap Adaptor	X24465	1.596	814.19	-360.50	-1389.54	1.682	783.18	7.83E-10	1.687	781.45	7.81E-08	4.8	62046.027	0.05
		1.798	741.21											
Evap Adaptor 2	X37538	1.600	3666.24	-3081.73	-8597.66	1.681	3417.28	3.42E-09	1.698	3364.89	3.36E-07	17	51040.012	0.17
		1.800	3050.44											
Detector Adaptor	X24462	1.596	1450.54	-776.91	-2690.84	1.688	1379.42	1.38E-09	1.696	1373.20	1.37E-07	8	58849.17735	0.08
		1.799	1292.88											
Detector Adaptor 2	X38321	1.601	1372.59	-869.46	-2764.29	1.6827	1301.24	1.30E-09	1.689	1295.77	1.30E-07	6.3	49113.05631	0.06
		1.800	1199.44											
L1 SOB IF	TVO-0014	4.240	4400	-792.46	-7760.20	4.254	4389.06	4.39E-09	4.258	4385.89	4.39E-07	4	9212.354779	0.04
		4.366	4300											
L1 Strap	X37402	4.216	999.84	-201.33	-1848.71	4.2265	997.81	9.98E-10	4.228	997.47	9.97E-08	1.7	17215.33204	0.02
		4.652	912.05											

