SUBJECT: SPIRE Shutter Thermal Study

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1 - Geometric Mathematical Model Description:

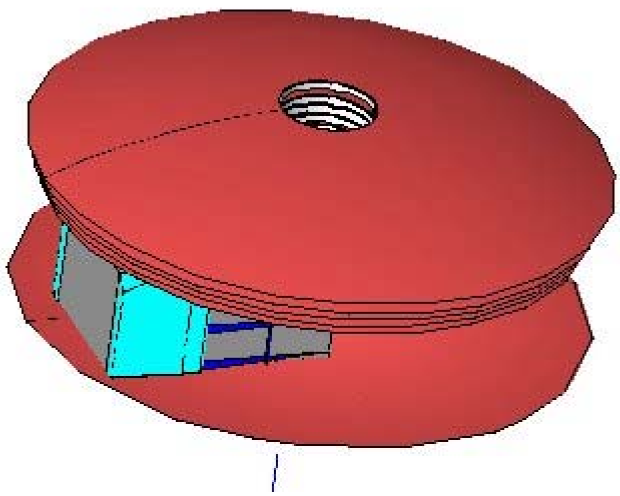


Figure 1 - Top View of Cryostat Apertures and Baffles (Cryo-cover removed).

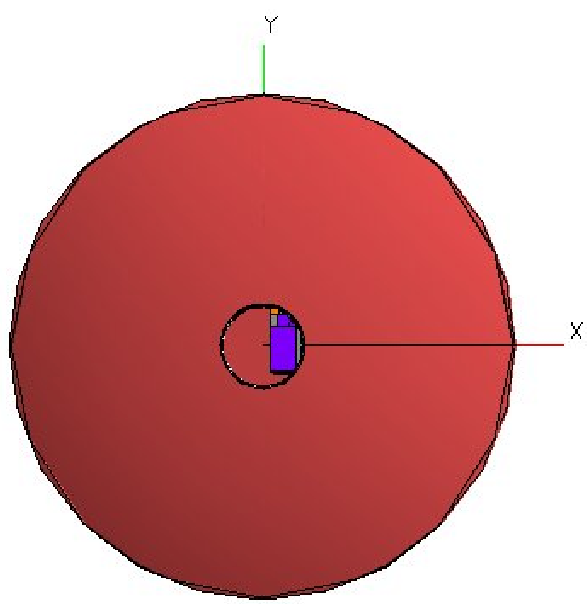
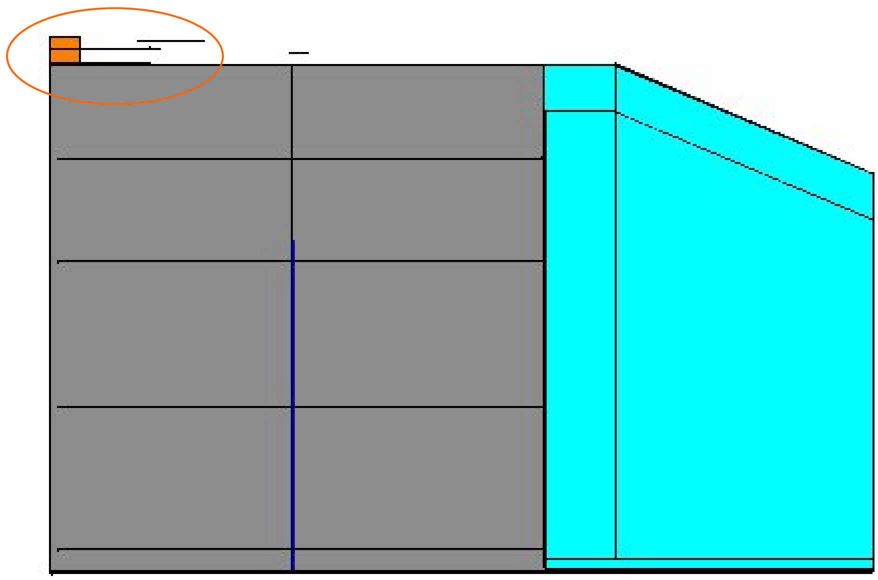


Figure 2 –Top View of the Cryostat and assumed shutter position (Cryo-cover removed).



