Report on the SPIRE Shutter PDR
Douglas Griffin
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ComDev, Cambridge Ontario.

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1. Circulation

John Coker	MSSL
Gary Davis	UoS
John Delderfield	RAL
John Hackett	ComDev
Ken King	RAL
Don Peterson	CSA
Bruce Swinyard	RAL
Eric Sawyer	RAL
Joe Taylor	UoS

2. Attendees

Terry Girard (Project manager, ComDev)
John Hackett (Technical manager, ComDev)
Dwight Caldwell (Mechanical, ComDev)
Bob Deschambault (EGSE, ComDev)
Joe Taylor (UoS)
Don Peterson (CSA)
Gary Davis (UoS)
Ed Sporbeck (Mechanical designer)
John Coker (MSSL)
Doug Griffin (RAL)

3. Introduction

The meeting was a Preliminary Design Review aimed at examining the baseline design of the Shutter design and the Shutter development program prior to proceeding into the Detailed Design. The actual state of the design presented at the meeting had progressed farther than this as a result of previous design meetings, teleconferences and email exchanges.

The principal objectives of the meeting were to:

(i) Confirm that the controlling documentation is correct
(ii) Review shutter usage forecast
(iii) Review shutter requirements so that they can be frozen
(iv) Review preliminary design of shutter
(v) Review schedule

The review panel members and responsibilities were:
Douglas Griffin: SPIRE Project Office / Systems Engineering representative
John Coker: SPIRE Shutter/FPU interface issues
Don Peterson: CSA representative

Several issues have arisen from the meeting and are listed in Table 5-3. Outstanding issues identified at the meeting are listed in Table 5-4. The review boards conclusions are contained in §6.

4. Documentation

The following documents were presented to the meeting:

(i) Design Requirements for the SPIRE Shutter Subsystem – Gary Davis
(ii) Shutter Usage Forecast – Joe Taylor
(iii) A copy of the overheads presented at the meetings

5. Meeting Summary

5.1. Project overview (Gary Davis)

A brief overview of the scientific goals of the Herschel program and on the design specifications of the SPIRE instrument was presented. An overview of the SPIRE consortium break down was also presented.

5.2. Documentation Structure (Don Peterson)

The list of the contractual documents between Com Dev and the Canadian Space Agency (CSA) was listed as follows:

SPIRE Structure ICD
SPIRE System budgets
SPIRE Harness definition
EGSE Specifications
Shutter usage forecast
Shutter design requirements and constraints
CSA Space Science PA Plan for shutter

5.3. Review of Shutter Requirements (Gary Davis)

A presentation of the proposed Shutter Subsystem requirements was made. This document has been written by Gary to consolidate the proposed changes to be included in the next issue of the SPIRE Instrument Requirement Document. There are significant differences between these requirements and those in the current issue of the IRD. These revised requirements are summarised as follows along with comments on the proposed changes:

Design Requirements

Requirement Number	Brief Description / Requirement Title	Review Comments
R01	Rejection of direct flux	These requirements update IRD-SHUT-R01. The quantitative requirement that exist in the IRD is removed due to the difficulties of quantifying meaningfully the stray light attenuation performance of a given design. The stray light performance of the design will be assessed approved by the SPIRE project office.
R02	Rejection of indirect flux (minimise stray light)	
R03	Vane emissivity > 0.9	The requirement that the vane match the spectral emissions of the Herschel telescope has been removed. (IRD-SHUT-R02)
R04	Vane emissivity accuracy. Need to have ± 2% emissivity.	This should not be a design driver as the shutter is not intended to provide a calibration source.

