CHS

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1. INTRODUCTION

1.1 Summary/Scope

This document constitutes the Executive Summary Report for the Project "*Cryogenic Heat Switch in the 30-80K temperature range*", ESA/ESTEC Contract Nr. 4000116152/15/NL/KML, and it is delivered as part of the data pack corresponding to the Final Review milestone.

This document provides a concise summary of the activities and achievements accomplished, and the further work to be carried out in the future.

1.2 Applicable and Reference Documents

1.2.1 Applicable Documents

DOC 1: Appendix 1 to AO/1-8369/15/NL/KML. Statement of Work Invitation to Tender Cryogenic Heat Switch in the 30-80K temperature range TEC-MTT/2015/3881/In/Tht. July 7th 2015

DOC 2: CHS/LDX/TNO/001, "TN1: Cryogenic Heat Switch – Literature Study"

DOC 3: CHS/LDX/TNO/002, "TN2: Cryogenic Heat Switch – Consolidation of Requirements"

DOC 4: CHS/LDX/PLN/001, "TN4: Cryogenic Heat Switch - Low Level Breadboard Test Plan"

DOC 5: CHS/LDX/PRO/001, "Flexible Thermal Link Stiffness Test Procedure"

DOC 6: CHS/LDX/PRO/004, "LBB Vespel Joints Tests Procedure"

DOC 7: CHS/LDX/PRO/005, "LBB Initial Functional Test Procedure"

DOC 8: CHS/LDX/RPT/001, "Vespel Joints Test Results"

DOC 9: CHS/LDX/RPT/002, "LBB Flexible Thermal Link Stiffness Test Report"

DOC 10: CHS/LDX/RPT/003, "LBB Initial Functional Test Report"

DOC 11: CHS/LDX/TNO/005, "TN7: Cryogenic Heat Switch – Design Description and Analysis Results"

DOC 12: CHS/LDX/PLN/002, "TN8: Cryogenic Heat Switch Elegant Breadboard Test Plan"

DOC 13: CHS/LDX/PRO/009, "EBB Physical Properties Test Procedure"

DOC 14: CHS/LDX/PRO/011, "EBB Vibration Test Procedure"

DOC 15: CHS/LDX/PRO/012, "EBB Thermal Vacuum Cycling Test Procedure"

DOC 16: CHS/LDX/PRO/013, "EBB Functional Tests Procedure"

DOC 17: CHS/LDX/RPT/005, "EBB FTL Stiffness Test Report"

DOC 18: CHS/LDX/RPT/006, "EBB Physical Properties Test Report"

DOC 19: CHS/LDX/RPT/007, "EBB Functional Tests Report"

DOC 20: CHS/LDX/RPT/009, "EBB Vibration Test Report"

DOC 21: CHS/LDX/RPT/010, "CHS Final Report"

1.2.2 Reference Documents

REF 1: INT/LDX/TEP/SPC/19/015/1/0. Cryogenic Heat Switch – GSTP Proposal, 1.0, 25th June 2019.

1.3 Definitions

Applicable Document	Document whose contents, fully or partially, have been considered as requirements
Reference Document	Document containing information used to elaborate or justify some of this document's content

1.4 Acronyms & Abbreviations

CDTI	Centro para el Desarrollo Tecnológico Industrial
CF	Cold Finger
CHS	Cryogenic-Heat Switch
CTE	Thermal Expansion Coefficient
DOC	Applicable Document
EM	Engineering Model
FTL	Flexible Thermal Link
GSTP	General Support Technology Programme
I/F	Interface
LBB	Low BreadBoard (Model)
MLI	Multilayer Insulation
NA	Non Applicable
REF	Reference Document
RT	Room Temperature
SC	Spacecraft
TBC	To be confirmed
TBD	To be defined
TRL	Technology Readiness Level
TRP	Technology Research Programme

1.5 Symbols

ºC	Celsius
G/g	Gravity acceleration
Hz	Hertz
K	Kelvin
Kg	Kilogram
mm	Milimeter
N	Newton
T	Temperature
W	Watts
Z_{ON}	ON Conductance
Z_{OFF}	OFF Conductance

2. PROJECT OBJECTIVES

2.1 Objectives

The objectives of this activity are to design, manufacture and test an Elegant Breadboard Model of a Cryogenic Heat Switch in the 30-80K range in order to answer the needs of potential future cryogenic missions, both for Earth Observation and Scientific applications.