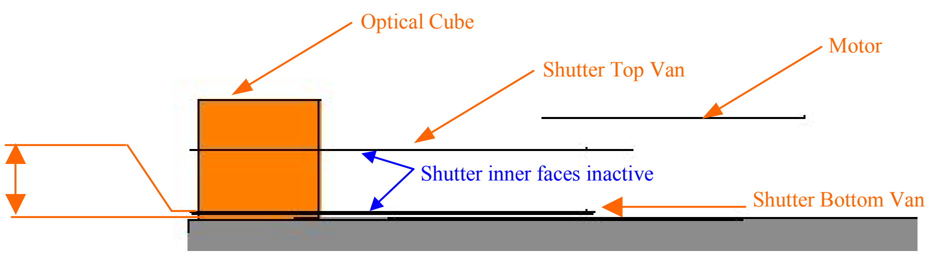


Figure 3 – Detailed view of the Spire Shutter simplified geometric model used in the analysis (Ref: Shutter_RTM_v2.xls. Dwight Caldwell email 11/10/01)

2 - Assumptions used for the Geometry and Material:

At this stage of the analysis, only few data were available and assumptions had to be done for the geometry and the material definition.

- *Cryostat Enclosure:*

A cryostat enclosure with a ~ 1.6 m diameter has been used in the geometrical model (ref: scaled from JD sketch with ray tracing). The support plate has been assumed to be at ~ 0.5 m from the instrument shield allowing the Shutter of the Spire instrument to be approximately at 50 mm from the instrument shield. A 2m radius has been used to produce the curvature of the shields and the following separation distances have been used between the shields (ref: Annex 6 p56 of SPIRE-AST-MOM-001238):

From	*To*	*Distance (mm)*
Instrument shield	Heat Shield 1	30
Heat Shield 1	Heat Shield 2	30
Heat Shield 2	Heat Shield 3	30
Heat Shield 3	CVV shield	45

Table 1- Shields Separation Distances

The shields, the cryostat enclosure and the cryo-cover have been defined as aluminum. For the purpose of the analysis, the aluminum emissivity was defined as a function of the temperature, as described in table 2.

Temperature (K)	*Emissivity*
293	0.06
240	0.05
214	0.033
154	0.03
91	0.02
25	0.0133

Table 2 – Aluminum emissivity versus Temperature

Ref:
"Thermophysical Properties Research Center"
Properties of aluminum and Aluminum alloys
Ed. Y.S. Touloukian and C.Y.Ho (October1973)
Data read from Analysed Curves for total hemispherical emissivity p206.

The baffle of each shield has been modeled by a cylinder with a diameter of the size of the aperture and a length of 22.5 mm (average between 20 and 25 mm). A black material with an emissivity of 0.8 has been assumed for each baffle (Information obtained on 7th May 02 telecon at RAL).

Remark: The emissivity data for the black material is at room temperature as no data about the "emissivity versus temperature" could be found for black materials.

- Spire Instrument:

A previously developed geometric model of the Spire instrument with a closed shutter has been used for the purpose of this analysis. The Spire model has been positioned on the support plate so that the relative position of its shutter with the cryostat aperture approximately matches the beam path as shown in figure 2 (description in draft of SPIRE-RAL-NOT_0001214, p.11, 18-04-02).

The main materials properties of Spire were as follows:

- Top surfaces – Esp = 0.02,
- Side Panels – Esp = 0.26,

All the shutter's components have an emissivity of 0.06 with the exception of the bottom vane which has an emissivity of 0.9. The figure 3 gives a description of the simplified geometry used for the shutter in the model. It can be seen that only the top and bottom face of the shutter have been modeled, therefore, the inner surfaces of the shutter top and bottom vane have been defined has inactive faces as they will not see any radiation because of the filling material between them.

