Qualification Challenges and Approaches for Cryogenic Temperature Testing of EEE Components in the ESA ARIEL Science Mission

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INTRODUCTION

In the recent years, Space Science instrument missions have required EEE parts capable of withstanding more extreme temperatures, reaching as low as 0 Kelvin!, surpassing the classical military range of [-55, +125] ºC.
In order to ensure the reliability of these EEE parts, mostly Passive components, a careful selection and testing are needed to get the required assurance on their performance.

Presently, ALTER is acting as the Components Procurement Parts Agency (CPPA) of the ESA ARIEL science mission. The mission's Payload is composed of a Module (SVM) and a Cold Payload Module (PLM). The operating temperatures on the PLM vary according to the instrument subsystem, ranging from 29K on the Active Cooler System (ACS) and ARIEL Infra-Red Spectrometer (AIRS) up to 100K.

In collaboration with ESA, ALTER has undertaken a comprehensive review and selection process for EEE components. These components are subjected to testing at cryogenic temperatures tailored to the specific conditions of each user's subsystem requirements. Most of these components fall into the category of passives, including capacitors, resistors, connectors, cables, thermistors, thermal sensors, heaters, and switches.

The current paper describes the qualification approach adopted, highlighting the challenges encountered during testing. It encompasses the testing flow, details about the equipment used in the tests, and the results gathered so far.

MISSION BACKGROUND AND EQUIPMENT INVOLVED

ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) is the fourth M-Class mission addressed as part of ESA's Cosmic Vision 2015-2025 plan. As a continuation of the tasks developed by PLATO mission, which are to identify new Exo-planets, ARIEL's main goal is characterize and study those, both individually and in groups, trying to correlate their characteristics to those of their host star.

To achieve this, Ariel Spacecraft carries a dedicated Payload which is distributed into a Cold Payload Module (PLM) and a Warm Service Module (SVM). Fig. 1 shows the distribution of different equipment within the whole payload onto these two subsystems as well as the working temperatures for each of them.

It is of particular interest to mention the harness that connects the TCU (Telescope Control Unit), located within the SVM to the M2M (M2 pointing mechanism) located within the PLM. This harness will be working at different temperature values on different parts depending on the exact location.

Another highlightable fact is that, as it can be seen in Fig.1 legend, there is equipment such as the Active Cooler System (ACS), where some electronics see temperatures as low as 29K.

Taking all of this, the equipment involved in Ariel PLM under the umbrella of CPPA procurement and the temperature ranges they will see are as listed in Table 1.