Requirement Number	Brief Description / Requirement Title	Review Comments
R05	Variation in the vane emissivity to be < 2%	Intended to guarantee a uniform radiometric loading of the bolometers. This would be difficult to measure.
R06	Vane temperature (9-25K)	The temperature range is revised on the basis that the shutter has high emissivity. This temperature range together with the revised vane emission requirement matches the range of expected radiometric loading of the bolometers by the Herschel primary mirror.(c.f. IRD-SHUT-R02)
R07	Vane temperature control; 16 set points	This is twice the number of temperature settings required in IRD-SHUT-R02
R08	Vane temperature accuracy (± 0.1K)	A requirement on the thermometry
R09	Vane temperature uniformity, 0.1K	This requirement is unnecessarily restrictive and should not become a design driver. The more important requirement is on the repeatability. This requirement may be pushing the design to be heavier than is necessary to achieve the required conductances across the shutter vane.
R10	Vane temperature repeatability ± 40mK	This guarantees that the shutter will provide similar radiometric loading to the detectors in both the SPIRE CQM cryostat and the Herschel CVV. It is unclear how this can be achieved when the measurement uncertainty is greater than this.
R11	Reliability > 99.99%	This requirement is intended to obviate the requirement that the shutter relax to the out of beam position in the event of failure. It is unclear how this requirement could be verified for the mechanical components.
R12	Mass must meet the allocation in the Budget Document (currently 200g).	It has been noted by the SPIRE Project Office that is budget allocation is not feasible and is to be increased. (473g TBC).
R13	FPU Thermal dissipation	The temperature of the FPU structure in the vicinity of the Shutter shall not rise above TBD K after TBD minutes from dissipation within the shutter assembly. The temperature is given as 1K and the time as 30minutes in the current version of the IRD (IRD-SHUT-R13). The instrument scientist is happy to relax the temperature requirement to 2K. The 30 minutes basically correspond to the steady state temperature.
R14	Thermal dissipation in cryoharness	This has been listed as being TBD. The dissipation per se is not as important as the transient thermal loads on to the cryostat are less important than the passive heat loads from the cryostat wall to the Herschel Optical Bench via conduction.

Requirement Number	Brief Description / Requirement Title	Review Comments
R15	Structural interface (shall conform to the Structure ICD)	This single requirement is intended to replace the requirements on the Eigenfrequency (IRD-SHUT-R08), Material compatibility (IRD-SHUT-R09) and space envelope (IRD-SHUT-R07).
R16	Harness interface (shall conform to the Harness Definition Document)	This was not addressed in the current issue of the IRD.
R17	Operating temperature (room temperature and at cryogenic temperature for operation of actuator, heater and thermometry)	Corresponds to IRD-SHUT-R05
R18	Operating orientation (any orientation)	Corresponds to IRD-SHUT-R05
R19	Transition time (less than actuation time)	Corresponds to IRD-SHUT-R10
R20	Thermal stabilisation (< 10 minutes)	This requirement is identical to IRD-SHUT-R11

ECR (Engineering Change Requests) are to be submitted to the SPIRE Project Office to add/delete/alter the requirements in the SPIRE IRD. These ECRs need to be submitted before 21 September 2001.

5.4. Presentation of the Shutter Usage Forecast (Joe Taylor)

The breakdown of the projected usage of the PFM Shutter during various phases of instrument level testing and Herschel level testing was presented. The total was found to be 21 cycles. A design value of 100 cycles was conservatively adopted.

5.5. Presentation of the Model Philosophy and Schedule (Joe Taylor)

A summary of the Shutter Deliverables is contained in Table 5-1.

Table 5-1 - Shutter deliverables

Model designation	Delivery date	Comments
STM	1 Aug 2002 (RAL)	Used to qualify the structure and to confirm the validity of the FEM analysis. Heaters will be included but motor will be a mass dummy. The shutter will tested on the SPIRE STM in the stowed position. The model will be mass, C.o.G. and form and fit compliant
CQM	Jan 2003 (RAL)	Used by SPIRE to qualify the shutter in the cryogenic environment. It will include a functionality test of the shutter. This implies that the shutter will be functionally available to the instrument AIV team.
PFM	1 October 2003	Fully compliant
QM	Non deliverable	Used at the subsystem level for qualification. The results of the qualification program will be available at the Shutter CDR (27 June 2003)
FS	10 Jan 2005	Fully compliant

5.6. Compliance to requirements (John Hackett)

The compliance/non compliance of the Shutter to the requirements (R01 to R20) contained in the Shutter Design Requirements Document (that has not been approved by the SPIRE Project Office) was presented. Com Dev presented a compliance matrix showing that all requirements were met or were TBD. Review board comments on the matrix follow:

The lowest level of qualification is by analysis. The following requirements will only be demonstrated by analysis:

R01-Rejection of direct flux

R02-Rejection of indirect flux

(In practice, Tony Richards will review and approve that the design is acceptable)

R08-Vane Temperature Accuracy

This is met assuming that the manufacturers requirement that the thermistor be recalibrated every 12 months.

