SUBJECT: THERMAL CONFIGURATION CONTROL DOCUMENT

PREPARED BY:	S. HEYS	**Date:** ………………
CHECKED BY:	J. DELDERFIELD (RAL)	**Date:** ……………….
	B.SWINYARD (RAL)	**Date:** ……………….
	B.WINTER (MSSL)	**Date:** ……………….
	L.DUBAND (CEA)	**Date:** ……………….
	T.CAFFERTY (JPL)	**Date:** ……………….
APPROVED BY:	K.KING (RAL)	**Date:** ……………….
	M.GRIFFIN (QMW)	**Date:** ……………….
	C.CUNNINGHAM (ROE)	**Date:** ……………….

CHANGE RECORD

ISSUE	DATE	SECTION	CHANGE
D1	03-11-00	-	New Document
D2	22-11-00	All	Sections rearranged.
		Table 6.2.1	Cone support dimensions updated
		Table 6.1.3	JFET enclosures attached with 4 bolts not 8.
		Table 6.1.3	L2 straps included
		Table 6.2.1	Level 2 to Level 1 harness updated
		Table 6.3.1	Detector harness changed from W/mm per wire to W/mm per 12ax.
		Table 6.3.3	Cu-Au-Cu on L0 straps changed to Cu-Ap-Cu.
		8.5	Constant Helium Mass Flow Rate
		Table 9.2	Mirror Drive OFF at 14:32
D3	23-11-00	Table 6.2.1	Harness budget changed to agree with Systems Budgets doc.
		Table 6.3.1	Cooler parasitic heat leak budget corrected.
		Table 6.3.1	Heat Switch couplings listed separately.
		Table 6.6.1	Cooler pump and evaporator Kevlar S/L updated
		Table 6.6.1	Cooler heat switch tube S/L updated
D4	09-01-01	Table 4.1	Detector stability requirements included and 300mK stage requirement updated.
		Table 6.2.2	Spectrometer Calibrator power reduced from 5mW to 1.5mW.
		Table 6.6.3	Spec Calibration source conductance added.
		Table 7.1	Spec Calibrator power updated.
		Table 8.4.2	Spec Calibrator masses updated.
		Table 8.5	Max rates of change updated.
		Table 9.1 and 9.2	Spectrometer Calibrator power reduced from 5mW to 1.5mW.
		Appendix A	Node 3300 (spec calibration source) added.
D5	16-01-01	Table 6.3.1	Cooler harness added. Cooler heat load budget corrected to 5mW.
		Table 6.6.1	Cooler links updated
		Figure 8.1.6	Figure Updated to show new cooler flange nodes
		Figure 8.1.9.3	Figure Updated to show new cooler flange nodes
		Figure 8.1.9.4	Figure Updated to show new cooler flange nodes
		Appendix A	New cooler flange nodes added
D6	01-03-01	Table 6.5.1	Cooler Strap diameter and xsections updated
		Table 6.5.2	Cooler Strap diameter and xsections updated
D7	21-03-01	Table 6.1.1	Harness corrected and heat load eliminated since isothermal harness assumed.
		Table 6.1.3	L2 Straps removed
		Table 6.2.1	Stainless to Manganin harness. L from 150mm to 100mm. Cone heat load increased.
		6	All heat load budgets replaced with estimates for all operating modes.

		Table 6.2.2	Powers updated to reflect budgets not estimates. Phot calibrator power corrected
		Table 6.3.1	1.7K Strap feedthrus updated from Kevlar to thin walled Stainless Steel tubes.
			Level 1 feedthru budget and harness budget increased
		Table 6.4.1	Harness made Manganin, 25mm long. Cooler heat load updated.
			Harness xsections updated Feedthru loads updated.
		Table 6.4.2	Feedthru Kevlar xsection corrected.
		Table 6.4.3	Power dissipation removed.
		Table 7.1	Cooler parasitics included in budget.
		8.1	Photometer calibrator power updated.
		Table 9.1	Node breakdown schematics updated.
		Table 9.2	BSM on in Spec mode at 1mW. Other powers updated to reflect budgets not estimates.
			BSM on in Spec mode at 1mW. Other powers updated to reflect budgets not estimates.
D8	18-04-01	5.1	Figure 5.1 added
		6	All heat loads updated.
		6.1.1, 6.2.1, 6.3.1.	Detector harness updated.
		Table 6.3.1	Cooler pump thread length changed from 39mm to 37mm. Cooler harness changed from constantan to manganin.
		Table 6.4.1	Evap-Shunt tube length changed from 110mm to 60mm.
		Table 6.6.1	Cooler couplings updated.
		Table 7.1	Cooler evaporator HS power included.
		Table 8.4.2	All masses updated.
		Table 9.1	Standby and Off Modes included.
		Table 9.2	Spec Calibrator Power stays at 2mW not 5mW.
		10, 11	Analysis results sections added.
		All	Sections rearranged.
D9	04-02-02	All	

ACRONYM LIST

BSM	Beam Steering Mechanism
FPU	Focal Plane Unit
HOB	Herschel Optical Bench
JFET	Junction Field Effect Transistor
L0	Temperature Level 0 (~1.8K)
L1	Temperature Level 1 (~4K)
L2	Temperature Level 2 (~10K)
SOB	SPIRE Optical Bench
SMEC	Spectrometer Mechanism
SPIRE	Spectral and Photometric Imaging Receiver
TBC	To Be Confirmed
TBD	To Be Defined
TMM	Thermal Mathematical Model

CONTENTS

1. SCOPE

This document describes the overall SPIRE cryogenic detailed thermal mathematical model (DTMM), consisting of the FPU, the JFET Enclosures and the HERSCHEL Cryostat ITMM. A breakdown of all the significant input parameters and assumptions is provided. This document should be updated as the instrument design iterates. Any modifications made to the SPIRE TMM should be referenced to this document.

2. APPLICABLE DOCUMENTS

2.1. ESA Applicable Documents

ID	TITLE	NUMBER
AD 2.1.1	FIRST/Planck Instrument Interface Document Part B (IID-B) Instrument "SPIRE"	PT-SPIRE-02124. Issue-Rev. No. 0-4 15-MAY-00
AD 2.1.2	FIRST Simplified Optical Bench Thermal Model	Fax Ref: SCI-PT/FIN-08132 24-AUG-00
AD2.1.3	FIRST/Planck Instrument Interface Document IID-Part A	SCI-PT-IIDA-04624 Issue 1/0 01-SEPT-00
AD2.1.4	RE: Simplified Thermal Model - AI#11 from Herschel FPU meeting	Email M.Linder 15-05-01
AD2.1.5	'PACS Meeting 5-9-0_SPIRE.ppt'	Email 'Re TMM' M.Linder 17-SEPT-01

2.1: ESA Applicable Documents

2.2. Dornier Applicable Documents

ID	TITLE	NUMBER
AD 2.2.1	FIRST Instrument I/F Study Final Report	FIRST-GR-B0000.009. Issue 1 02-FEB-00

Table 2.2: Dornier Applicable Documents

2.3. RAL Applicable Documents

ID	TITLE	NUMBER
AD 2.3.1	SPIRE Thermal Transient Cases for Cryostat Study	SPIRE-RAL-NOT-xxx (14-DEC-99)
AD 2.3.3	Conceptual Design For the 300mK Thermal Strap	SPIRE-RAL-MOM-xxx 25-APR-00
AD 2.3.4	SPIRE Inputs For Cryostat and Instrument Thermal Modeling	RAL 15-MAY-00 -update
AD 2.3.5	SPIRE FPU TMM Specification	S.Heys 30-MAY-00
AD 2.3.6	SPIRE Radiative Heat Loads	e-mail, A.Richards, 09-JUN-00
AD 2.3.7	Change To Requirements/Spec on the Cooler and Thermal Strap	e-mail B.Swinyard 04-JUL-00
AD2.3.8	Thermal Summit QMW 25/26 Sept 00	SPIRE-RAL-MOM-000516
AD2.3.9	SPIRE Harnessing, etc	09-DEC-00 J.Delderfield

AD2.3.10	SPIRE Harness	SPIRE-RAL-PRJ-000608 Draft 0.1 27-MAR-01 J.Delderfield
AD2.3.11	FPU Thermal Sensitivity to SMECm Power	SPIRE-RAL-NOT-000771 31-JUL-01
AD2.3.12	SPIRE Harnessing etc	Fax J.Delderfield 19-SEPT-01
AD2.3.13	SPIRE IID-B UPDATE #5	HR-SP-RAL-ECR-009 19-Nov-01

Table 2.3: SPIRE Applicable Documents

2.4. MSSL Applicable Documents

ID	TITLE	NUMBER
AD 2.4.1	PROVISIONAL SPIRE (FIRST) Interface Drawing	A1 5264 300 Issue 5 21-MAR-00
AD 2.4.2	Here It Is	e-mail B.Winter 13-JUN-00
AD 2.4.3	Structure-Optics ICD	Spire ICD 1.1/1.2 Issue 1 B.Winter 13-JUN-00
AD2.4.4	FIRST/SPIRE A Frame Analysis	e-mail B.Winter 12-JUL-00
AD 2.4.5	Thermal Conductance SP1 Analysis and 6082 Data	e-mail B.Winter 23-SEPT-00
AD 2.4.6	SPIRE Cold Strap Lengths	J.Coker 02-OCT-00
AD2.4.7	Re: SPIRE - Thermal Assumptions	e-mail B.Winter 11-OCT-00
AD2.4.8	Structure-Mass	Issue 0.11 B.Winter 14-JUN-00
AD2.4.9	Re: FPU Cone Support	e-mail B.Winter 22-NOV-00
AD2.4.10		e-mail B.Winter 14-MAR-00
AD2.4.11	Structure Mass issue 1.0Beta.xls	B.Winter JAN-01
AD2.4.12	Thermal Strap Support Level-0	MSSL-technote-SPIRE-02 Issue 1: JUL-01
AD2.4.13	Detector box support thermal analysis	MSSL-technote-SPIRE-03 Issue 1: JUL-01
AD2.4.14	Herschel/SPIRE thermal model data, taken from FEA issue 8 first cut	Email B.Winter 20-10-01
AD2.4.15	Fax	Fax from C.Brockley-Blatt to S.Heys 04-FEB-02
AD2.4.16	Cone Mount 2K Photometer Box	A2-5265 312 Issue 1 29-JAN-02
AD2.4.17	Blade	A2 5264 302-1 Issue 4 23-JUN-00
AD2.4.18	A-Frame Thermal test Results.doc	12-OCT-00

		B.Winter

Table 2.4: SPIRE MSSL Applicable Documents

2.5. QMW Applicable Documents

ID	TITLE	NUMBER
AD 2.5.1	The SPIRE Instrument For FIRST	SPIRE Meeting Munich -vue graphs 29-MAR-00
AD 2.5.2	SPIRE A Bolometer Instrument For FIRST	Proposal Submitted to ESA FEB-98
AD2.5.3	SPIRE Spect Calibrator	email P.Hargrave 04-JAN-01
AD2.5.4	Sensitivity Models for SPIRE	SPIRE-QMW-NOT-000642 M.Griffin Jan 2002
AD2.5.5	SPIRE thermal stability requirements	Email M.Griffin 22-JAN-02
AD2.5.6	Sam_therm.doc	Peter Hargrave (email) 04-SEPT-01
AD2.5.7	Photometer Calibrator -Subsystem Specification Document	SPIRE-QMW-PRJ-001101 1.0 07-SEPT-01 P.HARGRAVE
AD2.5.8	RE: SPIRE spect calibrator	Email P.HARGRAVE 21-MAR-01

Table 2.5: SPIRE QMW Applicable Documents

2.6. CEA Applicable Documents

ID	TITLE	NUMBER
AD 2.6.1	Preliminary Comments	e-mail L.Duband 7-JUN-00
AD 2.6.2	Cryogenic Sorption Cooler – Detailed Design of Engineering Models – Test Plan	TN/SBT/SC/99-04 Iss 0 Rev 0 L.Duband 22-JUN-00
AD 2.6.3	Cryogenic Sorption Cooler –Technical Requirements for the Engineering Models and Related Preliminary Design	SBT/CT/99-02
AD 2.6.4	Cryogenic Sorption Cooler ESA Contract: 12942/98/NL/PA	Presentation 07-SEPT-00
AD 2.6.5	Straps	e-mail L.Duband 27-SEPT 00
AD2.6.6	Frigio 3 He - Ensemble	QM Drawing 29/04/99
AD2.6.7	A Thermal Switch For Use At Liquid Helium Temperatures In Space-Borne Cryogenic Systems	L.Duband Cryocoolers 8 1995
AD2.6.7	RE: Spec. update	e-mail L.Duband 23-NOV-00
AD2.6.8	RE: SPIRE Thermal	e-mail L.Duband 28-MAR-01
AD2.6.9	Re: SPIRE Cooler Queries	email L.Duband 27-NOV-01

Table 2.6: SPIRE CEA Applicable Documents

2.7. JPL Applicable Documents

ID	TITLE	NUMBER
AD 2.7.1	Array Design	SPIRE Technology Downselect Meeting JPL vue graphs 01-FEB-00
AD 2.7.2	SPIRE7TR.dat	T.Cafferty (e-mail) 13-JUN-00
AD 2.7.3	Thermal Properties	e-mail T.Cafferty 04-AUG-00
AD 2.7.4	Re: More FPU Thermal Information	e-mail T.Cafferty 12-AUG-00
AD2.7.5	FPU Thermal Properties Summary	T.Cafferty 11-JUL-00
AD2.7.6	Mass.xls	SEPT-00
AD2.7.7	Temperature Stability Requirements For SPIRE	04-JAN-01 J.Bock
AD2.7.8	Bda_thermal_1.xls	09-FEB-01 T.Cafferty
AD2.7.9	12axJB.xls	09-FEB-01 T.Cafferty
AD2.7.10	Re: SPIRE thermal configuration control document	e-mail T.Cafferty 25-MAR-01
AD2.7.11	JFET-to-BDA harness thermal issues	e-mail T.Cafferty 14-APR-01
AD2.7.12	EM Membrane Thermal.xls	e-mail Terry Cafferty 22-09-01
AD 2.7.13	Re: SPIRE Thermal Model	e-mail T.Cafferty 13-JUN-00
AD2.7.14	Detector Subsystem Specification Document	SPIRE-JPL-PRJ-000456 Version 3

Table 2.7: SPIRE JPL Applicable Documents

2.8. ROE Applicable Documents

ID	TITLE	NUMBER
2.8.1	Mass Budget v3.0	15-MAR-01 C.Cunningham

Table 2.8: SPIRE ROE Applicable Documents

2.9. Miscellaneous Applicable Documents

ID	TITLE	NUMBER
AD 2.9.1	Properties of Aluminium and Aluminium Alloys	Touloukian Y.S.
AD 2.9.2	Properties of Materials at Low Temperatures (Phase A). A compendium.	Johnson V.J. Pergamon 1961
AD 2.9.3	RAL Thermal Database	
AD 2.9.4	RAL Planck Thermal Model	
AD2.9.5	Thermal Conductance of Gold Plated Metallic Contacts At Liquid Helium Temperatures	Peter Kittel
AD2.9.6	Thermal Conductance of Pressed Metallic Contacts Augmented With Indium Foil Or Apeizon Grease At Liquid Helium Temperatures	Salerno and Kittel
AD2.9.7	Thermal Conductance of Augmented Pressed Metallic Contacts At Liquid Helium Temperatures	Salerno, Kittel and Spivak

Table 2.9: Miscellaneous Applicable Documents

2.10. LAM Applicable Documents

ID	TITLE	NUMBER
2.10.1	Spectrometer Mirror Mechanism Design Description	LAM PJT SPI NOT 200008 Ind 3 15-MAY-01 D.Poluquien
2.10.2	Spectrometer Mirror Mechanism Subsystem Specification	LAM.PJT.SPI.NOT.200002 Ind 8 12-OCT-01 D.Poluquien

Table 2.10: SPIRE LAM Applicable Documents

2.11. COMDEV Applicable Documents

ID	TITLE	NUMBER
2.11.1	Shutter RTM v21.xls	11-OCT-01 Dwight Caldwell

Table 2.11: SPIRE COMDEV Applicable Documents

2.12. ATC Applicable Documents

ID	TITLE	NUMBER
2.12.1	Beam Steering Mirror Subsystem Specification Document	SPIRE-ATC-PRJ-000460 30-JAN-02 Iain Pain

Table 2.12: SPIRE ATC Applicable Documents

3. INTRODUCTION

A detailed thermal mathematical model of the SPIRE instrument has been created in ESATAN v.8.7.1. Input parameters for this model originate from various sources, as referenced in Section 2. The thermal model and all input parameters are to be maintained under configuration control, with this document and the TMM updated only as any design changes or material properties modifications are approved.
The primary aim of the TMM is to provide information on the thermal performance of the SPIRE FPU as follows:

- The steady-state temperatures of the various components within the FPU, when under nominal conditions for each mode of operation.
- Stabilisation time required after change of operating mode from Photometer to Spectrometer.
- The effect of transients (e.g. cooler recycling and mechanism power cycling) on the ultimate stability of the 300mK detector stage.
- Provide input to thermal design through analysis of proposed design modifications.
- Provide information on HERSCHEL interface temperatures and heat loads through incorporation of HERSCHEL Cryostat reduced node model into the SPIRE DTMM.
- Correlation of the SPIRE ITMM for delivery to ESA.
- Demonstrate that SPIRE meets thermal interface requirements (max heat loads to L0, L1 and L2).

4. INSTRUMENT THERMAL REQUIREMENTS

The thermal requirements of the SPIRE instrument are summarised below in Table 4.1.

Parameter	Specification	Reference
Telescope Temperature Drift	180mK/hr (for 80K, $\varepsilon=5\%$)	AD2.5.4/ AD2.5.5
Telescope Stability*	1mK/$\sqrt{\text{Hz}}$	AD2.7.7
Level 1 Temperature Drift	20mK/s	AD2.5.4/ AD2.5.5
Level 1 Noise*	5mK/$\sqrt{\text{Hz}}$	AD2.7.7
Level 0 Temperature Drift	290mK/s (for 5K absolute)	AD2.5.4/ AD2.5.5
Level 0 Noise*	9.1K/$\sqrt{\text{Hz}}$	AD2.7.7
Detector temperature	T <310mK	AD2.3.7
Detector Temperature Drift Rate	<0.06mK/hr	AD2.5.4/ AD2.5.5
Detector Temperature Noise	<0.7mK/$\sqrt{\text{Hz}}$ in the signal band, dictated by the SLW channel.	AD2.5.4/ AD2.5.5
Max average load to Herschel L2	50mW @12K	AD2.3.13
Max average load to Herschel L1	18.25mW @5K 9.12mW @4.25K	AD2.3.13
Max average load to L0 Enclosures strap	5mW @1.8K	AD2.3.13
Max average load to L0 Cooler Pump strap	2mW @1.74K	AD2.3.13
Max average load to L0 Cooler Evap strap	1mW @1.71K	AD2.3.13

* Drift Scanned/Extended Emission observing modes specify more stringent stabilities (see AD2.7.7). However these are not absolute requirements.