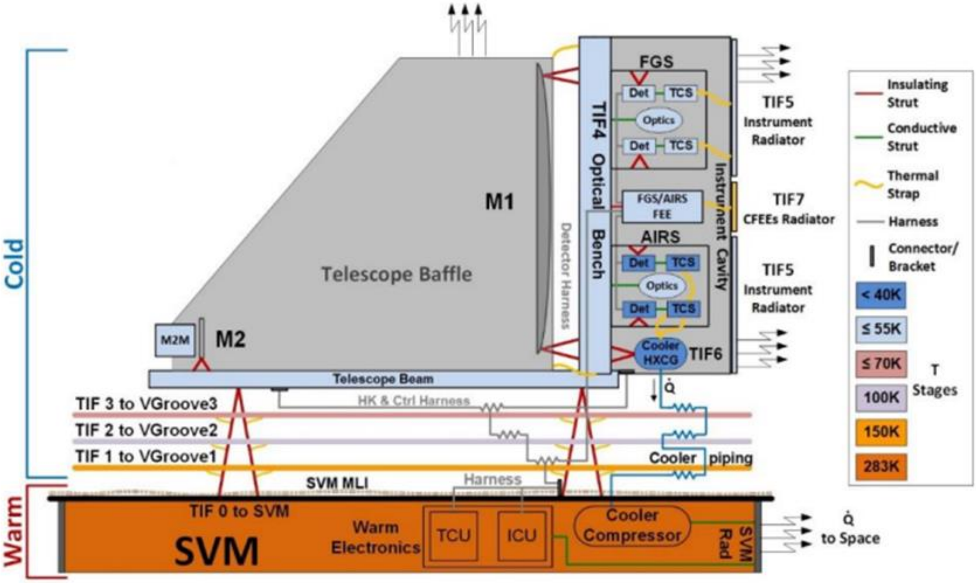


Figure 1: ARIEL Payload description

Table 1: ARIEL PLM equipment and temperature ranges

Equipment	Acronym	Minimum Operating Temp.	Maximum Operating Temp.	Minimum Non-Operating Temp.	Maximum Non-Operating Temp.
Active Cooler System	ACS	29K	45K	29K	323K
Telescope Assembly	TA	42K	63K	37K	323K
IR Spectrometer	AIRS	47K	63K	37K	323K
M2 Mechanism Harness	M2M Harness	37K	63K	37K	323K
Fine Guidance System	FGS	42K	63K	37K	323K
V-Groove Radiators	VGR	42K	63K	37K	323K
PLM Instrument Radiator	PLM IR	42K	63K	37K	323K
Telescope Baffle	TB	42K	63K	37K	323K

TESTING CANDIDATES AND DISCUSSION

Each equipment listed previously is under the responsibility of a different user, both in terms of design and procurement and therefore their DCLs state which components are subject to cryogenic temperature conditions.

From all the components included in affected DCLs, a comprehensive analysis has been performed in order to select the candidates for testing.
For this selection, the following aspects have been considered:

1- The temperature values seen by the parts: when a component tested is covering other similar ones, the most stringent conditions affecting the family has been selected. For example, if a single thermistor is used by two Users on the ACS and AIRS equipment, ACS conditions have been considered for the testing.

2- Family coverage: The candidates have been selected on the intention to have representative results for all families under study, which gather connectors, cables, capacitors, resistors, thermistors, flexible heaters and a microswitch.
3- Technology corners coverage: from each family/series, it has been selected the candidate which is more critical in relation to the technology represented. For example, from ESCC 4001/023 qualified resistors, the candidate selected is 4001023047981B2 (PHR 2010 7K98 0,1% 500mW 25ppm/ºC Chip) which is the largest size from all the specification procured (chip 2010) and the highest resistance value within this size (7980 Ω).

Having all of above into consideration, the parts selected for testing are shown below in Table 2.

Many parts, in particular connectors and their accessories and cables will be tested under the umbrella of the same testing plan. The rationale behind is that the project has tried to group parts in order to reduce the number of test campaigns; this allows not only to significantly adjust the cost of the total testing, but also to reduce the total lead time.

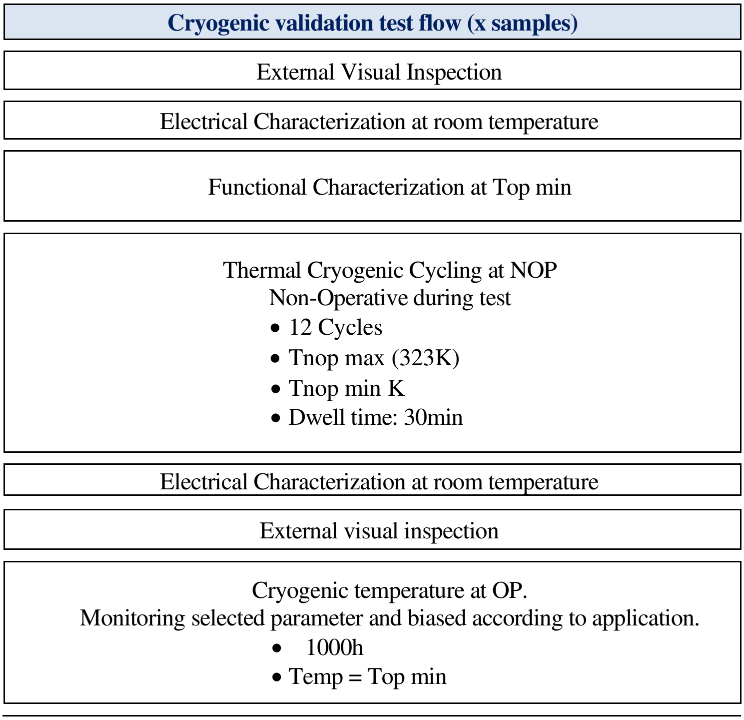
Table 2: List of candidate parts for Cryogenic Testing

