SUBJECT: SPIRE CRYOGENIC INTERFACE THERMAL MATHEMATICAL MODEL (ITMM)

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CHANGE RECORD

ISSUE	DATE	SECTION	CHANGE
1.0	20-06-01	-	New Document
2.0	12-12-02	All	Rewritten

ACRONYM LIST

BSM	Beam Steering Mechanism
DTMM	Detailed Thermal Mathematical Model
FPU	Focal Plane Units
HOB	Herschel Optical Bench
HS	Heat Switch
IF	Interface
IGMM	Interface Geometrical Mathematical Model
ITMM	Interface Thermal Mathematical Model
JFET	Junction Field Effect Transistor
L0	Herschel Temperature Level 0
L1	Herschel Temperature Level 1
L2	Herschel Temperature Level 2
L3	Herschel Temperature Level 3
LDVT	Inductive Position Transducer
PCAL	Photometer Calibration Source
RGMM	Reduced Geometrical Mathematical Model
RTMM	Reduced Thermal Mathematical Model
SCAL	Spectrometer Calibration Source
SMEC	Spectrometer Mechanism
SOB	SPIRE Optical Bench
SPIRE	Spectral and Photometric Imaging Receiver
TBC	To Be Confirmed
TBD	To Be Defined

CONTENTS

1. SCOPE

This document defines the reduced node Interface Thermal Mathematical Model (spirntrm.d – Issue 2) of the SPIRE instrument FPU. This ITMM is a simplified version of the detailed thermal model (spir20ntrm.d) and is provided for incorporation into the HERSCHEL Cryostat thermal model. Updates to this model will be necessary as the SPIRE design iterates. A description of the SPIRE Interface Geometrical Mathematical model (spirengrm.erg) is also given. The HERSCHEL reduced geometrical and thermal models (Issue 1, PDR status) have been used to perform the correlation between the detailed and interface thermal models of SPIRE. Please note that patch for the Level 3 was not included in the HERSCHEL RTMM at the time of the correlation.

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"	SCI-PT-IIDB/SPIRE-02124 Issue 2.2 01/07/02
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 3.0 01/07/02

Table 8.2.1-1 – ESA Applicable Documents

2.2. Astrium 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
AD2.2.2	HERSCHEL Reduced Model Issue1 (EPLM PDR status)	K. Wagner 08-JUL-2002
AD2.2.3	Steady-State and Transient Patches for the H_EPLM RTMM	K. Wagner 28-OCT-2002
	L3 Patch for H_EPLM RTMM	K. Wagner 11-NOV-2002

Table 8.2.1-1 - Astrium 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 2.3.2	SPIRE Inputs For Cryostat and Instrument Thermal Modeling	RAL 15-MAY-00 -update
AD 2.3.3	Instrument Requirement Document Issue 1.1	SPIRE-RAL-PRT-000034 2-JAN-02
AD 2.3.4	SPIRE Thermal Configuration Control Document	SPIRE-RAL-PRJ-000560 Issue: D11
AD 2.3.5	SPIRE Detailed Thermal Model Spir20ntrm.d	AS GOIZEL 6-DEC-02
AD 2.3.6	SPIRE Detailed Geometrical Model ral_spire18_g.erg	AS GOIZEL 4-NOV-02
AD 2.3.7	SPIRE Interface Thermal Model Spirntrm.d	AS GOIZEL 6-DEC-02
AD 2.3.8	SPIRE Interface Geometrical Model Spirengrm.d	AS GOIZEL 4-NOV-02

Table 8.2.1-1 - SPIRE Applicable Documents

3. INSTRUMENT THERMAL REQUIREMENTS

3.1. SPIRE Interface Requirements with HERSCHEL

PARAMETER	SPECIFICATION	REFERENCE
Level 2 Load / Interface Temperature	TBD	
Level 1 Load / Interface Temperature	TBD	
Level 0 Enclosure Load / Interface Temperature	TBD	
Level 0 Enclosure Load / Interface Temperature	TBD	
Level 0 Enclosure Load / Interface Temperature	TBD	

Table 8.2.1-1 - SPIRE Interface Thermal Requirements with HERSCHEL

All requirements are still to be negotiated via the IID-B.

3.2. SPIRE Internal Requirements

PARAMETER	SPECIFICATION	REFERENCE
FPU Bulk Temperature	~4K	-
Cooler Interface Temperature	4K	-
Detector Module Interface Temperature	~1.8K	-
Detector temperature	T <310mK	AD2.3.3
300mK detector array stability*	670nK/√Hz between 0.03 and 25Hz.	AD2.3.3
1.8K stage stability*	9.1K/√Hz	AD2.3.3
4K stage stability*	5mK/√Hz	AD2.3.3
80K stage stability*	1mK/√Hz	AD2.3.3

* Drift Scanned/Extended Emission observing modes specify more stringent stabilities (see AD2.7.7). However these are subject to evaluation.

Table 8.2.1-1 - SPIRE Instrument Thermal Requirements

4. INSTRUMENT THERMAL DESIGN OVERVIEW

The SPIRE FPU and JFET Boxes are mounted off the HERSCHEL Cryostat Optical Bench on isolating supports, surrounded by the HERSCHEL Instrument Shield. Four temperature stages on the FPU are used to achieve the 300mK detector temperature, with nominal temperatures of 10K, 4K, 1.8K and 300mK. Each stage below 10K 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.

Please note that although the Level 3 stage is part of the current baseline, it had not been implemented at the time of the correlation between the SPIRE DTMM and ITMM. The old interface has therefore been used for the JFETs enclosures which are bolted on the HOB rather than on isolation supports.

STAGE	*SPIRE COMPONENTS*	*HEAT SINK*
Level 2	JFET boxes	HERSCHEL L3 Vent Pipes
Level 1	SOB structure/ mechanisms / mirrors	HERSCHEL L1 Vent Pipes
Level 0	FPU detector boxes / dichroics / mirrors	HERSCHEL L0 LHe Tank
300mK	FPU detectors / cooler thermal link	SPIRE ^{3}He Sorption Cooler

Table 8.2.1-1 - SPIRE Temperature Stages and Heat Sinks

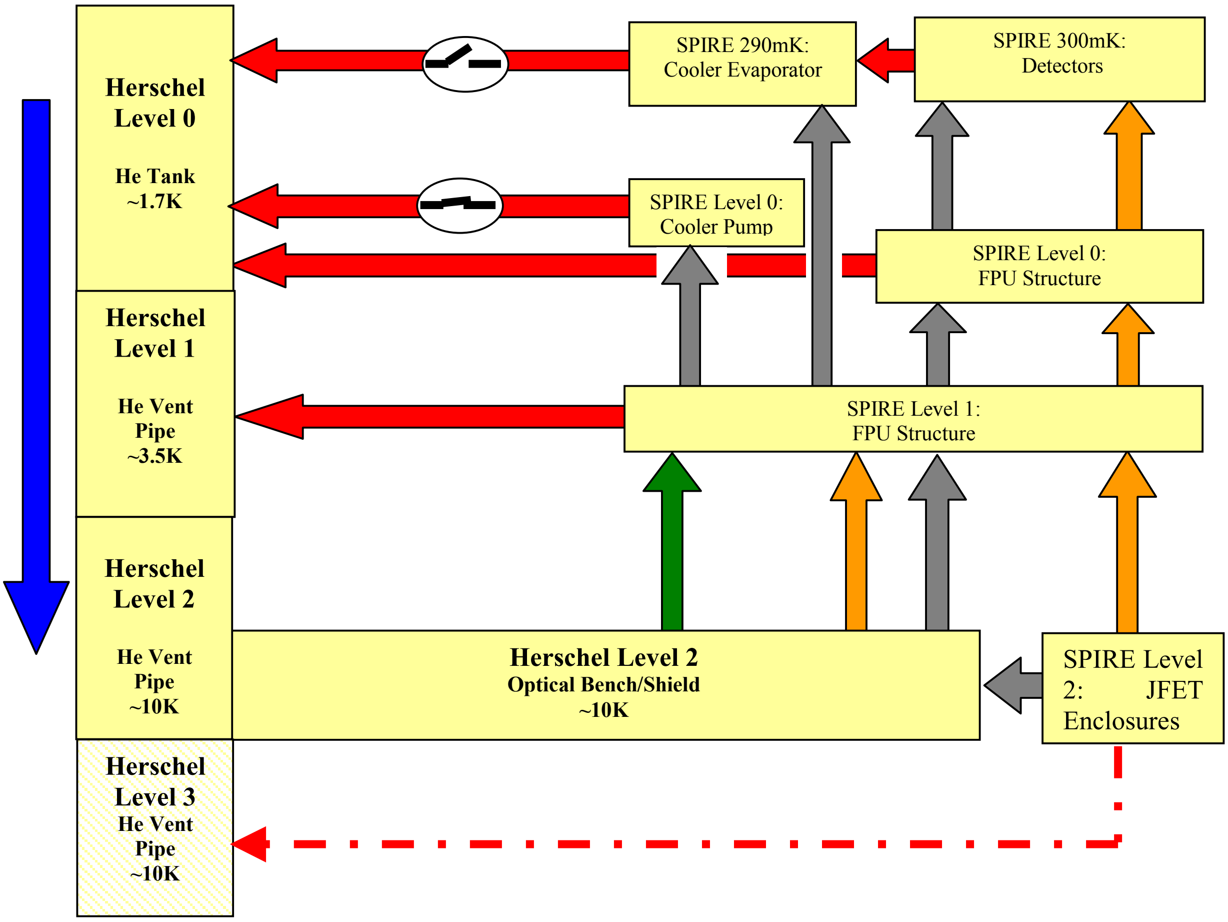
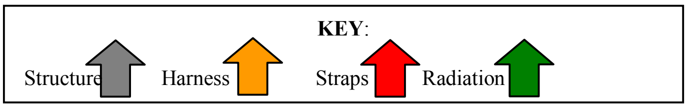


Figure 3.2-1 - SPIRE Temperature Stages and Heat Sinks



5. SPIRE INTERFACE GEOMETRICAL MODEL

The interface geometrical model of SPIRE (spirengrm.erg) is a reduced version of the SPIRE geometric model “ral_spire18_g.erg”. The IGMM consists of three nodes described in the table below.

