Spectrometer Calibrator (SCAL)

Subsystem Specification Document

SPIRE Ref.: SPIRE-QMW-PRJ-001105
Cardiff Ref.: HSO-CDF-SP-001
Issue: 1.0

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Last Modified on: 5 September 2001
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Distribution list

Update history

Date	Version	Remarks
7/9/01	1.0	First issue of SCAL specifications as separate document – previous specifications held in Calibrators SSSD.

List of Acronyms

Term	Meaning	Term	Meaning
AD	Applicable Document	IR	Infrared
ADC	Analogue to Digital Converter	IRD	Instrument Requirements Document
AIV	Assembly, Integration and Verification	IRTS	Infrared Telescope in Space
AME	Absolute Measurement Error	ISM	Interstellar Medium
AOCS	Attitude and Orbit Control System	JFET	Junction Field Effect Transistor
APART	Arizona's Program for the Analysis of Radiation Transfer	ISO	Infrared Space Observatory
APE	Absolute Pointing Error	LCL	Latching Current Limiter
ASAP	Advanced Systems Analysis Program	LIA	Lock-In Amplifier
ATC	Astronomy Technology Centre, Edinburgh	LVDT	Linear Variable Differential Transformer
AVM	Avionics Model	LWS	Long Wave Spectrometer (an instrument used on ISO)
BDA	Bolometer Detector Array	MAC	Multi Axis Controller
BFL	Back Focal Length	MAIV	Manufacturing, Assembly, Integration and Verification
BRO	Breault Research Organization	MCU	Mechanism Control Unit = HSMCU
BSM	Beam Steering Mirror	MGSE	Mechanical Ground Support Equipment
CBB	Cryogenic Black Body	M-P	Martin-Puplett
CDF	Cardiff, Department of Physics & Astronomy	NEP	Noise Equivalent Power
CDMS	Command and Data Management System	NTD	Neutron Transmutation Doped
CDMU	Command and Data Management Unit	OBS	On-Board Software
CDR	Critical Design Review	OGSE	Optical Ground Support Equipment
CEA	Commissariat a l'Energie Atomique	OMD	Observing Modes Document
CMOS	Complimentary Metal Oxide Silicon	OPD	Optical Path Difference
CoG	Centre of Gravity	PACS	Photodetector Array Camera and Spectrometer
CPU	Central Processing Unit	PCAL	Photometer Calibration source
CQM	Cryogenic Qualification Model	PFM	Proto-Flight Model
CVV	Cryostat Vacuum Vessel	PID	Proportional, Integral and Differential (used in the context of feedback control loop architecture)
DAC	Digital to Analogue Converter	PLW	Photometer, Long Wavelength
DAQ	Data Acquisition	PMW	Photometer, Medium Wavelength
DCU	Detector Control Unit = HSDCU	POF	Photometer Observatory Function
DDR	Detailed Design Review	PROM	Programmable Read Only Memory
DM	Development Model	PSW	Photometer, Short Wavelength
DPU	Digital Processing Unit = HSDPU	PUS	Packet Utilisation Standard
DSP	Digital Signal Processor	RAL	Rutherford Appleton Laboratory,
DQE	Detective Quantum Efficiency	RD	Reference Document
EDAC	Error Detection and Correction	RMS	Root Mean Squared
EGSE	Electrical Ground Support Equipment	SCAL	Spectrometer Calibration Source
EM	Engineering Model	SCUBA	Submillimetre Common User Bolometer Array
EMC	Electro-magnetic Compatibility	SED	Spectral Energy Distribution
EMI	Electro-magnetic Interference	SMEC	Spectrometer Mechanics
ESA	European Space Agency	SMPS	Switch Mode Power Supply
FCU	FCU Control Unit = HSFCU	SOB	SPIRE Optical Bench
FIR	Far Infrared	SOF	Spectrometer Observatory Function
FIRST	Far Infra-Red and Submillimetre Telescope	SPIRE	Spectral and Photometric Imaging Receiver
FOV	Field of View	SRAM	Static Random Access Memory
F-P	Fabry-Perot	SSSD	SubSystem Specification Document
FPGA	Field Programmable Gate Array	STP	Standard Temperature and Pressure
FPU	Focal Plane Unit	SVM	Service Module
FS	Flight Spare	TBC	To Be Confirmed
FTS	Fourier Transform Spectrometer	TBD	To Be Determined
FWHM	Full Width Half maximum	TC	Telecommand
GSFC	Goddard Space Flight Center	URD	User Requirements Document
HK	House Keeping	UV	Ultra Violet
HOB	Herschel Optical Bench	WE	Warm Electronics
HPDU	Herschel Power Distribution Unit	ZPD	Zero Path Difference
HSDCU	Herschel-SPIRE Detector Control Unit		
HSDPU	Herschel-SPIRE Digital Processing Unit		
HSFCU	Herschel-SPIRE FPU Control Unit		
HSO	Herschel Space Observatory		
IF	Interface		
IID-A	Instrument Interface Document - Part A		
IID-B	Instrument Interface Document - Part B		
IMF	Initial Mass Function		

