THERMAL ANALYSIS AND DESIGN OF AN S-BAND HELICAL ANTENNA FOR LEO SATELLITES

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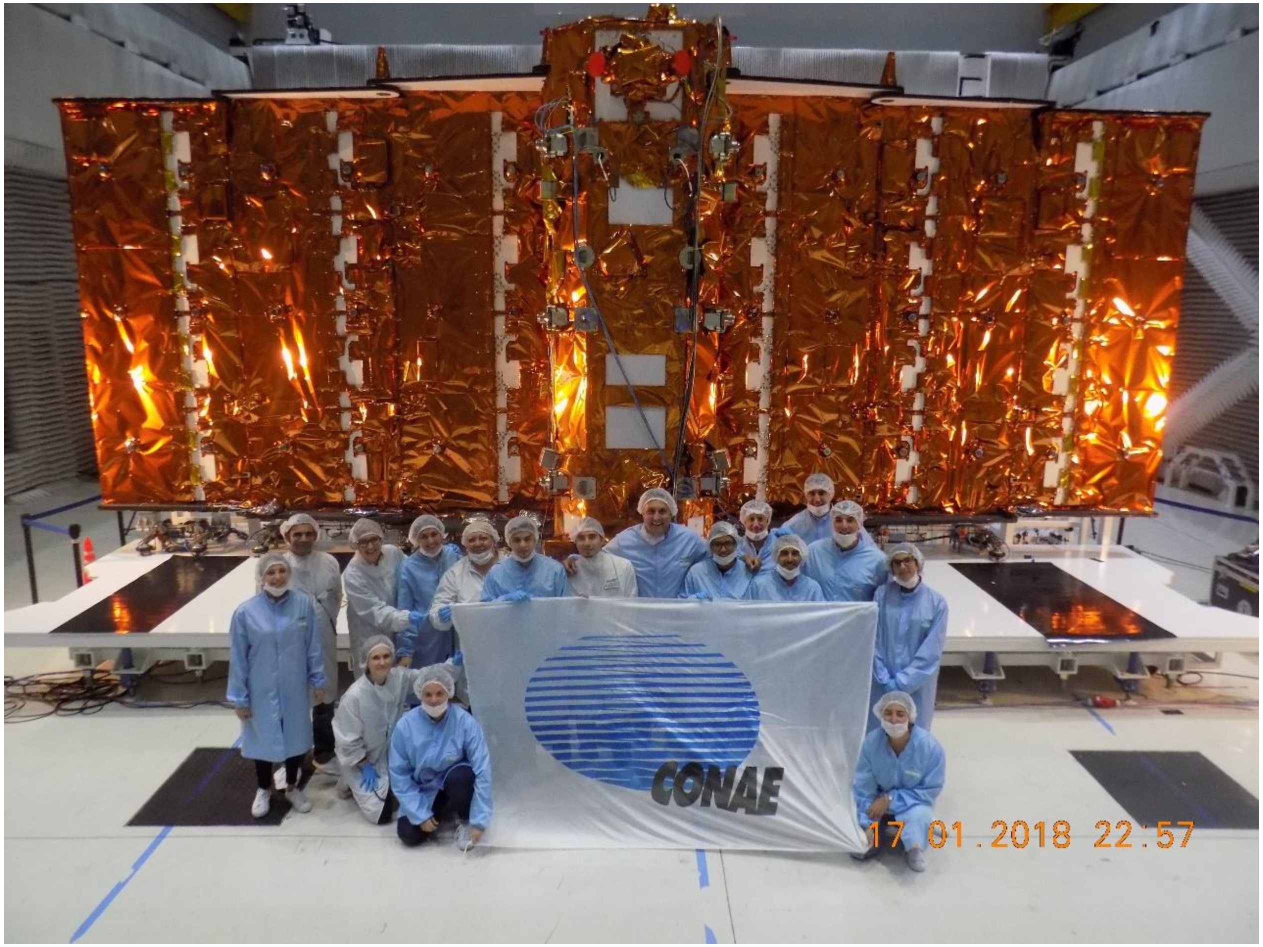
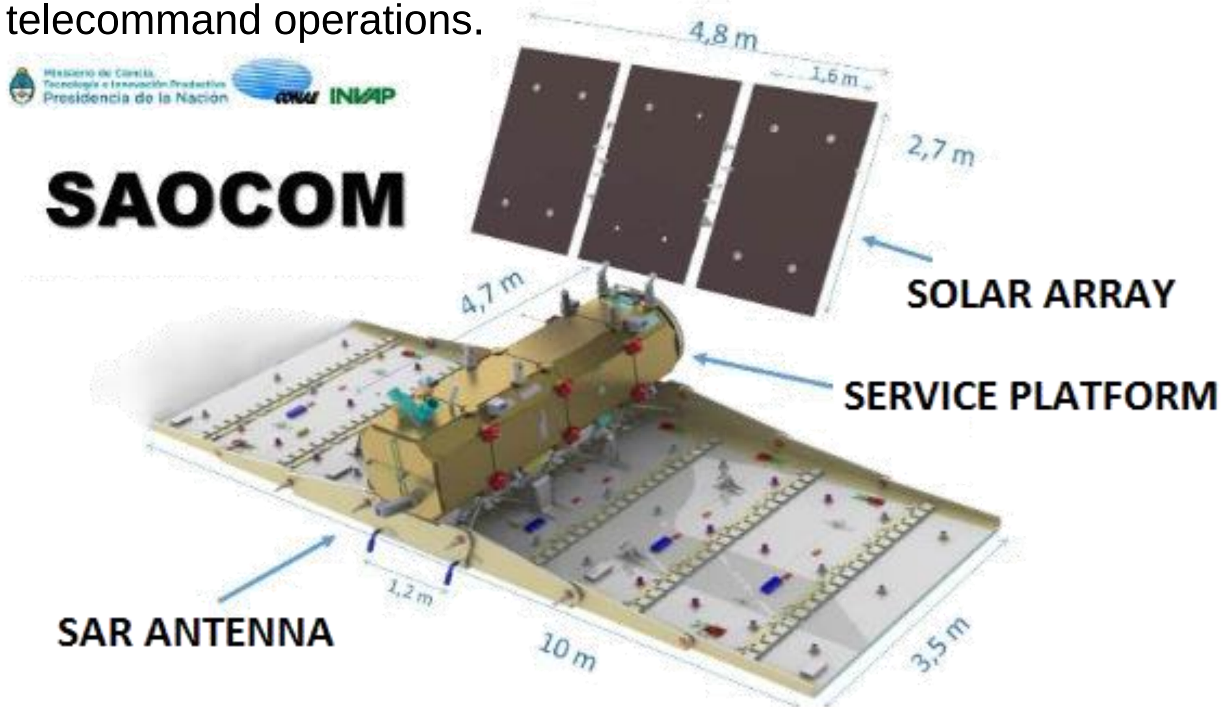
Introduction