The Switch architecture is as follows: it links two Cold Finger I/Fs (corresponding to both Nominal and Redundant cryocoolers) to a Detector I/F (or any other element to be cooled down), and allows to thermally connect and disconnect one Cold Finger or the other from the Detector I/F. In addition, the Switch itself must provide mechanical decoupling between the Cold Fingers and the Detector I/F.

The main functions of the Cryogenic Heat Switch should be then the following:

- To ensure a sufficient thermal coupling between the ON (or active) Cold Finger and the Detector → high thermal conductance along the ON thermal path (Z_{ON})
- To guarantee a sufficient thermal decoupling between the OFF (or inactive) Cold Finger and the detector → low thermal conductance along the OFF thermal path (Z_{OFF})
- To be able to Thermally Switch from one Cold Finger to the other
- To mechanically decouple the cold fingers from the detector → mechanical decoupling system has to be incorporated in the device itself

3. PROJECT DEVELOPMENT

The Project has followed the usual approach for technological developments up to TRL4:

- Consolidation of Requirements and Preliminary design
- Low Level Breadboarding Activities to close the remaining trade-offs
- Detailed Design of the Cryogenic Heat Switch
- Manufacturing of the Elegant Breadboard Model
- Testing and exploitation

4. LIDAX CRYOGENIC HEAT SWITCH DESCRITION

4.1 Design Overview

The working principle of the CHS is based on the CTE property of the materials. It is a passive mechanism (no input power needed) that operates when temperature changes by the activation of the cryocoolers. Due to the different CTEs of the materials involved the components shrink when going to cryogenic temperature and close the thermal circuit between coolers and Detector.

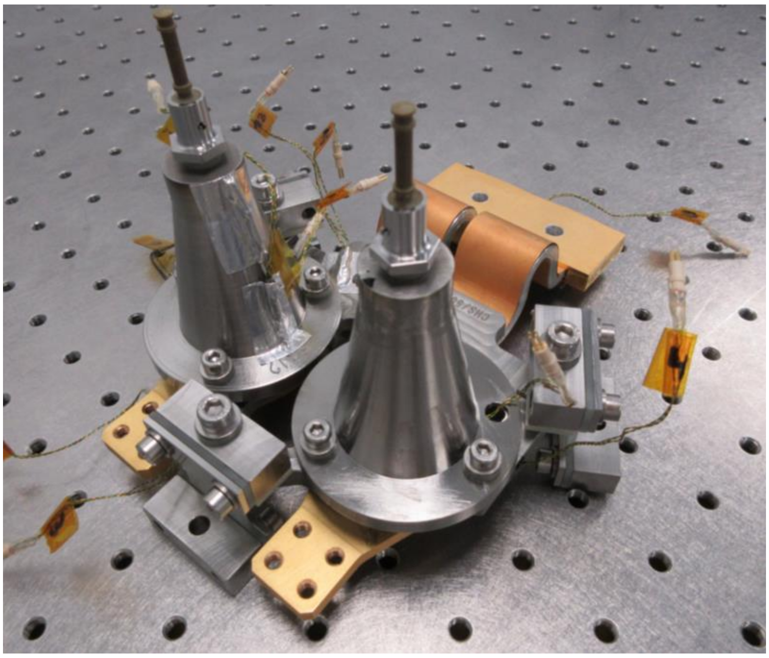

Figure 1: CHS overview (no MLI)

The CHS is composed of two closing mechanisms in a parallel configuration that act independently. Each one of the two switching mechanisms is connected to one cryocooler (nominal and redundant). Nominally, only one Switch would be working, the one connected to the Nominal cryocooler. If this cryocooler fails, its corresponding switch will open automatically. Then, once the Redundant cooler is turned ON, its corresponding switching mechanism will get closed and the thermal connection between cooler and detector (or any other element to be cooled down) will be restored.

The switching mechanisms parallel configuration allows to connect both cryocoolers to the system at the same time, doubling the cooling power in case it were needed.

In addition, defining the initial gap between the two parts which close the Switches, it is possible to set the closing temperature.

Finally, in order to keep open the switch connected to the cooler in OFF status, the thermal path between both coolers I/Fs (Thermal Beams) is designed to have a very low conductance (OFF conductance). This way, the non-operative switch stays warm while the other has cooled down and shrinks to produce the closing.