NODE	DESCRIPTION	IR-EMISSIVITY
801	Photometer JFET Enclosure	0.2
802	Spectrometer JFET Enclosure	0.2
803	SPIRE FPU *	0.2

Table 5 - SPIRE IGMM Thermal Optical Properties

Note * - the FPU node 803 also includes the instrument aperture for which an emissivity of 1.0 has been set.

The SPIRE IGMM has been integrated into the HERSCHEL RGMM (Issue 1, PDR Status). An “in-orbit” radiative case has then been performed to obtain the radiative coupling between the SPIRE IGMM nodes and the HERSCHEL RGMM nodes.

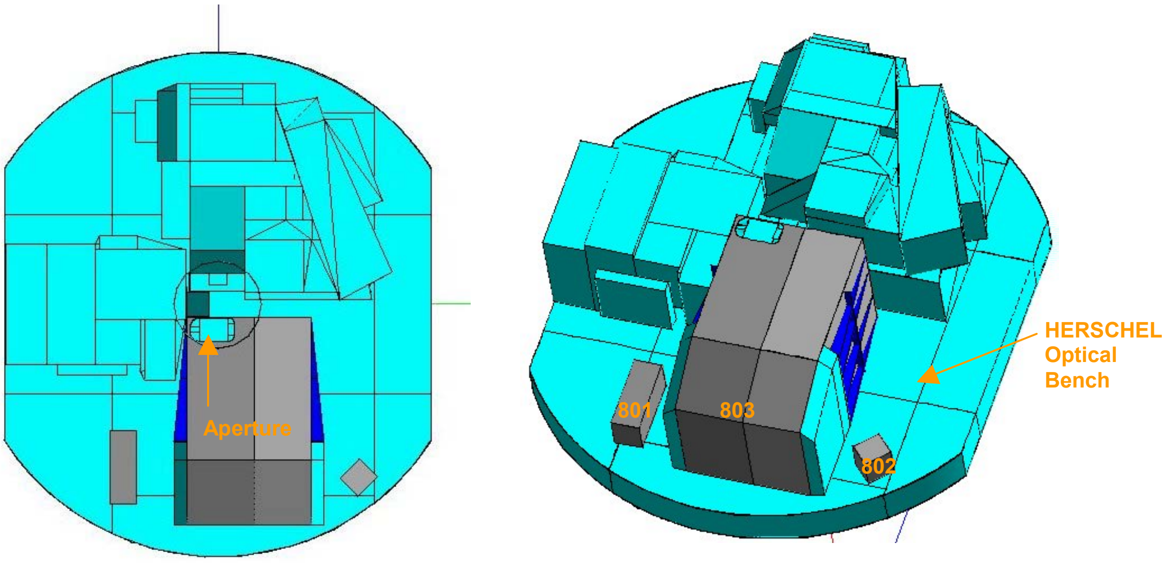


Figure 5 - SPIRE IGMM Integrated with PACS and HIFI on the HERSCHEL Optical Bench

6. SPIRE INTERFACE THERMAL MODEL - NODAL BREAKDOWN

6.1. SPIRE and HERSCHEL Interface Nodes Definition

The table 6.1.1 hereafter describes the nodes of the SPIRE ITMM, which interface with the HERSCHEL RTMM. A brief description of the HERSCHEL interface nodes is also given in table 6.1.2. for information.

NODE NUMBER	NAME	DESCRIPTION
800	L1 Strap IF @ SOB	Attachment Point of L1 strap on the SPIRE side.
801	PHOTOMETER JFET ENCLOSURE	Mounted off the HOB.
802	SPECTROMETER JFET ENCLOSURE	Mounted off the HOB.
803	FPU OPTICAL BENCH	Mounted off the HOB on isolated supports.
804	RF FILTER BOXES	Attachment Point for RF harness on SPIRE side.
814	L0 Enclosures External Strap	Attachment Point for the HeII main tank Interfaces on SPIRE side.
815	L0 Pump External Strap	Attachment Point for the HeII main tank Interfaces on SPIRE side.
816	L0 Evaporator External Strap	Attachment Point for the HeII main tank Interfaces on SPIRE side.

Table 8.2.1-1 - SPIRE Interface Nodes with HERSCHEL

NODE NUMBER	NAME	DESCRIPTION
10	MAIN Helium II TANK	HERSCHEL Cryostat - Boundary Node at 1.7K.
338	Vent line wall	Attachment Point of L1 strap on the HERSCHEL side.
376,378,379 380,381	HERSCHEL Optical Bench	Attachment Point for the SPIRE FPU and JFETs supports and harness on the HERCHEL side.
9301	SPIRE int. harn. 11	Attachment Point for SPIRE RF harness on HERSCHEL side.