- The two SAOCOM satellites are part of the Argentine and Italian Emergency Management System, SIASGE. The SIASGE constellation is made up by four Italian satellites, Cosmo Skymed, and two Argentine satellites, SAOCOM 1A and 1B.



Introduction

- The systems under study are two pairs of S-Band frequency helical antennas mounted on the service platform and SAR antenna of CONAE's SAOCOM 1A and 1B satellites. These antennas are part of the SAOCOM command data handling subsystem and are responsible for the communications of the satellite with the ground control station for telemetry and telecommand operations.



- The S-Band antennas are divided in two sets, with the only differences being their support structure and their location. The location factor plays a huge role on how the antennas behave thermally. Starting from the location and the environment they are subjected to (solar radiation, albedo, Earth IR and aerodynamic heating flux) a set of critical study cases is defined for each of the pairs.

Contents

Contents

Environmental parameters and study cases

To cover all the possible operational scenarios of the SAOCOM satellites, the thermal analysis is carried out using 3 β-angle (angle between the orbit plane and solar vector):

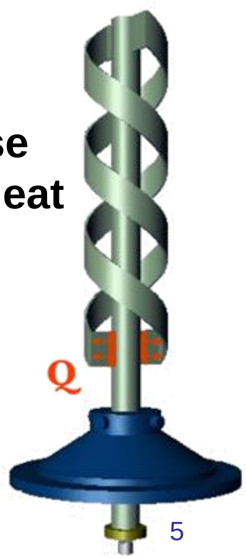
- **3.1°**
- **27°**
- **31.5°**

The external heating sources have been evaluated during different times of the year, resulting in "hot" (perihelion + high Earth's surface emissivity + maximum albedo) and "cold" (aphelion + low Earth's surface emissivity + minimum albedo factor) parameters.

Table 1. Values used for external heating sources. [1]

Set name	Solar [W/m^2]	Albedo	Earth IR [W/m^2]
Hot	1414	0.42	233.016
Cold	1318	0.34	191.013

When these S-Band antennas operate, they dissipate 0.45 watts. For the purpose of the thermal analysis, in agreement with the S-Band antennas designer, this heat load (Q) was placed as show in the image.

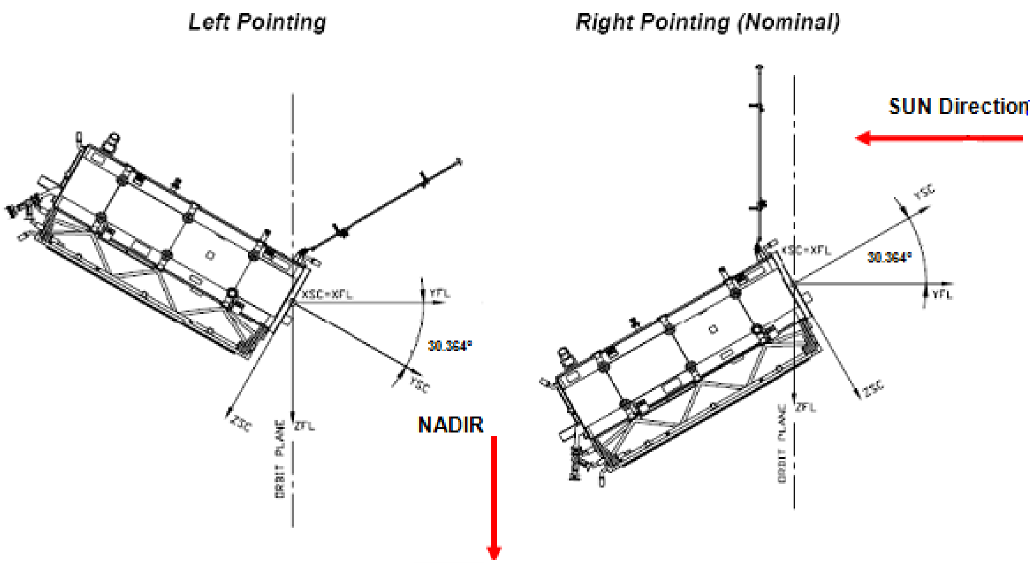


Environmental parameters and study cases

For mission requirements reasons, the SAR instrument (SAOCOM satellite payload) has two attitudes for the SAR acquisition, Right Looking and Left Looking

In the following image can be seen:

- **S band antenna locations**
- **Boundary condition assumed for the SAOCOM service platform**
- **SAR antenna reduced and correlated TMM**