Table of Contents

1. Scope

This specification defines the requirements and specifications applied to the performance, design, qualification and interfaces of the SPIRE Spectrometer Calibrator (SCAL) subsystem. It is applicable to the STM, the CQM, the PFM and the FS as described in this document.

2. Documents

2.1. Applicable documents

All applicable documents are listed in the AD chapter of the CIDL (HSO-CDF-LI-029).

3. Subsystem Description

3.1. General overview

The SPIRE Fourier Transform Spectrometer (FTS) uses two broadband, high-efficiency, intensity beam splitters in a Mach-Zender configuration. This configuration has two input ports, and the measured spectrum represents the difference between the two radiant inputs at these ports. One input is located at a 26-mm diameter pupil image of the telescope, at which the radiant input will be dominated by the emission from the telescope itself (several pW of power over the FTS range), with the signal from all except the brightest astronomical sources being negligible by comparison. The Spectrometer Calibrator (SCAL) is located at a complementary pupil at the second input port of the FTS, as shown in Figure 1 and Figure 2, and its function is to provide a thermal input that mimics the dilute 80-K black body emission of the telescope. This allows the large telescope background to be nulled, thereby reducing the dynamic range requirements for the detector sampling: ideally, if the telescope spectrum is perfectly nulled, the dynamic range is then dictated by the (much smaller) power from the astronomical source.

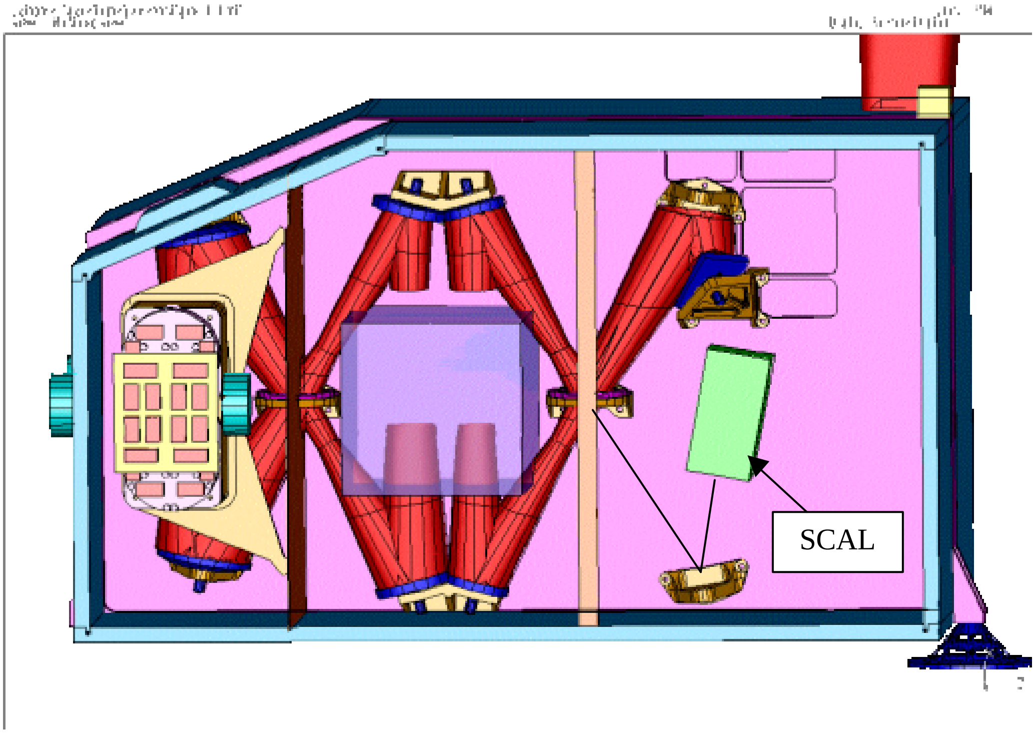

Figure 1 Layout of the SPIRE spectrometer, showing the location of SCAL.