Table 8.2.1-2 - HERSCHEL Interface Nodes with SPIRE

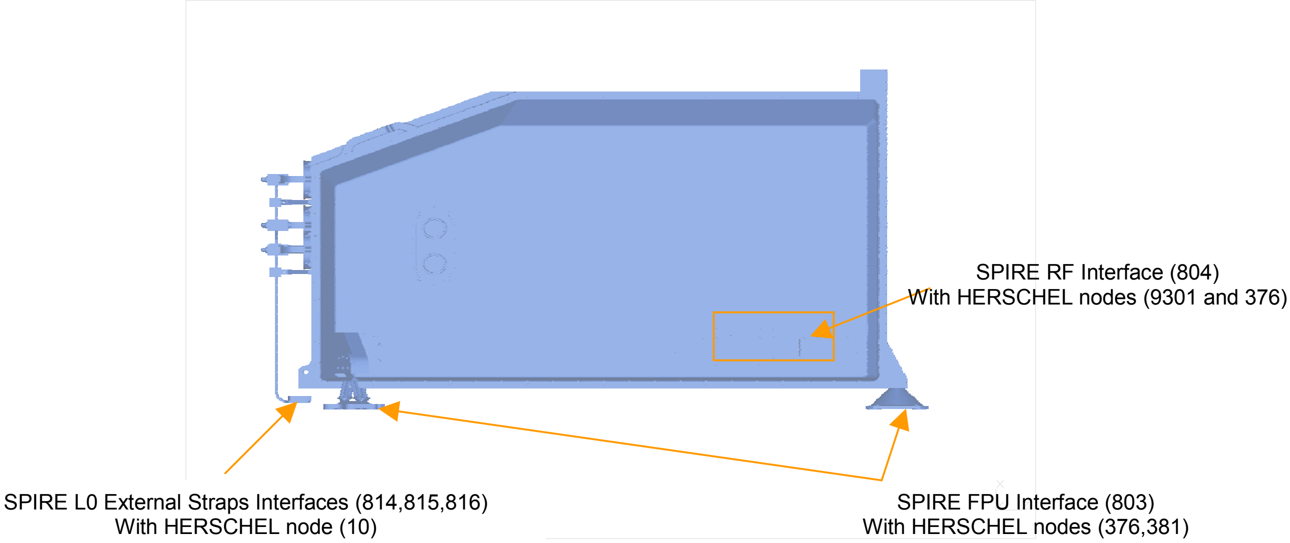


Figure 6.1-1 -SPIRE Interface Nodes Description

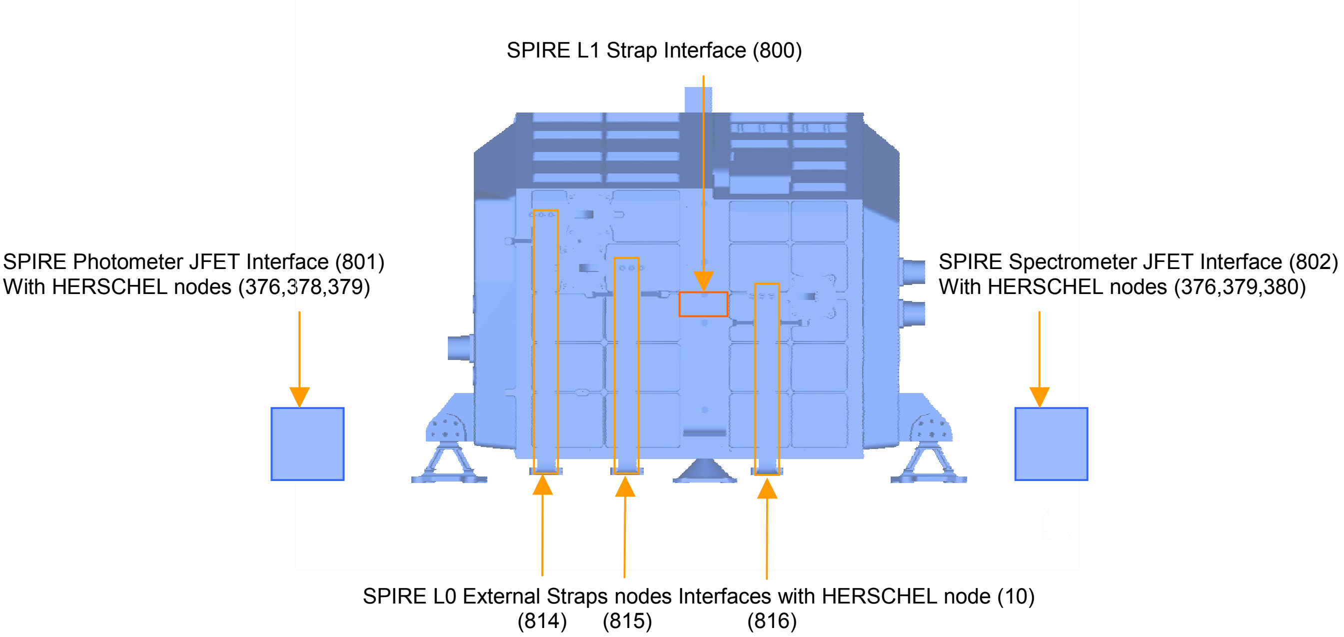


Figure 6.1-2 - SPIRE Interface Nodes Description

6.2. SPIRE NODES

NODE NUMBER	NODE NAME	DESCRIPTION	LOCATION	MATERIAL	MASS
Level 2					
801	PHOTOMETER JFET ENCLOSURE		Hard mounted to HOB	Aluminium Alloy 6082	2.348
802	SPECTROMETER JFET ENCLOSURE		Hard mounted to HOB	Aluminium Alloy 6082	0.813
Level 1					
800	L1 Strap IF @ SOB	SPIRE side of strap attachment joint	Mounted Off SOB	Epoxy	0.001
803	FPU OPTICAL BENCH	L1 SPIRE Optical Bench, Side Panels and optics	Mounted Off HOB on insulating supports	Aluminium Alloy 6082	26.75
804	RF FILTER BOXES		Hard mounted to SOB	Aluminium Alloy 6082	1.465
805	BEAM STEERING MECHANISM	Mechanism	Hard mounted to SOB	Aluminium Alloy 6082	1.1
806	SMECm	Mechanism	Hard mounted to SOB	Aluminium Alloy 6082	1.043
807	PHOTOMETER CALIBRATOR	Calibration Source	Hard mounted to SOB	Aluminium Alloy 6082	0.03
808	SPECTROMETER CALIBRATOR	Calibration Source	Mounted to SOB on insulating supports	Aluminium Alloy 6082	0.0002
Level 0					
809	PHOTOMETER DETECTOR ENCLOSURE	L0 Enclosure housing Spectrometer Detector Modules	Mounted Off SOB on insulating supports	Aluminium Alloy 6082	3.56
				Stainless Steel	0.114
				Invar	0.192
				Silicon	0.048
810	SPECTROMETER DETECTOR ENCLOSURE	L0 Enclosure housing Photometer Detector Modules	Mounted Off SOB on insulating supports	Aluminium Alloy 6082	1.468
				Stainless Steel	0.076
				Invar	0.128
				Silicon	0.032
811	L0 Enclosure Flexible Strap	1.8K Enclosures Internal Strap	At FPU Cover	Aluminium	0.0062
812	L0 Pump Flexible Strap	Cooler Pump Internal Strap	At FPU Cover	Aluminium	0.0062
813	L0 Evaporator Flexible Strap	Cooler Evaporator Internal Strap	At FPU Cover	Aluminium	0.0062
814	L0 Enclosure External Strap	1.8K Enclosures External Strap	SPIRE side of strap attachment joint	Aluminium	0.0454
815	L0 Pump External Strap	Cooler Pump External Strap	SPIRE side of strap attachment joint	Aluminium	0.0523
816	L0 Evaporator External Strap	Cooler Evaporator External Strap	SPIRE side of strap attachment joint	Aluminium	0.0653
Cooler					
817	COOLER PUMP		Mounted Off SOB on insulating supports	Titanium	0.15
818	COOLER SHUNT		Suspended between evaporator and pump	Titanium	0.01
819	COOLER EVAP		Mounted Off SOB on insulating supports	Titanium	0.084
820	COOLER EVAP HEAT SWITCH	Heat Switch to L0 Sink	Mounted Off SOB on insulating supports	Titanium	0.074
821	COOLER PUMP HEAT SWITCH	Heat Switch to L0 Sink	Mounted Off SOB on insulating supports	Titanium	0.074

NODE NUMBER	NODE NAME	DESCRIPTION	LOCATION	MATERIAL	MASS
300mK					
822	PHOTOMETER DETECTORS	300mK Photometer Detectors and cooler strap	Mounted Off Detector Enclosure on insulating supports	Invar	0.435
				Copper	0.709
823	SPECTROMETER DETECTORS	300mK Spectrometer Detectors and cooler strap	Mounted Off Detector Enclosure on insulating supports	Invar	0.281
				Copper	0.254

Table 8.2.1-1 – SPIRE ITMM Nodes Description

Note: The masses described in the above table are nominal values and do not include any margin.

The SPIRE internal and external L0 straps descriptions are given in in light grey to highligth the fact that although aluminium has been used to define those nodes, this material is not part of the baseline yet.

6.3. SPIRE ITMM OVERVIEW

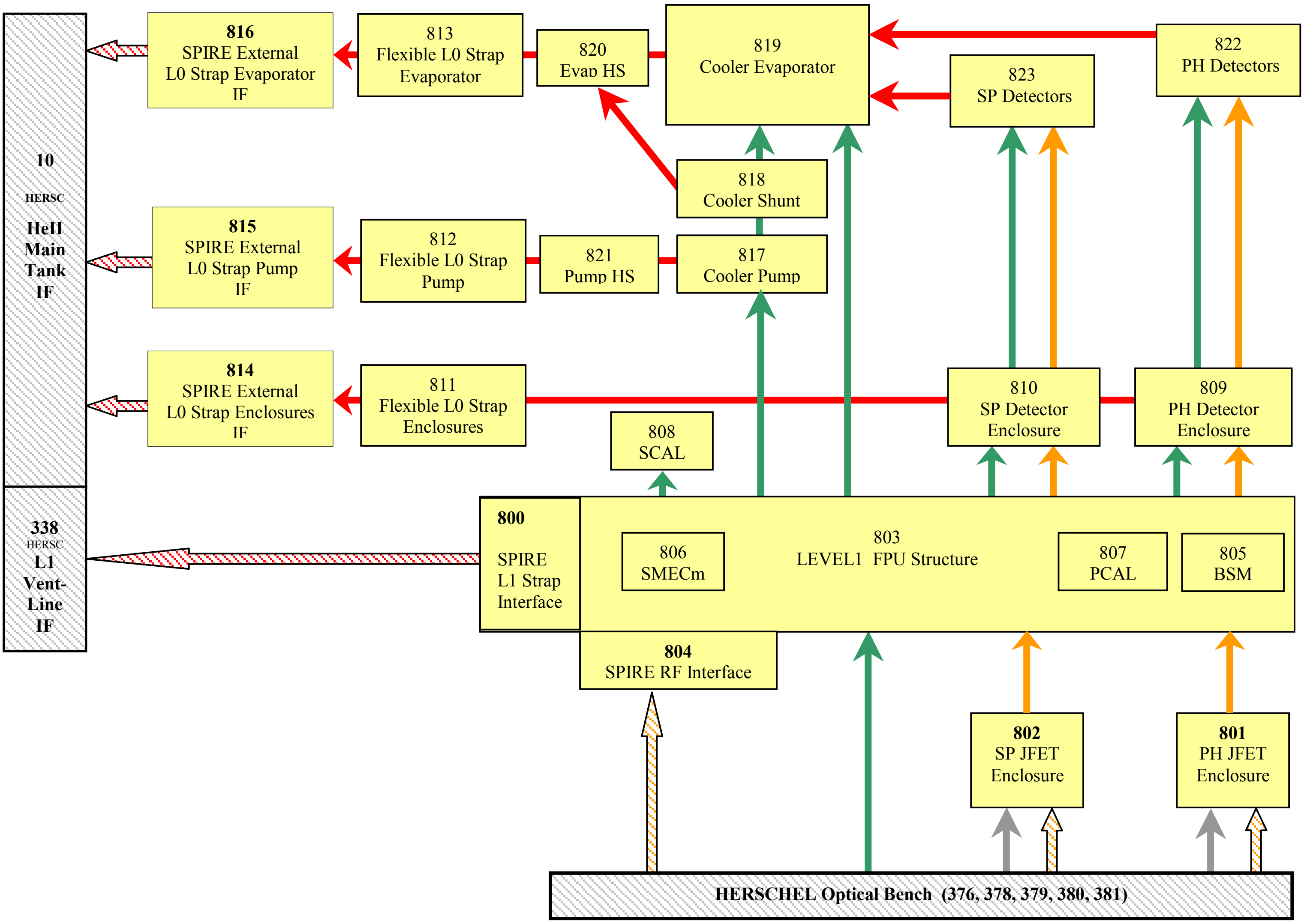
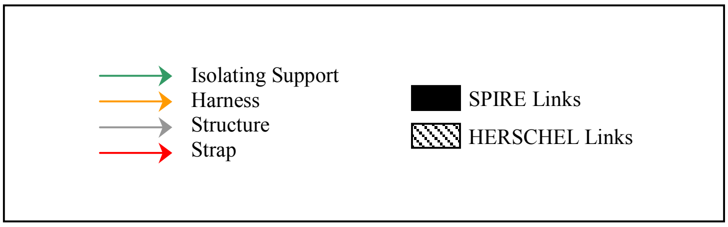


Figure 6.3-1 – SPIRE ITMM Overview



7. SPIRE INTERFACE THERMAL MODEL - COUPLINGS

7.1. HERSCHEL-SPIRE Interface Couplings

The table hereafter describes the interface couplings of SPIRE with HERSCHEL (Level3 not implemented). For information, the shaded areas describe HERSCHEL own couplings as defined in the RTMM Issue1.

HERSCHEL NODE 1	SPIRE NODE 2	DESCRIPTION	MATERIAL	X-SECTION (m^2)	LENGTH (m)	INTERFACE @ N1 (W/K)	INTERFACE @ N2 (W/K)
338	800	L1 Strap	Commercial Copper	20E-06	0.22	Cu/Cu 0.4	Cu / Epoxy / Cu ~ 0.117
378,379	801	PJFET mounted off the HOB	Al-Al	4 bolts	-	-	-
376	801	PJFET harness to the HOB	Stainless Steel Brass Teflon	21.5E-06 0.85E-06 170.2E-06	0.3	2 x 0.025	-
379,380	802	SJFET mounted off the HOB	Al-Al	4 bolts	-	-	-
376	802	S JFET harness to the HOB	Stainless Steel Brass Teflon	6.15E-06 0.59E-06 52.43E-06	0.3	2 x 0.025	-
376	803	SPIRE FPU Support Feet Cone	Stainless Steel	53.154E-06	0.0334	-	-
381	803	SPIRE FPU Support Feet 2 A Frames	Stainless Steel	44.2E-06	0.027	-	-
376	804	RF harness	Stainless steel Brass Teflon	7.371E-06 6.17E-06 55.73E-06	0.3	3 x 0.025	-
9301	804	RF harness	Stainless steel Brass Teflon	2.94E-06 1.88E-06 27.57E-06	0.3	-	-
10	814	SPIRE L0 Enclosures Strap to HeII Tank	High Conductivity Copper	10.0E-05	0.58**	Cu/Cu 0.4	Cu/Cu 0.4
10	815	SPIRE L0 Pump Strap to HeII Tank	High Conductivity Copper	4.0E-05	0.62**	Cu/Cu 0.4	Cu/Cu 0.4
10	816	SPIRE L0 Evaporator Strap to HeII Tank	High Conductivity Copper	4.0E-05	0.68**	Cu/Cu 0.4	Cu/Cu 0.4

Table 8.2.1-1 - HERSCHEL / SPIRE Interface Conductances

* This interface includes an electrical isolation joint which is part of the SPIRE internal Couplings.