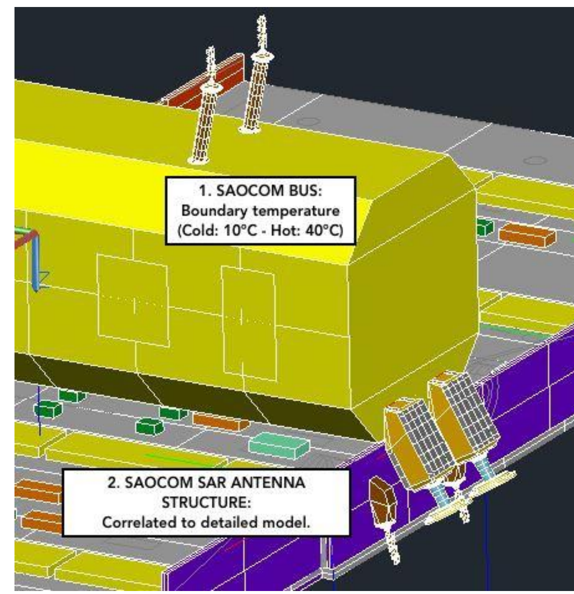


Table 2. Allowable Flight Temperatures and margins for the S-Band Antennas [3]

	AFT		With margins	
	Min Temperature [°C]	**Max Temperature [°C]**	**Min Temperature [°C]**	**Max Temperature [°C]**
Helical Antenna	-60	70	-45	55

Environmental parameters and study cases

The criteria to define the study cases was:

- **The cases must include long time exposure to the Sun or under eclipse**
- **Combined with the presence or not of power dissipation and BOL/EOL optical properties.**

Following these lines, 17 study cases were defined. Only the dimensional cases has been presented in this paper.

Table 3. Study cases for the SAOCOM 1 S-Band Antennas Thermal Analysis [1]

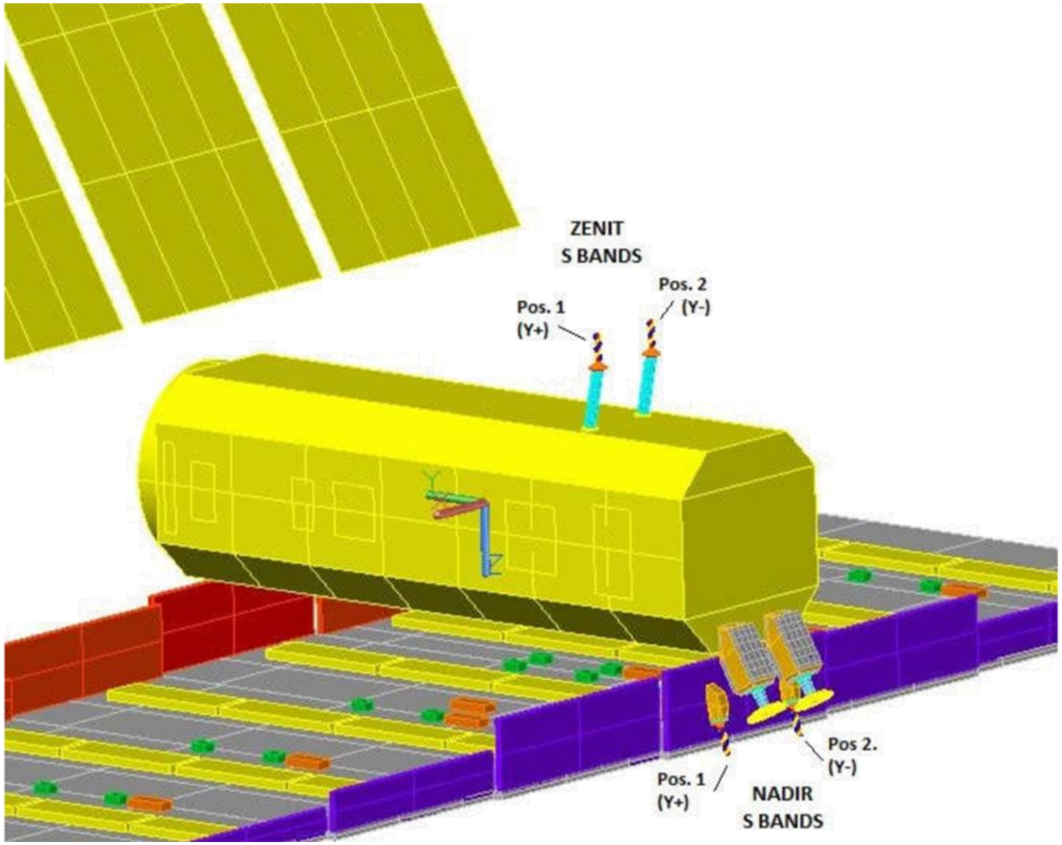
Case number	Zenith/ Nadir	β-angle	External heating source set	BOL/ EOL	Power dissipation	Notes
1	Zenith	31.5	Hot	EOL	0.45 W	
2		3.1	Cold	BOL	-	
3	Both	31.5	Cold	BOL	-	*Left Looking maneuver*
4	Nadir	3.1	Hot	EOL	0.45 W	
5		3.1	Hot	EOL	-	*Left Looking maneuver*
6	Both	05/13/15 11:16 UTC	Cold + Free Molecular Heating	BOL	-	*Launch trajectory*
7	Both	11/23/15 23:46 UTC	Hot + Free Molecular Heating	BOL	-	*Launch trajectory*

Thermal Mathematical Model (TMM) description

- **The Thermal Mathematical Model (TMM) was modeled and simulated using Thermal Desktop® (C&R Technologies®).**
- **Both the S-Band antennas and the satellite are modeled both in finite elements and finite differences.**
- **The S-Band models were integrated to a reduced model of the satellite to minimize the calculation time.**

Zenith S Band Antenna TMM

Nadir S Band Antenna TMM



Thermal Mathematical Model (TMM) description

Table 4. Thermo-Physical Properties of the Materials of the S-Band Antennas [6]