Part type	**Componet Number**	**Mfr**	**Nº of samples**
0805 2.2nF, NPO 10% 50V (A612CE0350KNC)	3009003062201KC	Kyocera AVX	10
0805 100nF, BME X7R, 10%, 100V	300904103104KE	Kyocera AVX	10
TAJ 2.2uF, Tantalum, 10%, 16V (TAJA225K016ESA)	301200102225KC	Kyocera AVX	10
100nF, CRX, 10% 25 V Cryo	SR1209CRX104Z1F	Presidio	5
MDM Solder Bucket 31S	340102902B31SFR164E	C&K	2 sets
Nano-D 85 Titane FLEX	NM-225-085-225-JC00-D55-E1Q	Airborn	2 sets
Nano-D 85 FLEX	NK-2G2-085-135-JC00-E1Q	Airborn	2 sets
Nano-D 85 CFEE	NK-2F2-085-435-TH00-E1Q	Airborn	2 sets
ND2SA15P… Nano-D 15 pins	340108601B15P	Axon	2 sets
ND2SA15S… Nano-D 15 sockets	340108601B15S	Axon	2
Space Splice	340109701B	C&K	2
HD Sub-D 26-pin Male	340100202BDAMA26PNMB	C&K	2
HD Sub-D 26-pin Female	340100202BDAMA26SNMB	C&K	2
HD Sub-D 26-pin Saver	340102002BDABMA26PSNMB	C&K	2
CHPHR0805 4.7R, 200 ppm/°C, 2% thick film	4001026024R70G6	Vishay Sfernice	5
PHR 2010 7K98 0,1% 500mW 25ppm/ºC Chip	4001023047981B2	Vishay Sfernice	5
Flexible Heaters M2 52x14 mm	4009002xxxxx	RICA Zoppas	5
RER55 28R0 1% 30W 30ppm/ºC Axial	RER55F28R0R	Vishay Dale USA	5
Microswitch	T6932	Petercem	3
QP1K0.232.2L73.B.0300	400601508040300	IST AG	5
Polyimide/Fluorthermoplast Insulated Wires and Cables	390101868B	Axon	1

Assembly of four ESCC 3901.019 silver plated copper, Variant 26 (P35862A), 1 Kapton KPT616 07/16 and 1 Kapton KPT01901/04	P559699	Axon	1
CEH 2807 INOX wire, CELLOFLON (expanded PTFE), and polymide, AWG28	P541327A	Axon	1

TESTING FLOW

The testing flow agreed within the project is shown in Fig. 2. The sequence is aimed at addressing the performance of the EEE components at the conditions in which they will operate during the mission.



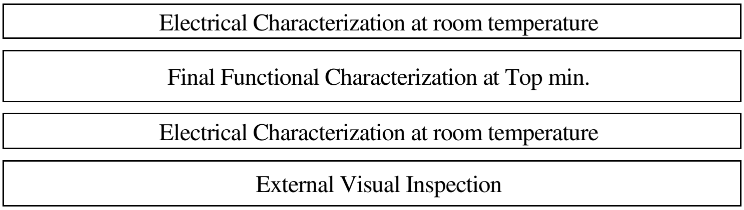


Figure 2: Cryogenic Testing Flow

The 12 cycles between maximum and minimum non-operating temperature range are intended to measure the thermal stress suffered by the component just by being at those temperatures, while the test is performed under no biasing conditions, on the contrary, the life test 1000h is designed to measure the fatigue suffered by the parts by working biased at the minimum operating temperature conditions. It is interesting to note that actually the parts will not be always working the minimum operating temperature, but on an estimation of 2000 cycles between minimum and maximum operating temperature during the mission lifetime. However, taking a look at Table 1 allows to see that minimum and maximum operating temperatures are quite similar for each equipment, so in order to avoid possible external stress or failures introduced by having such high number of cycles on the set-up, the 2000 cycles are replaced by a test at minimum operating temperature at a constant temperature and with a duration of 1000h, similar to that of the 2000 cycles (2 cycles per hour).

EQUIPMENT USED

The testing is performed at ALTER facilities in Madrid, Spain, by our experts, making use of a close-loop Helium cryostat capable of reaching the extremely low temperatures of 29K that the test flow requires for some of the equipment (Fig.3).