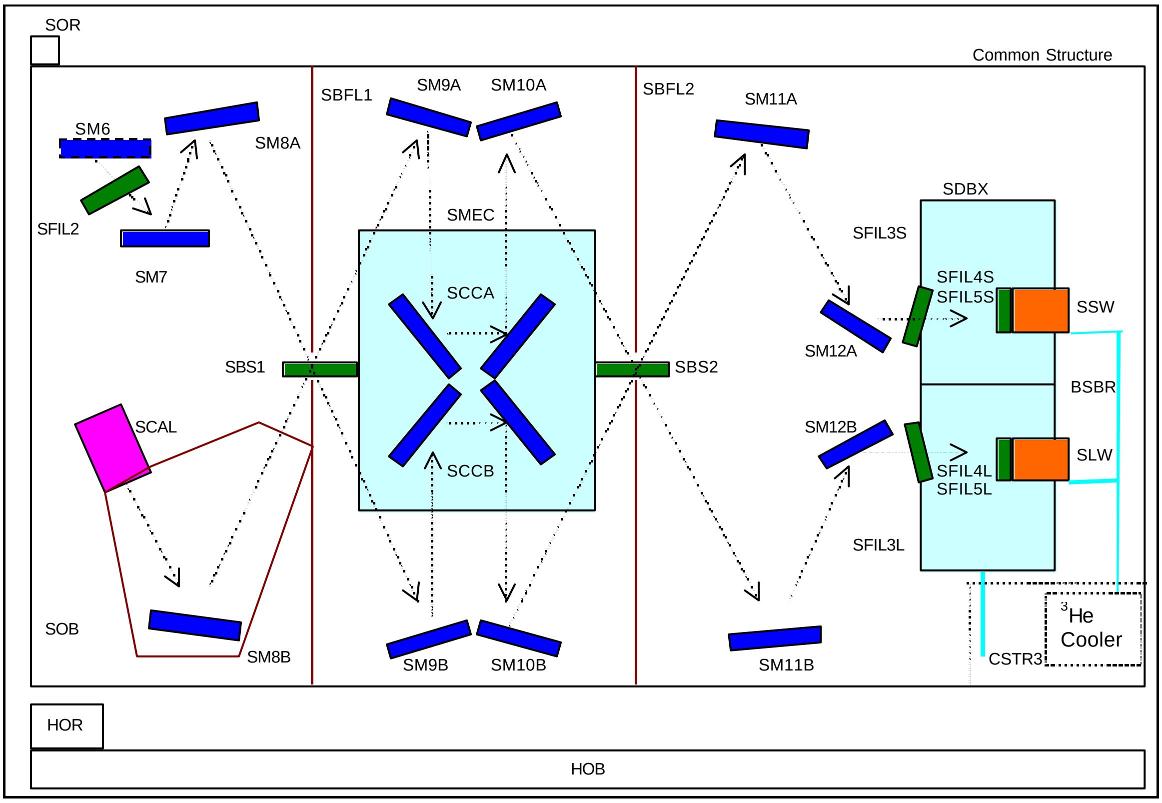

Figure 2 Topological diagram of spectrometer side of the SPIRE instrument showing the position of SCAL, and the baffle to which it interfaces.

3.2. Outline Subsystem design

SCAL will employ two sources at the second input port to the FTS. As this port is a pupil, the effective can be control emissivity by using a geometrical fill factor. A black (emissivity ~ 1) source (SCAL_A(P)) that fills only 4% of the pupil area, produces an effective emissivity of ~ 4%. A second, smaller source (SCAL_B(P)) is provided to accommodate the possibility that the telescope emissivity is lower than the nominal 4%. This source will have an effective geometric emissivity of ~ 2%. If the telescope emissivity is higher than expected, both sources can be used together to match the telescope spectrum to within the requirements (although not necessarily meeting the SCAL overall dissipation requirements in this case). In order to provide full redundancy, two secondary sources (SCAL_A(R), SCAL_B(R)) are included, which are identical to the primary sources. Radiation shields are used between the sources to minimise radiant heating of passive sources by the active source(s). The plate to which the source assemblies are mounted forms the back plane of a cavity at Level-1 temperature (which we take here to be ~ 5 K), and is also blackened. SCAL is thus non-reflecting, avoiding any potential standing waves that could be set up between the detectors and SCAL.