Table 4.1: SPIRE Instrument Thermal Requirements

5. INSTRUMENT THERMAL DESIGN

5.1. Overview

The SPIRE FPU and two JFET enclosures are mounted off the HERSCHEL Cryostat Level 2 Optical Bench (HOB) and surrounded by the HERSCHEL Instrument Shield. Four temperature stages are used to achieve the required detector temperature. These are referred to as Level 2, Level 1, Level 0 and 300mK with nominal temperatures of 10K, 4K, 1.8K and 300mK respectively. Each stage below Level 2 is cooled via thermal straps to the Cryostat Vent Pipes or LHe Tank. Stringent specifications are placed on the allowable heat loads between these stages, in order to maximise mission life and to guarantee the interface temperatures as shown in Table 5.1.

SPIRE Stage	SPIRE Components	Heat Sink	Heat Sink Temperature at Interface	Maximum Average Heat Lift	Reference
Level 2	JFET boxes	HERSCHEL Optical Bench	12K	50mW	AD2.3.13
Level 1	SOB structure/ mechanisms / mirrors	HERSCHEL L1 Vent Pipes	5K 4.25K	18.25mW 9.12mW	AD2.3.13
Level 0	FPU detector boxes	HERSCHEL L0 LHe Tank	1.8K	5mW	AD2.3.13
Level 0	FPU cooler pump	HERSCHEL L0 LHe Tank	1.74K	2mW	AD2.3.13
Level 0	FPU cooler evap	HERSCHEL L0 LHe Tank	1.71K	1mW	AD2.3.13
0.3K	FPU detectors / cooler thermal link	SPIRE ^{3}He Sorption Cooler	<290mK	10μW	AD2.3.7

Table 5.1: SPIRE Temperature Stages and Heat Sinks

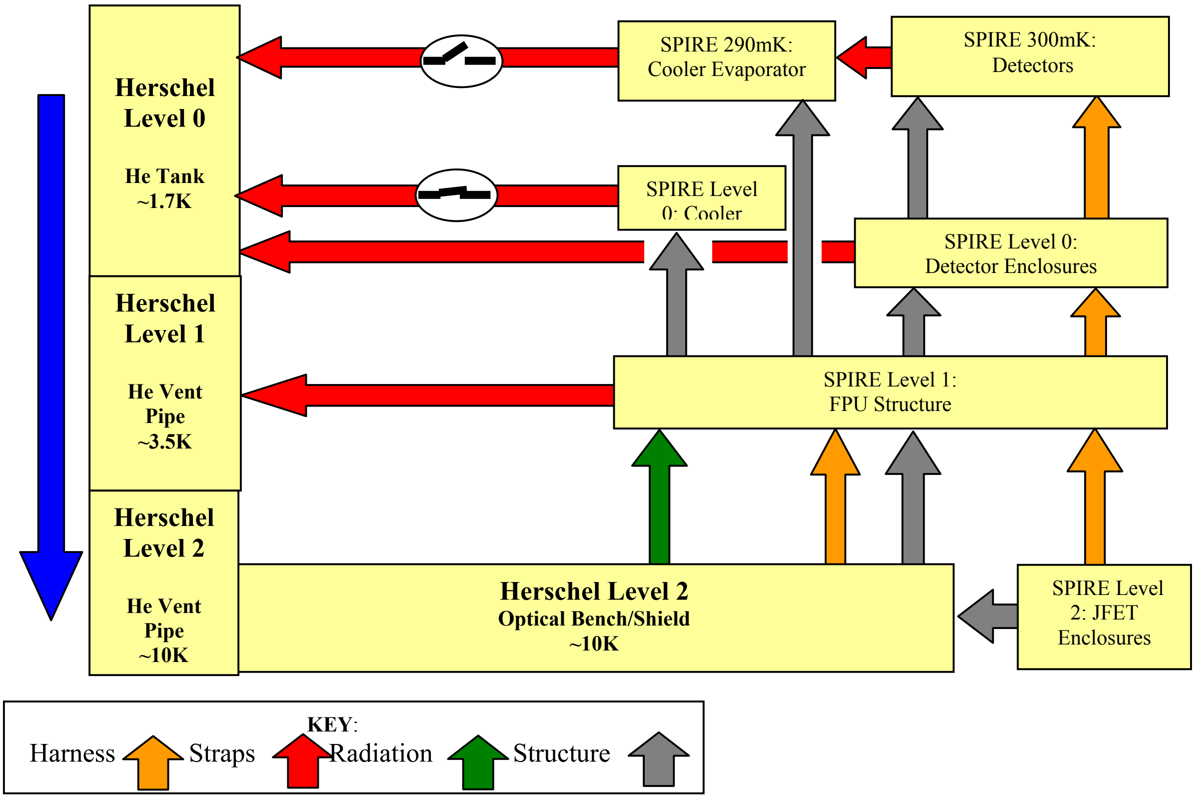


Figure 5.1: SPIRE Temperature Stages and Heat Sinks

5.2. Level 2: JFET Enclosures

The JFET chips are mounted in sets of 24 pairs on Silicone Nitride membranes. The membranes are supported within modules, with two membranes per module. The Photometer and Spectrometer JFETs are housed in separate dedicated enclosures. he Photometer Enclosure houses six modules, the Spectrometer two. These enclosures are hard mounted to the Level 2 HOB, which acts as a heat sink for the dissipated electronics power. The enclosures are linked to the HERSCHEL Shield 1 (at ~35K) via a harness. This harness is sunk to the HOB Level 2 stage prior to connection with the SPIRE JFET enclosures.

5.3. FPU Level 1

The SPIRE FPU Level 1 structure consists of an Aluminium Alloy 6082 Optical Bench (SOB) with the spectrometer and photometer assemblies mounted on opposite sides. Aluminium walls surround each assembly and are hard bolted to the SOB. The SOB forms the mechanical interface for the mirrors, mechanisms and the sorption cooler. These components are hard bolted to the SOB. The key thermal design features of the Level 1 stage are as follows:

- FPU mounted off the Level 2 HOB using three isolating, stainless steel supports (one cone and two A-frames).
- SOB attached to the HERSCHEL L1Vent Line (at approximately 4K) via a copper strap.
- Low conductance manganin detector harness from Level 2 JFET enclosures.
- Low conductance housekeeping harness from Level 2 HOB.

5.4. FPU Level 0

The five detector BDAs require conductive and radiative interfaces at approximately 1.8K. This is achieved by housing the detectors in enclosures mounted off the SOB and cooled via straps to the HERSCHEL L0 sink. Separate enclosures are used for the photometer and spectrometer detectors. The key thermal design features of these enclosures are as follows:

- Boxes mounted from the Level 1 SOB on three insulating stainless steel supports.
- Boxes cooled via a copper strap from HERSCHEL L0. This strap runs from the HERSCHEL Cryostat through a light tight feed through in the FPU Level 1 wall, to the Spectrometer Level 0 enclosure wall and then onto the Photometer Level 0 enclosure.
- Low conductance manganin harness from Level 1.

5.5. FPU 300mK Assembly

5.5.1. Detectors

The Photometer and Spectrometer channels contains three and two BDAs respectively. The detector feedhorns, bolometer arrays and filters require to be held at <310mK. The key thermal design features used to achieve this are as follows:

- 300mK stage supported off Level 0 detector flange using Kevlar 29 thread.
- Low conductance Kapton and Constantan harnessing between the 300mK and Level 0 stages.
- Copper straps from detectors to cooler cold tip at 290mK, supported off Level 0 using Kevlar thread.

5.5.2. Cooler to Detector Thermal Straps

The five Photometer and Spectrometer BDAs are coupled to the cooler cold finger via two separate thermal busbars. These straps are manufactured from high purity copper and are supported on Kevlar threads from the Level 0 enclosure walls. The straps pass through light tight feedthrus on entry to the Level 0 enclosures.

5.6. Helium 3 Sorption Cooler

- The sorption cooler structure is hard mounted to the FPU SOB.
- Kevlar threads are used to isolate the evaporator, pump and shunt from the cooler Level 1 stage.
- The pump and evaporator are linked to the HERSCHEL L0 sink via Helium 3 gas-gap heat switches and copper straps.
- The pump heat switch is ON during normal operations.
- The evaporator heat switch is OFF during normal operations.
- Recycling carried out every 48 hours (TBC) and should be completed in less than 2 hours.

- During recycling the evaporator heat switch is ON and the pump heat switch is OFF. The pump is heated to 40K for approximately 1 hour before the pump heater is switched OFF and the heat switch states are reversed. The pump then cools back to 1.8K, whilst the evaporator cools to <290mK. Separate HERSCHEL Cryostat L0 straps are therefore necessary to prevent large increases in evaporator temperature, as the hot pump is re-connected to Cryostat the after recycling.

5.7. Component Power Dissipation

The power dissipations for the various components are given in Table 5.7 below.

Component	Peak Power (mW)	Mean Power (mW)	Comments	Reference
Photometer Cold Read-Out Electronics	42.0	42.0	ON constantly in Photometer Mode	AD2.7.14
Spectrometer Cold Read-Out Electronics	14.1	14.1	ON constantly in Spectrometer Mode	AD2.3.8
Cooler Evap Heat Switch	0.2	0.0	On during cooler recycling	AD2.3.8
Cooler Pump Heat Switch	0.2	0.2	On constantly when cooler ON	AD2.3.8
Cooler Heater	 200	 200 25	ON during cooler recycling: 0mins- 30mins 30mins-60mins	AD2.3.8
Cooler Pump		1.02	Helium heat load	
Cooler Shunt		0.005	Helium heat load	
Photometer Calibrator	4.0 (required) *2.0 (goal)	0.1	ON for 10 sec/hr during Photometer Mode.	AD2.5.7
Spectrometer Calibrator	*5.0 (required) *2.0 (goal)	2.0**	ON in Spectrometer Mode	*AD2.5.3 **AD2.5.8
Beam Steering Mechanism	*4.0	*4.0 1.0	ON in Photometer Mode ON in Spectrometer Mode	*AD2.12.1
SMECm Actuator	**8.9	1.8 (required) *1.56 (goal)	ON (cycling) during Spectrometer Mode (see Figure 5.8)	*AD2.10.1 **AD2.3.11
SMECm LVDT	0.1	0.1	ON during Spectrometer Mode	AD2.10.1
SMECm Encoder	0.5	0.5	ON during Spectrometer Mode	AD2.10.1

Table 5.7: Component Power Dissipation

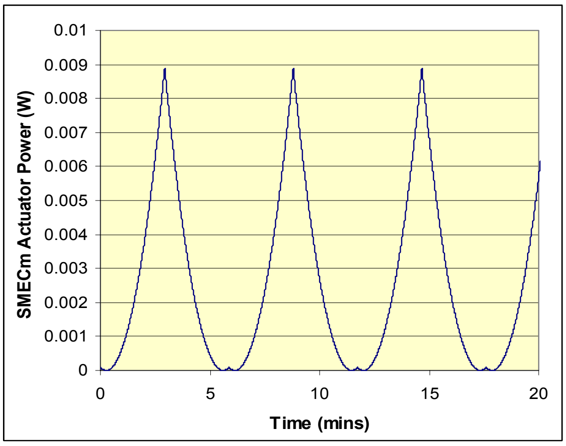


Figure 5.7: Spectrometer Mirror Mechanism Actuator Power Profile

6. THERMAL MATHEMATICAL MODEL

6.1. Nodal Breakdown

The SPIRE thermal model consists of approximately 180 diffuse nodes representing the SPIRE FPU, 17 diffuse nodes for the JFET enclosures, a single boundary node to represent the Cooler Cold Tip and five boundary nodes to represent the HERSCHEL Cryostat. A full nodal breakdown of the TMM can be found in Appendix A.

6.1.1. Herschel Interface

The Herschel-SPIRE interfaces are represented by boundary nodes as follows: 35K Shield; Level 2 Instrument Shield; Level 2 HOB; Level 1 Vent and Level 0 Superfluid Helium Tank.

6.1.2. Level 2 JFET Enclosures

The JFET enclosures, and their associated modules are assumed to be isothermal and are represented by single diffuse nodes, hard mounted to the HERSCHEL Optical Bench boundary node. Each group of 24 JFET pairs, mounted on membranes within the modules is represented by a single node, as shown in the Figure below. The membrane is represented by a single temperature dependant conductance, which accounts for membrane and lead conductance and radiation. This allows predictions of mean JFET chip temperature for a given power input and boundary conditions. Maximum and minimum chip temperatures are estimated from the mean value. The harnesses between the JFET enclosures and the warm electronics are sunk to the HOB.

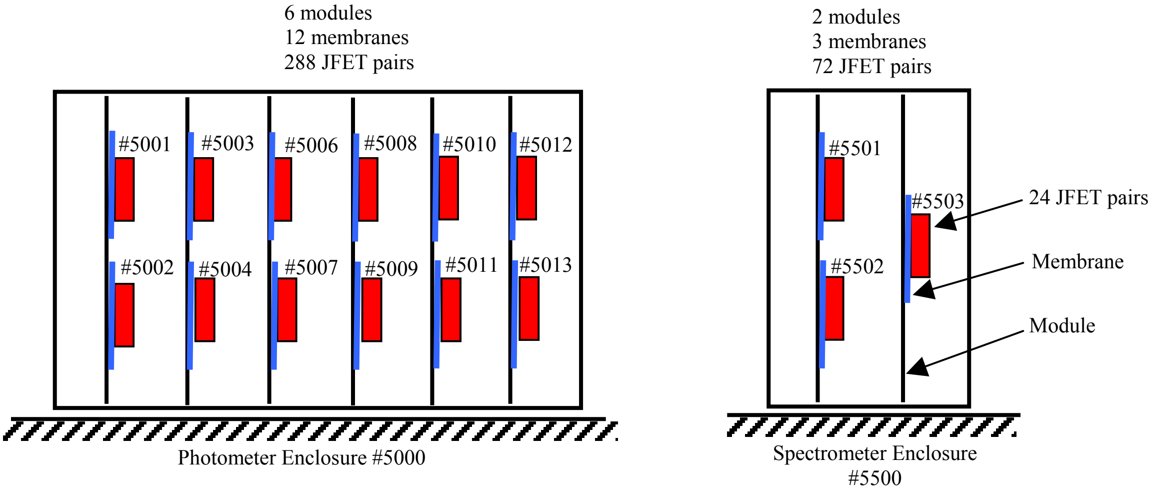


Figure 6.1.2: JFET Enclosure TMM Nodal Breakdown

Base temperature K		10	Tbase			Tbar = (Tbase + Tave)/2		
Q/pair	Q/24 pairs		Thot	Tcold	Tave	Tspread	G/24 pairs	Tbar
mW	mW		K	K	K	K	mW/K	K
0.005	0.12		20.0	18.4	19.2	1.6	0.0130	14.6
0.010	0.24		26.3	23.8	25.1	2.5	0.0159	17.5
0.020	0.48		37.5	33.6	35.6	3.9	0.0188	22.8
0.030	0.72		47.4	42.5	45.0	4.9	0.0206	27.5
0.040	0.96		56.6	50.8	53.7	5.8	0.0220	31.9
0.050	1.20		65.2	58.5	61.9	6.7	0.0231	35.9
0.060	1.44		72.4	65.1	68.8	7.3	0.0245	39.4
0.070	1.68		80.1	72.1	76.1	8.0	0.0254	43.1
0.080	1.92		87.5	78.8	83.2	8.7	0.0262	46.6
0.090	2.16		94.6	85.3	90.0	9.3	0.0270	50.0
0.100	2.40		101.5	91.6	96.6	9.9	0.0277	53.3
0.115	2.76		111.4	100.6	106.0	10.8	0.0288	58.0
0.125	3.00		117.8	106.4	112.1	11.4	0.0294	61.1
0.150	3.60		133.1	120.2	126.7	12.9	0.0309	68.3
0.175	4.20		147.3	133.2	140.3	14.1	0.0322	75.1
0.200	4.80		160.5	145.4	153.0	15.1	0.0336	81.5

Table 6.1.2: JFET Temperature Dependant Membrane Conductance (ref AD2.7.12)

6.1.3. Level 1 FPU Structure

The FPU structure is discretised along all axes in order to show temperature gradients through the instrument. A total of 10 nodes are used to represent the walls of the Spectrometer and Photometer and 16 nodes for the Optical Bench.

The FPU structure is mounted from the HERSCHEL Optical Bench on a single cone foot and two A-frame feet. Due to the non-uniform cross sectional area of the Cone Foot and the variation in conductivity across the foot with temperature, the cone is discretised into ten nodes to improve the accuracy of the TMM. The A-Frames have a constant cross section and are therefore modelled as a simple conductive coupling between the HERSCHEL Optical Bench and the FPU.

6.1.4. Mechanisms and Calibration Sources

The mechanisms are modeled by a single node, with an associated power dissipation and heat capacity. The components are assumed to be hard mounted to the structure with gold coated aluminium to aluminium interfaces. The conductance across this interface is varied according to temperature.

6.1.5. Beam Steering Mechanism

The BSM is modelled as a single node, hard mounted to the SOB.

6.1.6. Spectrometer Mirror Mechanism

The SMECm is discretised into four nodes as shown in Table 6.1.6a.

Node No	Node Name	Material	Mass (g)
3200	SMECm Base and Mirrors	Aluminium	369
3210	SMECm Actuator	Aluminium	436
3220	SMECm LVDT	Aluminium	100
3230	SMECm Encloder	Aluminium	263
TOTAL			1168

Table 6.1.6a SMECm TMM Nodes (AD2.10.1)

Node No	Node Name	Node No	Node Name	Material	No.off	X Section	Length
3200	SMECm Base and Mirrors	1120/ 1210	SOB	Al-Gold-Al bolted interface	4	-	-
3210	SMECm Actuator	3200	SMECm Base and Mirrors	Al-Gold-Al bolted interface	4	-	-
3220	SMECm LVDT	3200	SMECm Base and Mirrors	Al-Gold-Al bolted interface	4	-	-
3230	SMECm Encloder	3200	SMECm Base and Mirrors	Al-Gold-Al bolted interface	4	-	-

Table 6.1.6b SMECm TMM Couplings

6.1.7. Spectrometer Calibrator

The Spectrometer Calibrator enclosure is hard mounted to the SOB. The two prime and two redundant calibration sources are isolated from the enclosure using isolating Torlon standoffs and Manganin leads. Heat is applied to individual sources during calibration phases, in order that the source temperature increases to 20K and remains at this temperature.

The SCAL is modelled as five nodes, one for the enclosure, the others for the four prime and redundant calibration sources, which are conductively isolated from the enclosure and heated to 20K during calibration.