3 - Assumption used to define the thermal environment of the Shutter:

With the exception of the shutter components, all nodes in the model have been defined as boundary nodes with the following temperatures (Annex 5 - p55 of SPIRE-AST-MOM-001238):

- CVV shield @ 293K,
- Heat shield 3 @ 214K,
- Heat shield 2 @ 154K,
- Heat shield 1 @ 91K,
- Heat shield 3 @ 25K,

Note: The worst hot case boundary definition has been used for each shield.

- Spire @ 4.5K,
- HOB @ 10K,

Finally, the analysis has been performed for a cryo-cover for ground temperature condition with no cooling:

- Cryo-cover @ 240 K (Annex 5 - p55 of SPIRE-AST-MOM-001238).

4 - Thermal Mathematical model description:

Name	*Node Nber*	*Temp (K)*	*Emissivity*	*Dimensions*
Cryo Cover	24015	240	0.05	radius = 0.14 m
CVV Shield	24014	293	0.06	Aperture radius = 0.14 m
Heat Shield 3	24013	214	0.033	Aperture radius = 0.14 m
Heat Shield 2	24012	154	0.03	Aperture radius = 0.14 m
Heat Shield 1	24011	91	0.02	Aperture radius = 0.14 m
Instrument Shield	24010	25	0.0133	Aperture radius = 0.135 m
CVV Baffle	24114	293	0.8	R = 0.14 m, h = 0.0225 m
Heat Shield Baffle	24113	214	0.8	R = 0.14 m, h = 0.0225 m
Heat Shield Baffle	24112	154	0.8	R = 0.14 m, h = 0.0225 m
Heat Shield Baffle	24111	91	0.8	R = 0.14 m, h = 0.0225 m
Instrument Shield Baffle	24110	25	0.8	R = 0.135 m, h = 0.0225 m
Cryostat Support Plate	1000	10	0.0133	R = 0.835m
Cryostat Cylinder Enclosure	5000	25	0.0133	R = 0.835m, h = 0.5 m
Spire Enclosure	30	4.5	Top Surface Eps = 0.02 Side Face Eps = 0.26	Shutter Closed

Table 3 - Boundary Nodes

Name	*Node Nber*	*Emissivity*
Shutter VaneBottom	1901	0.9
Shutter VaneTop	1902	0.06
Shutter VaneTab	1903	0.06
Shutter VaneMotor	1904	0.06
Shutter base plate under motor	1905	0.06
Shutter base plate under latch	1906	0.06
Shutter Latch	1907	0.06

Table 4 - Diffuse Nodes[*]

Note: The conductive links defining the shutter interface with the Spire Instrument have been taken from the previously developed thermal model ITMM01c.d. This assumes an Aluminium-Aluminium bolted interface.

5 – Shutter Temperatures During Ground Testing:

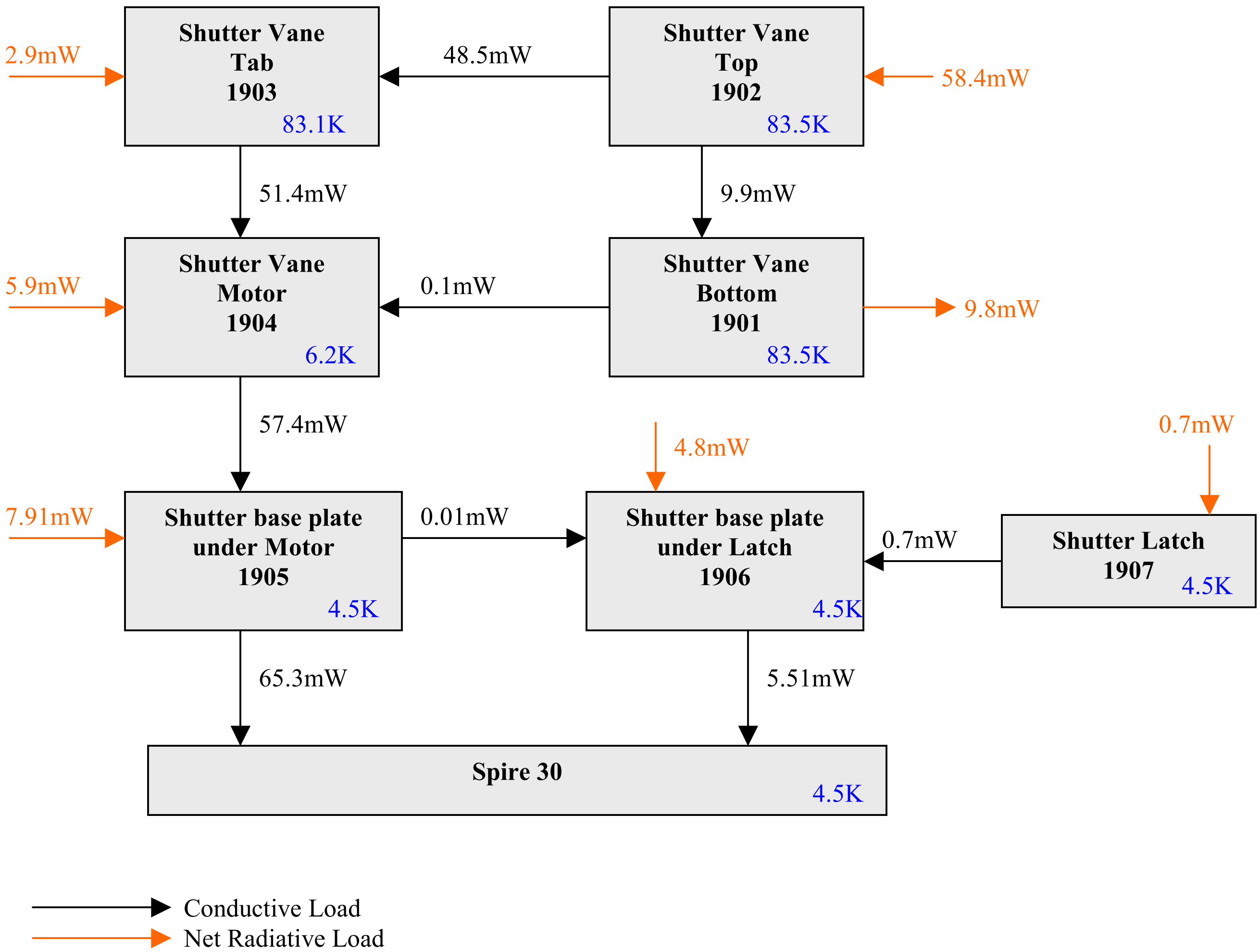
For a Cryo-cover @ 240K:

Node	Description	Temp (K)
30	Spire	4.5
1000	HOB Support Plate	10
1901	VANE_BOTTOM	83.5
1902	VANE_TOP	83.5
1903	VANE_TAB	83.1
1904	MOTOR	6.2
1905	BASE PLATE UNDER MOTOR	4.5
1906	BASE PLATE UNDER LATCH	4.5
1907	APETURE_LATCH	4.5
5000	Cryostat Enclosure	25
24010	Instrument Shield @ 25K	25
24011	Thermal shield1 @ 89-91K	91
24012	Thermal shield2 @ 148-15	154
24013	Thermal shield3 @ 211-21	214
24014	CVV @ 293K	293
24015	Cryo-Cover	240
24110	IS Baffle @ 25K	25
24111	HS1 Baffle @ 89-91K	91
24112	HS2 Baffle @ 148-154K	154
24113	HS3 Baffle @ 211-214K	214
24114	CVV Baffle @ 293K	293

Table 5 – Shutter Temperature as a result of a steady state analysis

Note: *The temperature of the shutter components is highlighted in blue.*

6 - Heat Flow Chart:



This flow chart only gives an overview of the conductive and radiative loads on the shutter's components.