Each source consists of an Aluminium end cap, with embedded heater and thermometer, on a Torlon strut for thermal isolation. The main design features of SCAL are shown in Figure 3.

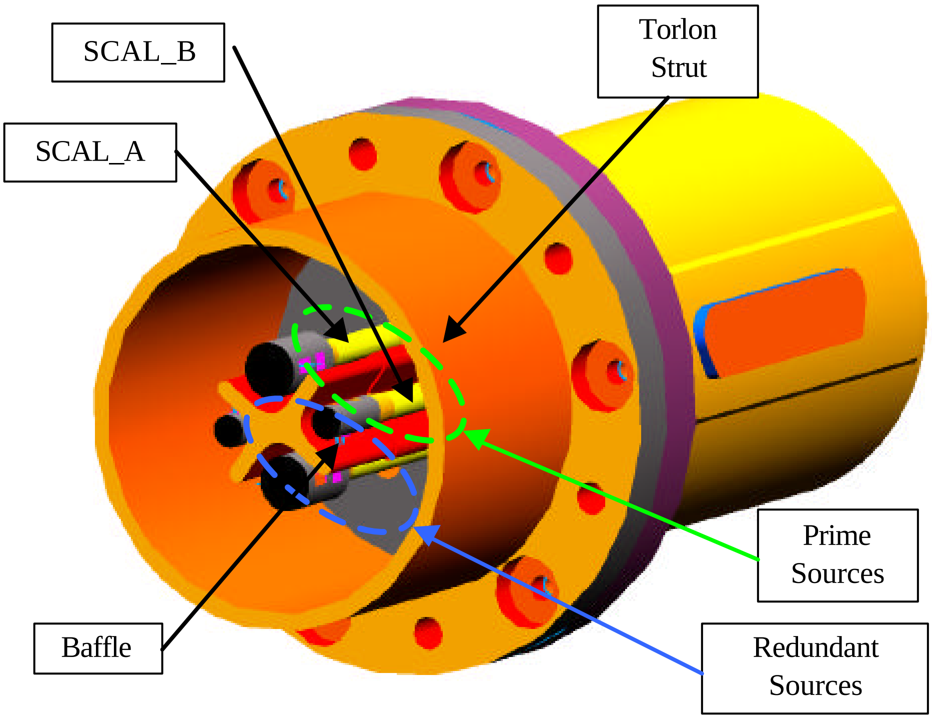

Figure 3 Model of SCAL assembly showing prime and redundant sources and baffle.

3.3. Mission profile

The proto-flight model of the spectrometer calibrator will be designed for 3 years (TBC) use on the ground, 2 years (TBC) storage, and 4.25 years (TBC) in orbit.

4. Specifications

4.1. Performance Requirements

SCAL Performance Requirements		
Requirement ID	**Description**	**Value**
IRD-CALS-R01	Radiated spectrum	Null the central maximum to accuracy of 5% (goal 2%) [TBC] Replicate the dilute spectrum of the telescope to an accuracy of better than 20% (goal 5%) [TBC] over 200-400 μm.
IRD-CALS-R02	Beam pattern	Replicate the appropriate beam pattern at the second input port pupil image. *This requirement has been deleted as SCAL can be designed as a Lambertian emitter.*
IRD-CALS-R03	Adjustability:	Zero - maximum in 256 steps
IRD-CALS-R04	Uniformity	The uniformity of the intensity from the calibration source across the second input port pupil image shall be better than TBD%. *Deletion of this requirement has been requested and is currently under consideration.*
IRD-CALS-R05	Repeatability and drift	The output intensity of the calibration source shall drift by no more than 1% over one hour of continuous operation. The absolute change in the output intensity of the source

		shall be no more than 15% over the mission lifetime
IRD-CALS-R06	Operation	The calibration source shall be capable of continuous operation for periods of up to 2 hours with no loss of operational performance.
IRD-CALS-R07	Number of operations	The calibration source shall be capable of up to 12000 operational cycles
IRD-CALS-R08	Transient response	SCAL should take no longer than 30 minutes (15 goal) to heat to operating temperature from 4 K, and no more than 3 hrs (30 min. goal) to cool from operating temperature to 4 K. *New requirement proposed by Cardiff.*