Node No	Node Name	Material	Mass (g)
3250	SCAL Enclosure	Aluminium	193
3260	SCAL Disc 01	Aluminium Epotek 920 Torlon	0.2041 1.5 0.138
3270	SCAL Disc 02	Aluminium Epotek 920 Torlon	0.2041 1.5 0.138
3280	SCAL Disc 03	Aluminium Epotek 920 Torlon	0.2041 1.5 0.138
3290	SCAL Disc 04	Aluminium Epotek 920 Torlon	0.2041 1.5 0.138
TOTAL			200

Table 6.1.7a SCAL TMM Nodes (AD2.5.6)

Node No	Node Name	Node No	Node Name	Material	No.off	X Section	Length
3250	SCAL Enclosure	1200	SOB	Al-Gold-Al bolted interface	4	-	-
3260/ 3270/ 3280/ 3290	SCAL Disc 01/02/03/04	3250	SCAL Enclosure	Torlon	1	3mm OD 1.5mm ID	20mm
3260/ 3270/ 3280/ 3290	SCAL Disc 01/02/03/04	3250	SCAL Enclosure	Manganin Wire	8	0.125mm diameter	60mm

Table 6.1.7b SCAL TMM Couplings (AD2.5.6)

6.1.8. Photometer Calibrator

The Photometer Calibrator is modelled as a single node, mounted within the BSM.

6.1.9. Shutter

The Shutter is discretised into seven nodes as shown in Table 6.1.9a.

Node No	Node Name	Material	Mass (g)
1901	Shutter-Vane Bottom	Aluminium	58
1902	Shutter-Vane Top	Aluminium	59
1903	Shutter-Vane Tab	Aluminium	8
1904	Shutter-Motor	Stainless Steel	234
1905	Shutter-Baseplate under Motor	Aluminium	31
1906	Shutter-Baseplate under Latch	Aluminium	10
1907	Shutter-Latch	Stainless Steel	39
TOTAL			439

Table 6.1.9a Shutter TMM Nodes (AD2.11.1)

Node No	Node Name	Node No	Node Name	Material	No.off	S/L (m)
1610	SPIRE FPU Top Cover	1905	Shutter-Baseplate	Al-Gold-Al bolted	2	-

			under Motor	interface		
1610	SPIRE FPU Top Cover	1906	Shutter-Baseplate under Latch	Al-Gold-Al bolted interface	2	-
1901	Shutter-Vane Bottom	1902	Shutter-Vane Top	Ti-6Al-4V	1	0.046
1902	Shutter-Vane Top	1903	Shutter-Vane Tab	Al 6061-T6	1	0.00066
1903	Shutter-Vane Tab	1904	Shutter-Motor	SS 304	1	0.000139
1904	Shutter-Motor	1905	Shutter-Baseplate under Motor	Al 6061-T6	1	0.0024
1905	Shutter-Baseplate under Motor	1906	Shutter-Baseplate under Latch	Al 6061-T6	1	0.00021
1906	Shutter-Baseplate under Latch	1907	Shutter-Latch	Al 6061-T6	1	0.004
1901	Shutter-Vane Bottom	1904	Shutter-Motor	SS 304	1	2.43E-07

Table 6.1.9b Shutter TMM Couplings (AD2.11.1)

6.1.10. Mirrors

Each mirror is modelled as a single node with an associated heat capacity. The mirrors are hard mounted to the structure via gold-coated aluminium to aluminium interfaces. The conductance across these interfaces are varied according to temperature.

6.1.11. Level 0 Enclosures

The photometer and spectrometer Level 0 enclosure walls are discretised into 3 nodes and 2 nodes respectively. Baffles and mirrors within the boxes are modelled as separate nodes, as are the detectors.

6.1.12. 300mK Assembly

The photometer and spectrometer thermal straps between the cooler cold tip and the detector 300mK stages are modelled using 6 and 2 nodes respectively, in order to show the critical temperature drops along these links. Figure 6.1 shows the nodal breakdown of the complete 300mK system.

6.1.13. Detectors

The detector model is a simplified version of the reduced node detector model provided by JPL (AD2.7.2). Each detector is discretised into 7 nodes as shown in Table 6.1.13a and Figure 6.1.

Node No	Node Name	Material	Mass (g)
##00	Detector L0	Aluminium Stainless Steel Invar Silicone	44 38 64 16
##10	Detector Strap Flange	Copper	7
##20	Detector Top Ring	Invar	49
##30	Detector Spacers	Invar	18
##40	Detector Bot Ring	Invar	29
##50	Detector Cover	Invar	31
##70:	Detector Feedhorn's:		
2770	Phot LW	Copper Stainless Steel	284 30
2870	Phot MW	Copper Stainless Steel	217 30
2970	Phot SW	Copper Stainless Steel	160 30
3770	Spec LW	Copper Stainless Steel	135 30
3870	Spec SW	Copper Stainless Steel	88 30
TOTAL per BDA			296 + Feedhorn

represents: 27 = Phot LW, 28=Phot MW, 29=Phot SW, 37=Spec LW, 38=Spec SW.

Table 6.1.13a Detector TMM Nodes (AD2.7.2, AD2.7.6)

Node No	Node Name	Node No	Node Name	Interface	Material	No. off	X-Section	Length
	SPIRE L0 Enclosure	##00	Detector L0	Al-Gold-Al bolted interface	-	-	-	-
##00	Detector L0	##20	Detector Top Ring	-	Kevlar 49	8	0.65mm diameter	25mm
##00	Detector L0	##40	Detector Bot Ring	-	Kevlar 49	8	0.65mm diameter	25mm
##20	Detector Top Ring	##30	Detector Spacers	Bolted Invar-Ap-Invar 0.66cm2	Invar	1	S/L 21.6mm	-
##30	Detector Spacers	##40	Detector Bot Ring	Bolted Invar-Ap-Invar 0.66cm2	Invar	1	S/L =21.6mm	-
##40	Detector Bot Ring	##50	Detector Cover	Bolted Invar-Ap-Invar 5.7cm2	-	1	-	-
##50	Detector Cover	##70	Detector Feedhorn	Bolted Invar-Ap-Invar 0.4cm2	-	1	-	-
##70	Detector Feedhorn	##10	Detector Strap Flange	Bolted Cu-Ap-Invar 2.7cm2	-	1	1mm diameter	60mm
##10	Detector Strap Flange	##20	Detector Top Ring	Bolted Cu-Ap-Invar 1cm2	-	1	-	-

represents: 27 = Phot LW, 28=Phot MW, 29=Phot SW, 37=Spec LW, 38=Spec SW.

Table 6.1.14b Detector TMM Couplings (AD2.7.2, AD2.7.13)

6.1.14. *Cooler*

The Cooler model is based on the nodal breakdown in AD2.6.1. A total of 6 nodes are used to represent the cooler as shown in Table 6.1.14a and Figure 6.1.

Node No	**Node Name**	**Material**	**Mass (g)**
4000	Cooler L1 Structure	Ti-6Al-4V	1000
4200	Cooler Pump	Ti-6Al-4V	150
4250	Cooler Shunt	Copper	10
4300	Cooler Evap	Ti-6Al-4V	84
4400	Cooler Pump Heat Switch -Cold	Ti-6Al-4V	37
4500	Cooler Evap Heat Switch - Cold	Ti-6Al-4V	37
4600	Cooler Pump Heat Switch -Base	Copper	37
4700	Cooler Evap Heat Switch - Base	Copper	37
TOTAL			1392

Table 6.1.14a Sorption Cooler TMM Nodes (AD2.6.1, AD2.6.8)

Node No	**Node Name**	**Node No**	**Node Name**	**Material**	**No.off**	**X-Section**	**Length**
1130	SOB	4000	Cooler L1 Structure	Al-Gold-Al bolted interface	4	-	-
4000	Cooler L1 Structure	4200	Cooler Pump	Kevlar 29	16	0.5mm diameter	37mm
4000	Cooler L1 Structure	4300	Cooler Evap	Kevlar 29	16	0.29mm diameter	31mm
4000	Cooler L1 Structure	4600	Cooler Pump Heat Switch -Base	Ti-6Al-4V	1	12.6mm OD 12.0mm ID	27mm
4000	Cooler L1 Structure	4700	Cooler Evap Heat Switch -Base	Ti-6Al-4V	1	12.6mm OD 12.0mm ID	27mm
4200	Cooler Pump	4250	Cooler Shunt	Ti-6Al-4V	1	10.4mm OD 10.0mm ID	38mm
4250	Cooler Shunt	4300	Cooler Evap	Ti-6Al-4V	1	10.4mm OD 10.0mm ID	60mm
4200	Cooler Pump	4400	Cooler Pump Heat Switch -Cold	Copper	1	5mm2	50mm
4300	Cooler Evap	4500	Cooler Evap Heat Switch -Cold	Copper	1	5mm2	50mm
4250	Cooler Shunt	4700	Cooler Evap Heat Switch -Base	Copper	1	5mm2	50mm

Table 6.1.14b Sorption Cooler TMM Couplings (AD2.11.1)

Node No	Node Name	Node No	Node Name	Description	Material	No. off	X-Section	Length
4400	Cooler Pump Heat Switch - Cold	4600	Cooler Pump Heat Switch - Base	Parasitic Conduction Thru Tube	Ti-6Al-4V	1	OD=7.2mm ID=7.0mm	50mm
4400	Cooler Pump Heat Switch - Cold	4600	Cooler Pump Heat Switch - Base	Gas Gap Conductance when T > 16K	Helium 3	1	OD=4.5mm ID=4.3mm Gap=0.1mm	45mm
4400	Cooler Pump Heat Switch - Cold	4600	Cooler Pump Heat Switch - Base	Radiative Coupling across concentric cylinders	Cu ε = 0.1	1	OD=4.5mm ID=4.3mm	49mm
4500	Cooler Evap Heat Switch -Cold	4700	Cooler Evap Heat Switch -Base	Parasitic Conduction Thru Tube	Ti-6Al-4V	1	OD=7.2mm ID=7.0mm	50mm
4500	Cooler Evap Heat Switch -Cold	4700	Cooler Evap Heat Switch -Base	Gas Gap Conductance when T > 16K	Helium 3	1	OD=4.5mm ID=4.3mm Gap=0.1mm	45mm
4500	Cooler Evap Heat Switch -Cold	4700	Cooler Evap Heat Switch -Base	Radiative Coupling across concentric cylinders	Cu ε = 0.1	1	OD=4.5mm ID=4.3mm	49mm

represents: 27 = Phot LW, 28=Phot MW, 29=Phot SW, 37=Spec LW, 38=Spec SW.

Table 6.1.14c Sorption Cooler Heat Switch TMM Couplings (AD2.6.9)

6.1.15. Straps

The tables below define the thermal straps coupling SPIRE FPU to the Herschel Cryostat, and the internal components within the FPU. Straps to the HERSCHEL L0 and L1 sinks are modelled as individual nodes with representative conductances and heat capacities.

Node No	Node Name	Node No	Node Name	Interface	Material	No. off	X-Section	Length
21000	Herschel L1 Sink	1330	SOB	Cu-Au-Cu 6.58cm2	Copper	1	20mm2	300mm
20000	Herschel L0 Sink	6100	SPIRE L0 Enclosure Strap Interface	Cu-Au-Cu 1.1cm2	Copper	1	20mm2	350mm
20000	Herschel L0 Sink	6200	SPIRE L0 Cooler Pump Strap Interface	Cu-Au-Cu 1.1cm2	Copper	1	20mm2	350mm
20000	Herschel L0 Sink	6300	SPIRE L0 Cooler Evap Strap Interface	Cu-Au-Cu 1.1cm2	Copper	1	40mm2	350mm

Table 6.1.15a Herschel-SPIRE Strap TMM Couplings

Node No	Node Name	Node No	Node Name	Interface	Material	No. off	X-Section	Length
6100	SPIRE L0	3410	Spec L0	Cu-Au-Cu	Copper	1	10mm2	54mm

	Strap Interface		Enclosure					
3410	Spec L0 Enclosure	2400	Photo L0 Enclosure	Cu-Ap-Cu 4cm2	Copper	1	10mm2	190mm
6200	Herschel L0 Strap Interface	4600	Cooler Pump Heat Switch Base	Cu-Ap-Cu 2cm2	Copper	1	5mm2	48mm
6300	Herschel L0 Strap Interface	4700	Cooler Evaporator Heat Switch Base	Cu-Ap-Cu 2cm2	Copper	1	5mm2	48mm

Table 6.1.15b SPIRE L0 Strap Internal TMM Couplings

From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference
Cover	Feedhorn	Contact Interface	-	-	-	In-Ap-In	0.4 cm^2	AD2.7.4
Feedhorn	300mK Flange	Internal Strap	Diameter 1mm = 0.78mm2	60mm	UHP Copper	Cu-ap-In	2.7 cm^2	AD2.7.4
Ph LW Flange Ph MW Flange Ph SW Flange Sp LW Flange Sp SW Flange	Busbar	Detector Strap	Diameter 2.5mm = 4.91mm2	60mm 113mm 53mm 54mm 54mm	UHP Copper	*Cu-Ap-Cu	2πR x 0.6 = 0.47cm^2	AD2.4.6 / AD2.7.4
Phot. Busbar	Phot. Feedthru	Busbar	Diameter 3mm = 7.1mm2	288mm	UHP Copper	*Cu-Ap-Cu	2πR x 0.6 = 0.57cm^2	AD2.4.6
Phot. Feedthru	Phot. Feedthru Flange	Level 0 Box Feedthru	Diameter 5mm = 19.6mm2	25mm	UHP Copper	*Cu-Ap-Cu	*1cm2	AD2.4.6
Phot. Feedthru Flange	Cooler Evaporator	Cooler Strap	9mm2	130mm	UHP Copper	*Cu-Ap-Cu	*1cm2	AD2.4.6 / AD2.3.3
Spec. Feedthru Flange	Cooler Evaporator	Cooler Strap	9mm2	244mm	UHP Copper	*Cu-Ap-Cu	*1cm2	AD2.4.6 / AD2.3.3

Table 6.1.15c SPIRE 300mK Strap Internal TMM Couplings

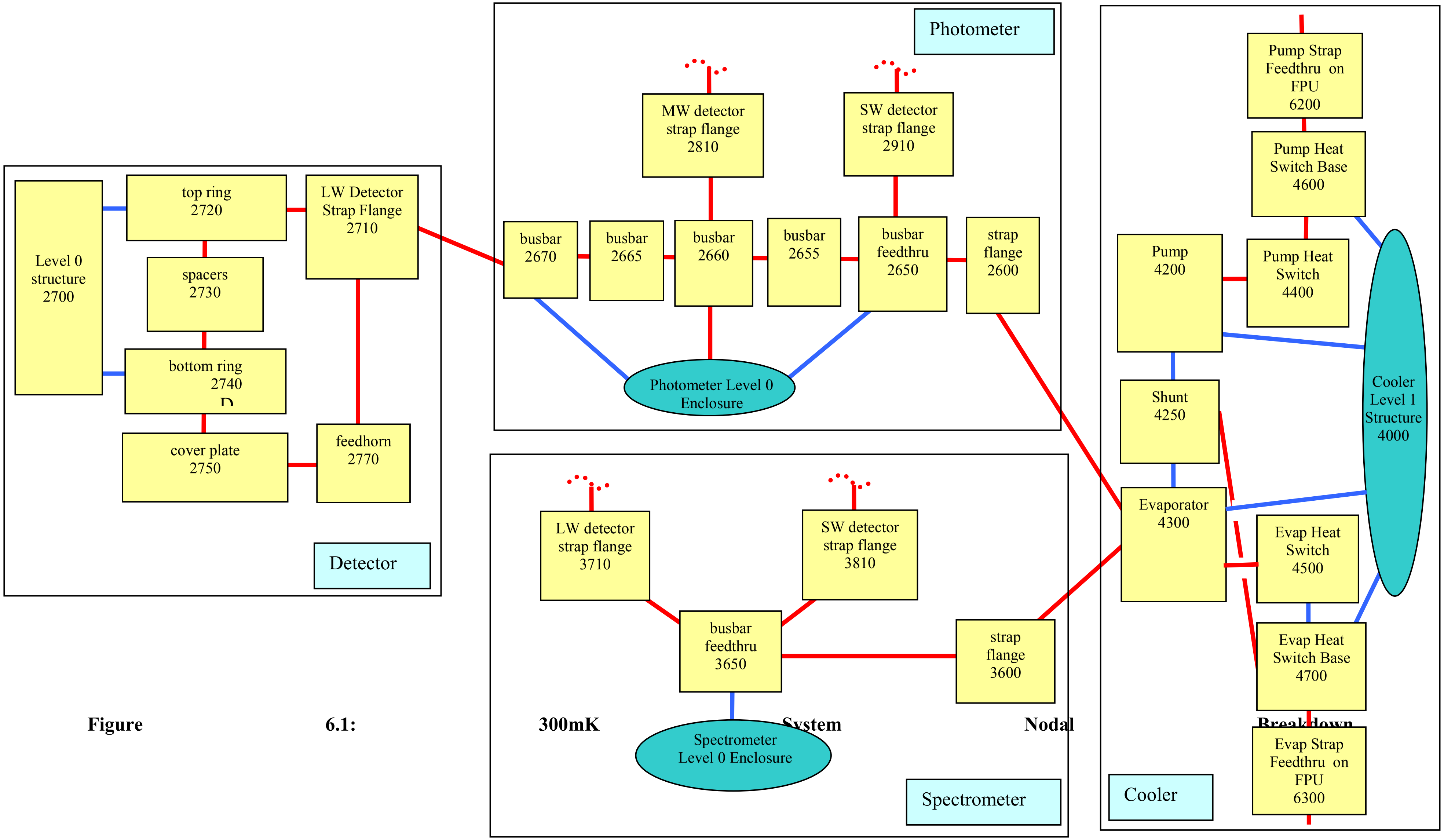


Figure 6.1: 300mK System Nodal Breakdown

6.2. Conductive Couplings

6.2.1. Thermal Conductivity

The thermal conductivity vs temperature relationships assumed for the various materials are given in Appendix B. The integrated thermal conductivity is used in couplings linking components at different temperature stages, in order that changes in conductivity with temperature are correctly accounted for in the analysis.

The conductivity of copper varies significantly with changes in purity and. Two grades of copper are therefore assumed:

-'Ultra High Purity Copper' for the L0 straps, the 300mK links and the detectors. This material exhibits a conductivity of 767W/mK at 2K. This is in close agreement with the value of 800W/mK at 2K given in AD2.2.1 for the L0 cryostat strap copper.

-A lower purity copper is assumed for the L1 straps. The material used has a conductivity of 138W/mK at 2K, which is in close agreement with the value of 140W/mK given in AD2.2.1 for the L0 strap copper.

These values will be updated following conductivity tests on the actual copper grade and configurations specified in the final design.

6.2.2. Joint Interface Conductance

All significant joint interface conductances are accounted for in the TMM. The conductance values assumed are varied with temperature and are dependant on the materials being joined and on the interface parameters. All critical interfaces in the 300mK Assembly are assumed to have interface conductances similar to that shown in Appendix D for Apeizon Grease interfaces. This is also the assumption for the L0 Straps. All other joints are assumed to have conductances similar to those shown for gold coated surfaces.

6.3. Radiative Couplings

Radiative couplings between the SPIRE FPU and JFET external walls and the HERSCHEL Cryostat are calculated by hand. The assumed emissivities and view factors are given in Table 6.3 below. Internal radiative loads have been shown to be of minor significance due to the low temperatures involved.