** A 0.6 factor had been assumed and applied to the lengths of the Level 0 straps initially provided in the HERSCHEL RTMM (Issue1) and so to account for the change in location of the HERSCHEL / SPIRE Level 0 interfaces, as described in the figure below.

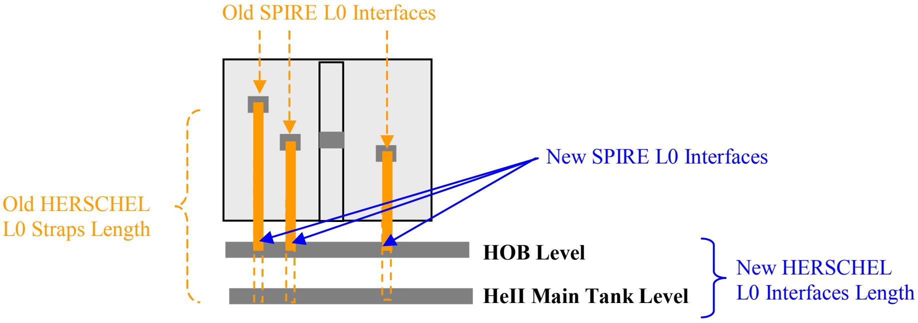


Figure 7.1-1 – Change in HERSCHEL / SPIRE Level 0 Interface Locations

7.2. HERSCHEL-SPIRE Radiative Coupling

The radiation couplings resulting from the “in-orbit” radiative case have been included into the SPIRE ITMM spirntrm.d as an “include” file. This file defines the radiative links existing between the SPIRE IGMM nodes and the RGMM nodes.

7.3. SPIRE Internal Couplings

NODE I	NODE J	DESCRIPTION	MATERIAL	X-SECTION (m^2)	LENGTH (m)
800	803	Electrical Insulation Joint Interface[1]	Epoxy	13 .0E-04	0.117 W/K
801	803	Photometer JFET Harness to SOB *Effective Conductance*	Stainless steel	A/ L = 1.837E-04 m	
			Manganin	A/ L = 2.695E-05 m	
			Teflon	A/ L = 6.32E-04 m	
801	803	Harness Vespel Supports	Vespel	7.5 x 5.0E-06	0.08
802	803	Spectrometer JFET Harness to SOB *Effective Conductance*	Stainless steel	A/ L = 3.923E-05 m	
			Manganin	A/ L = 5.6233E-06 m	
			Teflon	A/ L = 1.323E-04 m	
802	803	Harness Vespel Supports	Vespel	7.5 x 5.0E-06	0.08
803	804	RF Filters Hard Bolted to FPU	Al-Au-Al	6 bolts	-
803	805	Mechanism Hard Bolted to FPU	Al-Au-Al	4 bolts	-
803	806	Mechanism Hard Bolted to FPU	Al-Au-Al	4 bolts	-
803	808	Spec Calibrator Insulated Support	Torlon	5.3E-06	0.02
803	809	Photometer Enclosure Supports - Cone - 2 A Frames	Stainless Steel	45.96E-06 2 x 25.0E-06	0.0346 0.0362
803	809	Photometer Enclosure Detector Harness *Effective Conductance*	Stainless Steel	A/L = 2.749E-04 m	
			Manganin	A/L = 6.886E-05 m	
			Teflon	A/L= 1.6144E-03 m	
803	809	Harness Vespel Supports	Vespel	9 x 5.0E-06	0.08
803	810	Spectrometer Enclosure Supports - 3 A Frames	Stainless Steel	3 x 10.38E-06	0.0346
803	810	Spectrometer Enclosure Detector Harness *Effective Conductance*	Stainless Steel	A/L = 6.061E-05 m	
			Manganin	A/L = 1.509E-05 m	
			Teflon	A/L = 3.552E-04 m	
803	810	Harness Vespel Supports	Vespel	6 x 5.0E-06	0.08
803	814	L0 external strap supports Off the SOB	Vespel	4 x 25.0E-06	0.03
803	815	L0 external strap supports Off the SOB	Vespel	4 x 25.0E-06	0.03
803	816	L0 external strap supports Off the SOB	Vespel	4 x 25.0E-06	0.03
805	807	Calibrator within BSM	Al-Au-Al	4 bolts	-
809	810	Photometer-Spectrometer Enclosures Internal Strap	Cu / Cu	-	0.147 W/K
			Copper	9.0E-06	0.198
			Cu / Epoxy / Cu	6.0E-04	0.03 W/K
809	822	Photometer Detector Supports	Kevlar	1.752E-05	0.023
		Photometer 300mK Busbar & Supports	Kevlar	4.07E-06	0.025

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[1] *A 0.425 factor has been applied to the original interface conductance as to get an appropriate SOB mean temperature and allow an appropriate correlation with the DTMM.*

NODE I	NODE J	DESCRIPTION	MATERIAL	X-SECTION (m^2)	LENGTH (m)
809	822	Photometer Harness	Kapton	1.254E-05	0.033
			Constantan	3.828E-07	0.033
810	*811*	*Internal L0 Flexible Strap - Enclosures*	*High Purity Aluminium*	*30.0E-06*	*0.076*
			Cooler Interface	*-*	*0.4 W/K*
810	823	Spectrometer Detector Support	Kevlar	1.15E-05	0.023
		Spectrometer 300mK Busbar & Supports	Kevlar	1.36E-06	0.025
810	823	Spectrometer Harness	Kapton	2.97E-06	0.033
			Constantan	9.57E-08	0.033
811	*814*	*External L0 Strap - Enclosures*	*High Purity Aluminium*	*1.25E-04*	*0.22405*
			Elec Isolation Interface	*-*	*0.4 W/K*
812	*815*	*External L0 Strap – Pump*	*High Purity Aluminium*	*1.25E-04*	*0.2585*
			Elec Isolation Interface	*-*	*0.4 W/K*
813	*816*	*External L0 Strap – Evaporator*	*High Purity Aluminium*	*1.25E-04*	*0.3225*
			Elec Isolation Interface	*-*	*0.4 W/K*
817	803	Pump Support	Kevlar	3.14E-06	0.037
817	818	Cooler Pump to Shunt	Ti6Al4V	6.41E-06	0.038
817	821	Pump Heat Switch ON @ ~ 1.78 K OFF @ 1.85 K	ON = 65.5mW/K OFF = 4.84 microW/K	-	-
818	819	Cooler Shunt to Evaporator	Ti6Al4V	6.41E-06	0.06
818	820	Internal Shunt strap	Copper	5.0E-06	0.05
819	803	Evaporator Support	Kevlar	3.14E-06	0.031
819	820	Evaporator Heat Switch ON @ ~ 3.5 K OFF @ 1.85 K	ON = 79.2 mW/K OFF = 4.84 microW/K	-	-
819	822	Cooler - Photometer Detector Strap	Copper	7.07E-06	0.130
819	823	Cooler - Spectrometer Detector Strap	Copper	7.07E-06	0.244
820	803	Evaporator HS Support	Ti6Al4V	1.16E-05	0.027
820	*813*	*Internal L0 Flexible Strap - Evaporator*	*High Purity Aluminium*	*30.0E-06*	*0.076*
			Cooler Interface	*-*	*0.4 W/K*
821	803	Pump HS Support	Ti6Al4V	1.16E-05	0.027
821	*812*	*Internal L0 Flexible Strap - Pump*	*High Purity Aluminium*	*30.0E-06*	*0.076*
			Cooler Interface	*-*	*0.4 W/K*

Table 8.2.1-1 – SPIRE Internal Conductance

Note: The conductances described in the above table are nominal values and do not include any margin.

Important note on the SPIRE Level 0 Internal and External Strap Dimensions:

In order to meet the overall conductance of 100 mW/K required for the SPIRE Level 0 evaporator strap (defined between the HERSCHEL HeII tank and the SPIRE cooler interface) an initial assumption has been to split this conductance equally between the following items:

- HERSCHEL Interface with HeII Tank,
- SPIRE External Level 0 Straps (between the HERSCHEL Interface and the SPIRE L0 Internal Strap),
- SPIRE Internal Level 0 Straps (between the SPIRE L0 External Strap and the cooler interface).

This represents a minimum overall conductance of 150 mW /K for the SPIRE evaporator Level 0 straps (from the HERSCHEL interface to the cooler), which should also account for the two following joint conductances:

- An electrical insulation joint conductance at the interface between the external and internal L0 straps,
- An interface between the internal L0 strap and the cooler.

At this stage of the analysis, the design of the SPIRE Level 0 straps is still under investigation. Although an overall conductance of 200 mW/K is currently the goal for the design of the SPIRE level 0 straps, a 150 mW/K overall conductance has initially been used in the present ITMM to represent the worst-case conditions in terms of loads and interface temperatures.

The SPIRE internal and external L0 straps dimensions and material descriptions are given in in light grey to highligth the fact that those are not part of the baseline yet. They have been used

7.4. Heat Switch and Cooler Status

NODE I	NODE J	DESCRIPTION	MODE					
			Photometer	**Spectrometer**	**Off**	**Average**	**Cooler Recycle**	**Mode Change**
817	821	Pump Heat Switch	ON	ON	OFF	ON	See 8.2.1	ON
819	820	Evaporator Heat Switch	OFF	OFF	OFF	OFF	See 8.2.1	OFF
819	-	Evaporator Node	Boundary At 0.29 K	Boundary At 0.29 K	Diffuse	Boundary At 0.29 K	See 8.2.1	Boundary At 0.29 K
VARIABLE		MODE	SWITCH_ON	SWITCH_ON	SWITCH_OFF	SWITCH_ON	See 8.2.1	SWITCH_ON

Table 8.2.1-1 – SPIRE Heat Switches and Evaporator Status

8. SPIRE INTERFACE THERMAL MODEL - POWER DISSIPATION

8.1. Steady-State Cases

Four steady-state cases have been defined to describe the various modes in which SPIRE will operate. For each mode, the worse case "mean power dissipation" has been used. A variable called "margin_fac" has also been defined in the SPIRE ITMM as to allow any desired margin to be applied to the SPIRE power dissipation. The defaults value of "margin_fac" is 1.2 (i.e. 20 % margin applied to the nominal data).