R09-Vane Temperature Uniformity

This is demonstrated by thermal FEM analysis. It has been stated that the vane emissivity will be measured by test. It appears that in testing the vane emissivity, the tacit assumption will be that the vane temperature will be isothermal. See the Review Panel Query #1.

R10-Vane Temperature Repeatability

R11-Reliability

The figure of 99.99% will be calculated. The accuracy of such a calculation for non EEE hardware is questionable.

R12,13,14-Thermal budget allocations.

The rest of the requirements will be demonstrated to be fulfilled through Test, Inspection or Demonstration with the associated greater level of confidence.

5.7. Shutter Mechanical Design (Dwight Caldwell)

The results of a trade-off study between the two conceptual shutter designs were presented to the meeting. The two designs were the so called cleaver design with a rotating vane that covers the optical aperture on the photometer FPU cover and the slider design which slides over the aperture. The conclusive result of the tradeoff indicated that the cleaver design was advantageous. There were several accommodation issues that made the slider design difficult to implement.

The cleaver design settled upon and has the following features:

The design incorporates a stepper motor and a 90° reduction gear box with a gear ratio of 67:1. (a separate gearbox with a 180:1 ratio is also available). The gear box uses MoS_2 dry lubricant. (Review Panel Query #2.

A position sensor will indicate the angular position of the shutter via the shutter EGSE.

The size of the shutter has been updated to incorporate the most recent beam rays.

A solenoid to lock the shutter out of the beams in the stowed position is currently baselined. This will not be a bi-stable solenoid and will therefore require that the solenoid be energised to release the vane latch when opening the shutter from the stowed position. When the shutter is rotated 85°, it is fully out of the beam but not stowed. A further 5° rotation brings the shutter into the stowed position by engaging the vane latch. No commercial source has been found for this solenoid and therefore the item would need to be developed by ComDev.

A flexible harness between the shutter vane and the axis of rotation of the stepper motor

The shutter vane is of sandwich construction. The aim is to thermally isolate the lower surface imaged by the detectors from the upper surface that is in radiative exchange with the instrument shield and the lid of the cryostat.

The stepper motor will be supplied by CDA. It has redundant windings.

The total estimated mass of the assembly excluding the harness is 473g w/o margin, 592g including margin.

The structure is fabricated from monolithic Al 6061 T651. The surfaces are passivated by the Aluchrome process.

The design margin on the torque capacity of the motor and gear box is 300%. In other words, the drive train ought to be able to provide 3x the torque required to raise the shutter against 1g in the vertical position.

A previous FEM analysis indicated the shutter assembly to have a first mode of vibration at 201Hz. This compares favourable with the MSSL requirement of 170Hz. This was conducted with a vane latch solenoid in place. If this solenoid was removed, it would make the vibration requirement very difficult to achieve and would necessarily make the rest of the assembly heavier to raise the frequency. This is a factor against the removal of the solenoid. (See Outstanding Issues #2)

The accommodation and space envelopes of the Shutter have been modified to avoid interference with the flight cryostat, ground test cryostat and the SPIRE alignment cube

An ICD drawing for inclusion in the SPIRE Structure ICD was presented.

5.8. Thermal design

The thermal design is based on FEM using both a radiative and conductive coupling. This analysis impacts on the:

(1) temperature level requirements of the shutter face, (both maximum and minimum temperatures),
(2) temperature uniformity requirements,
(3) heat up and cool down times,
(4) FPU heat load requirements.