	BOL			EOL		
Surface finish	ε_{IR}	α_s	ε_{eff}	ε_{IR}	α_s	ε_{eff}
Brass	0.04	0.34	-	0.04	0.34	-
White paint	0.16	0.91	-	0.38	0.88	-
MLI	0.78	0.43	0.05	0.61	0.79	0.05

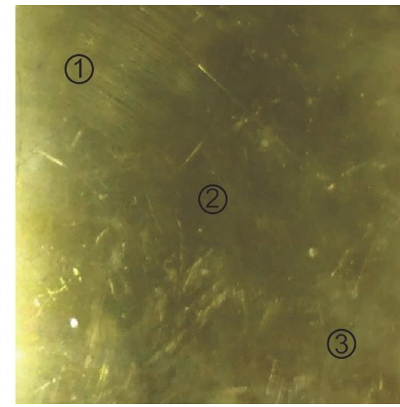


Table 5. Measurement Results for the Brass Sample

Sample measured	Measurement Points	ε_{IR}	Average ε_{IR}	α_s	Average α_s
Brass	1	0,040	**0.04**	0,332	**0.34**
	2	0,035		0,342	
	3	0,039		0,333	

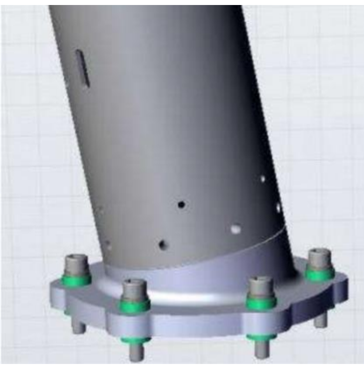
Table 6. Optical Properties of the Surfaces of the S-Band Antennas [4] [5] [6]

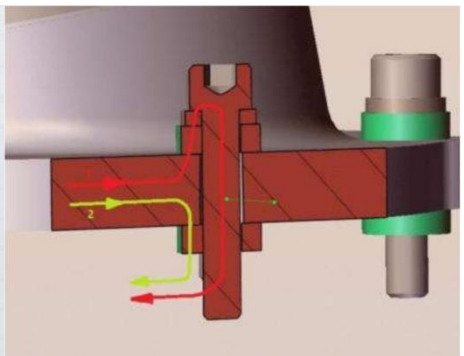
Material	Density	c_p [J/K/kg]	k [W/m/K]
Brass	8700	380	120
Aluminum 6061 T6	2700	896	167
Stainless Steel	8030	-	16.3

Thermal Mathematical Model (TMM) description

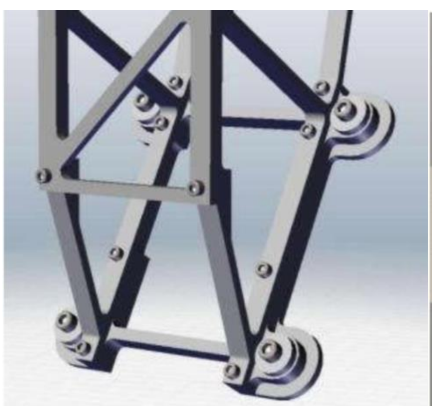
Table 7. Materials in the S-Band Antennas Bolted Joints. [6]

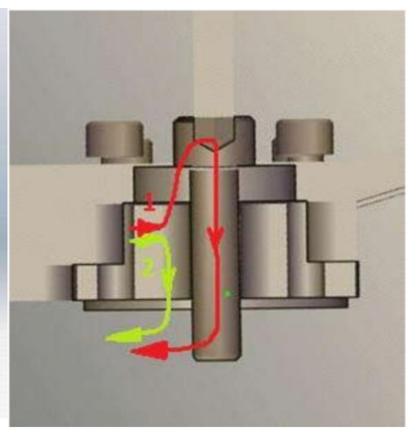
Material	Conductivity (k) [W/m/K]
Aluminum	167.9
G10	0.36
Stainless Steel	7





TOTAL CONDUCTANCE for Zenith S band antenna Bolted Joint	**0.0232 W/m/K**



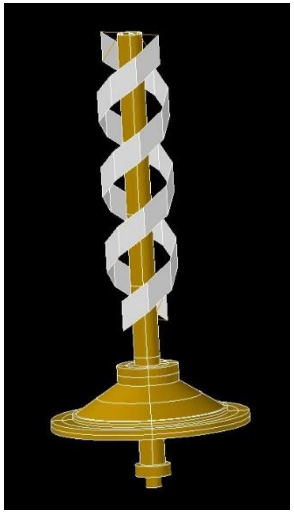


TOTAL CONDUCTANCE for Zenith S band antenna Bolted Joint	**0.0678 W/m/K**

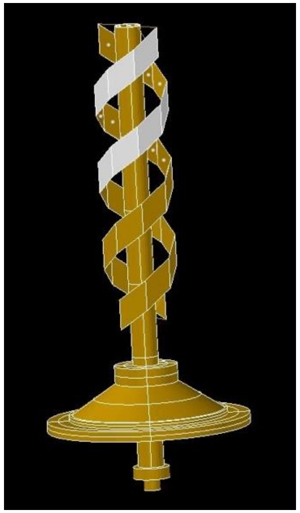
Proposed Thermal Control configurations

Table 8. Summary of The Proposed Thermal Control Configurations

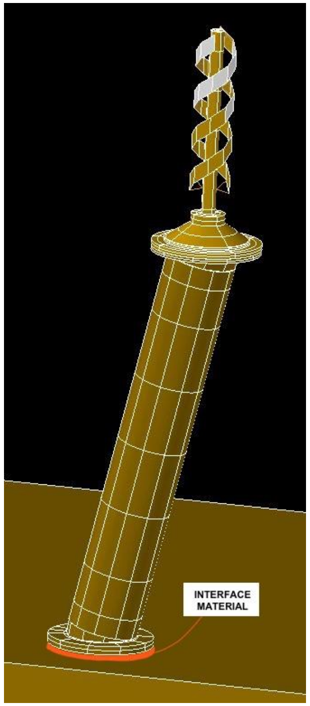
Configuration	Thermal Coating Used	Other Thermal Control
A	**White paint** (Internal + External)	N/A
B	**White Paint** (50% External) **Brass** (50% External + 100% Internal)	N/A
C	**White Paint** (50% External) **Brass** (50% External + 100% Internal)	**Zenith**: **Interface Material** between support and satellite's bus