Surface i	**Surface j**	**Emissivity i**	**Emissivity j**	**View Factor**
FPU external side walls	HERSCHEL Instrument Shield	0.26	0.05	*0.5
FPU external side walls	HERSCHEL Optical Bench	0.26	0.05	*0.5
FPU external base	HERSCHEL Instrument Shield	0.26	0.05	*0.0
FPU external base	HERSCHEL Optical Bench	0.26	0.05	*1.0
JFET Boxes	HERSCHEL Optical Bench	0.26	0.05	*0.5
JFET Boxes	HERSCHEL Instrument Shield	0.26	0.05	*0.5

*Approximation

Table 6.3: Radiative Exchange Coupling Parameters

6.4. Heat Capacities

6.4.1. Specific Heat Capacity

The assumed specific heat capacity vs temperature relationships for the various materials used within the TMM are shown in Appendix C.

6.4.2. Masses

The masses assumed for all SPIRE components are shown in Table 6.4.2. Nodes representing the HERSCHEL ITMM have zero associated thermal mass. Their rate of change of temperature is therefore restricted within the TMM as described in Section 6.5.

Sub-System	Component	No. Off	Total Mass (kg)	Material	Reference
Level 1 Structure	Optical Bench	1	8.000	Al 6082	AD2.4.8
	TOTAL		**8.000**		
Level 1 Structure Photometer Cover	back panel	1	0.632	Al 6082	AD2.4.11
	base plate	1	1.440	Al 6082	
	front panel	1	0.825	Al 6082	
	top cover	1	0.960	Al 6082	
	top rear cover	1	0.489	Al 6082	
	outer panel	1	3.133	Al 6082	
	SUB-TOTAL:		**7.479**		
Level 1 Structure Spectrometer Cover	back panel	1	0.488	Al 6082	AD2.4.11
	base plate	1	0.515	Al 6082	
	front panel	1	1.172	Al 6082	
	top cover	1	0.672	Al 6082	
	top rear cover	1	0.781	Al 6082	
	outer panel	1	3.133	Al 6082	
	SUB-TOTAL:		**6.761**		
Level 1 Structure Mounting	A-frame	2	0.250	Stainless Steel	AD2.4.11
	Cone	1	0.170	Stainless Steel	AD2.4.11
	SUB-TOTAL:		**0.420**		
Level 1 Structure Photometer mounts and clamps	CM3, CM5, CM7 – mount	1	0.650	Al 6082	AD2.4.8
	PM6, SM6 – mount	1	0.120	Al 6082	AD2.4.8
	PM9 – mount	1	0.010	Al 6082	AD2.4.8
	PM10 – mount	1	0.010	Al 6082	AD2.4.8
	PM11 –mount	1	0.010	Al 6082	AD2.4.8
	dichroic clamp + mount	2	0.200	Al 6082	AD2.4.8
	SUB-TOTAL:		**1.000**		
Level 1 Structure Spectrometer mounts and clamps	beam splitter mount + clamp	2	0.200	Al 6082	AD2.4.8
	SM7 – mount	1	0.115	Al 6082	AD2.4.8
	SM8/11 –mount	4	0.384	Al 6082	AD2.4.8
	SM9/10 – mount	2	0.288	Al 6082	AD2.4.8
	SM12 –mount	2	0.020	Al 6082	AD2.4.8
	SUB-TOTAL		**1.007**		
Level 1 Structure Bulkhead/mirror mounts/baffles	Photometer Baffle	1	1.200	Al 6082	AD2.4.11
	Spectrometer Baffle	2	0.680	Al 6082	AD2.4.11
	RF Filter Boxes	1	1.465	Al6082	AD2.4.11

	SUB-TOTAL		**3.345**		
Mirrors Photometer	CM3	1	0.183	Al 6082	AD2.4.3
	CM5	1	0.360	Al 6082	AD2.4.3
	PM6	1	0.027	Al 6082	AD2.4.3
	PM7	1	0.300	Al 6082	AD2.4.3
	PM8	1	0.056	Al 6082	AD2.4.3
	PM9	1	0.223	Al 6082	AD2.4.3
	PM10	1	0.065	Al 6082	AD2.4.3
	PM11	1	0.060	Al 6082	AD2.4.3
	SUB-TOTAL		**1.274**		
Mirrors Spectrometer	SM6	1	0.029	Al 6082	AD2.4.3
	SM7	1	0.044	Al 6082	AD2.4.3
	SM8	2	0.112	Al 6082	AD2.4.3
	SM9	2	0.074	Al 6082	AD2.4.3
	SM10	2	0.112	Al 6082	AD2.4.3
	SM11	2	0.194	Al 6082	AD2.4.3
	SM12	2	0.050	Al 6082	AD2.4.3
	SUB-TOTAL		**0.615**		
Mechanisms	Beam Steering Mechanism	1	1.100	Aluminium	AD2.8.1
	SMECm base	1	0.369	Aluminium	AD2.10.1
	SMECm actuator	1	0.436	Aluminium	AD2.10.1
	SMECm encoder	1	0.263	Aluminium	AD2.10.1
	SMECm LVDT	1	0.100	Aluminium	AD2.10.1
	SUB-TOTAL		**2.400**		
Calibration Sources	Photometer Calibrator	1	0.030	Aluminium	AD2.8.1
	Spectrometer Calibrator Enclosure	1	0.193	Aluminium	AD2.8.1
	Spectrometer Calibration Source	1	0.0072	Aluminium 5.2g Kapton 1.25g Adhesive 0.75g	AD2.5.3
	SUB-TOTAL		**0.230**		
Level 0 Structure	Level 0 Photometer Box	1	1.835	Al 6082	AD2.4.11
	Level 0 Spectrometer Box	1	1.345	Al 6082	AD2.4.11
	SUB-TOTAL		**3.180**		
Detectors Common	Level 0 Structure	5 5 5 5	0.220 0.190 0.320 0.080	Al St. Steel Invar Silicon	AD2.7.6
	Top Ring	5	0.245	Invar	AD2.7.6
	Spacer	5	0.092	Invar	AD2.7.6
	Bottom Ring	5	0.145	Invar	AD2.7.6
	SUB-TOTAL		**1.292**		

Detectors Photometer LW	Detector Cover	1	0.031	Invar	AD2.7.6
	Detector Strap	1	0.007	Copper	AD2.7.6
	Feedhorn	1	0.314	Copper	AD2.7.6
	SUB-TOTAL		**0.352**		
Detectors Photometer MW	Detector Cover	1	0.058	Invar	AD2.7.6
	Detector Strap	1	0.005	Copper	AD2.7.6
	Feedhorn	1	0.247	Copper	AD2.7.6
	SUB-TOTAL		**0.310**		
Detectors Photometer SW	Detector Cover	1	0.058	Invar	AD2.7.6
	Detector Strap	1	0.005	Copper	AD2.7.6
	Feedhorn	1	0.190	Copper	AD2.7.6
	SUB-TOTAL		**0.253**		
Detectors Spectrometer LW	Detector Cover	1	0.031	Invar	AD2.7.6
	Detector Strap	1	0.007	Copper	AD2.7.6
	Feedhorn	1	0.165	Copper	AD2.7.6
	SUB-TOTAL		**0.203**		
Detectors Spectrometer SW	Detector Cover	1	0.058	Invar	AD2.7.6
	Detector Strap	1	0.005	Copper	AD2.7.6
	Feedhorn	1	0.118	Copper	AD2.7.6
	SUB-TOTAL		**0.181**		
Cooler	Level 1 Structure	1	1.000	Titanium	AD2.6.8
	Pump	1	0.150	Titanium	AD2.6.8
	Shunt	1	0.010	Copper	AD2.6.8
	Evaporator	1	0.084	Titanium	AD2.6.8
	Pump Heat Switch	1	0.074	Titanium	AD2.6.8
	Evaporator heat Switch	1	0.074	Titanium	AD2.6.8
	SUB-TOTAL		**1.392**		
300mK Link	Photometer Busbar	1	0.018	Copper	calculated
	Photometer Level 0 Feedthru	1	0.035	Copper	AD2.4.11
	Spectrometer Level 0 Feedthru	1	0.035	Copper	AD2.4.11
	SUB-TOTAL		**0.034**		
Straps	L1	1	0.027	Copper	calculated
	L0 – Level 0 Enclosures	1	0.152	Copper	calculated
	L0-Pump	1	0.081	Copper	calculated
	L0-Evaporator	1	0.162	Copper	calculated
	SUB-TOTAL		**0.422**		
	FPU TOTAL:		**40.140**		

JFET Enclosures	Photometer	1	5.270	Aluminium	AD2.8.1
	Spectrometer	1	1.720	Aluminium	AD2.8.1
	JFET TOTAL		**6.990**		

Table 6.4.2: SPIRE -Mass Breakdown

6.5. ANALYSIS CASE DEFINITIONS

6.5.1. Steady-State Cases

Table 6.5.1 shows the power dissipations assumed for each steady-state analysis case.

Component	**Node No.**	**POWER (mW)**			
		Photometer Operation	**Spectrometer Operation**	**Standby Mode**	**Off Mode**
Photometer JFET Chips (per Membrane)	5001-5012	3.5mWx12 membranes	0.0	3.5x12	0.0
Spectrometer JFET Chips (per Membrane)	5501-5503	0.0	4.7mWx3 membranes	0.0	0.0
TOTAL L2 (JFET) Dissipation	**-**	**42.0**	**14.1**	**42.0**	**0.0**
Photometer Calibrator	2090	0.1	0.0	0.0	0.0
Spectrometer Calibrator -Disc 01	3260	0.0	5.0	0.0	0.0
Beam Steering Mechanism	2100	4.0	1.0	0.0	0.0
SMECm actuator	3210	0.0	1.8	0.0	0.0
SMECm encoder	3230	0.0	0.5	0.0	0.0
SMECm LVDT	3220	0.0	0.1	0.0	0.0
TOTAL L1 (FPU) Dissipation	**-**	**4.1**	**8.4**	**0.0**	**0.0**
Cooler Pump Heat Switch (mean)	4400	0.2	0.2	0.0	0.0
Cooler Pump Heater	4200	0.0	0.0	0.0	0.0
Cooler Pump Helium Load	4200	1.02	1.02	0.0	0.0
Cooler Shunt Helium Load	4250	0.005	0.005	0.0	0.0
TOTAL L0 (FPU) Dissipation	**-**	**1.225**	**1.225**	**0.0**	**0.0**

Table 6.5.1: Steady-State Case Definition

6.5.2. Operational Mode Change –Photometer to Spectrometer

Analysis is performed to predict the time taken for the FPU temperature to stabilise after a change in the mode of operation.

Time (mm:ss)	**Sub-System**	**Node No.**	**Status**	**Power Dissipation (mW)**
00:00	Ph. Cold Read-Out Electronics	5001-5012	ON	42.0
00:00	Cooler Pump	4200	ON	1.02
00:00	Cooler-Shunt	4250	ON	0.005
00:00	Cooler-Pump HS	4400	ON	0.2
00:01	Photometer Calibrator	2090	ON	2.0
10:00	Photometer Calibrator	2090	OFF	0.0
10:01	Ph. Cold Read-Out Electronics	5001-5012	OFF	0.0
10:01	Sp. Cold Read Out Electronics	5501-5503	ON	14.1
10:02	Ph. Beam Steering Mechanism	2100	ON	1.0
10:02	Spectrometer Calibrator	3260	ON (heating to 20K)*	5.0
-	Spectrometer Calibrator	3260	ON (stabilising at 20K)*	2.0
10:32	SMECm actuator Enclode LVDT	3210 3220 3230	ON(scanning)	0-8.9 0.1 0.5
14:32	SMECm actuator Enclode LVDT	3210 3220 3230	OFF	0.0 0.0 0.0
14:32	Spectrometer Calibrator	3260	ON*	5.0
-	Spectrometer Calibrator	3260	ON (stabilising at 20K)*	2.0

*Power of 5W applied until calibration source reaches 20K. Power then reduced to 2mW.

Table 6.5.2: Operational Mode Change Case Definition

6.5.3. Cooler Recycling

Analysis is performed to predict the level of disturbance caused to FPU temperatures during Cooler Recycling, and the time taken to stabilise after re-cycling.

During this analysis the Cooler Cold Tip is changed from a diffuse to a boundary node as recycling starts. After 1 hour, when cryopumping starts, the cold tip is converted to a boundary node, whose temperature is reduced at a constant rate to 0.29K. This cooling rate used is based on cooler test results given in AD2.6.4.

Time (h:mm:ss)	Sub-System	Node No.	Status	Power (mW)	Reference
0:00:00	Ph. Cold Read-Out Electronics	5000	OFF	0	AD2.3.1
0:00:00	Mechanisms / Calibrators	-	OFF	0	AD2.3.1
0:00:00	Cooler	4300	OFF	0	AD2.3.1
0:00:01	Cooler Evap HS Cooler Pump HS	4500 4400	ON OFF	0.2 0	AD2.3.1
0:00:02	Cooler Pump Heater	4200	ON	200	AD2.3.8
0:25:00	Cooler Pump Heater	4200	ON	25	AD2.3.8
0:55:00	Cooler Pump Heater	4200	OFF	0	AD2.3.8
0:55:01	Cooler Evap HS Cooler Pump HS	4500 4200	OFF ON	0 0.2	AD2.3.1
0:55:02	Cooler / Detectors	4300	Cryopumping to 290mK @ constant rate	0	AD2.6.4
0:55:02	Cooler Pump	4200	ON	1.02	
0:55:02	Cooler Shunt	4250	ON	0.005	
1:30:00	Ph. Cold Read Out Electronics	5000	ON	42.0	AD2.3.1
1:40:00	Photometer Calibrator	2090	ON	2	AD2.3.1
1:42:00	Photometer Calibrator	2090	OFF	0	AD2.3.1
1:42:01	Beam Steering Mechanism	2100	ON	4	AD2.3.1
2:12:00	Beam Steering Mechanism	2100	OFF	0	AD2.3.1

Table 6.5.3: Cooler Recycling Case Definition

6.5.4. Herschel-SPIRE Assumed Boundary Temperatures

Boundary temperatures at the Herschel SPIRE interface nodes are taken from the IID-B maximum values for Photometer mode (where the SPIRE dissipation at L2 is high). Boundary temperatures for other cases are based on values shown in AD2.1.5. These will be updated once a representative TMM of the Herschel Cryostat is received.

Interface	Node	Temerature (K)			
		Photometer	Spectrometer	Standby	Off
L2 HOB	10000	12*	9.8**	12.0*	7.5**
L2 Shield	24000	12*	9.8**	12.0*	7.5**
L1	6000	5*	4.1**	5*	2.6**
L0 Enclosures	6100	1.8*	1.8*	1.8*	1.8*
L0 Pump	6200	1.74*	1.74*	1.74*	1.74*
L0 Evap	6300	1.71*	1.71*	1.71*	1.71*

*IID-B Max Values
**AD2.1.5

Table 6.5.4: Assumed Herschel-SPIRE Interface Temperatures

7. STEADY-STATE ANALYSIS RESULTS

7.1. Level 2 Heat Flows

7.1.1. Level 2 Heat Load

From	**To**	**Description**	**XSection**	**Length**	**Material**	**Interface Type**	**Contact Area**	**Reference**	**Heat Load Estimate (mW)**			
									PHOT	**SPEC**	**STNDBY**	**OFF**
HOB	Photometer JFET Box	Harness	72-off 12-ax cables 12-off screened twisted pairs	0.2m	Stainless Steel	-	-	AD2.2.1/ AD2.7.10/ AD2.3.10	0*	0*	0*	0*
HOB	Spectrometer JFET Box	Harness	18-off 12-ax cables 3-off screened twisted pairs	0.2m	Stainless Steel	-	-	AD2.2.1/ AD2.7.10/ AD2.3.10	0*	0*	0*	0*
MAXIMUM AVERAGE HEAT LOAD TO SPIRE L2:									**0**	**0**	**0**	**0**

*Isothermal harness: assumed to be sunk to L2 prior to SPIRE cold stages. Loads on L2 assumed NOT part of SPIRE budget.

7.1.2. Level 2 Average Power Dissipation

Component	**Reference**	**Power Estimate (mW)**			
		PHOT	**SPEC**	**STNDBY**	**OFF**
Photometer JFET Box	AD2.3.8	42.0	0.0	42.0	0.0
Spectrometer JFET Box	AD2.3.8	0.0	14.1	0.0	0.0
MAXIMUM AVERAGE POWER DISSIPATION AT SPIRE L2:		**42.0**	**14.1**	**42.0**	**0.0**

7.1.3. Level 2 Heat Sink

From	**To**	**Description**	**XSection**	**Length**	**Material**	**Interface Type**	**Contact Area**	**Reference**	**Heat Load Estimate (mW)**			
									PHOT	**SPEC**	**STNDBY**	**OFF**
Photometer JFET Box	HERSCHEL Optical Bench	Bolted	-	-	-	Al-Al	4 bolts	AD2.1.3	39.1	-1.6	39.1	-0.9
Spectrometer JFET Box	HERSCHEL Optical Bench	Bolted	-	-	-	Al-Al	4 bolts	AD2.1.3	-0.7	13.6	-0.7	-0.2
ESTIMATED SPIRE HEAT LOAD TO HERSCHEL L2:									38.4	12.0	38.4	-1.1

7.1.4. Level 2 Summary

PARAMETER	Heat Load Estimate (mW)			
	PHOT	**SPEC**	**STNDBY**	**OFF**
HEAT LOAD ON SPIRE L2:	**42.0**	**14.1**	**42.0**	**0.0**
ESTIMATED SPIRE HEAT LEAK FROM L2 TO L1:	19.4	12.5	19.5	6.9
ESTIMATED HEAT LOAD TO HERSCHEL L2:	**22.6**	**1.7**	**22.5**	**-6.9**
IID-A MAXIMUM AVERAGE HEAT LOAD BUDGET TO HERSCHEL L2:	**50.0**	**50.0**	**0.0**	**0.0**

7.2. Level 1 Heat Loads

7.2.1. *Level 1 Heat Load*

From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference	Heat Load Estimate (mW)			
									PHOT	SPEC	STNDBY	OFF
HERSCHEL Optical Bench	FPU L1 Stage	Cone Foot	Max diameter=64.4mm Min diameter = 16.8mm 0.5mm thick	33mm	Stainless Steel	-	-	2.4.15	7.1	4.6	7.1	2.6
HERSCHEL Optical Bench	FPU L1 Stage	2 A-Frame Feet	2 x 17mm2 = 34mm2 *factor = 0.65	27mm	Stainless Steel	-	-	AD2.4.17	7.0	4.6	7.1	2.6
Photometer JFET Box	FPU L1 Stage	Harness	72-off 12-ax cables 12-off screened twisted pairs Over Shields: 2.23E-6m2	100mm	Manganin + Stainless Steel Shields Constantan	-	-	AD2.3.4 AD2.3.8 AD2.7.10 AD2.3.10 AD2.7.11	2.9	1.6	2.9	0.9
Spectrometer JFET Box	FPU L1 Stage	Harness	18-off 12-ax cables 3-off screened twisted pairs Over Shields: 5.57E-07m2	100mm	Manganin + Stainless Steel Shields Constantan	-	-		0.7	0.5	0.7	0.6
HERSCHEL Optical Bench	RF Filter Boxes	Harness	2E-06 5.57E-06 1.24E-05		Stainless Steel Brass PTFE			AD2.3.12	1.6	1.1	1.7	0.2
SOB	FPU Walls	Radiation	-	-	-	-			0.08	0.04	0.08	0.01
MAXIMUM AVERAGE HEAT LOAD TO SPIRE L1:									**19.4**	**12.5**	**19.5**	**6.9**

*factor included to give heat flows which agree with test results in AD2.4.18.