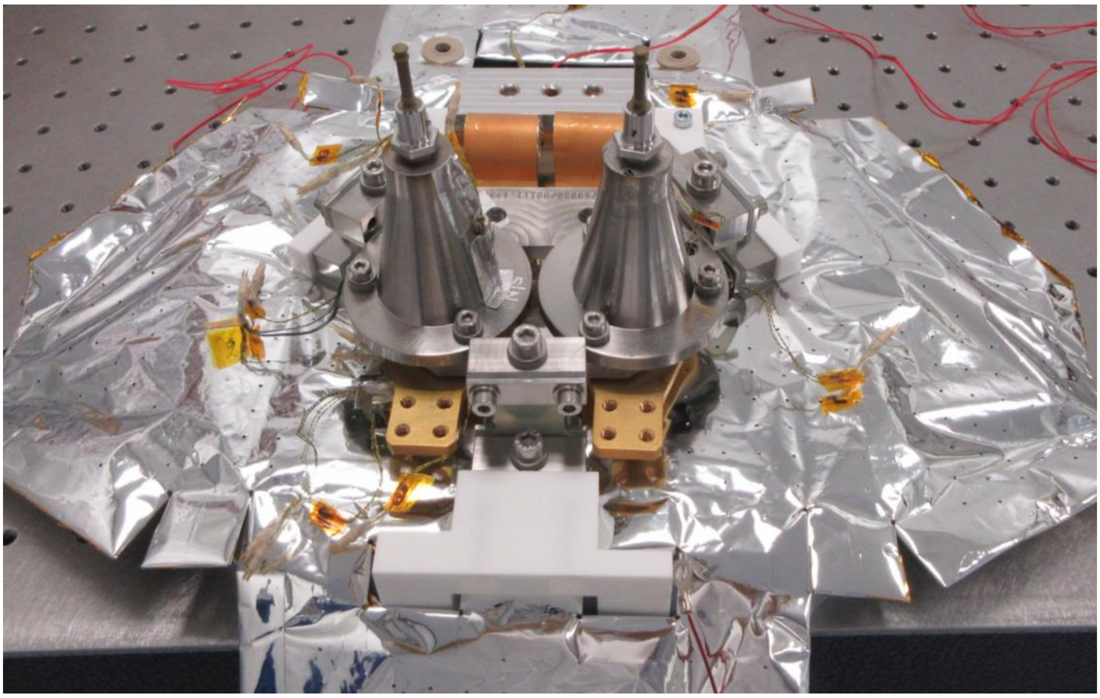

Figure 2: CHS overview (MLI integration)

The CHS is coupled to the Detector by means of a Flexible Thermal Link (FTL) which works as mechanical decoupling system isolating the element to be cooled from the vibrations coming from the cryocoolers. The connection to the Cold Fingers consists of a solid conductive part called Thermal Beam. Finally the device is fixed to the SC by 3 insulating supports.