Configuration A



Configuration B



Configuration C

Orbit Temperature Results

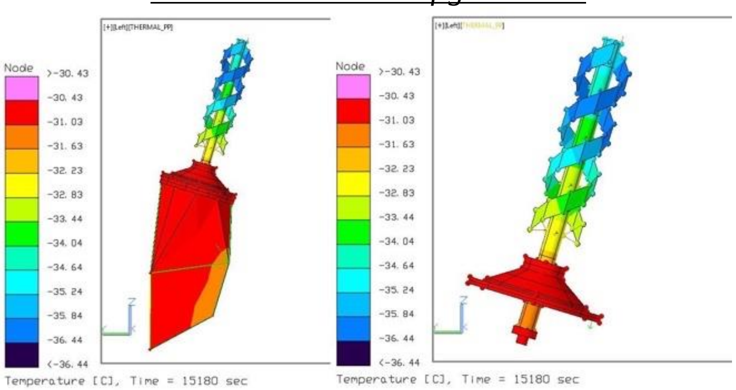
Table 9. Nadir S- Band: Summary of the Proposed Thermal Control Configurations

	Original TMM			Configuration A			Configuration B		
Case	Min T	Max T	Margin	Min T	Max T	Margin	Min T	Max T	Margin
3	-21.25	14.73	38.75	-52.45	-28.34	7.55	-36.44	-12.48	23.56
4	32.50	72.49	-2.49	-1.44	9.64	58.56	17.30	34.33	35.67
5	-12.37	71.94	-1.94	-45.52	9.20	14.48	-29.40	34.31	30.60

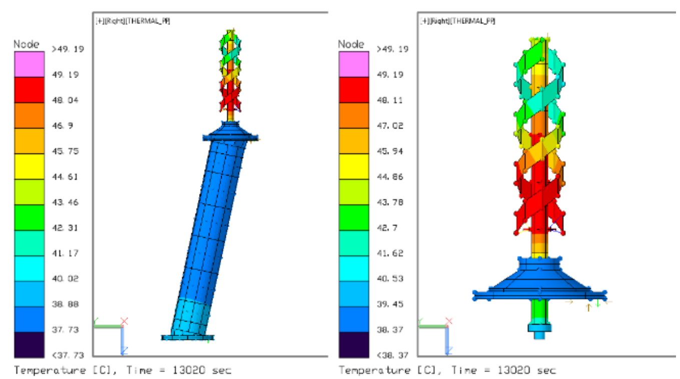
Table 10. Zenith S- Band: Summary of the Proposed Thermal Control Configurations

	Original TMM			Configuration A			Configuration B			Configuration C		
Case	Min T	Max T	Margin	Min T	Max T	Margin	Min T	Max T	Margin	Min T	Max T	Margin
1	24.12	68.92	1.08	-29.02	8.60	30.98	-1.53	35.59	34.41	10.22	49.20	20.80
2	-53.43	-51.58	6.57	-74.25	-62.91	-14.25	-63.38	-56.65	-3.38	-36.00	-21.79	24.00
3	-53.40	4.42	6.60	-74.25	-62.91	-14.25	-63.38	-56.65	-3.38	-36.00	-21.79	24.00