7.2.2. *Level 1 Average Power Dissipation*

Component	Reference	Power Estimate (mW)			
		PHOT	SPEC	STNDBY	OFF
Photometer Calibrator	AD2.3.1	0.1	0.0	0.0	0.0
Spectrometer Calibrator	AD2.3.1	0.0	5.0	0.0	0.0
Beam Steering Mechanism	AD2.3.1	4.0	1.0	0.0	0.0
Spectrometer Mirror Drive	AD2.3.1	0.0	2.4	0.0	0.0
MAXIMUM AVERAGE POWER DISSIPATION AT SPIRE L1:		**4.1**	**8.4**	**0.0**	**0.0**

7.2.3. Level 1 Heat Sink

From	**To**	**Description**	**XSection**	**Length**	**Material**	**Interface Type**	**Contact Area**	**Reference**	**Heat Load Estimate (mW)**			
									PHOT	**SPEC**	**STNDBY**	**OFF**
FPU Wall	HERSCHEL L1 Vent Pipes	L1 Strap	20mm x 1mm = 20mm2	300mm	‘ISO’ Copper	*Cu-Au-Cu (both ends)	4.7x1.4 = 6.58cm2	AD2.1.2 / AD2.2.1	18.6	17.6	14.7	5.9

7.2.4. Level 1 Summary

PARAMETER	**Heat Load Estimate (mW)**			
	PHOT	**SPEC**	**STNDBY**	**OFF**
ESTIMATED HEAT LOAD ON SPIRE L1:	23.5	20.9	19.5	6.9
ESTIMATED HEAT LEAK FROM SPIRE L1 TO L0:	4.9	3.2	4.8	1.0
ESTIMATED HEAT LOAD ON HERSCHEL L1 STRAP:	**18.6**	**17.6**	**14.7**	**5.9**
IID-B MAXIMUM AVERAGE HEAT LOAD BUDGET TO HERSCHEL L1:	**18.25**	**18.25**	**TBD**	**TBD**

7.3. Level 0 Heat Loads

7.3.1. Level 0 Heat Load

From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference	Heat Load Estimate (mW)			
									PHOT	SPEC	STNDBY	OFF
L1 SOB	Level 0 Box Strap	Strap Supports	2-off: 5mm x 5mm	30mm	Vespel SP1	-	-	AD2.4.12	0.05	0.03	0.05	0.01
L1 SOB	Cooler Evaporator Strap	Strap Supports	2-off: 5mm x 5mm	30mm	Vespel SP1	-	-	AD2.4.12	0.05	0.03	0.05	0.01
L1 SOB	Cooler Pump Strap	Strap Supports	2-off: 5mm x 5mm	30mm	Vespel SP1	-	-	AD2.4.12	0.05	0.03	0.05	0.01
L1 SOB	Phot. L0 Box	Cone	Max diameter=61mm Min diameter=12mm Thickness=0.5mm	34.6mm	Stainless Steel	-	-	AD2.4.16	1.01	0.68	0.98	0.20
L1 SOB	Phot. L0 Box	2-off A-Frames	S/L =0.00065x2= 0.00013m	-	Stainless Steel	-	-	AD2.4.13	0.92	0.60	0.90	0.18
L1 SOB	Spec. L0 Box	3 Tube Supports	S/L=0.0003x3= 0.0009m2	-	Stainless Steel	-	-	AD2.4.13	0.67	0.45	0.66	0.13
L1 SOB	Phot. LW Detector L0	Detector Harness	12-off 12-ax 2-off STPs	25mm	Manganin + Stainless Steel shields	-	-	AD2.3.8 AD2.7.4 AD2.7.10 AD2.3.10	0.15	0.10	0.15	0.03
L1 SOB	Phot. MW Detector L0	Detector Harness	24-off 12-ax 4-off STPs	25mm	Manganin + Stainless Steel shields	-	-		0.29	0.19	0.29	0.06
L1 SOB	Phot. SW Detector L0	Detector Harness	36-off 12-ax 6-off STPs	25mm	Manganin + Stainless Steel shields	-	-		0.43	0.28	0.42	0.08
L1 SOB	Spec. LW Detector L0	Detector Harness	6-off 12-ax 1-off STPs	25mm	Manganin + Stainless Steel shields	-	-		0.08	0.05	0.08	0.02
L1 SOB	Spec. SW Detector L0	Detector Harness	12-off 12-ax 2-off STPs	25mm	Manganin + Stainless Steel shields	-	-		0.15	0.10	0.15	0.03
L1 Cooler	L0 Cooler	Pump Support	16 threads x 0.5mm diameter = 3.14mm^2	37mm	Kevlar Thread	-	-	AD2.6.7/ AD2.6.8	0.006	0.004	0.006	0.001
L1 Cooler	L0 Cooler	Evap / Pump Heat Switch	2-off: OD = 12.6mm ID = 12.0mm	27mm	Ti6Al4V	-	-	AD2.6.7	1.03	0.70	1.01	0.20
L1 Cooler	L0 Cooler	Harness	40-off 38AWG wires	100mm	Manganin	-	-	*	0.005	0.003	0.005	0.001
MAXIMUM AVERAGE HEAT LOAD ON SPIRE L0:									**4.89**	**3.25**	**4.78**	**0.96**

*Assumption

7.3.2. *Level 0 Average Power Dissipation*

Component	Reference	Power Estimate (mW)				
		RECYCLE	PHOT	SPEC	STNDBY	OFF
Cooler Heat Switch	AD2.3.8	0.2	0.20	0.20	0.0	0.0
Cooler Pump Heater	AD2.3.8	200mW for 30mins every 48 hours = 2.08mW 25mW for 30mins every 48 hours = 0.26mW	1.01	1.01	0.0	0.0
MAXIMUM AVERAGE POWER DISSIPATION AT SPIRE L0:		**2.54**	**1.21**	**1.21**	**0.0**	**0.0**

7.3.3. *Level 0 Heat Sink*

From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference	Heat Load Estimate (mW)			
									PHOT	SPEC	STNDBY	OFF
FPU L1 Feedthru	HERSCHEL L0	L0 Enclosures Strap	20mm x 1mm = 20mm2	*350mm	UHP Copper	*Cu-Ap-Cu (both ends)	4.7x1.4 = 6.58cm2	AD2.2.1	3.73	2.46	3.66	0.74
FPU L1 Feedthru	HERSCHEL L0	Cooler Pump Strap	20mm x 1mm = 20mm2	*350mm	UHP Copper	*Cu-Ap-Cu (both ends)	4.7x1.4 = 6.58cm2	AD2.2.1/ AD2.6.5	1.79	1.61	0.56	0.12
FPU L1 Feedthru	HERSCHEL L0	Cooler Evaporator Strap	20mm x 2mm = 40mm2	*350mm	UHP Copper	*Cu-Ap-Cu (both ends)	4.7x1.4 = 6.58cm2	AD2.2.1/ AD2.6.5	057	0.39	0.57	0.11
ESTIMATED SPIRE HEAT LOAD TO HERSCHEL L0:									**6.09**	**4.45**	**4.79**	**0.96**

7.3.4. *L0 Summary*

PARAMETER	Heat Load Estimate (mW)			
	PHOT	SPEC	STNDBY	OFF
ESTIMATED HEAT LOAD ON SPIRE L0:	6.09	4.45	4.78	0.96
ESTIMATED HEAT LEAK FROM SPIRE L0 TO 300mK STAGE:	0.031	0.031	0.000	0.00
ESTIMATED HEAT LOAD ON HERSCHEL L0 STRAPS:	**6.06**	**4.42**	**4.79**	**0.96**
IID-B MAXIMUM AVERAGE HEAT LOAD BUDGET TO HERSCHEL L0:	**8.00**	**8.00**	**TBD**	**TBD**

7.4. 300mK Heat Loads

7.4.1. *300mK Heat Load*

From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference	Heat Load Estimate (µW)			
									PHOT	**SPEC**	**STNDBY**	**OFF**
L0 Box	300mK Phot. Busbar	Busbar Support	2 threads x 0.3mm2 x 4 attachment points = 2.4mm2	20mm	Kevlar 49 Thread	-	-	AD2.4.7	1.11	1.01	-	-
L0 Box	300mK Phot. Feedthru	L0 Feedthru Support	6 threads x 0.3mm2 = 1.8mm2	15mm	Kevlar 49 Thread	-	-	AD2.4.10	1.18	1.06	-	-
L0 Box	300mK Spec. Feedthru	L0 Feedthru Support	6 threads x 0.3mm2 = 1.8mm2	15mm	Kevlar 49 Thread	-	-	AD2.4.10	0.94	0.91	-	-
L0 Detector	300mK Detector	5 Detector Supports	5 x 16 threads x 0.65mm diameter = 26.5mm2	25mm	Kevlar 49 Thread	-	-	AD2.7.8	9.56	8.82	-	-
L0 Detectors	300mK Detectors	Harness	17.3mm2 0.27mm2	30mm	Kapton Constantan	-	-	AD2.7.8	3.71	3.41	-	-
L1 Cooler	L0 Cooler	Evap Support	16 threads x 0.29mm diameter = 1.06mm2	31mm	Kevlar Thread	-	-	AD2.6.7	2.9	1.9	-	-
Shunt	Evaporator	Tube	OD = 10.4mm ID = 10.0mm	60mm	Ti6Al4V	-	-	AD2.6.8	9.8	9.7	-	-
Shunt	Evaporator	Harness	4-off 38AWG wires	100mm	Manganin	-	-		0.1	0.1	-	-
Evap Heat Switch	Evaporator	Heat Switch Leaks	Heat Switch OFF	-	-	-	-	Table 6.1.14c	4.1	4.1	-	-
MAXIMUM AVERAGE HEAT LOAD TO SPIRE 300mK STAGE									**33.3**	**31.0**	-	-

7.4.2. 300mK Average Power Dissipation

Component	Reference	Power Estimate			
		PHOT	**SPEC**	**STNDBY**	**OFF**
Temperature Control Heaters	-	0µW	0µW	0µW	0µW
MAXIMUM AVERAGE POWER DISSIPATION AT SPIRE 300mK STAGE		**0.0µW**	**0.0µW**	**0.0µW**	**0.0µW**

7.4.3. 300mK Heat Sink

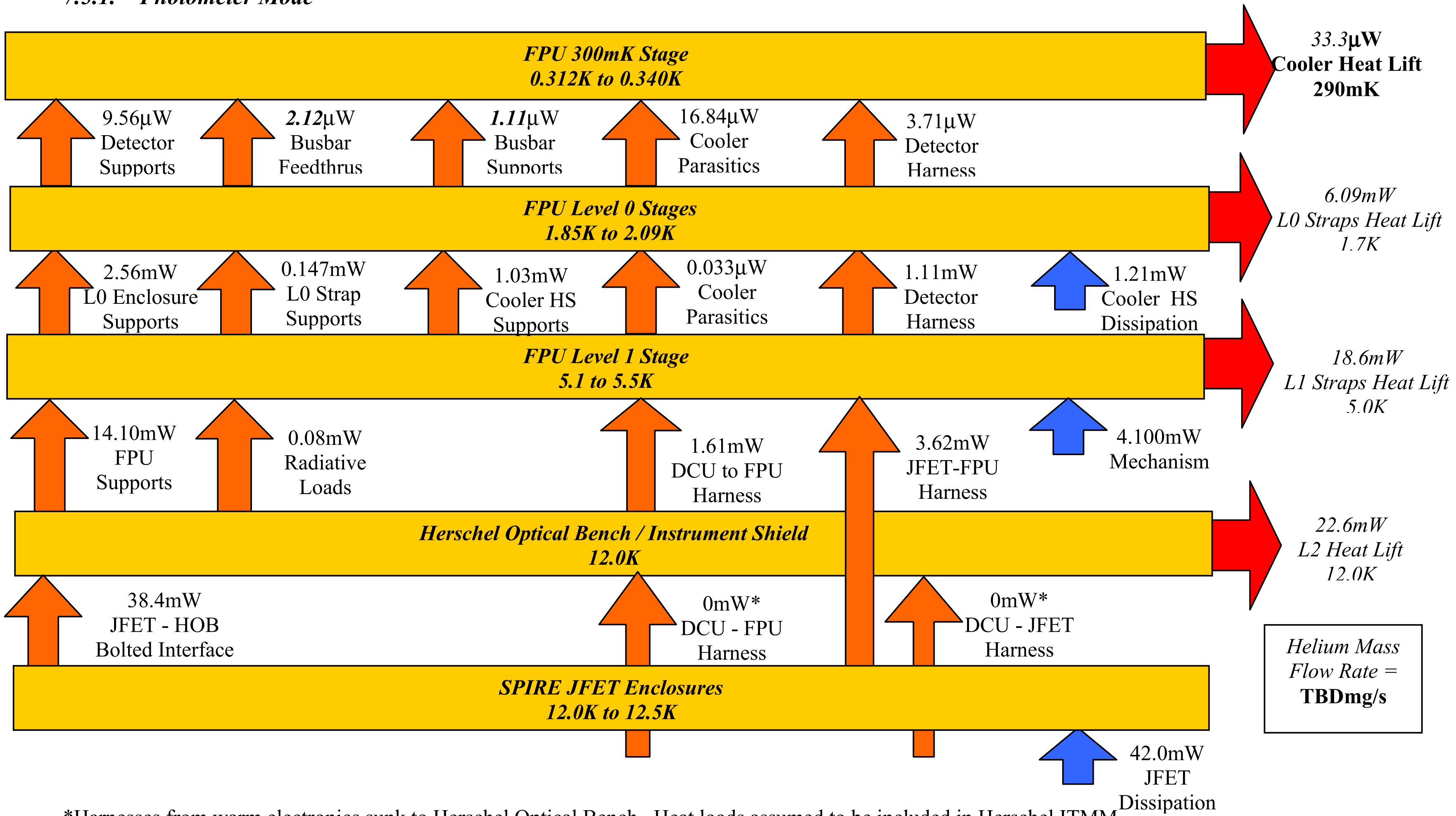
From	To	Description	XSection	Length	Material	Interface Type	Contact Area	Reference	Heat Load Estimate (µW)			
									PHOT	**SPEC**	**STNDBY**	**OFF**
300mK Assembly /Cooler	Cooler Cold Tip	Busbars + Cooler Parasitics	-	-	-	-	-	-	33.3	31.0	-	-

7.4.4. 300mK Summary

PARAMETER	Heat Load Estimate (µW)			
	PHOT	**SPEC**	**STNDBY**	**OFF**
ESTIMATED HEAT LOAD ON SPIRE COOLER 300mK COLD TIP:	**33.3**	**31.0**	-	-
ESTIMATED COOLER HOLD TIME (hrs)	**44.7**	**48.0**	-	-