7 – Radiative Heat load breakdown for top and bottom vanes of the shutter:

Shutter
Vane Bottom
Node : 1901
Esp = 0.9

Node	(mW)
Spire	-25.835
HOB Support Plate	-0.043
VANE_TOP	0
VANE_TAB	0
MOTOR	-0.001
BASE PLATE UNDER MOTOR	-0.04
BASE PLATE UNDER LATCH	-0.001
APETURE_LATCH	0
Cryostat Enclosure	-0.043
Instrument Shield @ 25K	-0.075
Thermal shield1 @ 89-91K	0.02
Thermal shield2 @ 148-15	0.522
Thermal shield3 @ 211-21	1.589
CVV @ 293K	4.616
Cryo-Cover	0.532
IS Baffle @ 25K	-0.124
HS1 Baffle @ 89-91K	0.024
HS2 Baffle @ 148-154K	0.593
HS3 Baffle @ 211-214K	1.938
CVV Baffle @ 293K	6.484

Total Input = 16.3
Total output = -26.1
Net Rad Heat = -9.8

Shutter
Vane Top
Node : 1902
Esp = 0.06

Node	(mW)
Spire	-0.355
HOB Support Plate	-0.038
VANE_BOTTOM	0
VANE_TAB	0
MOTOR	-0.001
BASE PLATE UNDER MOTOR	-0.001
BASE PLATE UNDER LATCH	-0.001
APETURE_LATCH	0
Cryostat Enclosure	-0.037
Instrument Shield @ 25K	-0.071
Thermal shield1 @ 89-91K	0.022
Thermal shield2 @ 148-15	0.706
Thermal shield3 @ 211-21	3.05
CVV @ 293K	11.818
Cryo-Cover	2.367
IS Baffle @ 25K	-0.299
HS1 Baffle @ 89-91K	0.095
HS2 Baffle @ 148-154K	2.361
HS3 Baffle @ 211-214K	8.562
CVV Baffle @ 293K	30.221

Total Input = 59.2
Total output = - 0.8
Net Rad Heat = 58.4

Note: A positive load represents a radiative heat load on the shutter from the node described. Therefore, the negative load represents a radiative heat load on the node described from the shutter.

8 - Discussion:

This preliminary study has emphasized that a temperature of 83.5 K is reached by the shutter when on ground condition and without any cooling.

- 51% of the total radiative loads on the shutter top vane comes from the CVV baffle and 20 % from the CVV shield both being at 293K,

- 14.5% of the total radiative loads on the shutter top vane come from the heat shield 3 baffle and 5.1% from the heat shield 3, both being at 214K.
  But in this case, it is important to note that the emissivity of the baffle has been defined at room temperature (Eps = 0.8) and it is probable that this load would decrease, as the effective emissivity at a 214 K temperature would be less than 0.8.

- The radiative load coming on the shutter top vane from the cryo-cover at 240K represents 4% of the total radiative heat load.

- The shutter bottom vane has a negative net radiative load which means that heat leaves the bottom vane. Because of its large view factor to Spire at 4.5K, most of the heat goes mainly into Spire.

- It can be noted however that some radiative load from the hottest shields and baffles reach the bottom vane of the shutter. This is caused by the multi-reflection of the beam of rays which find their way in the small gap between the shutter bottom vane and the Spire top surface, as described in figure 3.

The results of this analysis must be interpreted with great care as a certain amount of assumptions had to be made. For example, if a detailed model of the shutter was used, it can be predicted than any incoming radiation on the shutter bottom vane would be completely blocked, hence reducing even more the temperature of the shutter by few Kelvin (76.6K predicted). Finally, the presence of others instruments within the cryostat would also have an impact of the actual view factors of the shutter with respect to its environment. This however would have a limited effect if most of the instruments were also at low temperature.