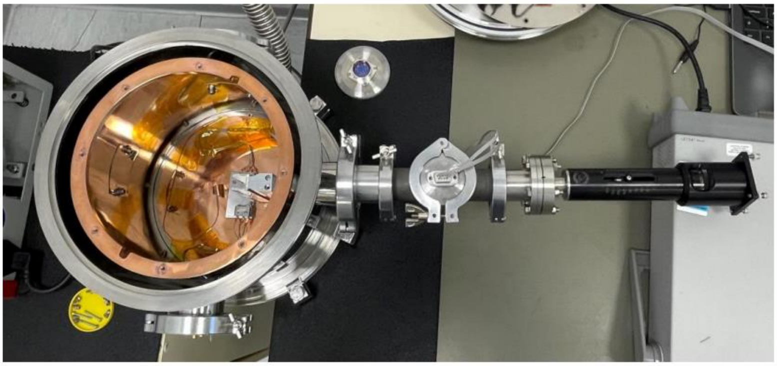


Figure 3: Closed-loop He Cryostat

The set-up makes use of a vacuum feedthrough that allows connection of the parts to the measurement equipment for monitoring the electrical characteristics (Fig.4).

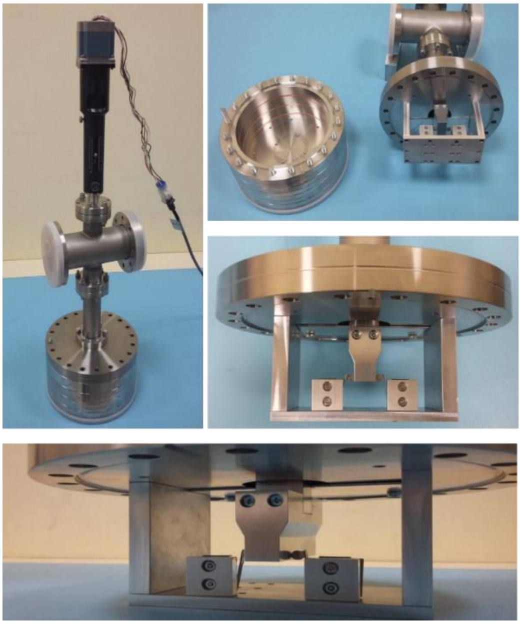


Figure 4: Feedthrough used on testing set-up

TESTING PERFORMED SO FAR AND RESULTS OBTAINED

A special case of the parts selected for testing is the microswitch manufactured by PETERCEM (FR) which will be used to know the status of the mechanism at cryogenic temperature values.
This part, previously ESCC QPL in the past, has been introduced as an alternative to Honeywell microswitch for Space, which currently has a long lead time (more than 40 weeks). On the other hand, it is still to be proven that the part manufactured by PETERCEM is able to withstand cryogenic temperatures.

For this reason, a de-risking plan, consisting of a functional verification at 40K, has been proposed by ALTER with review and agreement of the user and ESA in order to test some samples and get some de-risking results that should give some confidence before submitting this part to the proper qualification according to testing flow described above. The de-risking test results should confirm that the Petercem microswitch is a valuable alternative to Honeywell microswitch.

Figure 5:T6932 Microswitch

This component's main characteristics are as shown in Table 3.

Table 3: Main Characteristics of T6932

Characteristic	**Value**	**Units**	**Conditions**
Operating Temperature	-55 to +125	ºC	
Storage Temperature	-55 to +150	ºC	
Contacts Resistance	≤50	mΩ	
Insulation Resistance	≥1000	MΩ in 500 Vdc	In 500Vdc
Dielectric Strength between terminals	500	V	(50Hz – 1mn)
Dielectric Strength between terminals and earth	1200	V	(50Hz – 1mn)
Weight	≤6.5	g	
Operating Force	≤5	N	
Release Force	≥1	N	
Pretravel	0.35-0.70	mm	
Differential Movement	0.05-0.45	mm	
Overtravel (do not exceed in use)	≥0.20	mm	
Mechanical Life	100,000	Cycles	

On an electrical sense, the current values are as per Table 4.

Table 4: Current values per voltage level and circuit type

Circuit Type Voltage Value	Resistant	Inductive	Qualified Life
115 Vac (400Hz)	1 A	1 A (L/R < 5 ms)	10,000 cycles
28 Vdc	4 A		
3 Vdc	100 μA		
30 mVdc	10 mA		40,000 cycles

The 4 samples used for this characterization are parts in stock coming from a lot used on SENTINEL-1 mission. The date code of the parts is DC 1640.

The test flow performed for de-risking purposes is spotted in Fig.6.