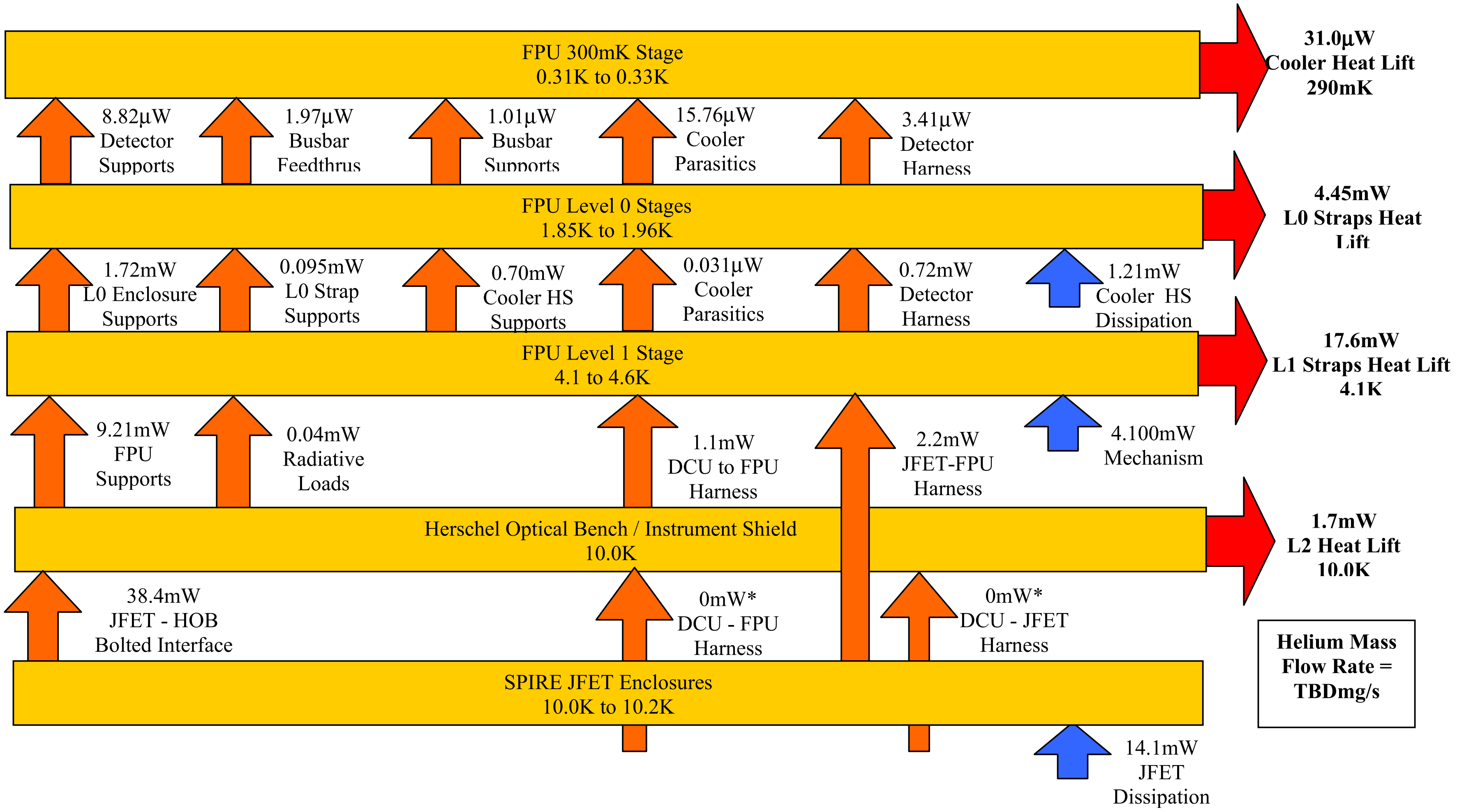
7.5. HEAT FLOW LADDER DIAGRAMS

7.5.1. *Photometer Mode*

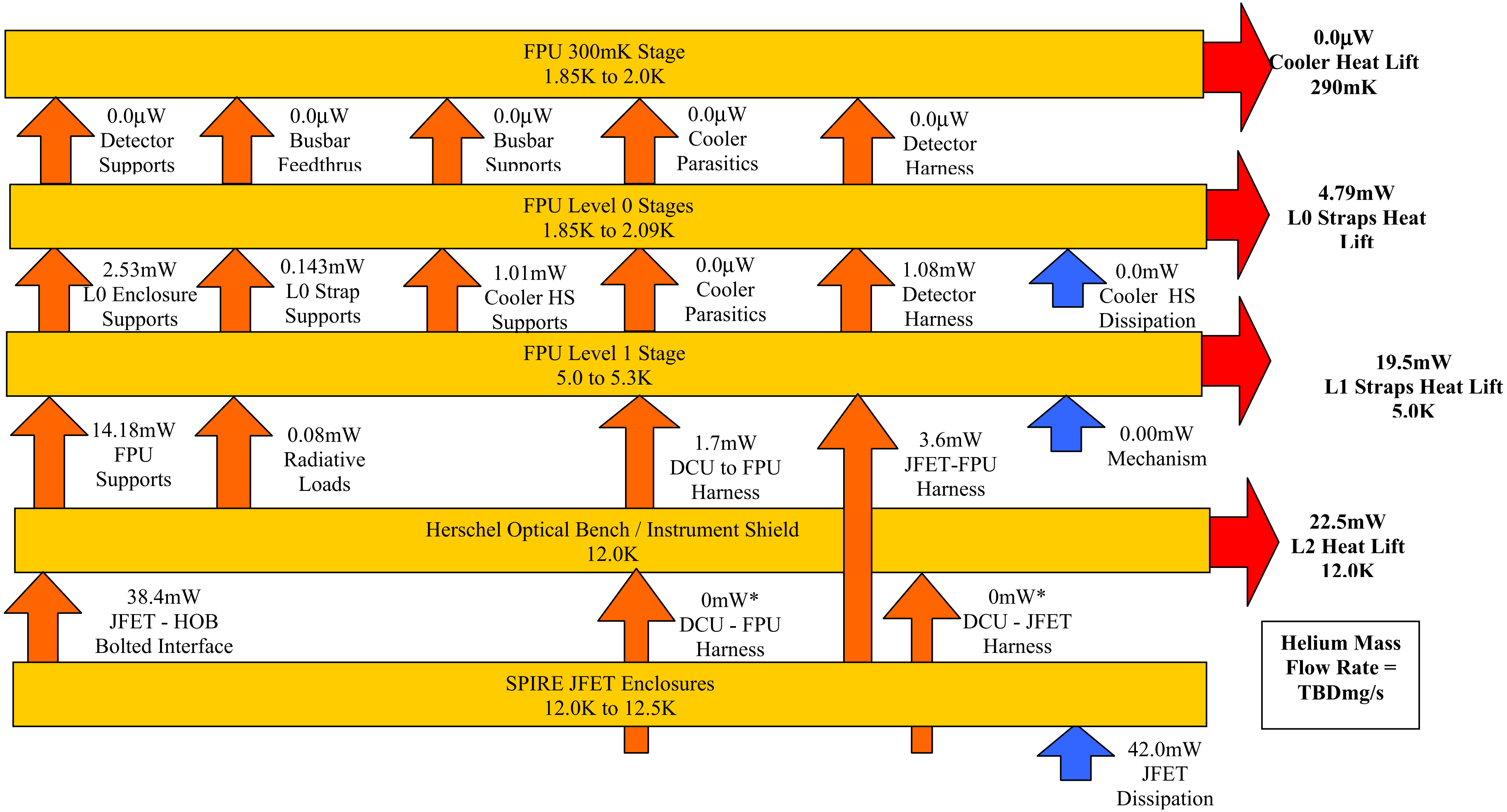


*Harnesses from warm electronics sunk to Herschel Optical Bench. Heat loads assumed to be included in Herschel ITMM.

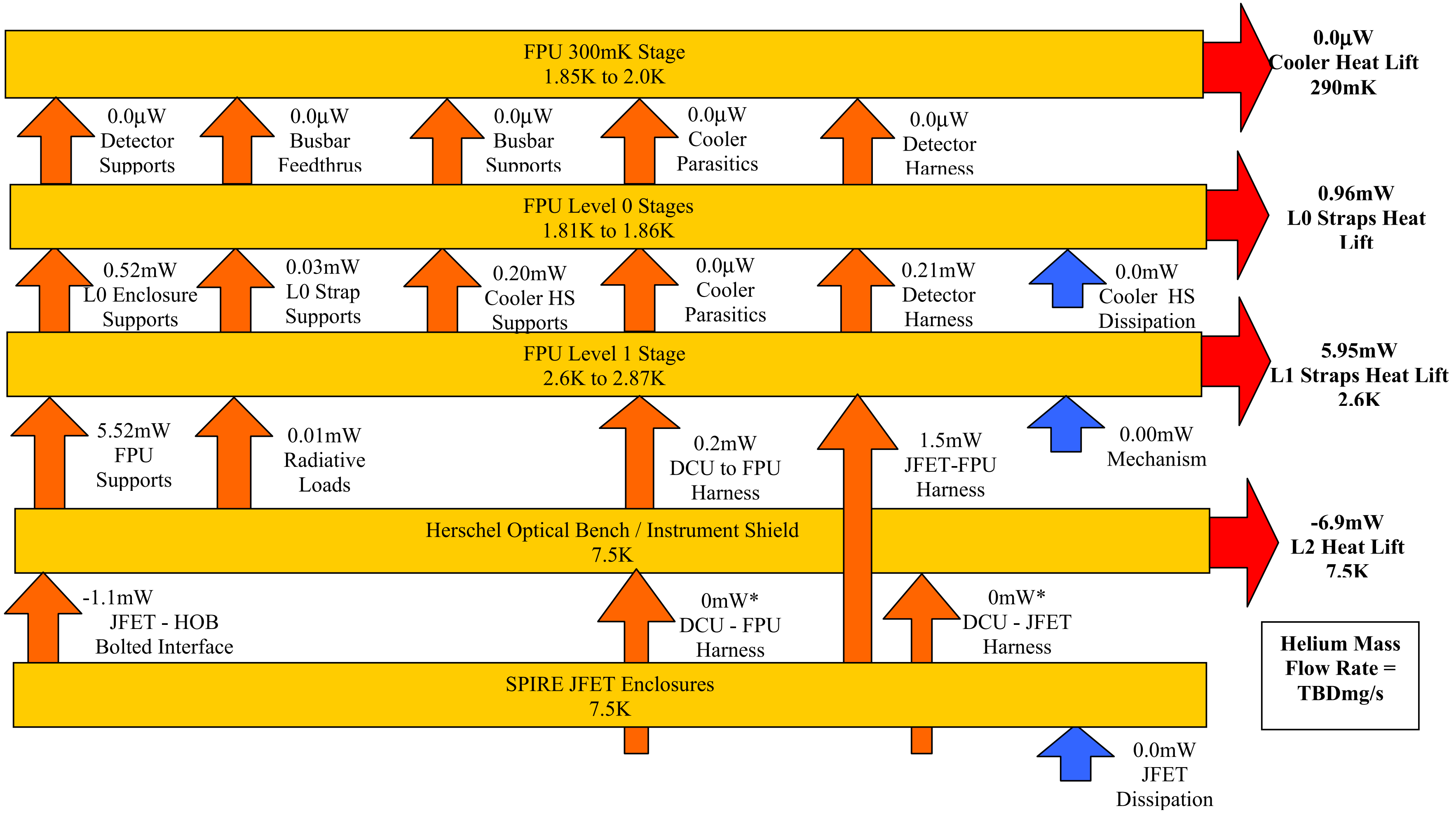
7.5.2. *Spectrometer Mode*



7.5.3. *Standby Mode*



7.5.4. *Off Mode*


FPU 300mK Stage
1.85K to 2.0K
0.0µW
Cooler Heat Lift
290mK
0.0µW
Detector
Supports
0.0µW
Busbar
Feedthrus
0.0µW
Busbar
Supports
0.0µW
Cooler
Parasitics
0.0µW
Detector
Harness
FPU Level 0 Stages
1.81K to 1.86K
0.96mW
L0 Straps Heat
Lift
0.52mW
L0 Enclosure
Supports
0.03mW
L0 Strap
Supports
0.20mW
Cooler HS
Supports
0.0µW
Cooler
Parasitics
0.21mW
Detector
Harness
0.0mW
Cooler HS
Dissipation
FPU Level 1 Stage
2.6K to 2.87K
5.95mW
L1 Straps Heat Lift
2.6K
5.52mW
FPU
Supports
0.01mW
Radiative
Loads
0.2mW
DCU to FPU
Harness
1.5mW
JFET-FPU
Harness
0.00mW
Mechanism
Herschel Optical Bench / Instrument Shield
7.5K
-6.9mW
L2 Heat Lift
7.5K
-1.1mW
JFET - HOB
Bolted Interface
0mW*
DCU - FPU
Harness
0mW*
DCU - JFET
Harness
Helium Mass
Flow Rate =
TBDmg/s
SPIRE JFET Enclosures
7.5K
0.0mW
JFET
Dissipation

8. TRANSIENT ANALYSIS RESULTS

8.1. Cooler Recycle

TBD-awaiting transient cryostat ITMM.

8.2. Photometer to Spectrometer Mode Change

TBD-awaiting transient cryostat ITMM.

9. CRITICAL THERMAL AREAS

9.1. Herschel- SPIRE Temperatures

The current Herschel ITMM is known to be out of date. Therefore the boundary conditions used in the TMM at present are worse-case values as defined in the IID-B or from Cryostat TMM results presented by ESA in September '01. Real boundary conditions are unknown due to the absence of a representative cryostat ITMM.

9.2. Transient Response of the Herschel Cryostat

The current Herschel ITMM is a steady state model and therefore has no thermal mass. As a result during transient analysis, boundary node temperatures are held at constant values. Since the response of these interfaces has a significant impact on the response of the instrument, the transient results of the SPIRE TMM will be inaccurate until a transient Herschel ITMM is available.

9.3. 300mK Heat Load

The predicted sorption cooler heat loads for Spectrometer and Photometer mode are above the 22µW maximum specified for cooler parasitics plus instrument 300mK load for a guaranteed 48 hour hold time. The effects of this load increase are:

- an increase in cold tip temperature,
- a reduction in cooler hold time.

The increase in cold tip temperature with heat load is not currently included in the TMM, but will result in an increase in predicted detector temperatures.

9.4. 300mK Temperature Gradients

The design of the thermal straps between the cooler cold tip and detectors includes a number of bolted joints. Reliable information on the conductance of such joints at 300mK is not yet available, and analysis has therefore relied upon extrapolation of results taken at above 1.6K (AD2.9.5 to 2.9.7). However this extrapolation is anticipated to give highly pessimistic results.

The detector feedhorns temperatures exceed 310mK in operational modes. The interface between the feedhorn and the detectors is an Invar –Invar interface, which is assumed to behave as a Stainless Steel joint in the absence of any test results. This assumption, coupled with the extrapolation of test data for Stainless Steel, result in high uncertainty in this conductance.

10. FUTURE WORK

In addition to ongoing upkeep of the model as the instrument design progresses, the following specific areas of work are anticipated:

10.1. Herschel Transient ITMM

Inclusion of a transient interface model of the Herschel Cryostat into the SPIRE TMM, as available.

10.2. Material Properties and Interface Conductances

Tests are currently underway to measure the temperature dependant conductivity of various coppers in order to select a suitable batch for the critical SPIRE components. In addition tests are planned to measure the interface conductance as a function of temperature for various joint configurations. These tests will be performed down to 290mK and the results included in the TMM.

10.3. 300mK Busbar Conductance

Thermal tests are underway on models of the 300mK busbar designs, in order to measure the actual temperature gradients and heat leak, hence allowing correlation of this critical section of the TMM.

APPENDIX A: FULL TMM NODE LISTING

Node Number	Node Name
1	spire_cone_foot1
2	spire_cone_foot2
3	spire_cone_foot3
4	spire_cone_foot4
5	spire_cone_foot5
6	spire_cone_foot6
7	spire_cone_foot7
8	spire_cone_foot8
9	spire_cone_foot9
10	spire_cone_foot10
1000	spire_L1_optical_bench
1010	spire_L1_optical_bench
1020	spire_L1_optical_bench
1030	spire_L1_optical_bench
1100	spire_L1_optical_bench
1110	spire_L1_optical_bench
1120	spire_L1_optical_bench
1130	spire_L1_optical_bench
1200	spire_L1_optical_bench
1210	spire_L1_optical_bench
1220	spire_L1_optical_bench
1230	spire_L1_optical_bench
1300	spire_L1_optical_bench
1310	spire_L1_optical_bench
1320	spire_L1_optical_bench
1330	spire_L1_optical_bench
1500	spire_L1_spect_base
1510	spire_L1_spect_top
1520	spire_L1_spect_+z
1530	spire_L1_spect_-z
1540	spire_L1_spect_+y
1600	spire_L1_photo_base
1610	spire_L1_photo_top
1620	spire_L1_photo_+z
1630	spire_L1_photo_-z
1640	spire_L1_photo_+y
1700	spire_L1_connector
1800	spire_L1_aperture_filter
1900	spire_RF_filter_box
1901	shutter_vane_bottom
1902	shutter_vane_top
1903	shutter_vane_tab
1904	shutter_motor
1905	shutter_bp_under_motor
1906	shutter_bp_under_latch
1907	shutter_latch
2000	photo_3_mirror_mount

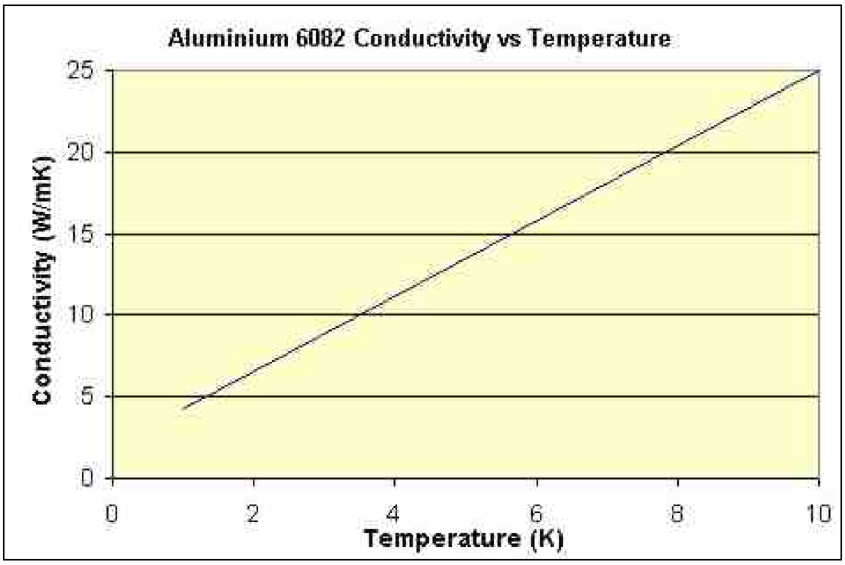
2030	photo_mirror3
2040	photo_mirror4
2050	photo_mirror5
2060	photo_mirror6
2070	photo_mirror7
2080	photo_mirror8
2090	photo_calibrator
2100	photo_bm_steering_mechanism
2150	photo_L1_baffle
2160	photo_L1_baffle
2170	photo_L1_baffle
2180	photo_L1_baffle
2400	photo_L0_box_px
2410	photo_L0_box_mid
2420	photo_L0_box_mx
2421	ph_cone_foot1
2422	ph_cone_foot2
2423	ph_cone_foot3
2424	ph_cone_foot4
2425	ph_cone_foot5
2426	ph_cone_foot6
2427	ph_cone_foot7
2428	ph_cone_foot8
2429	ph_cone_foot9
2430	ph_cone_foot10
2450	photo_L0_baffle
2500	photo_L0_dichroic1
2510	photo_L0_dichroic2
2520	photo_L0__mirror9
2530	photo_L0__mirror10
2540	photo_L0__mirror11
2600	cooler_photo_strap_flang
2650	photo_busbar_feedthru
2655	photo_busbar_cold
2660	photo_busbar
2665	photo_busbar
2670	photo_busbar_warm
2700	photo_LW_detector1_L0
2710	photo_LW_detector1_strap
2720	photo_LW_detector1_top_r
2730	photo_LW_detector1_space
2740	photo_LW_detector1_bot_r
2750	photo_LW_detector1_cover
2770	photo_LW_det1_feedhorn1
2800	photo_MW_detector2_L0
2810	photo_MW_detector2_strap
2820	photo_MW_detector2_top_r
2830	photo_MW_detector2_space
2840	photo_MW_detector2_bot_r
2850	photo_MW_detector2_cover

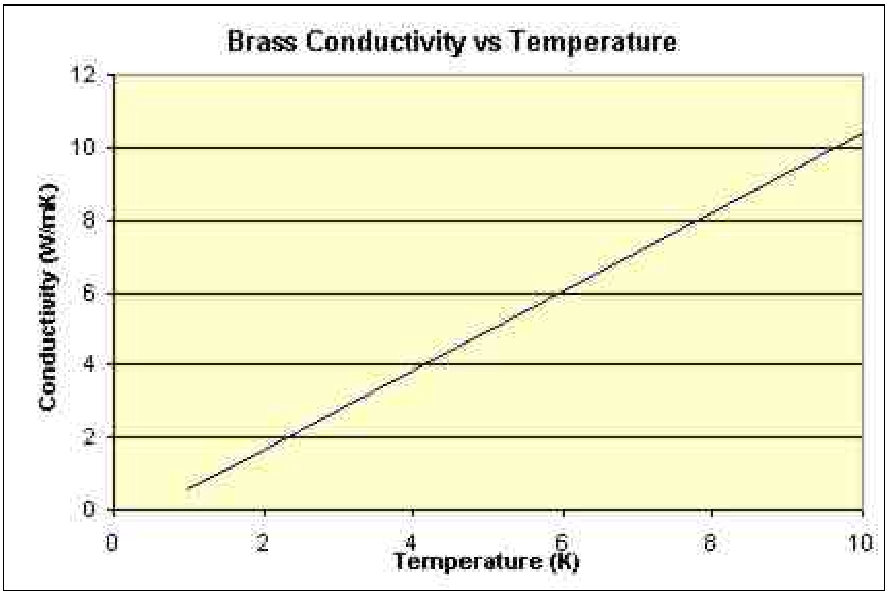
2870	photo_MW_det2_feedhorn2
2900	photo_SW_detector3_L0
2910	photo_SW_detector3_strap
2920	photo_SW_detector3_top_r
2930	photo_SW_detector3_space
2940	photo_SW_detector3_bot_r
2950	photo_SW_detector3_cover
2970	photo_SW_det3_feedhorn3
3000	spect_input_fold_mirrorA
3010	spect_collimatorA
3020	spect_collimatorB
3030	spect_beam_divider1
3040	spect_fold_mirror1A
3050	spect_fold_mirror2A
3060	spect_fold_mirror1B
3070	spect_fold_mirror2B
3080	spect_rooftop_mirrorA
3090	spect_rooftop_mirrorB
3100	spect_beam_divider2
3110	spect_camera_mirrorA
3120	spect_camera_mirrorB
3200	spect_SMECm_base
3210	spect_SMECm_actuator
3220	spect_SMECm_LVDT
3230	spect_SMECm_encoder
3250	SCAL_enclosure
3260	SCAL_disc01
3270	SCAL_disc02
3280	SCAL_disc03
3290	SCAL_disc04
3400	spect_L0_box_px
3410	spect_L0_box_mx
3450	spect_L0_baffle
3460	spect_mirror12A
3470	spect_mirror12B
3600	spect_busbar_strap_flang
3650	spect_300mK_feedthru
3700	spect_LW_detector1_L0
3710	spect_LW_detector1_strap
3720	spect_LW_detector1_top_r
3730	spect_LW_detector1_space
3740	spect_LW_detector1_bot_r
3750	spect_LW_detector1_cover
3770	spect_LW_feedhorn1
3800	spect_SW_detector2_L0
3810	spect_SW_detector2_strap
3820	spect_SW_detector2_top_r
3830	spect_SW_detector2_space
3840	spect_SW_detector2_bot_r
3850	spect_SW_detector2_cover