NODE NUMBER	NODE NAME	MEAN POWER DISSIPATION (mW)			
		Photometer	**Spectrometer**	**Off**	**Average**
801	PH. JFET	42.0	0.0	0.0	6.722
802	SP. JFET	0.0	14.1	0.0	2.257
805	BSM	3.0	0.2	0.0	0.424
806	SMECm	0.0	3.2	0.0	0.328
807	PH. CALIBRATOR	0.033	0.033	0.0	0.011
808	SP. CALIBRATOR	0.0	5.25	0.0	0.84
817	PUMP Nominal *	1.5	1.5	0.0	1.106
818	SHUNT	0.005	0.005	0.0	0.222
819	EVAP	0.0	0.0	0.0	0.04
820	EVAP HS	0.0	0.0	0.0	0.001
821	PUMP HS	0.2	0.2	0.0	0.065

Table 8.2.1-1 – SPIRE Operation Mode Power Dissipation Profile for Steady-State Analysis

* Important Note on the SPIRE pump dissipation:

When SPIRE is in operation, the power dissipation by the cooler pump depends on the total evaporator load and is calculated using the following expression:

Pump Internal Dissipation (mW) ~ Total Evaporator Load (mW) x 50.0 **[*Equation 8.1-1*]**

A nominal power dissipation has been fixed to 1.5 mW and is applied to the SPIRE pump (node 817) each time the instrument is in operation (not during recycling). This corresponds to an initial cooler total load of 30µW. The required pump internal dissipation is calculated using the above equation and the "missing pump dissipation" is iterated at each time step and applied to the node 812 located along the Pump L0 flexible strap. This approach allows an accurate L0 pump load to be reached at the end of steady state and provide a good estimation of the load during transient runs while limiting instability in the model as the pump power dissipation is re-iterated according to the evaporator load.

Note: The power disispation described in the above table are nominal values and do not include any margin.

8.2. Transient Cases

8.2.1. Cooler Recycling

During recycling, the Cooler Cold Tip is changed from a boundary to a diffuse node as recycling starts. After 55 minutes, when Cryopumping starts, the cooler is converted to a boundary node, whose temperature is reduced at a constant rate of 0.105K/min to 290mK. The cooldown of the cooler usually takes between 20 and 30 min while the overall cooler recycling should not last more than 2 hrs. A nominal 1.5 hrs has been allocated to the recycling in this case. Heat switch states and therefore input powers and conductance are switched during this analysis as described in table 8.2.1. A Margin factor can be applied to the pump, shunt evaporator and heat switches power dissipations during recycling if needed.

TIME (H:MM:SS)	NODE NUMBER	NODE NAME	STATUS	POWER (MW)
0:00:00	All	SPIRE	OFF	0.0
RECYCLE				
0:00:01	820 821	EVAP HS PUMP HS	ON OFF	0.2 0.0
0:00:02	817	PUMP	NET LOAD	142.1
	818	SHUNT	-	57.8
	819	EVAP	-	5.79
0:25:00	817	PUMP	NET LOAD	25.0
	818	SHUNT	NET LOAD	6.9
	819	EVAP	-	5.79
0:55:00	817	PUMP	OFF	0.0
	818	SHUNT	NET LOAD	0.0
	819	EVAP	-	5.79
COOLDOWN				
0:55:01	820 821	EVAP HS PUMP HS	OFF ON	0.0 0.2
0:55:02	817	PUMP	NET LOAD (until evap reaches 290mK).	17.07
0:55:02	818	SHUNT	(until evap reaches 290mK).	0.0
0:55:02	819	EVAP	Cryopumping to 290mK @ 0.105K/min	0.0
~1:15:00	820 821	EVAP HS PUMP HS	OFF ON	0.0 0.2
	817	PUMP	ON	50 x Evaporator load (mW)
	818	SHUNT	NET LOAD	0.0054
	819	EVAP	Boundary @ 0.29 K	-
END OF RECYCLING				
1:30:00		End of Time allocated to Recycling		
1:30:01		Start SPIRE Operation		

Table 8.2.1-1 - Nominal SPIRE Recycling Profile (no margin factor applied)

Note: The power disispation described in the above table are nominal values and do not include any margin.

8.2.2. SPIRE Nominal Operation Timeline

The following assumptions have been used when defining the nominal SPIRE operation timeline:

- SPIRE is in nominal operation for 48 hrs,
- SPIRE operation starts with a cooler recycling during which the instrument is in the OFF mode,
- SPIRE operates half the time in spectrometer mode then switches to the photometer mode,
- Both the minimum and maximum power dissipation cases are being looked at during both the spectrometer and photometer modes.

The table 8.2.2 describes the proposed nominal SPIRE operation timeline and the table 8.2.3 provides a more detailed description of the power dissipation profiles used during the SPIRE operation.

TIMELINE (hr:min)		INSTRUMENT OPERATION	PERIOD (min)
00:00	48:00	**SPIRE in OFF mode** During PACS operation	2880
48:00	49:30	**SPIRE Cooler Recycling** JFET and Mechanisms OFF	2970
49:30	61:30	**SPIRE in Spectrometer Mode - *** SMECm in R =1000 mode	3690
61:30	73:30	**SPIRE in Spectrometer Mode** SMECm in R =10 mode	4410
73:30	85:00	**SPIRE in Photometer Mode** BSM in Chopping Mode	5100
85:00	96:00	**SPIRE in Photometer Mode - *** BSM in Scanning Mode	5760
96:00	144:00	**SPIRE in OFF mode** During HIFI operation	8640

Table 8.2.2-1 – SPIRE nominal operation timeline

* *Worst-case power dissipation*

TIMELINE		From 49:30 to 61:30		From 61:30 to 73:30		From 73:30 to 85:00		From 85:00 to 96:00	
Node Number	Node Name	Status	Power (mW)	Status	Power (mW)	Status	Power (mW)	Status	Power (mW)
801	P. JFET	OFF	0.0	OFF	0.0	ON	42.0	ON	42.0
802	S. JFET	ON	14.1	ON	14.1	OFF	0.0	OFF	0.0
805	BSM	ON	0.2	ON	0.2	ON	1.9	ON	3.0
806	SMECm	ON R =1000	3.2	ON R =10	0.9	OFF	0.0	OFF	0.0
807	PCAL	ON	0.033	ON	0.033	ON	0.033	ON	0.033
808	SCAL	ON	5.25	ON	5.25	OFF	0.0	OFF	0.0
817	PUMP	ON	1.5	ON	1.5	ON	1.5	ON	1.5
818	SHUNT	ON	0.005	ON	0.005	ON	0.005	ON	0.005
819	EVAP	0.29 K		0.29 K		0.29 K		0.29 K	
820	EVAP HS	OFF	0.0	OFF	0.0	OFF	0.0	OFF	0.0
821	PUMP HS	ON	0.2	ON	0.2	ON	0.2	ON	0.2
PACS		OFF	-	OFF	-	OFF	-	OFF	-
HIFI		OFF	-	OFF	-	OFF	-	OFF	-

Table 8.2.2-2 – SPIRE Power Dissipation Profile during Nominal Operation

9. SPIRE INTERFACE THERMAL MODEL OPERATION

When operating the SPIRE ITMM, the following variables need to be setup:

- The variable “ANALYSIS” must be set according to the type of analysis being performed: either 'STEADY_STATE' or 'TRANSIENT'.
- The variable “margin_fac” must be set to define the level of margin to be applied on the SPIRE power dissipation (default value is 1.2).

A variable called MODE is used to describe the instrument status. This variable has been defined for each steady-state case as either “SWITCH_ON” or “SWITCH_OFF”. This variable is then checked at each iteration and the Heat Switches and Evaporator status set accordingly as described in table 7.4.1.

At the end of each steady-state run, please make sure that the following items have been set properly:

- Heat Switches Status HS_EVAP_STATE and HS_PUMP_STATE is either ON or OFF as described in table 7.4.1,
- Heat switches gas conductance has been set properly according to their status:
    - HS_EVAP_GAS and HS_PUMP_GAS should be 0.0 when heat switch is OFF,
    - HS_EVAP_GAS and HS_PUMP_GAS should be around 0.06-0.07 W/K when heat switch is ON during normal operation.
- Check that the cooler evaporator is a boundary node at 0.29K when the instrument is operating and a diffuse node when the instrument is in OFF mode.
- The variable “q_pump_add” applied on the node 812 is either:
    - 0.0 when SPIRE is not operating i.e. “SWITCH_OFF” mode,
    - Equal to [(50 x Total Cooler)/1000000)-0.0015] as defined by equation 8-1-1.

For information, some instability issues have been encountered in transient analysis when integrating the SPIRE ITMM into the HERSCHEL RTMM. To compensate for these instabilities, the following nodes capacitances have been set to zero:

800:	L1 interface,
805,806,807:	BSM, SMECm and PCAL,
811,812,813:	Three Internal L0 straps,
814,815,816:	Three External L0 straps.

The cooler load is computed (“Tot_Cooler load”) at each time step and is then used to evaluate the pump internal power dissipation (“q_pump_add”) as well as the cooler hold time (“Cooler_hold”) for a given steady-state case.

In annex B some transient profiles resulting from the SPIRE ITMM / DTMM correlation are shown. The ITMM curves have been defined with brighter colours to allow easy distinction with the DTMM curves.

- The SPIRE cooler recycling spreads over the “2880 min - 2970 min” period,
- The SPIRE operation spreads over the “2970 min – 5760 min” period.

10. ANALYSIS ASSUMPTIONS AND UNCERTAINTIES

The SPIRE ITMM is a reduced node version of the ESATAN SPIRE DTMM, spir20ntrm.d. All interface critical aspects of the instrument have been incorporated into the ITMM, whilst more detailed information, such as temperature gradients across the SOB, detectors and straps, internal heat flows, cooler thermodynamic performance, etc have not been included in significant details. In addition the 300mK stage of the instrument is modelled at a basic level to ensure the accuracy of Level 0 interfaces, rather than to accurately predict the loads and temperatures at the detector stage (i.e. total cooler load). Therefore inaccuracies at this stage in the ITMM are expected and acceptable.