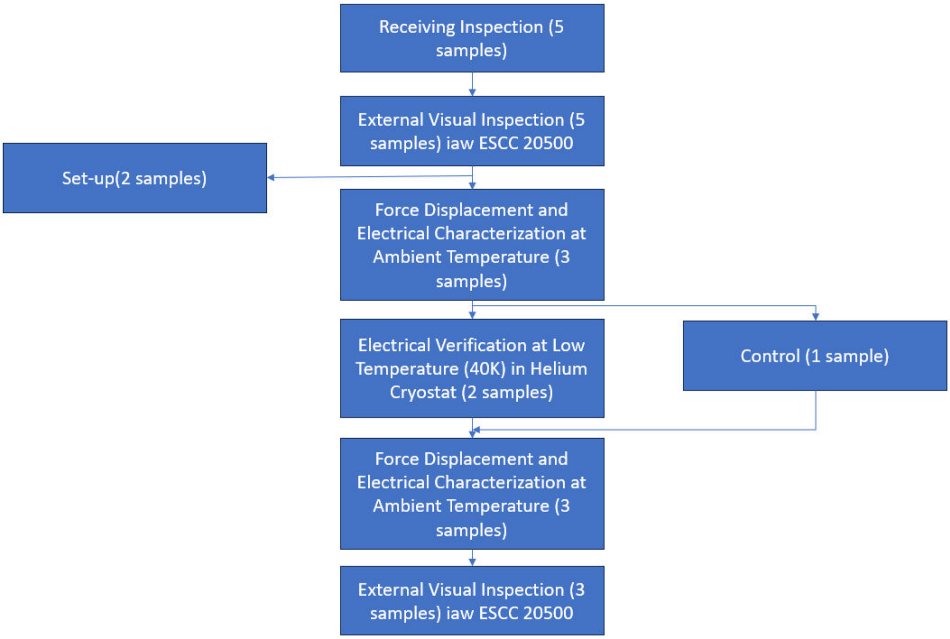


Figure 6: Testing Flow of the microswitch de-risking

Thus, the characterization of the microswitches at 40 K was done as follows:

First, the force-displacement and electrical measurement of contact resistance at room temperature without mounting the samples in the set-up is measured.

Then, samples will be placed under test in the set-up avoiding the contact with the switching tool. This is necessary to prevent the heat dissipation through the linear feedthrough.
After that, samples will be cooled until 40K.

Then, manual movement of the linear feedthrough while monitoring the electrical contacts of the switches under test (the two switches will be actioned simultaneously) will be made. The ON-OFF switching will be repeated 5 times for repeatability purposes.

Afterwards, parts will be heated again until they reach ambient temperature.

Finally, the force-displacement and electrical measurement of contact resistance at room temperature will be repeated for comparison with the first step after the cooling-heating process and results obtained will be analysed.

In relation to the test flow already described, it is presented in Fig.7 the results obtained for each step:

- Initial External Visual Inspection: None of the samples received showed any defects.
- Initial Force – Displacement (before cryogenic verification):

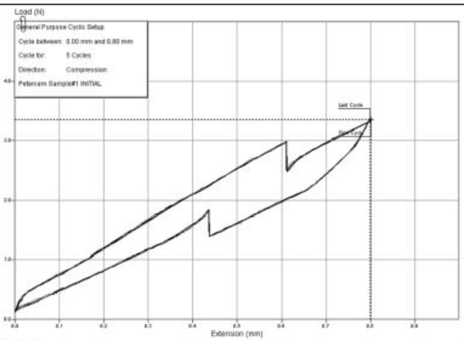
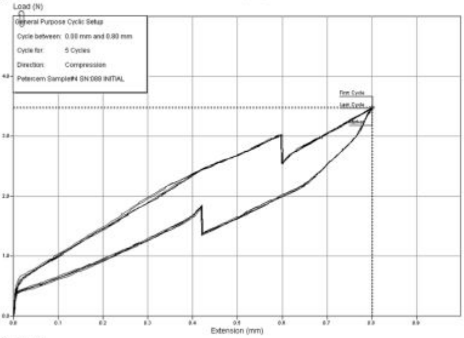
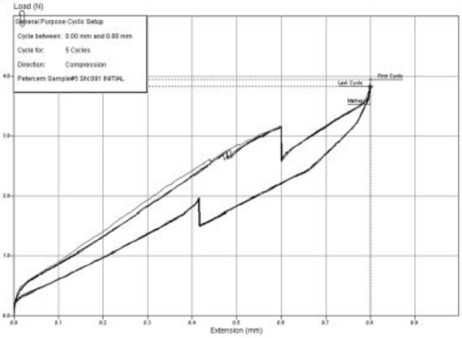
SN069 Reference Sample Extension to switch: 0.62mm Force to switch: 3.0N Extension to release: 0.44mm Force to release: 1.4N	
SN088 Sample to be verified at 40K Extension to switch: 0.60mm Force to switch: 3.0N Extension to release: 0.43mm Force to release: 1.4N	
SN091 Sample to be verified at 40K Extension to switch: 0.60mm Force to switch: 3.2N Extension to release: 0.42mm Force to release: 1.5N	