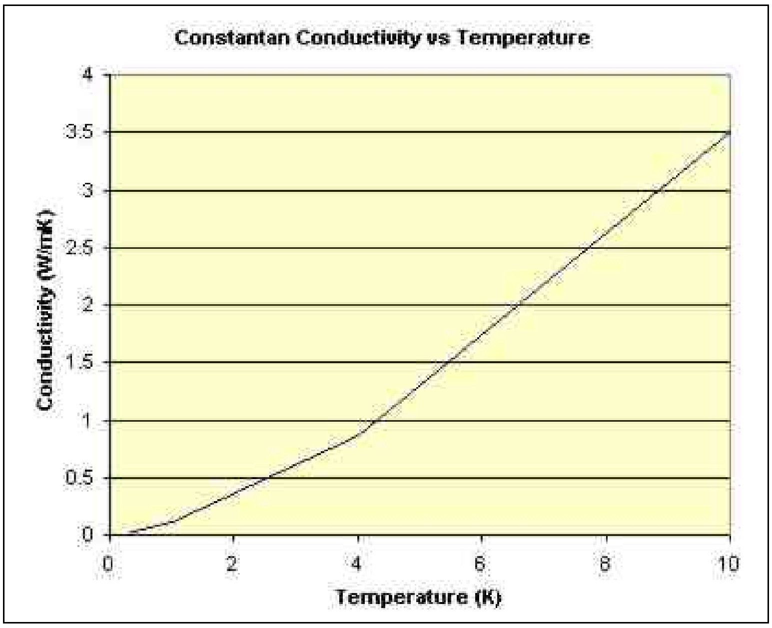
3870	spect_SW_feedhorn1
4000	cooler_L1_structure
4200	cooler_pump
4250	cooler_shunt
4300	cooler_evap
4400	cooler_pump_HS_cold
4500	cooler_evap_HS_cold
4600	cooler_pump_HS_base
4700	cooler_evap_HS_base
5000	photo_JFET_enclosure
5001	photo_JFET_mem1
5002	photo_JFET_mem2
5003	photo_JFET_mem3
5004	photo_JFET_mem4
5005	photo_JFET_mem5
5006	photo_JFET_mem6
5007	photo_JFET_mem7
5008	photo_JFET_mem8
5009	photo_JFET_mem9
5010	photo_JFET_mem10
5011	photo_JFET_mem11
5012	photo_JFET_mem12
5500	spect_JFET_enclosure
5501	spect_JFET_mem1
5502	spect_JFET_mem2
5503	spect_JFET_mem3
6000	L1_strap_main_structure
6100	L0_strap_L0_enclosures
6200	L0_strap_cooler_pump
6300	L0_strap_cooler_evap
10000	Herschel_L2_optical_bench
20000	Herschel_L0_helium_tank
21000	Herschel_L1_cooling_pipe
23000	Herschel_35K_shield
24000	Herschel_instrument_shield

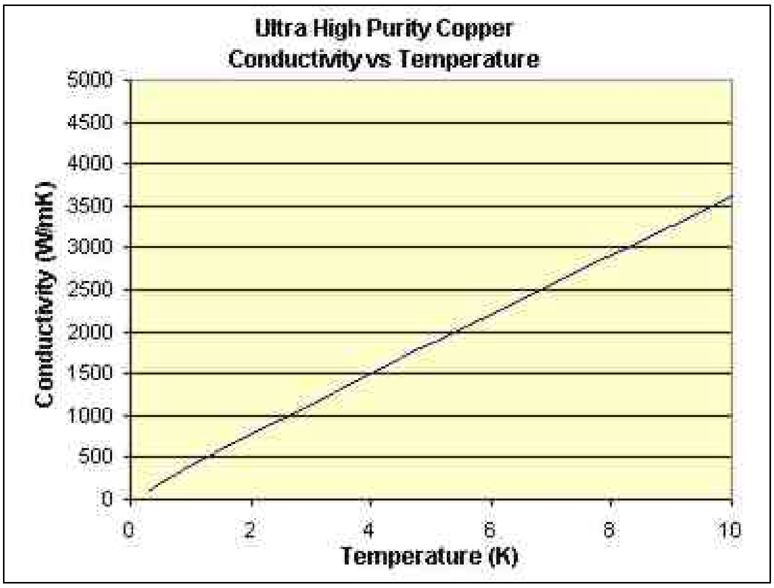
Table A1: TMM Node Listing

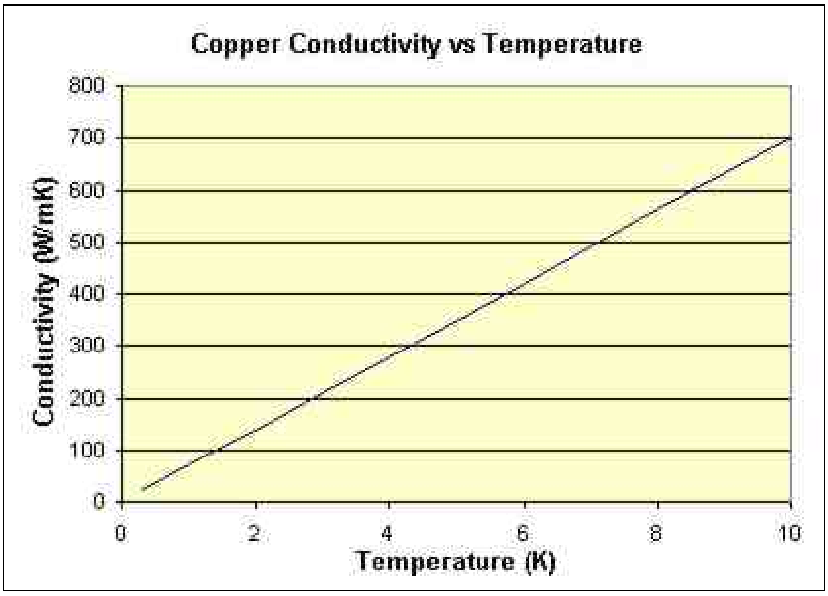
APPENDIX B: TEMPERATURE DEPENDANT THERMAL CONDUCTIVITIES

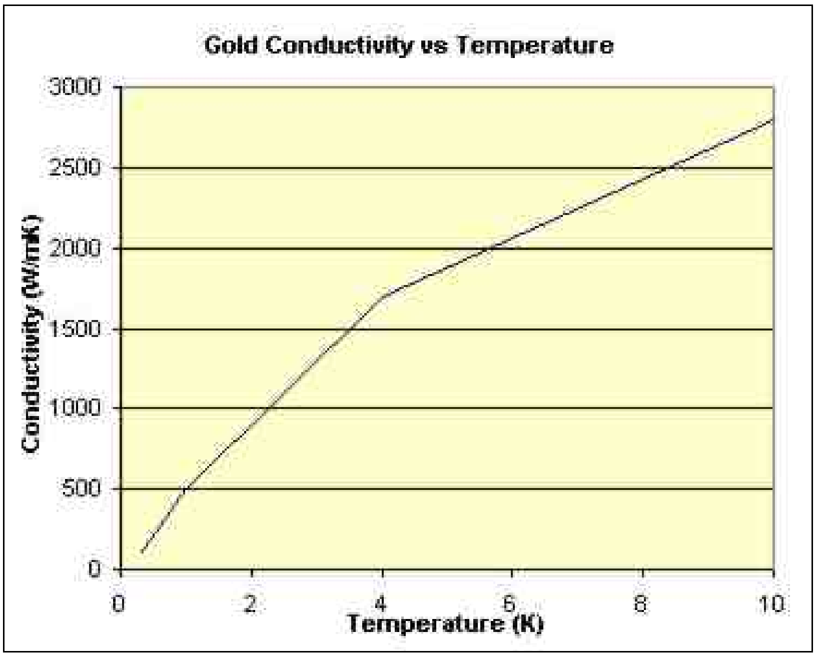


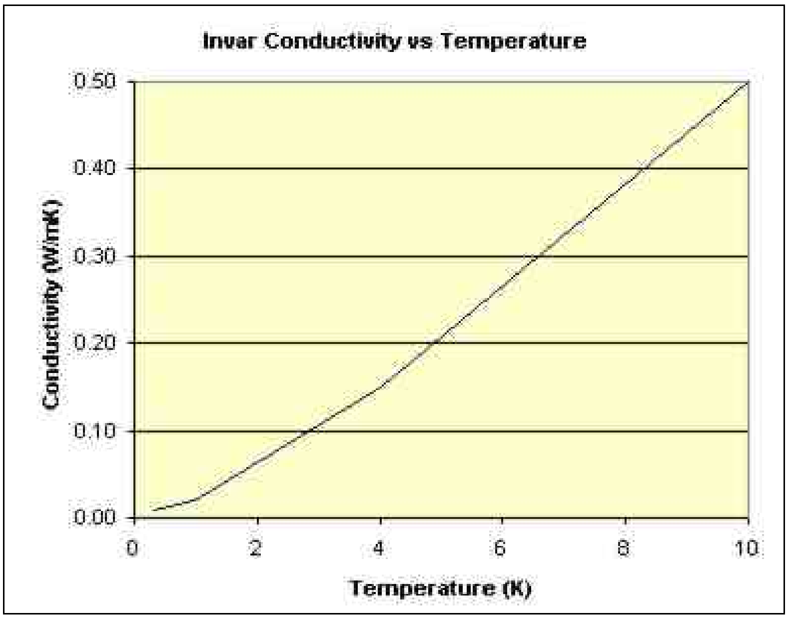


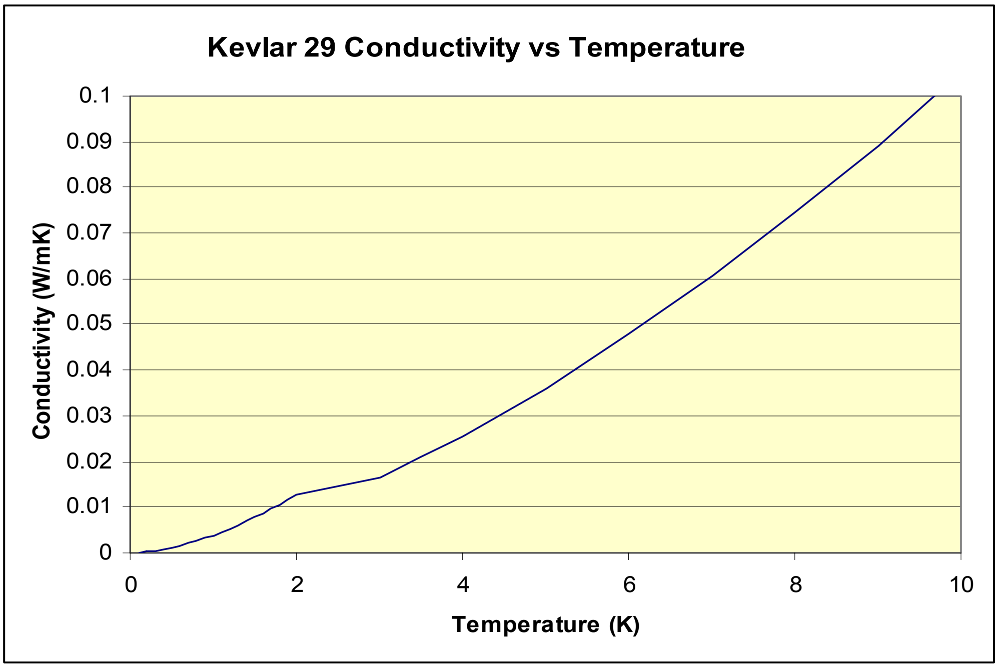

Constantan Conductivity vs Temperature
Conductivity (W/mK)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
Temperature (K)


Ultra High Purity Copper
Conductivity vs Temperature
Conductivity (W/mK)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Temperature (K)

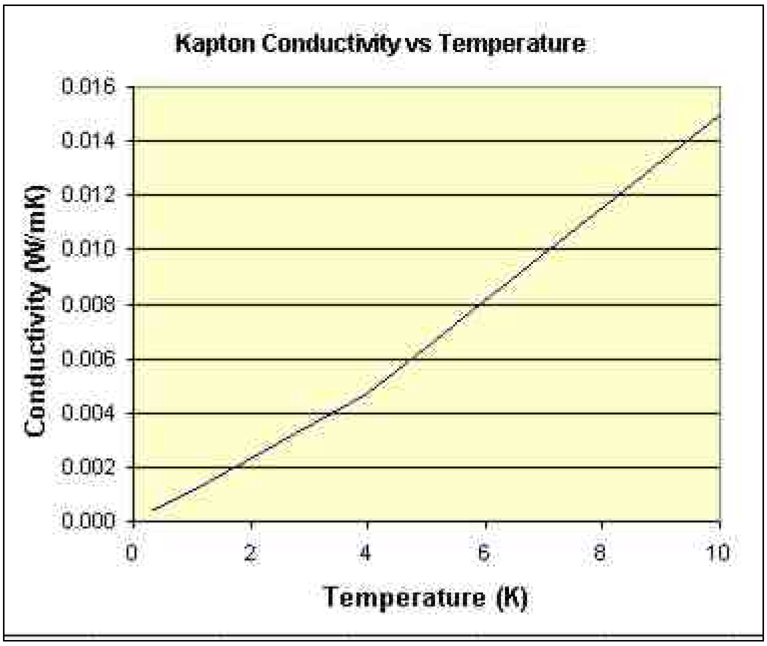

Copper Conductivity vs Temperature
Conductivity (W/mK)
0
100
200
300
400
500
600
700
800
Temperature (K)
0
2
4
6
8
10

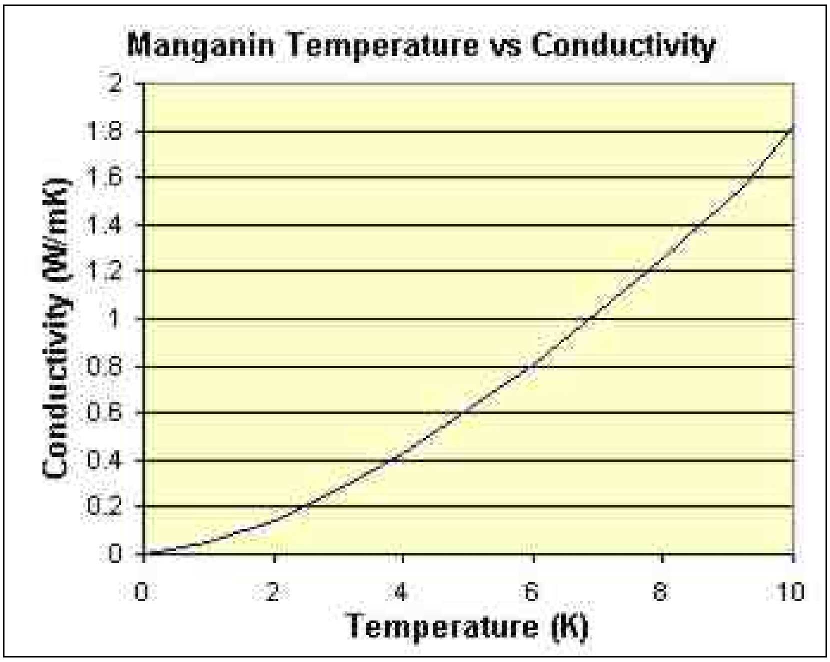

Gold Conductivity vs Temperature
Conductivity (W/mK)
0
500
1000
1500
2000
2500
3000
Temperature (K)
0
2
4
6
8
10