6.2 L1 Characterisation Test

6.2.1 Temperature Stability

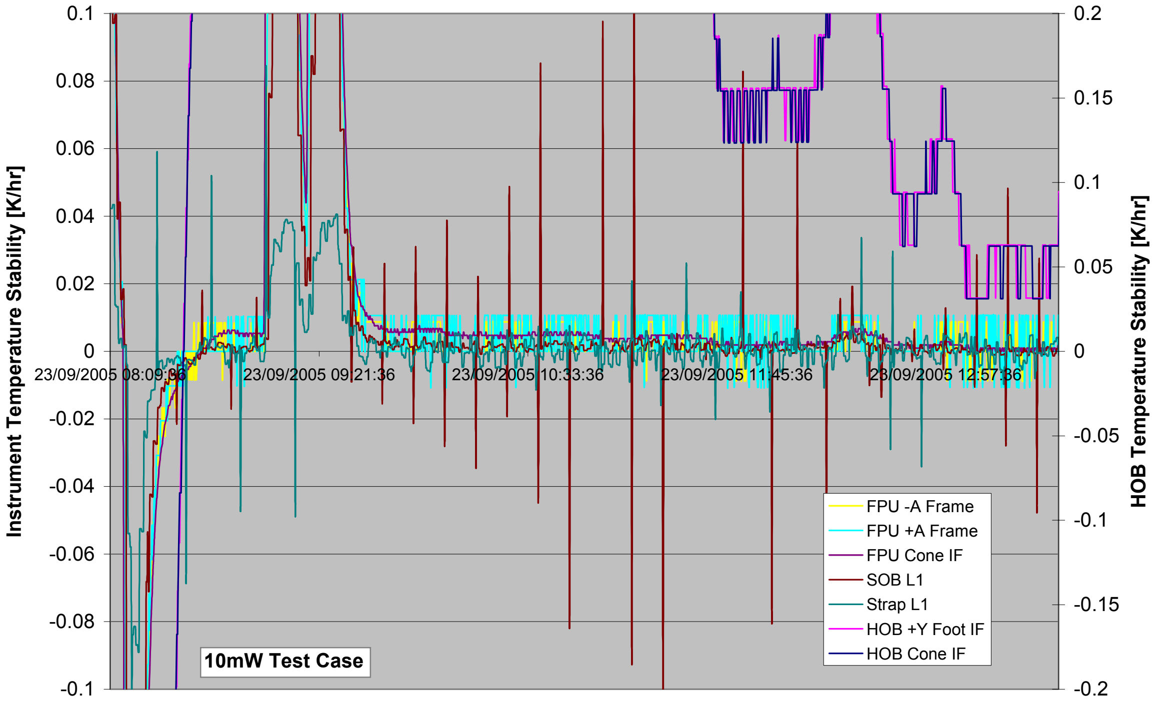


Figure 6-3 – Temperature Stability Profile for the 10mW Test Case

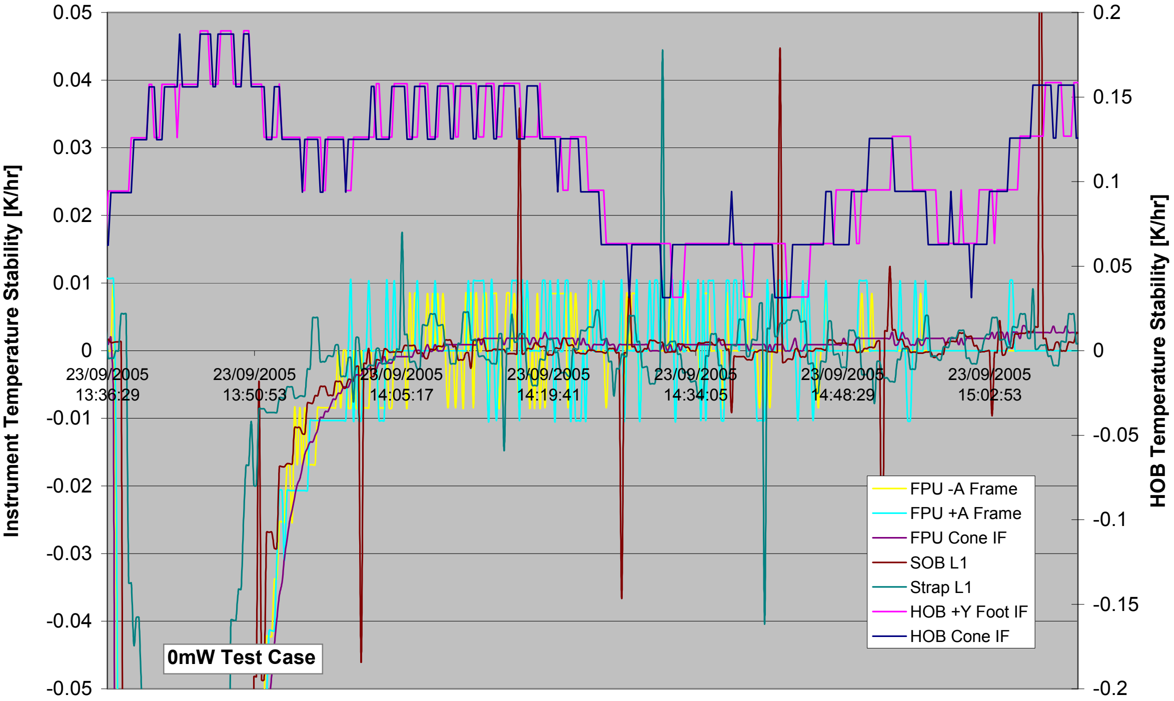


Figure 6-4 - Temperature Stability Profile for the 0mW Test Case

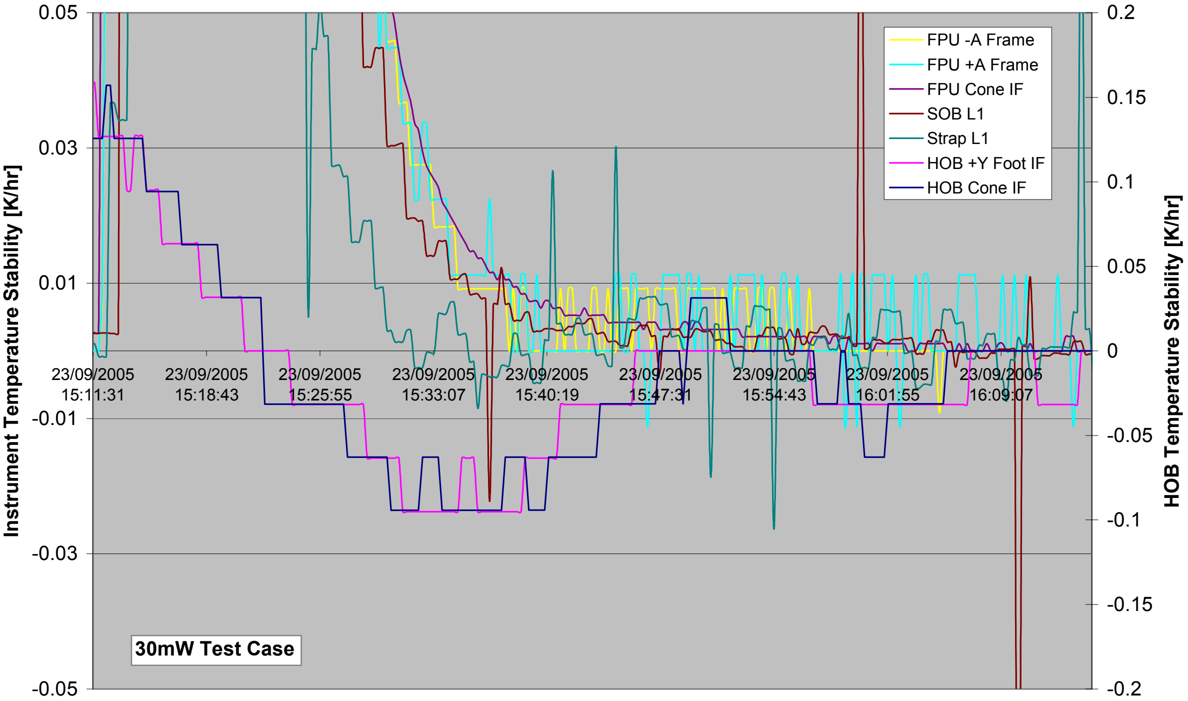


Figure 6-5 - Temperature Stability Profile for the 30mW Test Case

6.2.2 FPU Heater Resistance versus Temperature

Table 6-2 and Table 6-3 describe the estimated change in FPU heater resistance as the L1 temperature changes as well as the impact on the FPU L1 heat load characterisation results.

Type Measur.	Time	Voltage	Current	Heater Resistance	FPU CONE	Temperature Gradient	Resistance Offset
-	[UT]	[mV]	[mA]	[ohms]	[K]	[K]	[Ohms]
4-wire	09:17:00	417.57	12	34.80	4.389	-	-
4-wire	09:34:00	591.79	17	34.81	4.446	0.057	0.0135
2-wire	15:48:00	983.09	-	-	4.655	0.266	0.0631

Table 6-2 – FPU Heater Resistance versus Temperature

Voltage	Heater Resistance	Heating Power
[mV]	[ohms]	[mW]
983.087	34.81	27.76
983.087	34.86	27.72