4.2. System Requirements

SCAL System Requirements		
Requirement ID	**Description**	**Value**
IRD-CALS-R09	Operating Voltage	No more than 28 V DC
IRD-CALS-R10	Power dissipation in the focal plane	Shall be within the specification given in the systems budget document *What is this specification? Systems budget document now states that total budget for spectroscopy is 8.4mW. This does not show the breakdown for SMEC and SCAL.*
IRD-CALS-R11	Mechanical envelope	The SCAL unit shall fit within a volume envelope to be specified by MSSL
IRD-CALS-R12	Thermal Isolation	The temperature of the SCAL housing and surrounding structure shall rise by no more than 1 K over the temperature of the FPU structure after one hour of continuous operation. To ensure that this requirement can be met, provision shall be made for a direct thermal strap from the SCAL housing to the SPIRE optical bench *The above change to this requirement has been requested by Cardiff team.*
IRD-CALS-R13	Operating Temperature	< 6 K
IRD-CALS-R14	Redundancy	Fully redundant systems shall be provided for the active elements.
IRD-CALS-R15	Thermometry	Thermometers shall be provided on the spectrometer calibrator.

4.3. Technical Requirements

SCAL Technical Requirements		
Requirement ID	**Description**	**Value**
SCAL-T1	Mass	< 200 gm

4.4. *Operational*

4.4.1. Operational Safety

Specification ID	Requirement Reference	Requirement	Compliant?
SCAL-SAFE-01	IRD-SAFE-R08	Failure of any sub-system, or one of its components, shall not affect the health of any other subsystem, the instrument or the interface with the satellite.	TBC
SCAL-SAFE-02	IRD-SAFE-R09	Failure of any component in a subsystem shall not damage any redundant or backup component designed to replace that component in the subsystem	TBC

4.4.2. Reliability

Specification ID	Requirement Reference	Requirement	Compliant?
SCAL-REL-01	IRD-REL-R01	As far as possible the total failure of a single sub-system shall not lead to the total loss of instrument operations.	Yes
SCAL-REL-02	IRD-REL-R03	Cold redundant hardware shall be provided wherever practicable within the instrument design.	Yes

4.5. *Discussion of requirements*

4.5.1. CALS-R01 (radiated spectrum)

The dynamic range is set by the intensity of the central maximum of the interferogram, which is in turn determined by the difference in the total power received from the two ports. The origin of this requirement is that in order to carry out low-resolution spectrophotometry with SPIRE, the central maximum must be nulled to a high level to prevent phase errors associated with inadequate sampling from affecting the spectrum.

Besides reducing the dynamic range, it is also desirable that the spectrum of the calibrator be identical or nearly identical to that of the telescope. Ideally they will be the same, resulting in a null interferogram when viewing blank sky. The requirement covers the range 200-400 μm, which is the prime band for the FTS. Nulling over the 400 - 670 μm range should be as good as possible but is not the subject of a specific requirement.

4.5.2. CALS-R02 (beam pattern)

Requirement deleted: SCAL has been designed as a non-reflective Lambertian emitter with the appropriate spectral properties.

4.5.3. CALS-R03 (adjustability)

In the design and modelling of the SPIRE instrument, the telescope is assumed to be at 80 K and to have an effective emissivity of 0.04. These values are both subject to uncertainty. The temperature is expected to be in the range 60-80 K. The emissivity is subject to much larger uncertainty - it could easily be a factor of two lower or higher - and the value will not be known until after launch. SCAL must therefore be adjustable in order to provide the required nulling and spectral matching over a wide range of conditions.

4.5.4. CALS-R04 (uniformity)

It was originally envisaged that the SCAL pupil would have to be uniformly bright. Analysis of the FTS performance shows that this is not the case. Being located at a pupil, the detectors view all parts of SCAL with the same angular distribution. *The Cardiff team has therefore requested that this requirement be deleted and the current design of SCAL assumes that the pupil does not need to be uniformly bright.*

4.5.5. CALS-R05 (repeatability and drift)

A typical long integration with the FTS may comprise a sequence of interferograms (each taking around one minute), repeated for an our or more. It is important that the power received from the calibrator not vary significantly on the timescale of an observation.