Figure 7: Initial Force-Displacement Test

- Verification at 40K: Fig.8 shows the evolution of the temperature (left axis) monitored during the cooling with the Helium cryostat and the resistance (right axis) of the NO (Normally Open) and NC (Normally Close) contacts of the two samples under test. Both samples switched properly repetitively at 40K and at room temperature before and after the cryogenic verification. Note that the resistance measurements were done with 2 wires connection and therefore it includes the wires and feedthrough resistance. An additional verification of the switching capability was performed during the cooling phase at 70K approximately to verify the correct behaviour of the setup. Two anomalies can be observed around the switching at 70k and in the end, with resistance values of 0Ω, which is not a possible value considering the measurements include wires and feedthrough resistance. The most likely cause is the manipulation of the equipment by the technician, or some reset of the measurement equipment. The graphs show that this phenomenon is common to the measurements of the two samples, which would support this theory, considering it is not an related to any of the samples, and that both of them have been measured simultaneously.

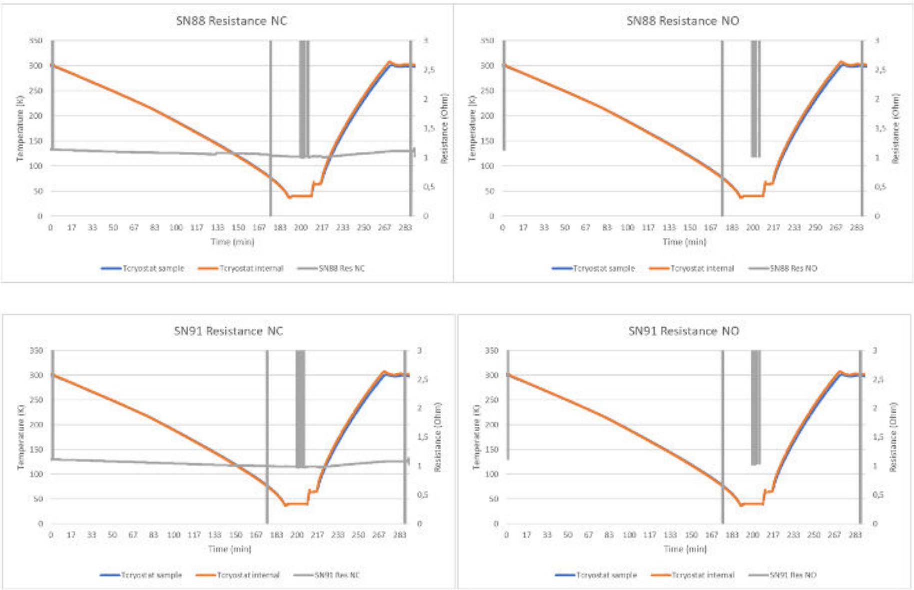


Figure 8: Temperature/Resistance over Time

Fig.8 shows that, for both samples, the NC contacts line starts at a certain value (around 1Ω) and rises to infinity when switching. On the other hand, for the NO contacts, the graphs show the opposite, starting on infinity values and going down to around 1Ω when switching. For practical purposes, the resistance scale on the graphs has been limited to 3Ω, although the data obtained shows correct values.
In relation to the resistance value obtained when contacts are closed, it is of interest to note that it is way higher than 50 mΩ, (contact resistance of the microswitch), which is in line to the fact that the measurements also account for the feedthrough and the cables resistance.