The model used the following thermal boundary conditions provided by Sam Heys and from estimates:

Instrument shield 12.7K e=0.05,
cryostat lid: 100K, e=0.1,
Photometer Cover 5.6K, e=0.999

The results of the analysis indicate that the lower vane temperature setting (9K) will not be able to be reached due to the passive radiative thermal loading from the cryostat lid. If the assumed radiance from the cryostat lid exceeds that assumed values quoted above, the situation will be worse. (Outstanding Issues #3) A possible solution to this problem will be the use of MLI on the upper surface of the shutter vane.

The vane temperature is approximately linear with heater power. (1 mW of power raises the vane temperature by approximately 5K). The power required to heat the vane to 25K is approximately 3mW.

The difference between the maximum and minimum vane surface temperature at 25K is estimated to be 70mK. (this is within spec.)

If the equilibrium power of 3mW was used to heat up the vane to 25K, the transition time would be over three hours. This long heat up time will be reduced by using a 30mW pulse of heating to decrease the heating time to approximately 10 minutes.

The cool down time is very slow (over four hours). This cannot be reduced as good thermal isolation is required between the shutter and the FPU to prevent the FPU from heating up during shutter operation.

The requirement on the heating of the FPU structure (i.e. the shutter will not cause the temperature of FPU structure to locally rise more than 2K) has not been demonstrated. ComDev has to provide a thermal model to the SPIRE thermal systems engineer (Sam Heys) to ascertain that this requirement has been met. (Outstanding Issues #4).

5.9. Electrical Design

A summary of the electrical design is contained below in point form in Table 5-2.

Table 5-2 - List of EEE items on the shutter subsystem.

Item	Description / Comments
Stepper motor	The current allocation for this item was originally 30mA. The motor selected requires 100mA or more. Several possibilities for circumventing this problem were discussed (primarily through running the motor with 100mA and a reduced duty cycle, or alternatively by running the circuit differentially and balancing the currents within the motor assembly). It was decided, in the first instance that a case would be made for an increase in the current allocation for the device.
Pin out of the shutter cryoharness	John Delderfield had made a proposal for the pin allocations on the connectors and types of cabling to be used in the cryoharness. The ComDev proposal differed in the means of returning the power (motor, solenoid and heater) currents to the EGSE. It was decided that ComDev would prepare a technical memo on the topic.
Heater elements	These elements have been sourced. (Tayco)
Vane latch solenoid	This is being developed in house by ComDev.
Dedicated shutter EGSE	This has been configured as a single PC that will be delivered together with the shutter.
Flexible harness connecting the rotating shutter vane to the fixed part of the shutter assembly	No commercial supplier could be found for this item. A prototype of a flexible Kapton harness that is wound around the output shaft of the gear box has been constructed. This was demonstrated at the meeting.
Launch latch position sense	This is a variable reluctance sensor developed by ComDev in house.
Shutter vane heater elements	These elements have been sourced. (Tayco)
Shutter vane temperature sensors	GaAs diode elements required for accuracy and to minimise the number of bias/readout wires.
Shutter rotary position sensor.	This is based on a variable reluctance sensor that is to be developed by ComDev. The shutter EGSE will have the drive circuitry for this sensor.
Connector material	The 15-way connector is to include a EMI back shell. The material is yet to be determined. (Aluminium alloy / SS)
Exposed internal shutter harness	It is unclear to the review panel as to whether the harnesses running from the MDM connector to the different components of the shutter are adequately shielded. (Review Board Query #3)
Vane latch state indicator	The requirement on the shutter is that they provide a interface with the s/c CDMU as per §6.8.2.3 of the Alcatel technical proposal. This was provided to the meeting. The shutter consortium expressed the desire to provide a variable reluctance position output to the CDMU.
Cryoharness resistance	ComDev requested information on the variation of cryoharness resistance between hot and cold conditions.

5.10. FMEA analysis

A provisional FMEA has been carried out. This will be formalised in the next stage of the project. 28 failure modes were defined.

5.11. Development plan

The development plan was presented including the deliverables for each shutter model and the model testing.

5.12. GSE (Robert Deschambault)

A brielf overview of the EGSE supplied with the shutter and the associated software was presented.