The in-orbit telescope temperature and emissivity are not expected to change significantly even on timescales of months. It is envisaged that the optimum settings for SCAL will be determined empirically early in the mission and should need only occasional checking and adjustment. A calibrator output drift less than 15% over the mission lifetime means that only occasional re-adjustment of the calibrator excitation levels will be needed.

4.5.6. CALS-R06 (operation)

SCAL operation . . .

4.5.7. CALS-R07 (number of operations)

In order to define the life-test requirement for SCAL, it is necessary to specify the number of operations that SCAL must be able to tolerate. This is derived using the following conservative assumptions:

Mission operational lifetime:	4.5 years
Fraction of lifetime for which SPIRE operates:	33%
Fraction of SPIRE time for which SCAL used:	50%
Number of operational hours per day:	21
Frequency with which SCAL is powerd down/up	Once every 2 hours
Margin factor (and allowing for ground operation):	1.5

These assumptions result in a total operation time of 238 days and a number of cycles of 4300 (a factor of three less than the 12,000 operations specified).

The Cardiff team therefore requests that IRD-CALS-R06 be changed to 4,500 operations instead of 12,000

Note: A continuous accelerated life test with 15-minutes per cycle will achieve 4500 cycles in approximately 47 full 24-hr days (the need for such a test is TBD).

4.5.8. CALS-R08 (transient response)

To minimise set-up time, it is desirable that SCAL can be warmed up or cooled down as quickly as possible. The envisaged operational scenario for Herschel and SPIRE involves each instrument being operated for substantial periods of time (e.g., one cooler cycle - equivalent to 48 hrs). During such a period when SPIRE is operating, the FTS or photometer are also likely to be used continuously for long periods of time (typically hours). The warm-up and cool-down time should therefore be on the order of minutes or tens of minutes. There is a trade-off here between stability (requiring a long time constant) and short warm-up time (requiring a short time constant).

Note that when SCAL is switched off to allow change-over from SPIRE FTS to photometer operation, there will be a settling time of at least 15 minutes associated with the JFETs, and in any case SCAL cannot be viewed by the photometer detectors. It should therefore be possible to start photometer operation as soon as the JFETs are warmed up without any delay imposed by SCAL cool-down.

4.5.9. CALS-R09 (operating voltage)

This requirement is dictated by maximum voltage that the warm electronics can provide.

4.5.10. CALS-R10 (power dissipation in the focal plane)

SCAL will be powered up continuously while the FTS is operating, and its dissipation will load the Level-1 (4-K) stage, the temperature of which is to a large extent determined by the total FPU dissipation. It is important that this load be as small as possible to avoid the Level-1 temperature being raised too much (and to maximise the Herschel lifetime).

4.5.11. CALS-R11 (mechanical envelope)

SCAL must fit within the available volume, which will be defined in the Structure Interface Control Document.

4.5.12. CALS-R12 (thermal isolation)

When SCAL is switched on, almost all of the electrical power will be conducted to the SCAL mounting (only a tiny fraction is actually radiated by the device). The rise in temperature of the environment must be small to avoid changes in the radiated power by the structure affecting the overall sensitivity of the system. The mounting and FPU structure must thus be designed to be able to conduct efficiently this power into the Herschel cryostat 4-K strap. In case it proves necessary, the SCAL housing and the SPIRE optical Bench must be equipped with appropriate lugs to allow a direct thermal strap to be fitted.

4.5.13. CALS-R12 (operating temperature)

The SOB temperature determines the nominal temperature of the SCAL housing. The current SPIRE thermal model predicts that this should be about 5 K. In practice this temperature could rise by one or two degrees depending on the total power dissipation of the SPIRE FPU. This will have no significant impact on the operation of SCAL.

4.5.14. CALS-R12 (redundancy)

SCAL is vital to the correct functioning of several key observing modes. It must therefore have fully redundant heaters and thermometers.

4.5.15. CALS-R12 (thermometry)

To null the telescope spectrum it is not strictly necessary to know the temperature of SCAL, merely to be able to adjust it to a suitable value. However, instrument calibration will be greatly assisted if the temperature is known.

4.5.16. SCAL-T1 Mass

A full mass breakdown is shown in .
However, we would like to retain our 200g allocation until after warm vibration tests have been completed.