Case 3 – Nadir – Configuration B

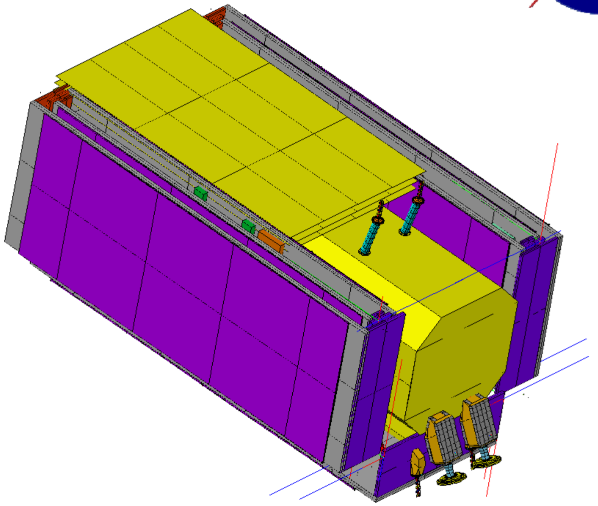


Case 1 – Zenith – Configuration C

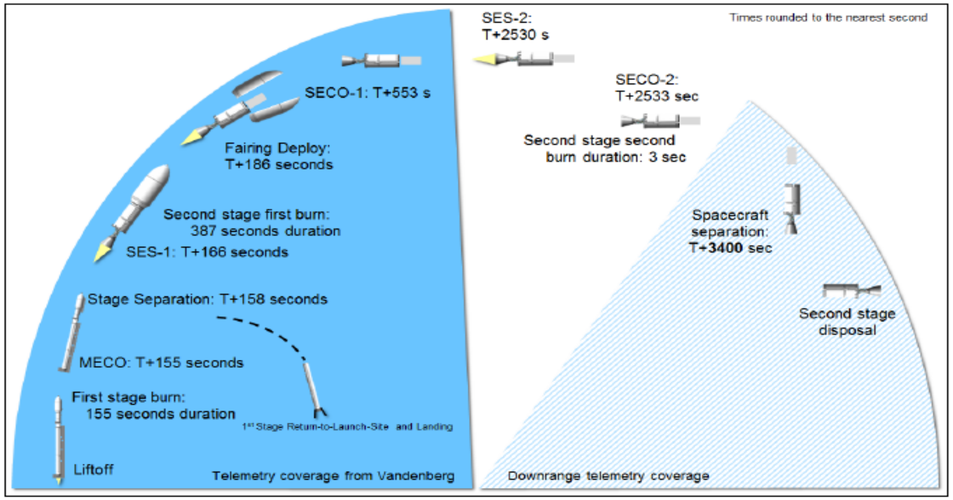


Launch Trajectory Thermal analysis

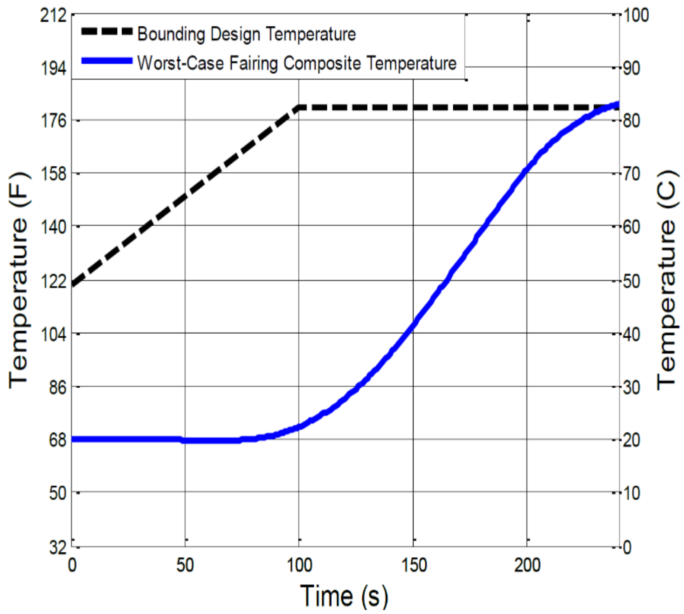
- To perform the launch trajectory thermal analysis, the following TMM configuration was used:



- Proposed launch trajectory sequence considered for thermal analysis.
- 183 seconds inside of fairing + 3217 seconds until spacecraft separation



- Fairing inner wall temperature. [8]



Launch Trajectory Thermal analysis

Cold Case 6 analysis hypotheses:

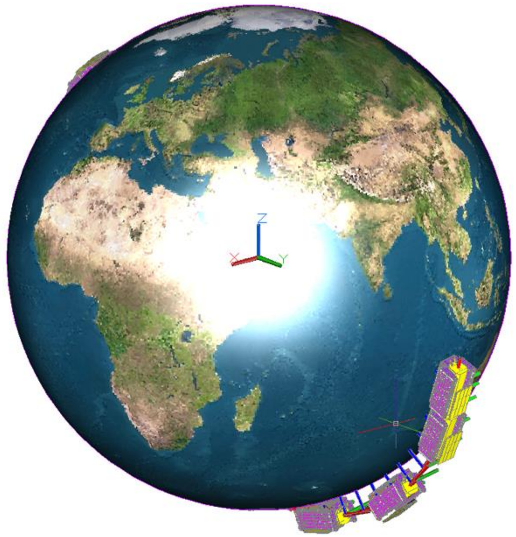
- The case analysis has been run in two phases.
- Phase 1: From Lift Off (T) to Fairing Deploy T+ 183 s. For this phase the thermal profile of the Figure 50 was assumed as a boundary condition. Only the radiation to a space node with this temperature (thermal profile of the Figure 50), was considered.
- Phase 2: From Fairing Deploy to Spacecraft Separation T+3217 s. (T+3400 s – T+183 s = 3217 s)
- During the Phase 2 it has been considered the FMH from reference [9].
- No Barbecue considered in this case.
- Launch Day and time survey: 05/13/15 11:16 UTC
- Trajectory: [9]
- Rotation: [9]
- Aerodynamic Heating: [9]
- Environmental Fluxes: Hot. Table 1.
- S/P Boundary Temperature: 22ºC

Hot Case 7 analysis hypotheses:

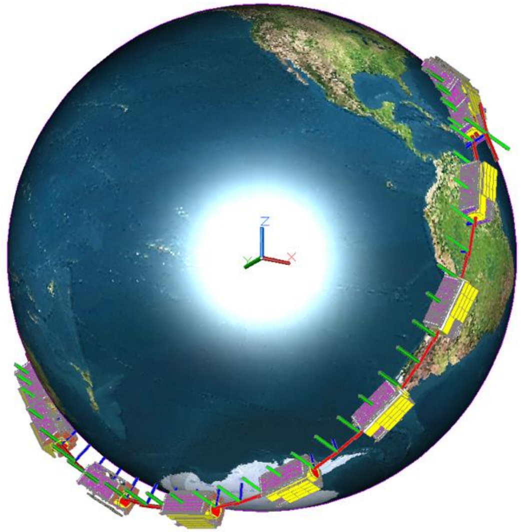
- The case analysis has been run in two phases.
- Phase 1: From Lift Off (T) to Fairing Deploy T+ 183 s. For this phase the thermal profile of the Figure 50 was assumed as a boundary condition. Only the radiation to a space node with this temperature (thermal profile of the Figure 50), was considered.
- Phase 2: From Fairing Deploy to Spacecraft Separation T+3217 s. (T+3400 s – T+183 s = 3217 s)
- During the Phase 2 it has been considered the FMH from reference [9].
- No Barbecue considered in this case.
- Launch Day and time survey: 11/23/15 23:46 UTC
- Trajectory: [9]
- Rotation: [9]
- Aerodynamic Heating: [9]
- Environmental Fluxes: Hot. Table 1.
- S/P Boundary Temperature: 28ºC