Table 6-3 FPU Heat Load versus FPU Heater Resistance

6.3 Cooler Pump Characterisation Test

6.3.1 Temperature Stability

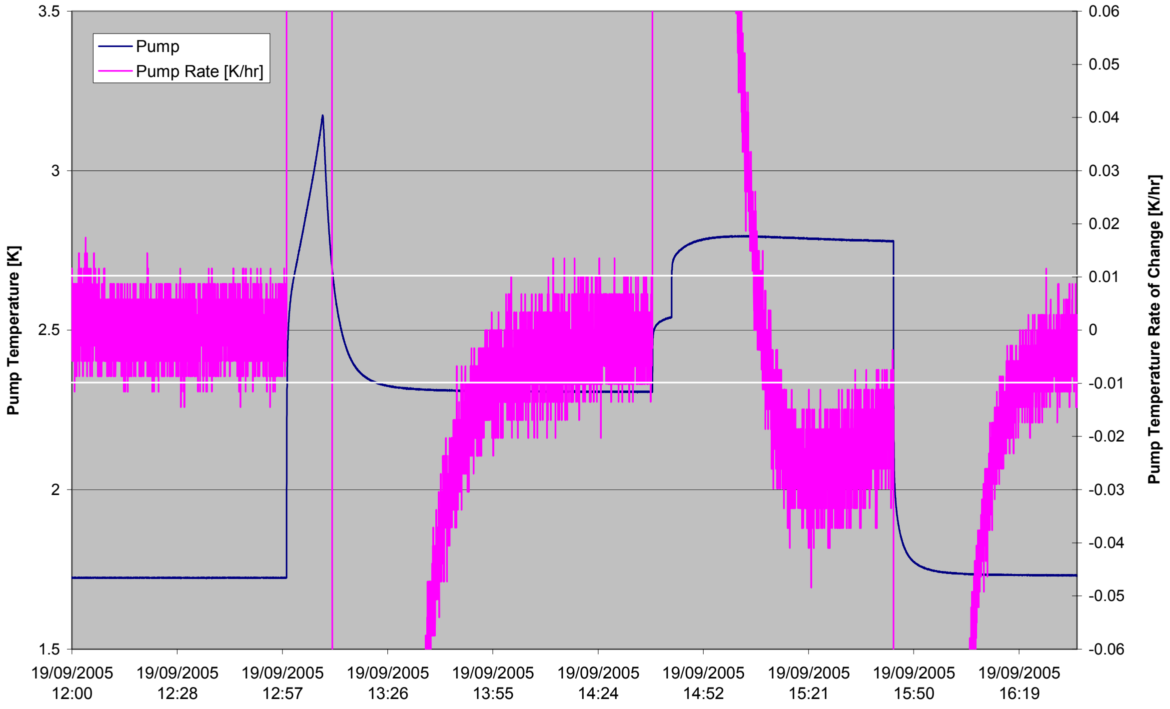


Figure 6-6 – Cooler Pump Temperature Rate of Change

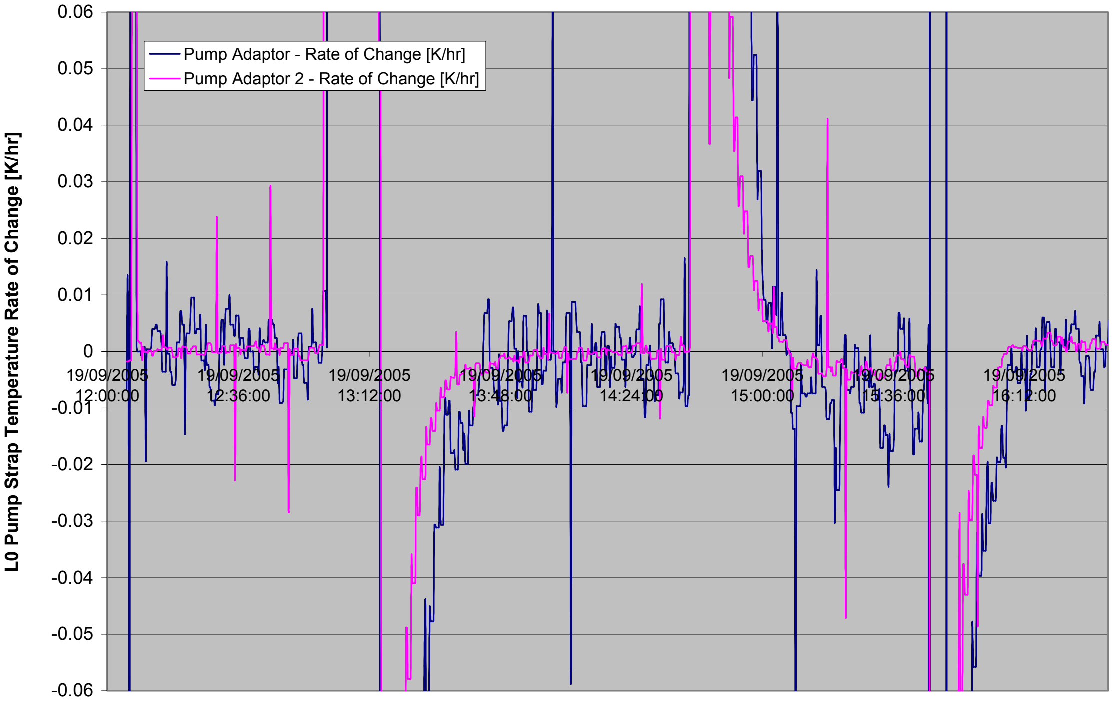


Figure 6-7 – MGSE L0 Pump Strap Temperature Rate of Change