In order to compare the ITMM with the DTMM, both models have been integrated into the HERSCHEL Reduced thermal model (issue1) in a similar way and with identical solver setting. The results obtained in steady-state analyses are for a constant mass flow rate of 2.2 mg/s while a varying mass flow rate has been used for transient analyses. The results of the correlation between the SPIRE DTMM and ITMM are shown in Appendix A, and demonstrate a good mean agreement in heat loads and temperatures for the three steady-state cases and also for the transient analysis. Some inconsistencies are present due to the simplified level of the ITMM. However these are anticipated to have a negligible effect on the accuracy of the SPIRE FPU representation within the overall Herschel cryostat TMM.

Inconsistencies Overview:

- Small oscillations can be observed for the ITMM pump load and interface temperatures profiles for the transient results – this is the result of applying the “missing pump power dissipation” to node 812 which having its mass set to zero for stability purpose. As a result the node does not have any inertia to compensate the changes in “missing pump power dissipation” as the cooler load changes.
- Applying the “missing pump power dissipation” to the L0 pump strap rather to the pump itself implies than the pump temperature will run slightly cooler than it should - but this does not have any impact the cooler performances at this simplified level.
- Please remember that the “total cooler load” is accurate within 4 - 5% and that the cooler hold time, which is evaluated from this data, should only be used as an indication of the cooler performances between the cases investigated.
- The remark above implies that the pump power dissipation will always be slightly under-estimated. However this discrepancy remains negligible and acceptable.

11. SUMMARY

The SPIRE ITMM operates properly and correlates within 1-2% for all cases. An average case has initially been defined but presents some instability in the current state for the node 806 (SMEC mechanism), caused by some temperature dependent properties.
Although the transient profiles show some oscillations in some places, it is foreseen that reassigning the capacitance of nodes, which had previously been set to zero should reduce and/or remove those oscillations.
The table below gives a general summary of the correlation conclusion.

	ITMM Load (mW)	***ITMM Interface Temperature (K)***
Level 2 Load	Good Correlation	-
Level 1 Strap IF	Equal or Slightly higher Conservative results	IF runs slightly cooler
Level 1 RF IF	see L2 load Conservative results	Lower IF temperature because of simplified version of FPU.
Level 0 Enclosure	Equal or Slightly higher Conservative results	IF runs slightly warmer
Level 0 Pump	Load slightly lower than for the DTMM because of the pump power dissipation dependence with the total cooler load.	IF temperature runs a bit hotter
Level 0 Evaporator	Equal or Slightly higher Conservative results	IF runs warmer
300 mK Cooler	Lower load caused by simplified version of the L0 and 300 mK stage	-
SMECm	-	124.5 K versus104 K in DTMM because simplified version of the mechanism mass.

ANNEX A: COMPARISON OF ITMM AND DTMM RESULTS

A1: Steady-State Results

	Spectro			Photo			Off		
	ITMM	DTMM	Ratio	ITMM	DTMM	Ratio	ITMM	DTMM	Ratio
Temperature (K)									
FPU At Cone	5.74	5.921	0.969	5.319	5.491	0.969	4.02	4.164	0.965
FPU At 1rst A Frame	5.74	5.855	0.980	5.319	5.435	0.979	4.02	4.122	0.975
FPU At 2nd A Frame	5.74	5.843	0.982	5.319	5.428	0.980	4.02	4.12	0.976
RF Interface on FPU	5.824	5.937	0.981	5.364	5.47	0.981	4.06	4.139	0.981
Level 1 Interface	5.318	5.32	1.000	4.967	4.967	1.000	3.828	3.819	1.002
Level 0 at Enclosure Strap	1.743	1.742	1.001	1.736	1.736	1.000	1.719	1.719	1.000
Level 0 at Pump Strap	1.748	1.748	1.000	1.744	1.744	1.000	1.704	1.704	1.000
Level 0 at Evaporator Strap	1.711	1.71	1.001	1.709	1.709	1.000	1.705	1.705	1.000
Loads (mW)									
Net P JFET L2 Load	1.071	1.079	0.993	40.453	40.571	0.997	0.796	0.795	1.001
Net S JFET L2 Load	13.81	13.83	0.999	0.345	0.346	0.997	0.204	0.203	1.005
FPU L2 Load	13.611	13.457	1.011	14.376	14.259	1.008	1.001	0.993	1.008
L1 Strap Load	20.971	20.973	1.000	17.5	17.49	1.001	9.562	9.49	1.008
L0 Enclosure Load	4.241	4.174	1.016	3.557	3.529	1.008	1.856	1.862	0.997
L0 Pump Load	2.61	2.615	0.998	2.393	2.407	0.994	0.235	0.223	1.054
L0 Evaporator Load	0.534	0.506	1.055	0.448	0.428	1.047	0.24	0.23	1.043
Total Level 0 Load	7.385	7.295	1.012	6.398	6.364	1.005	2.331	2.315	1.007
Total Cooler (microW)	37.37	38.24	0.977	34.77	35.65	0.975	-	-	-
Cooler Hold Time (hrs)	39.43	37.92	1.040	42.4	40.7	1.042	-	-	-
MEAN AGREEMEMNT	-	-	1.011	-	-	1.007	-	-	1.015

*Agreement does not include 300mK loads.