Launch Trajectory Thermal analysis

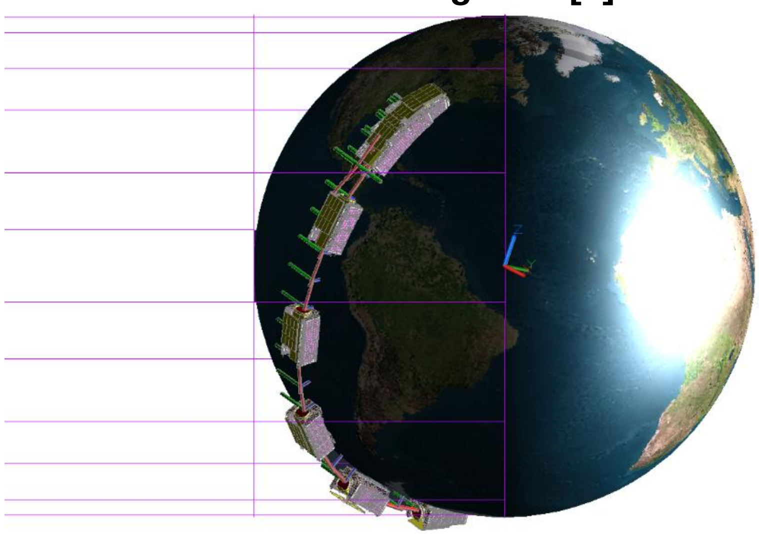
Sun view of the Launch Trajectory for the Cold Case 6. [9]



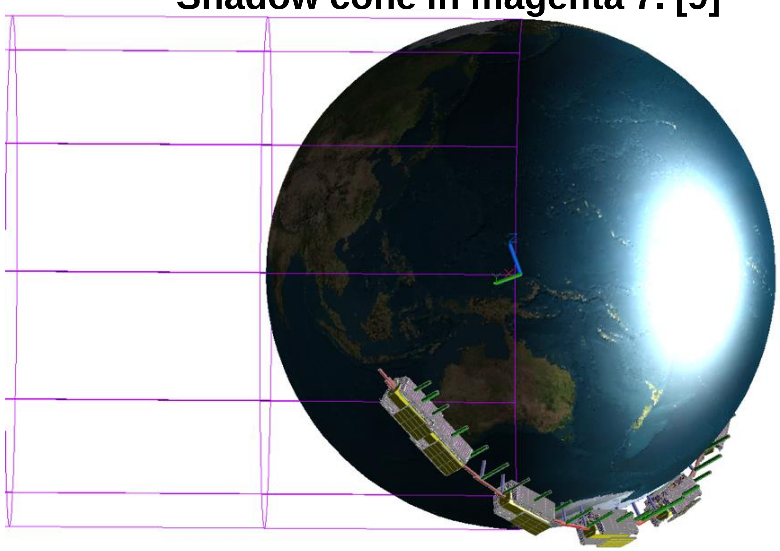
Sun view of the Launch Trajectory for the Hot Case 7. [9]



Cold Case 6 Launch Trajectory. Shadow cone in magenta. [9]



Hot Case Launch Trajectory. Shadow cone in magenta 7. [9]

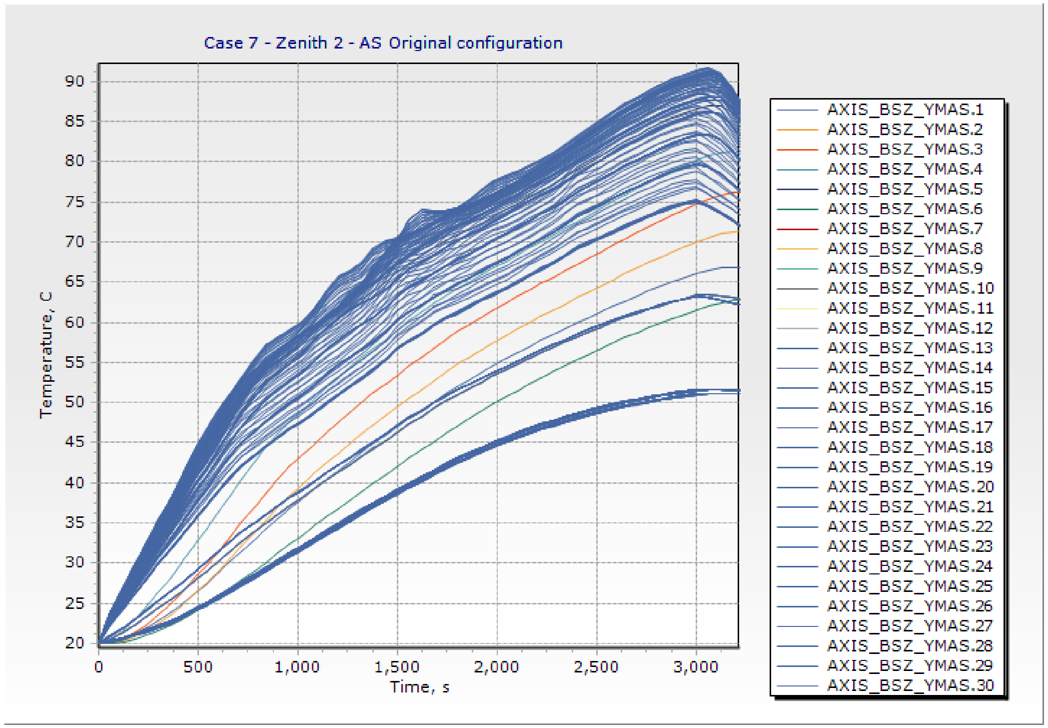


Launch Trajectory Thermal analysis

According to the thermal analysis for cases 1 through 5, the best configuration for the passive thermal control of the S Band antennas should be:

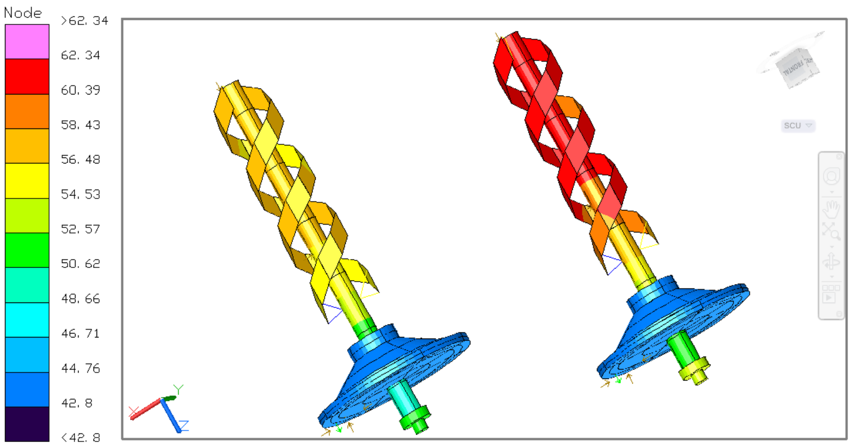
- **Nadir: Configuration B.**
- **Zenith: Original configuration.**

In this image it can be seen that the s band antenna 2 for the case 7 do not fulfill the requirement of maximum temperature +70 °C. For this reason, the configuration C shall be tested for the Zenith antennas.



Launch Trajectory Thermal analysis

In this image it can be seen that the s band antenna 2 for the case 7 fulfill the requirement of maximum temperature +70 °C. For this reason, the configuration C will be adopted for the Zenith antennas.



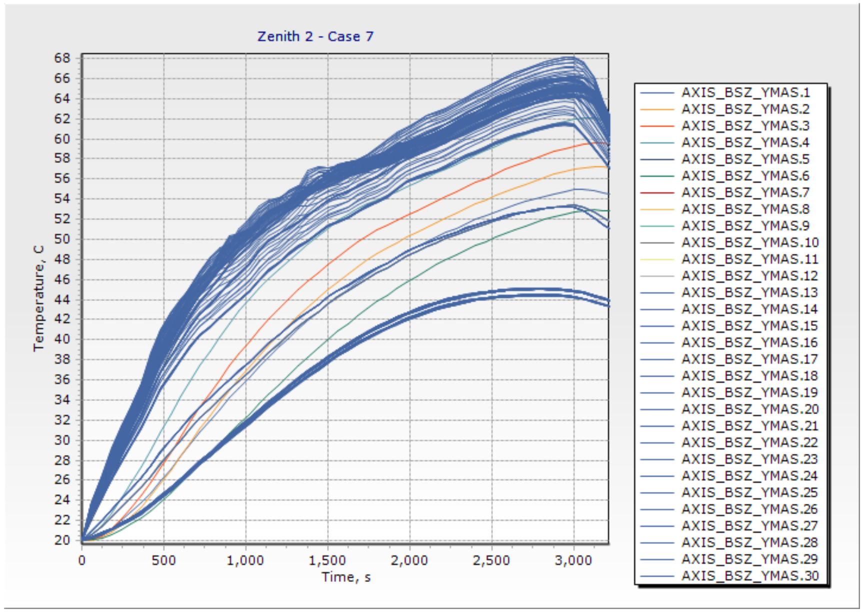


Table 11. Configuration C Hot Case 7 – Temperatures for the Zenith S-Band

	Min [°C]	Max [°C]	Margin
Zenith 1	20	68	2
Zenith 2	20	69	1

Analysis and Discussion

- For the S-Band antennas located at the **Nadir position,** there was a **significant improvement in their results** with **Configurations A and B**.

- These antennas are exposed for long periods of time to the solar radiation, so painting them white offers a quick solution to this problem. Whether Configuration A or B will be implemented depends more on the manufacturing process and Radio Frequency performances than the thermal analysis, as both offered good results.

- In the case of the **Zenith S-Band** antennas, **configurations A and B do not provide better results**, as these antennas have colder conditions. Nonetheless, **in the launch trajectory thermal analysis, these antennas had zones exceeding the allowable temperatures.**

- Then, for **Zenith S-Band, Configuration C** would be the **best option**: the white paint would allow for better emissivity, improving the hot cases, while the thermal interface material (RTV566) would let heat flow into the system in the cold cases.

- **For the Zenith S-Band , the reduced thermal design margin for this phase will be accepted due that the launch trajectory is a phase of a short period of time in the mission, and the s band antenna has been qualified in thermal vacuum for a maximum temperature value of + 80 °C**

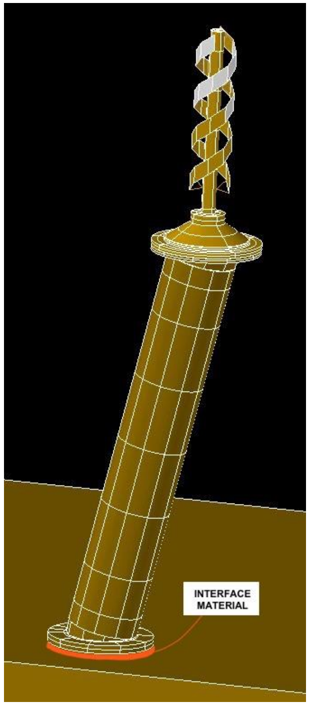
Final Implementation and Conclusions

- The configurations finally adopted for these antennas were:

  Nadir: Configuration B.

  Zenith: Configuration C.

Nadir S Band Antenna Configuration B



Zenith S Band Antenna Configuration C

To conclude, the thermal analysis and design process carried out for the S-Band helical antennas for the SAOCOM satellites gave as a result multiple options for these antennas to fulfill their requirements. It was necessary to evaluate different configurations due to the variety of the environmental parameter values, thus, simulating three configurations for the Nadir antennas and four for the Zenith ones.