Fig. 9 shows a detail of the five times switching verification at 40K:

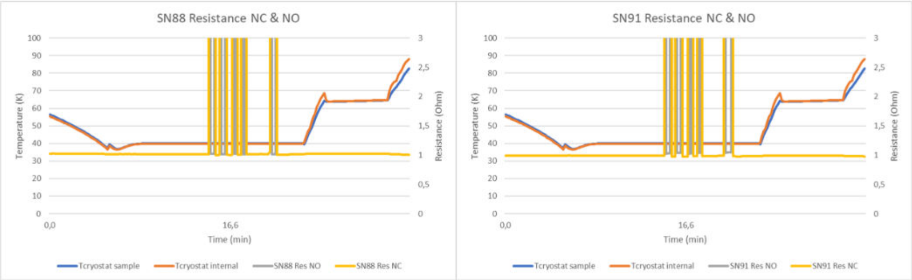


Figure 9: Details on 5-times switching

As it can be seen in Fig.9, the graphs of the NC and NO contacts matches perfectly for each of the samples.

- Final Force – Displacement (after cryogenic verification):

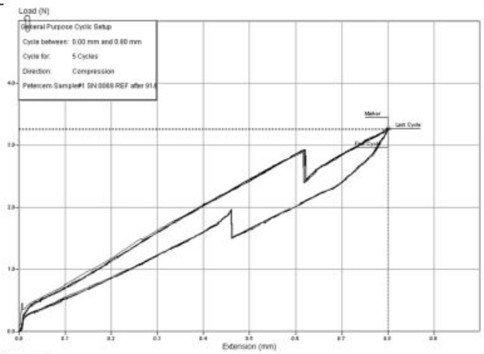
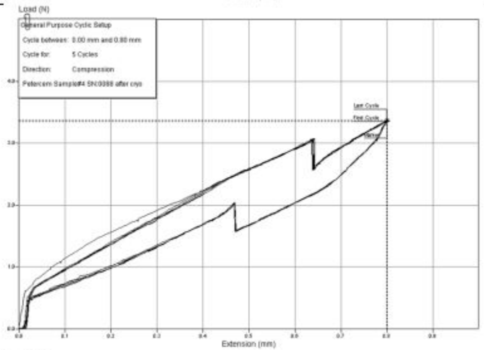
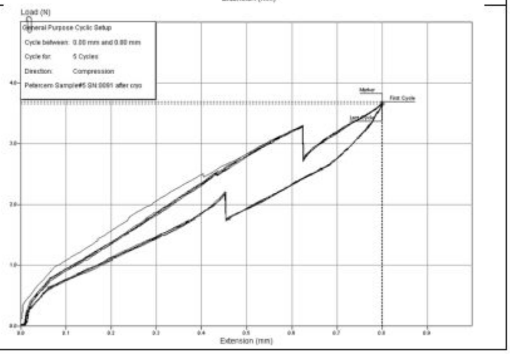
SN069 Ref Sample not submitted to cryogenic verification Extension to switch: 0.62mm Force to switch: 2.9N Extension to release: 0.46mm Force to release: 1.5N	
SN088 Sample verified at 40K Extension to switch: 0.62mm Force to switch: 3.1N Extension to release: 0.46mm Force to release: 1.6N	
SN091 Sample verified at 40K Extension to switch: 0.61mm Force to switch: 3.3N Extension to release: 0.45mm Force to release: 1.7N	

Figure 10: Final Force-Displacement Test

- Final External Visual Inspection: None of the samples showed any defects.

As it can be seen according to Fig.10 presented, the force-displacement values of each of the microswitches are not affected by the temperature, so the results obtained are quite similar between the initial and the final measurements, with little deviation.

In relation to the electrical characterization at 40K, the resistance values stay reasonably steady during the whole period of the test, even in the cryogenic temperature range, only being affected by the switching cycles.

FURTHER STEPS

ARIEL mission importance does not only relate to the characterization of Exoplanets, but also, by means of the EEE parts working in its PLM, on the characterization of passive parts working at cryogenic temperature values. This study will allow to know how passive parts manufactured within Europe, from different families, behave under these extreme conditions, which is not as known as their behaviour within the classical military temperature range of [-55ºC, +125ºC].
Therefore, when available, testing results will become a first small database of European Passive EEE parts characterization at extreme low temperatures, providing a background and valuable heritage for future missions.

Currently, ALTER is finalizing the procurement of all the candidate parts as well as preparing the set-ups for performing the testing on the candidates. Results may be presented on SPCD 2026.

On the de-risking test performed on the PETERCEM microswitch, the results obtained provide first positive feedback that can support the initial selection of the component and the procurement of the flight batch.

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