A2: Cooler Temperature Profile during Recycling

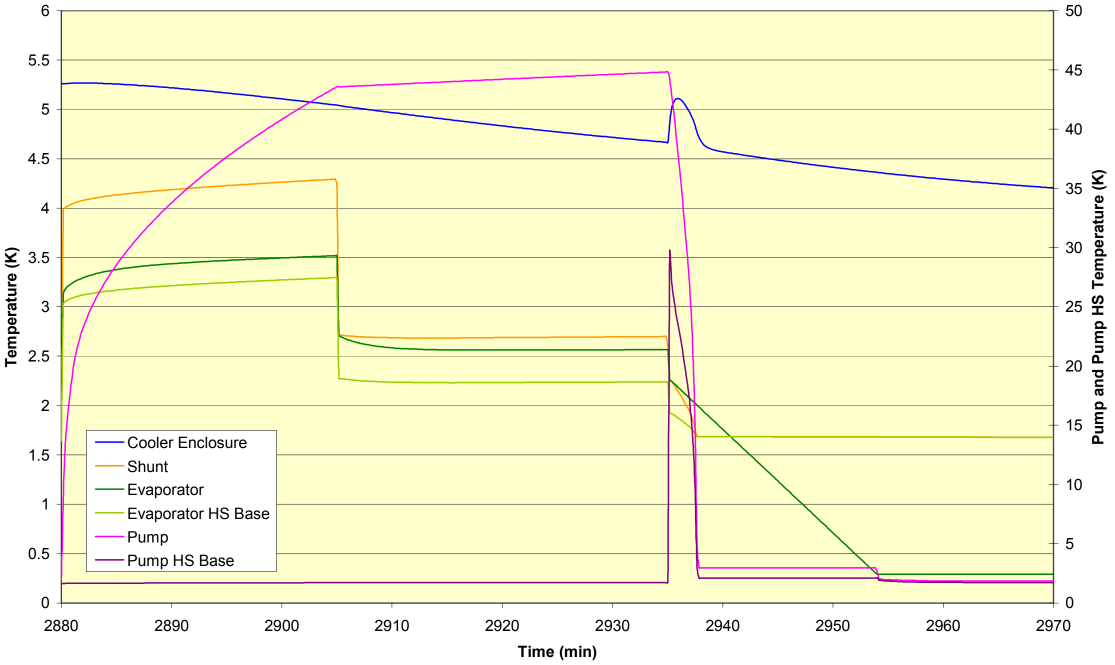


Figure A-2.1 – SPIRE DTMM Cooler Temperature Profile during recycling

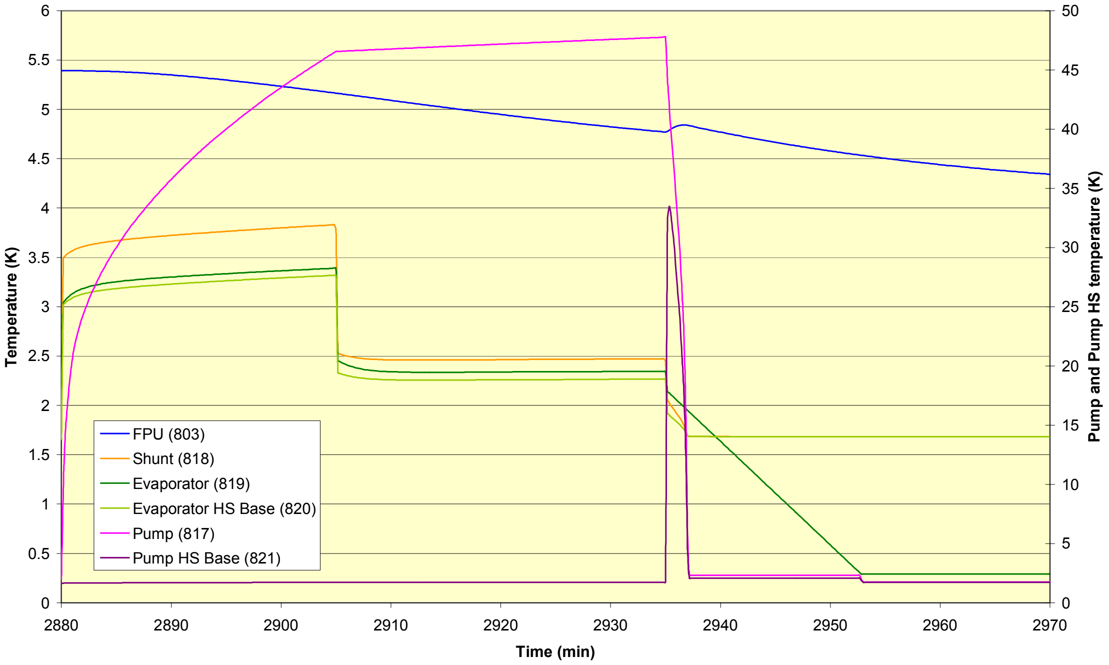


Figure A-2.2 – SPIRE ITMM Cooler Temperature Profile during recycling

A3: Power Dissipation Profiles used for SPIRE DTMM and ITMM

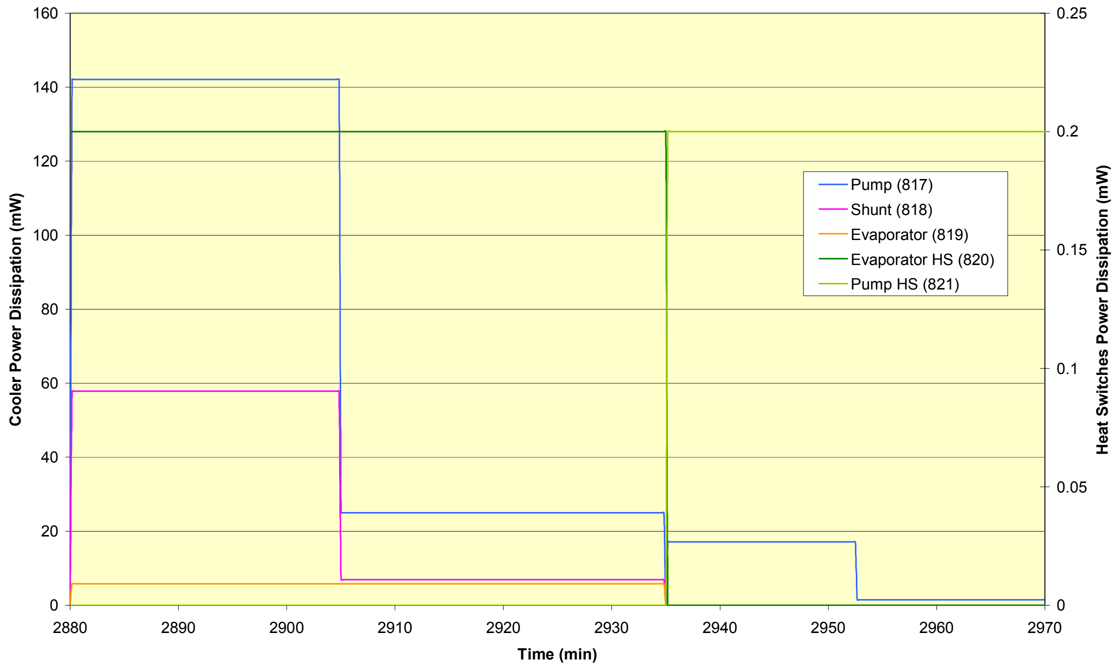


Figure A-3-0-1 – SPIRE Cooler Power Dissipation Profile during Recycling

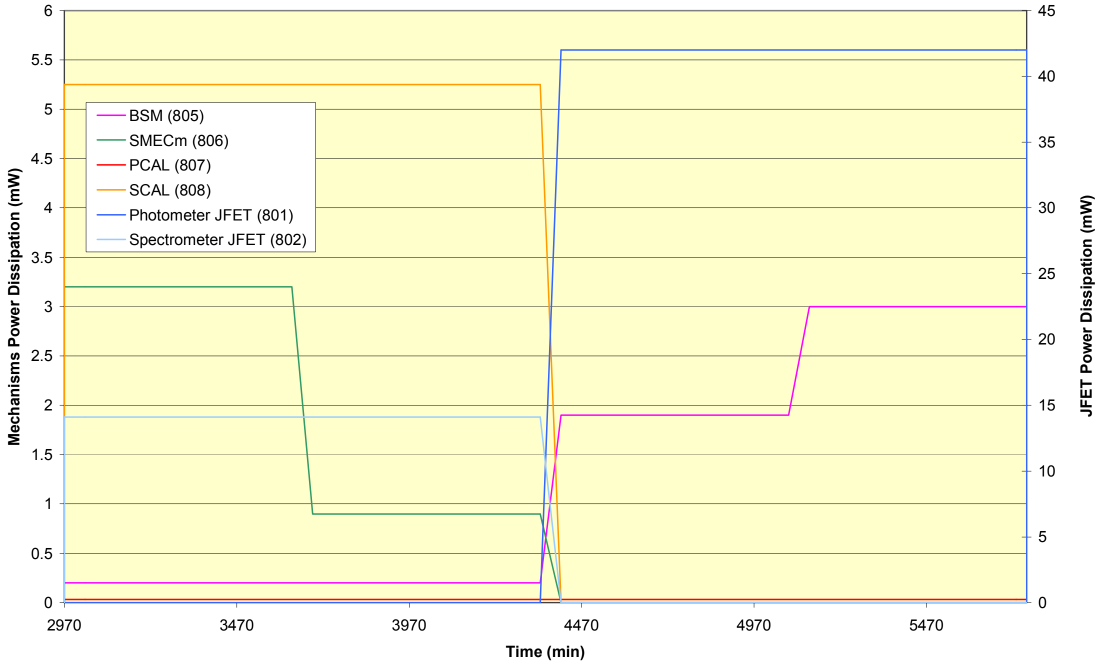


Figure A-3-2 – SPIRE Mechanism Power Dissipation Profile during Operation

A4: Level 1 and Level 0 Loads Correlation during SPIRE recycling and operation

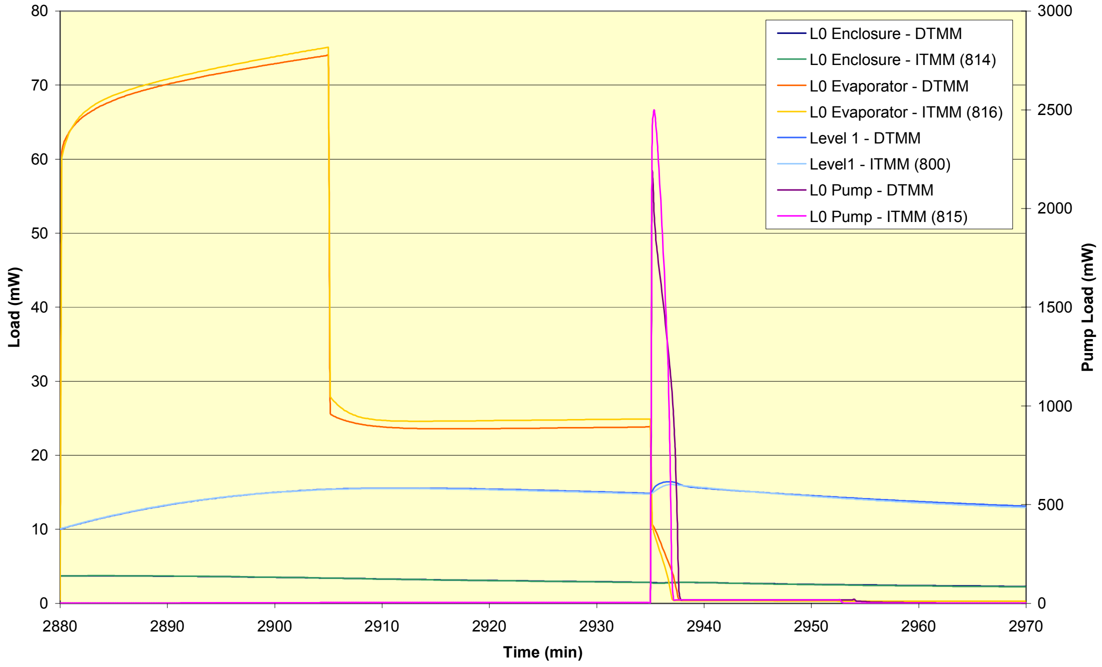


Figure A-4-0-1 – SPIRE DTMM / ITMM loads Correlation During Cooler Recycling

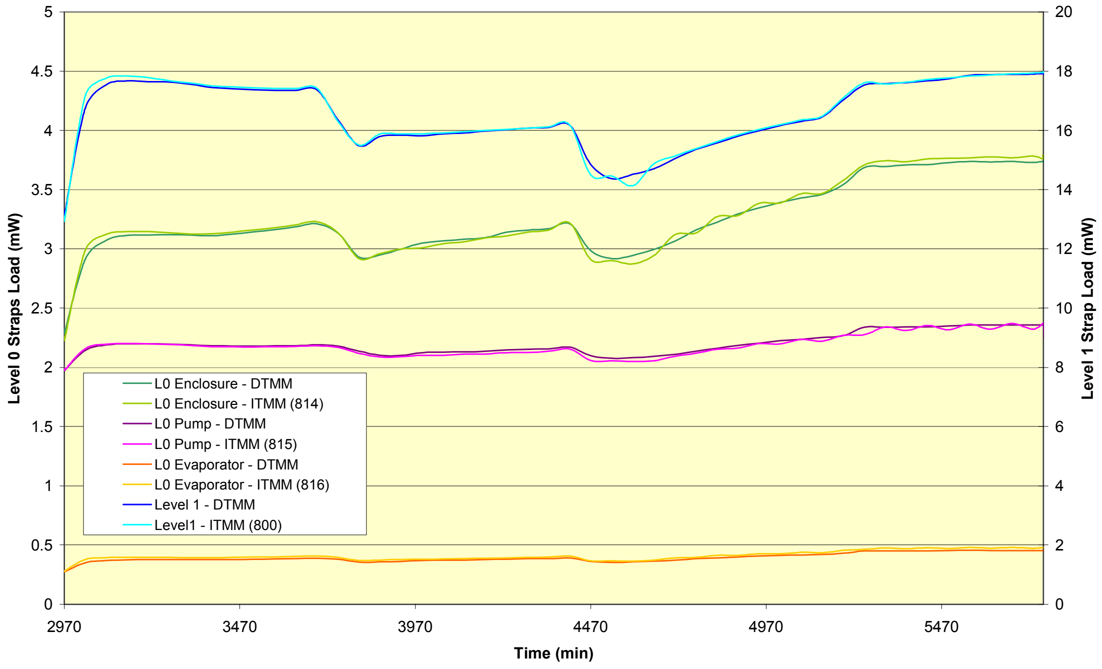


Figure A-4-0-2 - SPIRE DTMM / ITMM loads Correlation During Operation

A5: Interfaces Temperature Correlation during SPIRE recycling and operation

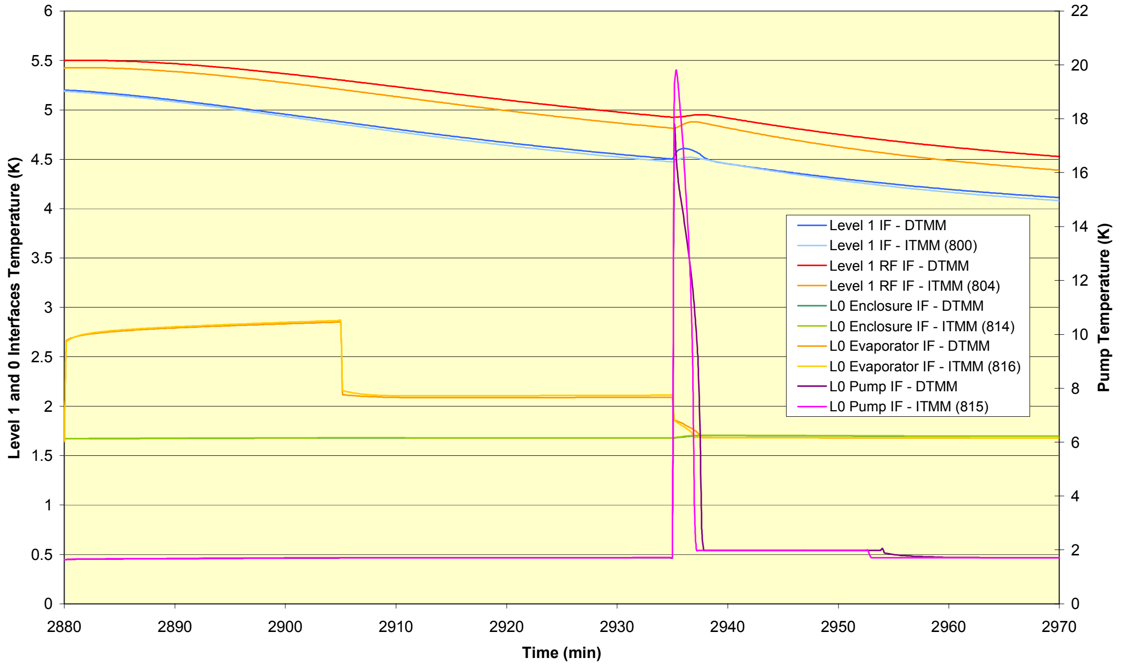


Figure A-5.0-1 - SPIRE DTMM / ITMM Interfaces Temperature Correlation During Cooler Recycling

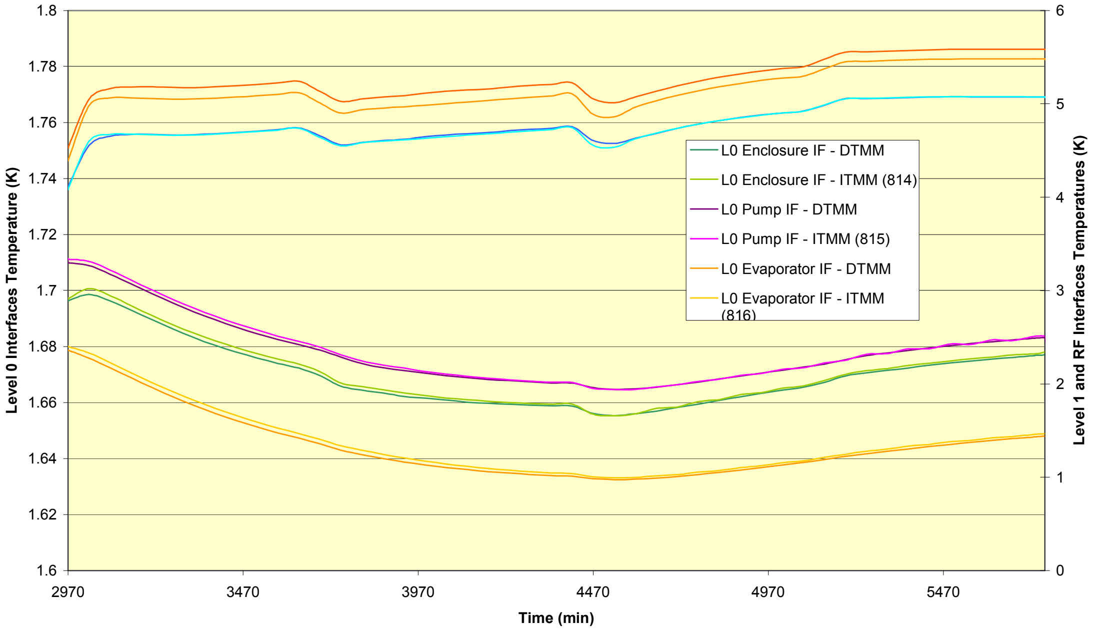


Figure A-5-0-2 - SPIRE DTMM / ITMM Interfaces Temperature Correlation During Operation

ANNEX B: SPIRE BSM AND SMECM POWER DISSIPATION PROFILES

B1: BSM

When SPIRE operates in Photometer mode, the SPIRE Beam Steering Mechanism (BSM) can be used in two different ways:

- BSM Scanning Mode: this mode represents the worst-case power dissipation during which the BSM mean power dissipation is 3 mW (see Figure B-1.1).

- BSM Chopping Mode: in this mode, the power dissipated by the BSM varies between 0.8 mW and 3 mW at a fixed frequency (see Figure B-1.2). The BSM mean power dissipation in this mode is therefore 1.9 mW which represents the BSM best power dissipation case when SPIRE operates in spectrometer mode.

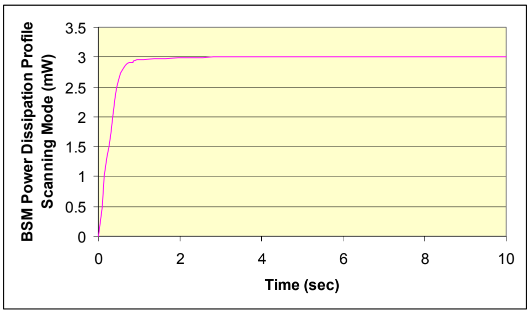