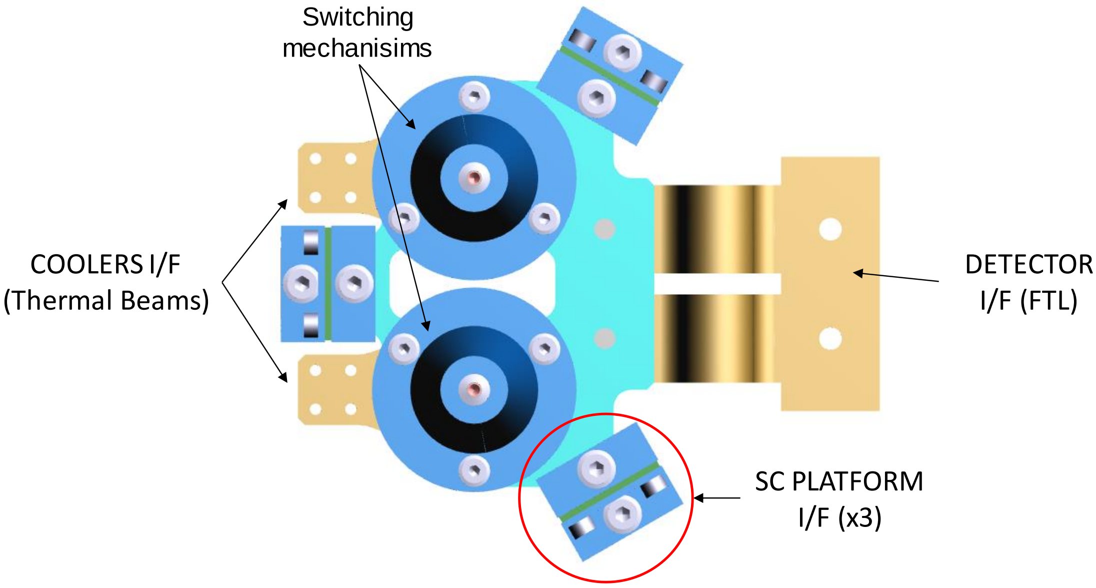

Figure 3: CHS interfaces (top view, MLI not shown)

5. CHS EBB TEST CAMPAIGN

The CHS Elegant BreadBoard has been submitted to a full test campaign, including functional tests at cryogenic temperature and complete vibration tests with QSL, Sine and Random tests.

The following Test Sequenced has been followed:

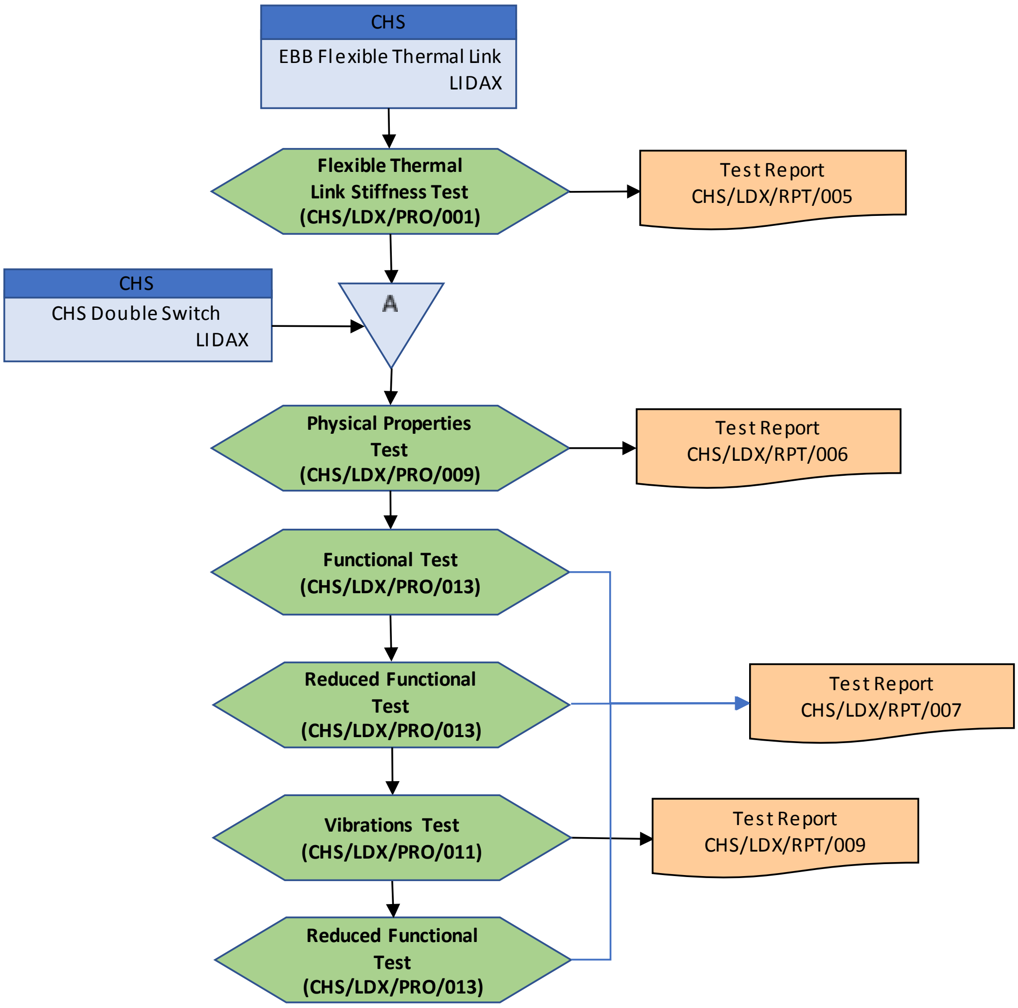

Figure 4: CHS EBB Test Campaign sequence

The CHS EBB has overcome the tests successfully, with no degradation at all and maintaining its original performance at the very end of the campaign.