4.6. Interface requirements

4.6.1. Mechanical interface

SCAL is mounted off the SCAL/SM8B baffle via six 4-40UNC bolts on a 42.5mm PCD. All bolt holes in this interface will be fitted with locking inserts.

4.6.2. Thermal interface

The main thermal interface will be the mechanical interface described above. However, provision will be made for the placement of a thermal strap from the SCAL baseplate direct to the SOB in the event that the thermal impedance of the main mechanical interface is too great.

4.6.3. Electrical interface

All wiring necessary for the operation of SCAL shall be designed to minimise any possible thermal effects on SCAL and on the heatsink.

4.7. Logistics requirements

SCAL will be delivered in a nitrogen purged box for storage. SCAL will be supplied with a cover for the normally open emitter face. We require that this cover remains in place unless the cleanliness of the environment is class 10,000 or better. For the purposes of integration to the instrument, it is permissible to remove the SCAL cover in a class 100,000 environment for short periods. We assume there will be no need to disassemble SCAL once delivered to RAL. If that need arises, members from Cardiff must be present.

4.8. Environmental requirements

4.8.1. Thermal environment

The design of SCAL shall be compatible with a 72 hour bake-out at 80°C.
Limits on the storage and handling temperature and humidity are as follows:-

- Storage and handling temperature – short duration <80°C,
  Continuous limit <50°C
- Humidity - <50%

4.8.2. Mechanical environment

SCAL will be designed to withstand >100g static loads in X, Y and Z directions.

4.8.3. Electrical environment

SCAL shall not generate any electrical noise in the vicinity of the detectors, nor shall it be sensitive to emitted radiation. SCAL shall not remain charged or be subject to electrical discharges.

4.8.4. Radiation environment

SCAL shall not be sensitive to ionising radiation.

4.9. Design requirements

4.9.1. Mass

The overall mass of SCAL shall be no more than 200g.

4.9.2. Structural

All structural elements shall be designed to exhibit a positive margin of safety (MOS) with respect to yield and ultimate loads. The margin of safety is defined as the ratio of the allowable loads (or stresses) to the applied load (stress):-

$$MOS = \frac{AllowableLoad(stress)}{AppliedLoad(stress)} - 1$$

Unless otherwise stated for all other requirements in this specification, a margin of at least 20% shall be included in the design. Allowable stresses shall be derived from MIL-HDBK-5. Other sources shall be subject to SPIRE PA manager approval.

4.9.3. Parts, materials & processes

4.9.3.1. General

The workmanship and materials used shall be, or shall be shown to be compatible in any future build, of a standard consistent with flight hardware.
The number of materials, mechanical parts types, and processes shall be minimized. Materials and mechanical parts that have been successfully used in similar space applications shall be preferred. Standard processes or known processes previously used in space applications shall be preferred.
Material justification shall prove the hardware structural integrity during the design life.

4.9.3.2. Magnetic materials

SCAL shall not use magnetic materials.

4.9.3.3. Fungus nutrient materials

Materials shall not support bacterial of fungal growth, and shall be sterilisable without any deterioration of their properties.

4.9.3.4. Flammable, toxic and unstable materials

Flammable, toxic and unstable materials shall not be used.

4.9.3.5. Cleanliness

SCAL shall be class 100 compatible following FED-STD-209-F.

4.9.3.6. Finish

Surface finish shall prevent deterioration from exposure to the environment. Aluminium surfaces shall be treated for corrosion protection coating. Thermal interfaces shall be gold plated.

4.9.3.7. Outgassing

Outgassing of the external surfaces of SCAL shall demonstrate a Total Mass Loss (TML) <1%, and a Collected Volatile Condesable Material (CVCM) <0.1%. PSS-01-702 shall be used as a guideline.

4.9.3.8. Susceptibility to stress corrosion

Metallic materials shall have high resistance to Stress Corrosion Cracking (SCC) and shall be chosen from table 1 of PSS-01-736. Materials and welds that are not listed, or whose SCC resistance is not known, shall be tested according to PSS-01-737.

4.9.3.9. Limited lifetime materials

All materials with limited-life characteristics shall be subject to lot/batch acceptance tests, to be agreed with the PA manager, and shall have their date of manufacture and shelf-life expiry date marked on each lot/batch.