Figure B-0-1.1 - BSM Scanning Mode

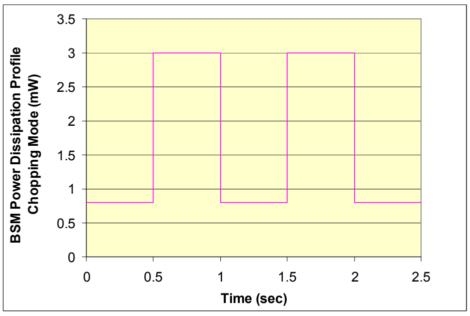


Figure B-1.0-2 – BSM Chopping Mode

Note: The power dissipations described above are nominal values and do not include any margin.

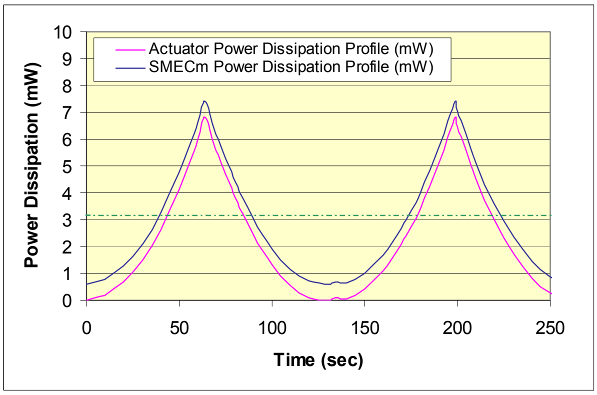
B2: SMECm

The SPIRE SMEC mechanism consists of three components:

- The actuator,
- The optical encoder,
- The LDVT.

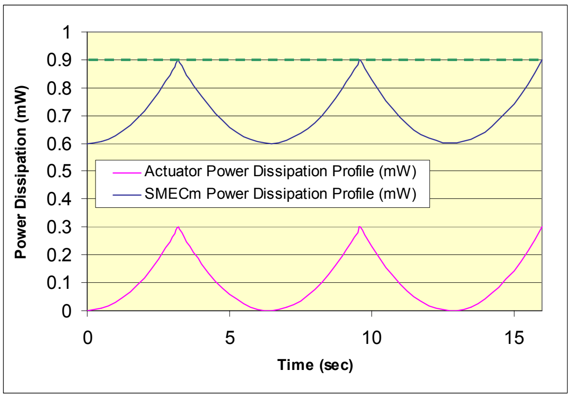
The nominal mean power dissipations of the encoder and LDVT are 0.5 mW and 0.1 mW respectively. When SPIRE operates in Spectrometer mode, the course of the SPIRE SMEC actuator can be set to three different displacement lengths. The power dissipation of the actuator varies with the courses selected. Only the two worst cases are considered here:

- R = 1000 “course” – this mode represents the longest scanning course that can be achieved by the SMECm actuator and also to the worst-case power dissipation where the actuator peak power dissipation is 6.8 mW (see Figure B-2.1.). This corresponds to a mean power dissipation of 3.2 mW (including the encoder and LDVT).
- R = 10 “course” – this mode represents the shortest scanning course that can be achieved by the SMECm actuator and also to the best-case power dissipation where the actuator peak power dissipation is only 0.3 mW (see Figure B-2.2.). This corresponds to a mean power dissipation of 0.9 mW (including the encoder and LDVT).



Displacement Mode	*R = 1000*
Actuator peak power	6.8 mW (Pink Curve)
Total SMECm peak power	7.4 mW (Blue Curve)
Total SMECm mean power	3.2 mW (Green Curve)

Figure B-2.0-1- SMECm Power Dissipation Profile In R = 1000 Mode



Displacement Mode	*R = 10*
Actuator peak power	0.3 mW (Pink Curve)
Total SMECm peak power	0.9 mW (Blue Curve)
Total SMECm mean power	0.9 mW (Green Curve

Figure B-2.2- SMECm Power Dissipation Profile In R = 10 Mode

Note: The power dissipations described above are nominal values and do not include any margin.