Details of the results obtained are provided in Table 1.

6. CONCLUSIONS

The Cryogenic Heat Switch, CHS, is a reliable and high performance thermal management solution, available for the space community, whose objective is to save mass and power in the future cryogenic missions working with active cooling.

This is an extremely interesting project, and starting from zero, LIDAX has developed a very solid, valid concept, based on CTE technology, which has demonstrated to be reliable, robust, and to have a good thermal performance in cryogenics.

The Project is considered fully successful, having reached a TRL4, and taking into account that the current development leaves the CHS design in a perfect status to carry out the next design evolution, to reach a TRL6, optimizing the device in mass, envelope and thermal performance.

The main characteristics of LIDAX's CHS are summarized as follows:

- ✓ The concept consists in a passive system based on differential CTE technology. No need for heaters; the Switch turns ON or OFF when the cryocoolers are switched ON/OFF.
- ✓ Materials have been selected as a compromise between thermal conductivity and the objective of avoiding Cold Welding (between the parts closing the switch), but also considering mechanical strength and space heritage.
- ✓ Equipment fully integrated in ISO7 conditions, and composed of low outgassing materials compatible with payloads, optical and opto-electronical instruments.
- ✓ The system guarantees mechanical decoupling between the Coolers and the Detector interface by means of a Flexible Thermal Link; vibrations are not transmitted to the element to be cooled down.
- ✓ The operative range covers a wide band within cryogenic temperatures, being possible to establish the set point between 20K to 100K.
- ✓ The switching mechanism is symmetric, reversible and adaptable to different cryocoolers and detectors I/Fs. Changing the shape and size of the FTL terminal and the Thermal Beams, multiple devices could be cooled down with the same Coolers and/or different Coolers can be used.
- ✓ It allows to operate both Coolers at same time in case an increase of cooling capacity is needed

The performance currently reached by LIDAX's CHS, verified by test, is as follows:

Features	Parameter	Unit	Value
General Design	Mass	Kg	1.187
	Size (with no MLI)	mm	156.9x174.5x120.6
	Size (with MLI)	mm	169.3x181.2x120.6
	Electrical Consumption	W	0
	Heat Transportation Distance	mm	145.7
	ON Thermal Conductance at 50K	W/K	0.31
	OFF Thermal Conductance at 50K	W/K	4.12E-4
	ON/OFF Conductance Ratio	-	752
	Parasitic Fluxes for Radiative & Conductive Environment at 293K	W	0.4* *Analysis value
Mechanical	1st Eigenfrequency	Hz	> 250
	Max Input Acceleration under Static Loading	g	50
	Max Input Acceleration under Dynamic Loading (Random Vibration)	g_{rms}	24.4
			21.5
			23.9
	Stiffness (FTL)	N/mm	1.93 ± 0.03 (X)
			3.33 ± 0.03 (Y)
			1.38 ± 0.03 (Z)
	Operative Life expectancy	cycles	>60

Table 1: LIDAX's Cryogenic Heat Switch performance (verified by test)

As a summary, the result of implementing LIDAX's CHS is:

- saving of input power in the Cooling System, reducing considerably the power budget of the instrument
- or reaching lower temperatures with the same input power
- or getting more margin

7. NEXT STEPS AND FURTHER WORK

Thanks to this TRP activity, the first steps to develop a Flight Cryogenic Heat Switch have been taken. The output of this Project is a solid, reliable and really working CHS. However, some improvements are needed in order to optimize the design in mass, envelope and thermal behavior, to make it fully attractive to the industry.

LIDAX's firm intention is to evolve the current CHS to improve its performance and to reach a Technology Readiness Level up to TRL8. This way, the CHS will fill a gap demanded by the space industry during the last years to allow saving cooling power and mass in all those thermal architectures including active cryocooling.

To achieve this goal, LIDAX has already submitted to the Spanish Delegation, CDTI, a proposal for a GSTP activity (see REF 1), to develop the CHS Engineering Model and to increase the current TRL from TRL4 to TRL6.