5.13. PA

An summary of the PA plan was presented. It was acceptable.

Actions

Group / Person	Action	Closure Date
D. Griffin	Confirm that the shutter STM need only be representative for the "out of beam" state.	24 July 2001
D. Griffin	Provide information regarding Herschel PLM GSE cavity status/characteristics.	24 July 2001
J. Coker	Confirm HIFI beam clearance and angle for new HIFI beam models.	24 July 2001
D. Griffin	Confirm that the cryoharness extends to the shutter subsystem.	24 July 2001
D. Griffin	Confirm splitting of harness after J27 and J28: shutter EGSE should not interface with flight hardware (lock sense lines) for the BSM and SMEC.	24 July 2001
D. Griffin	Current rating for 10 Ohm wires: currently 30mA. Is reduced duty cycle at 120mA acceptable?	24 July 2001
D. Griffin	Current rating for 10 Ohm wires is 30mA relevant and accurate for the shutter? The vane actuator requires a minimum of 50mA, 100mA if constructed with redundant windings.	24 July 2001
Com Dev	Can the latch be driven with opposite polarity to minimise the current on the return line?	24 July 2001
D. Griffin	Clarify information presented in the Alcatel note on latch sensing. Does the resistance value (10 Ohms) represent the micro-switch or the micro-switch + harness? Would it be continually sensed or would a duty cycle be applied?	24 July 2001
D. Griffin	Request for information regarding final vane stowing and latching, and accessibility of shutter EGSE connector.	24 August 2001
Com Dev	Prepare and issue a note regarding vane latch telemetry monitoring at S/C level.	27 July 2001
Com Dev	Forward schedule to CSA.	18 July 2001
D. Griffin	Follow-up: cryostat lid temperature and emissivity.	24 August 2001
USK (JKT)	Provide details of QMW black and qual. status/program.	27 July 2001
Com Dev	Provide harness table with current limits	18 July 2001
Com Dev	Provide ICD and solid model	20 July 2001
Com Dev	Discuss thermal model with Sam Heys	27 July 2001
Com Dev	Comment on common return for sensors and drive vs. return on shield.	24 July 2001
CSA (DP)	Formally request that the mass allocation for the shutter be revised.	24 July 2001

Table 5-3 - Review board queries.

Number	Review Board Query
1	The vane temperature is being qualified by analysis while the vane emissivity is being qualified by test. Presumably the uniformity of the emissivity is being measured by uniformity of the radiance assuming that the temperature of the shutter surface is isothermal. Would it not be better to combine the shutter temperature uniformity and the shutter emissivity requirements into a single requirement on the uniformity of radiance at a given temperature?
2	Confirm that the MoS_2 lubricant is contained and sealed within the gearbox.
3	Confirm that the internal shutter harnesses are adequately shielded

Table 5-4 - Outstanding issues

Number	Outstanding Design Issues
1	The current version of the SPIRE Instrument Requirements Document states that the shutter will relax to the out of beam position upon failure. The Shutter consortium wish to get a waiver for this requirement. They will submit a technical memorandum and an ECR to justify this.
2	A vane latch solenoid to ensure that the shutter remains in the stowed position is baselined in the design. The shutter consortium see this as un-necessary and will write a technical memorandum justifying the removal of the device from the design. Contained in this memo, should be some calculation that indicates that the natural vibration requirements are met with the removal of the device.
3	The design temperature and emissivity of the lid of the cryostat in the ground test configuration need to be determined.
4	Analysis on the heating of the FPU by the shutter needs to be performed. ComDev need to provide a reduced thermal model of the shutter to the SPIRE thermal systems engineer.

6. Conclusions

It was the opinion that the shutter development programme as presented at the meeting was progressing satisfactorily and will meet the key requirements.

Several outstanding issues on the basic configuration of the shutter exist, viz.;

1. The means of fulfilling the reliability / passive safe failure mode.
2. The configuration of the interface with the satellite CDMU.

These need to be resolved at project level before the development can continue.

Douglas Griffin

Monday, 10 September 2001