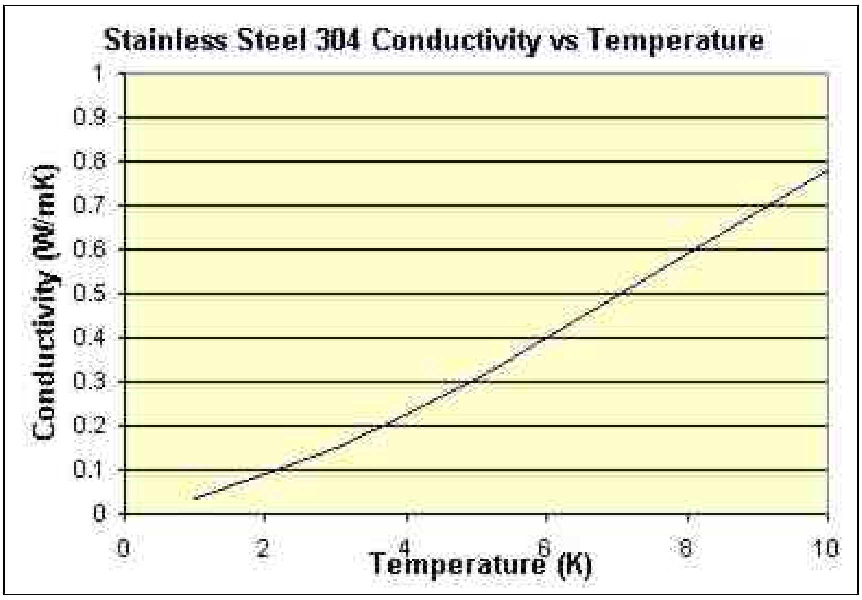


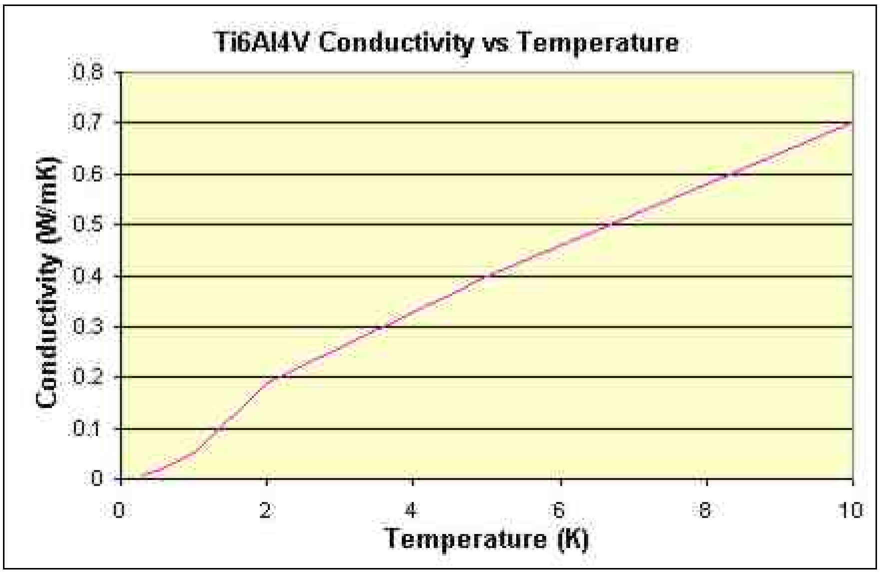


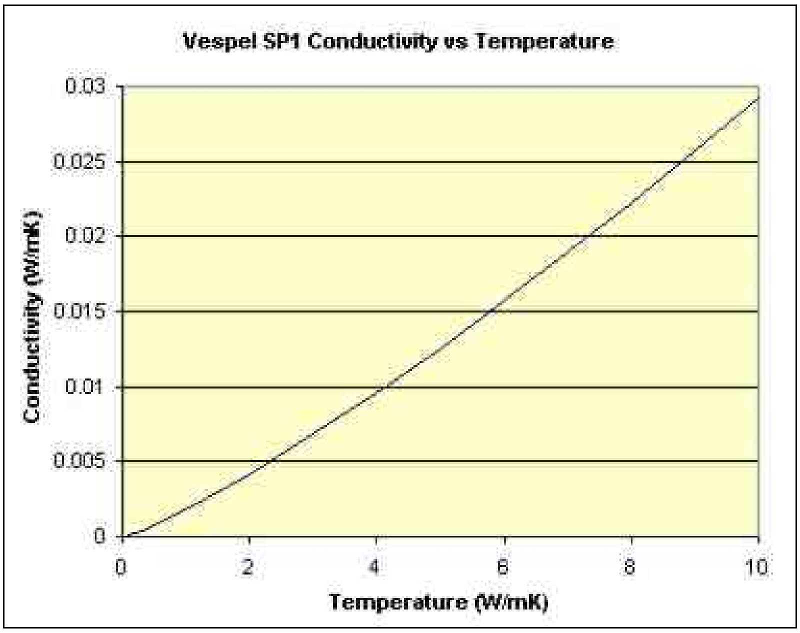
Ref:
0-2K: 'Low Temperature Thermal Conductivity of Kevlar', Ventura et al Cryogenics 40 (2000) 489-491
2K-300K: 'Experimental Charachterisation of Kevlar 29', TNS4 Iss 0 Rev 1, 15-11-01, Duband, CEA.


Kapton Conductivity vs Temperature
Conductivity (W/mK)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
2
4
6
8
10
Temperature (K)


Manganin Temperature vs Conductivity
Conductivity (W/mK)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Temperature (K)

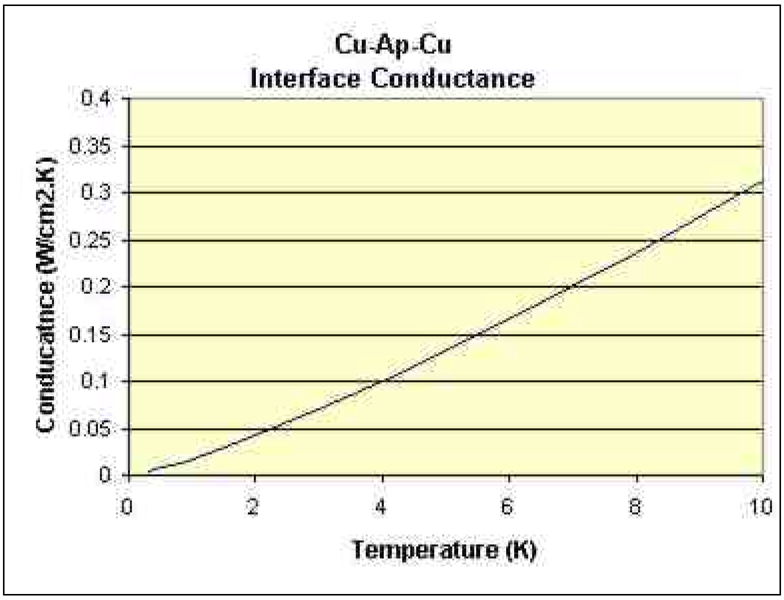

Stainless Steel 304 Conductivity vs Temperature
Conductivity (W/mK)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Temperature (K)

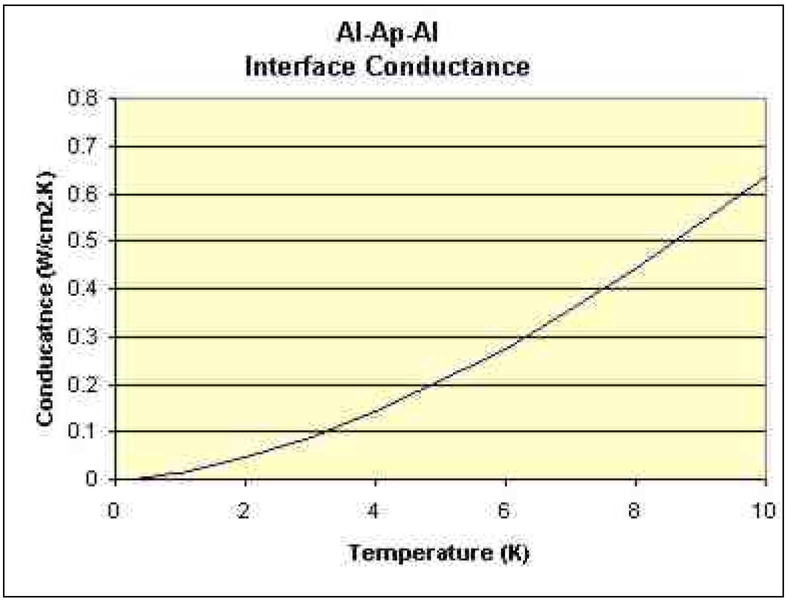

Ti6Al4V Conductivity vs Temperature
Conductivity (W/mK)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Temperature (K)

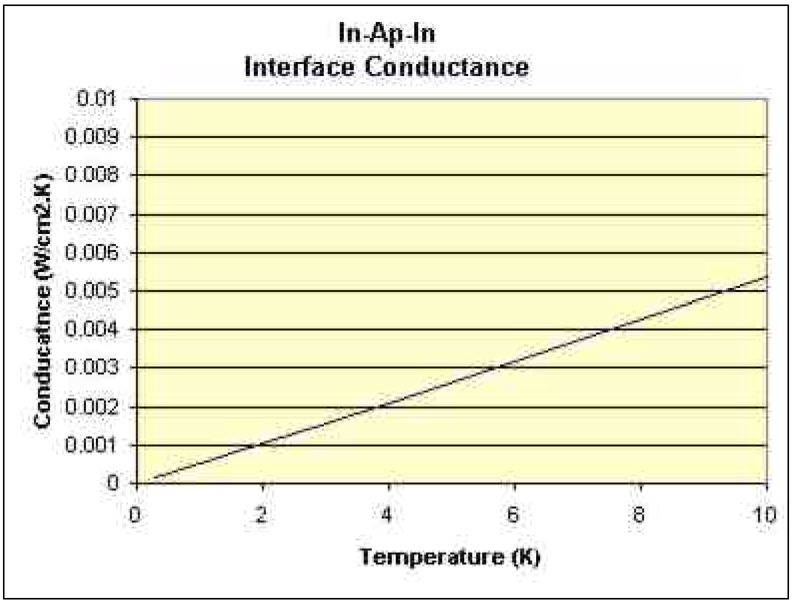

Vespel SP1 Conductivity vs Temperature
0.03
0.025
0.02
0.015
0.01
0.005
0
Conductivity (W/mK)
0
2
4
6
8
10
Temperature (W/mK)

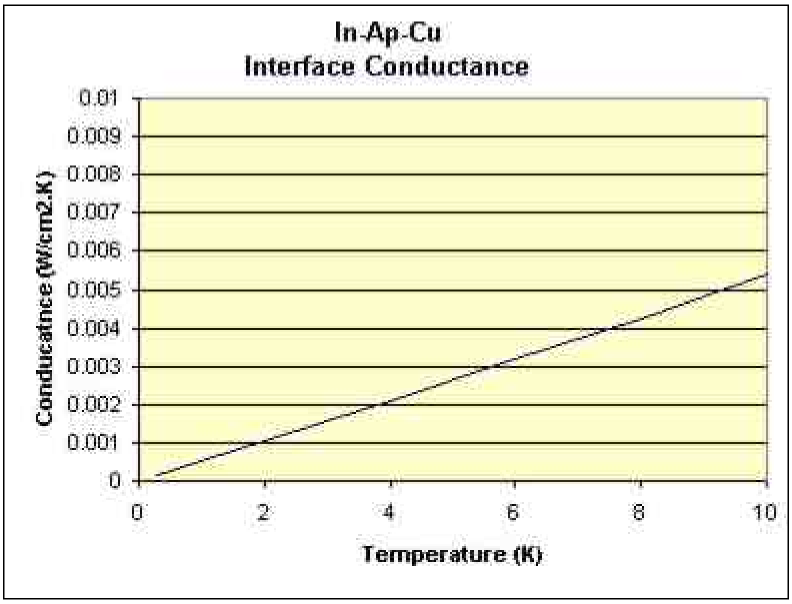
APPENDIX C: JOINT CONTACT CONDUCTANCE

Apeizon Grease Interfaces

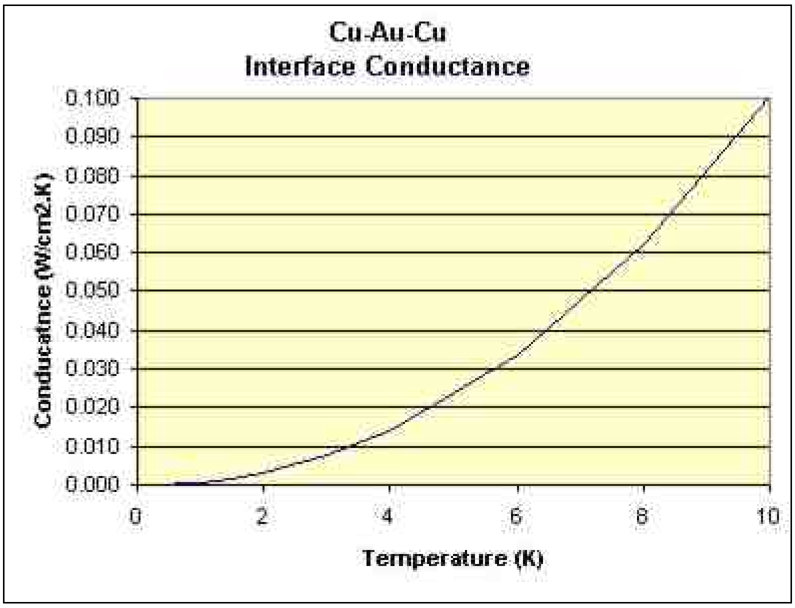


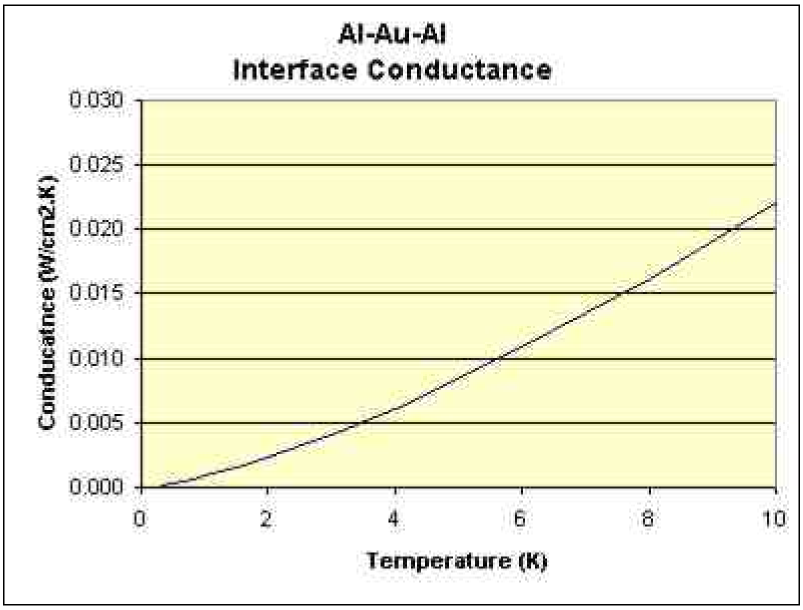


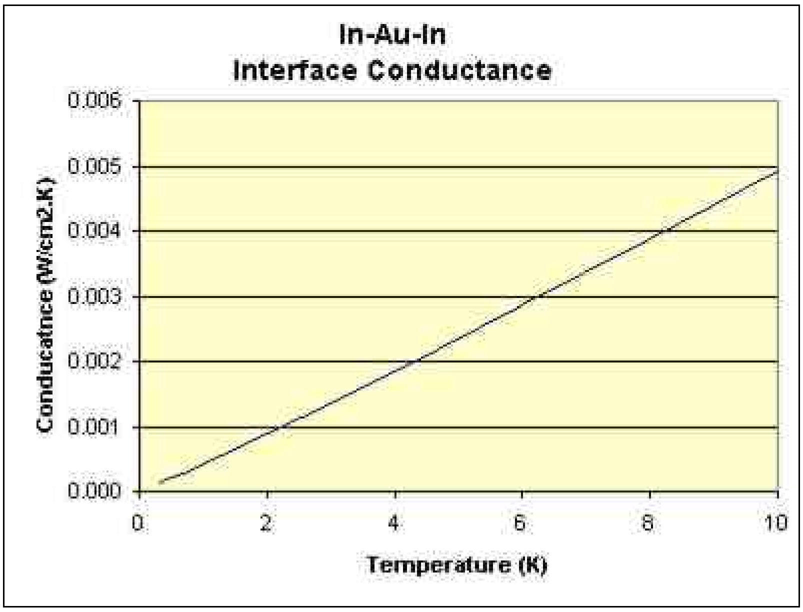


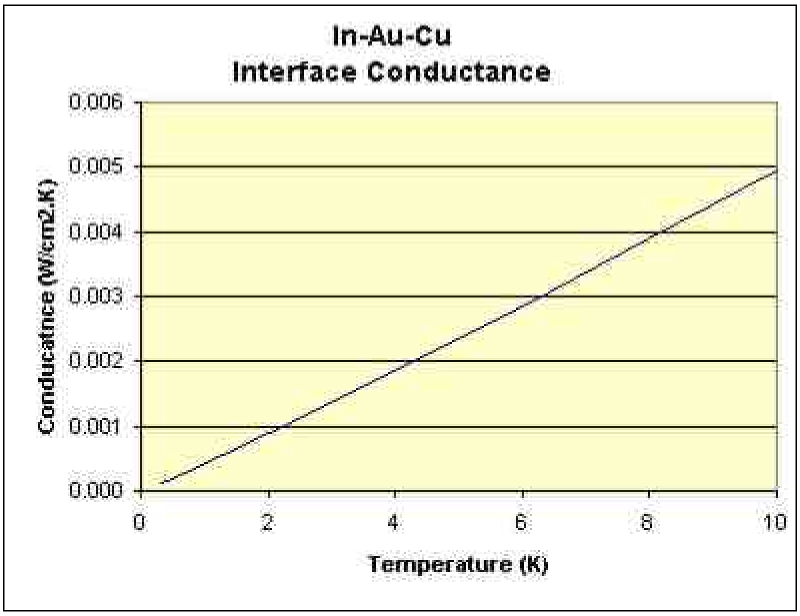


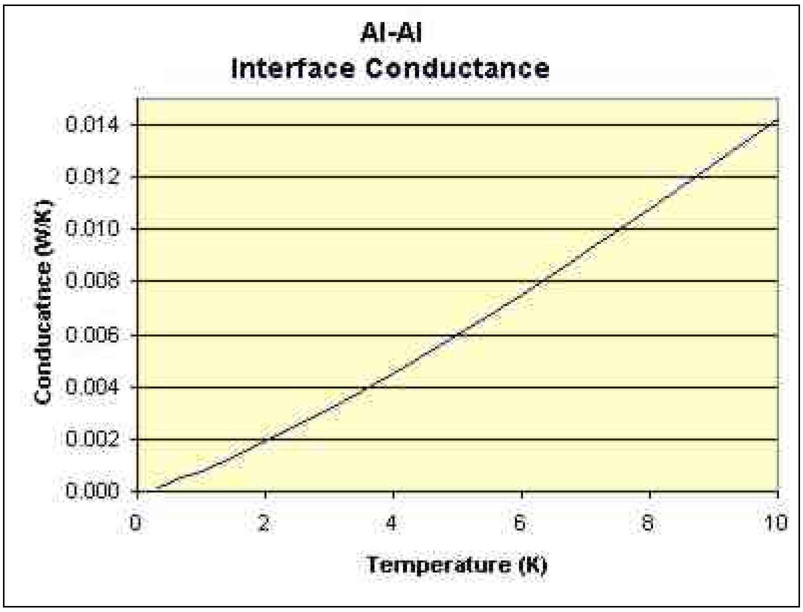
Gold Plated Interfaces


Cu-Au-Cu
Interface Conductance
Conducatnce (W/cm2.K)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
0
2
4
6
8
10
Temperature (K)


Al-Au-Al
Interface Conductance
Conducatnce (W/cm2.K)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
2
4
6
8
10
Temperature (K)


In-Au-In
Interface Conductance
Conducatnce (W/cm2.K)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
2
4
6
8
10
Temperature (K)


In-Au-Cu
Interface Conductance
Conducatnce (W/cm2.K)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
2
4
6
8
10
Temperature (K)



References

Interface Name	Description	Assumed Contact Force	Reference
Cu-Ap-Cu	Uncoated Copper - Apeizon - Uncoated Copper	670N	AD2.9.6
Cu-Ap-In	Uncoated Copper – Apeizon - Uncoated Invar	670N	*AD2.9.6
In-Ap-In	Uncoated Invar – Apeizon - Uncoated Invar	670N	*AD2.9.6
Al-Ap-Al	Uncoated Aluminium – Apeizon - Uncoated Aluminium	670N	AD2.9.6
Cu-Au-Cu	Gold Plated Copper - Gold Plated Copper	670N	AD2.9.5
Al-Au-Al	Gold Plated Aluminium – Gold Plated Aluminium	670N	AD2.9.5
Al-Al	Aluminium-Aluminium	670N	AD2.9.5

*Assume that Invar behaves as Stainless Steel.

Table C1: Joint Interface Conductances