# Qualification Results for Cryogenic Temperature Testing of EEE Components in the ESA ARIEL Science Mission

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## INTRODUCTION

ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) is the 4th medium-class (M4) mission of ESA's Cosmic Vision programme. Orbiting the Sun–Earth Lagrange point L2, the mission will study the atmospheres of about 1,000 exoplanets, revealing their chemical composition, thermal structures and weather patterns. The spacecraft is composed of a warm Service Module (SVM) and a cold Payload Module (PLM), the latter reaching temperatures as low as 29 K (see Figure 1).

At the SPCD 2024 symposium, ALTER, acting as Co-ordinated Parts Procurement Agency (CPPA) for the ARIEL payload on behalf of ESA, presented the challenges and the approach for the qualification of EEE parts at cryogenic temperatures [1]. Since then, seven cryogenic test runs have been completed at ALTER facilities, covering microswitches, wires and cables, flexible heaters, Nano-D connectors, a precision chip resistor and a platinum temperature sensor, a set of ceramic and tantalum capacitors and thick-film resistors, and finally Sub-D, Micro-D connectors and splices.

The present paper reports the outcome of this campaign, with emphasis on the set-ups used, the criticalities faced and the behaviour observed on each component family, together with the lessons learnt considered relevant for future missions.

## PREVIOUSLY, ON SPCD 2024…

The 2024 paper described the background of the activity, the selection of candidates and the test flow defined for the cryogenic validation. Only a short recap is given here; for further details, the reader is referred to "Qualification Challenges and Approaches for Cryogenic

Temperature Testing of EEE Components in the ESA ARIEL Science Mission", SPCD 2024 [1].

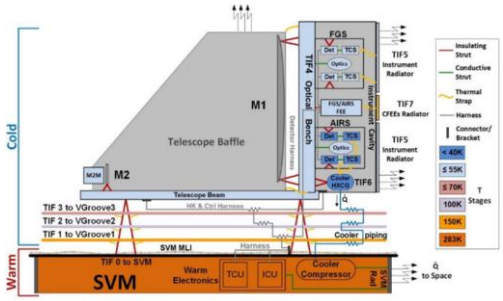



*Figure 1: ARIEL Payload description (PLM: cold Payload Module; SVM: warm Service Module)*

Table 1 gathers the PLM qualification temperature ranges applicable to the equipment hosting the parts under study, as extracted from ESA-ARIEL-PL-TN-003. These ranges drive the test conditions applied to each candidate.

*Table 1: ARIEL PLM qualification temperature ranges (ESA-ARIEL-PL-TN-003)*

| Equipment | Non-Op | Op | Safe (1) | Decon (2) |
|---|---|---|---|---|
| ACS CHX (RAL Tech), as for AIRS SCA | 29K–323K | 29K–45K | 29K–63K | 29K–240K |
| AIRS CFEE (CEA) | 37K–323K | 47K–73K | 37K–73K | 47K–175K |
| AIRS CU, excl. SCA and CFEE (CEA) | 37K–323K | 47K–63K | 37K–63K | 47K–175K |
| FGS FOM, excl. SCA and SCE (CBK) | 37K–323K | 47K–63K | 37K–63K | 47K–175K |
| Instrument Radiator (Admatis) | 37K–323K | 47K–63K | 37K–63K | 47K–175K |
| M2M Mechanism (SENER) | 37K–323K | 47K–63K | 37K–63K | 47K–175K |
| TA Baffle (Active Space) | 37K–323K | 42K–63K | 37K–63K | 42K–175K |
| TOB & optics (Leonardo / INAF) | 37K–323K | 47K–63K | 37K–63K | 47K–180K |
| VG3 (BG) | 41K–323K | 47K–68K | 41K–68K | 41K–135K |
| VG2 (BG) | 70K–323K | 75K–120K | 70K–120K | N/A |
| VG1 (BG) | 110K–323K | 115K–175K | 110K–175K | N/A |
| PIP elements: DISC (RAL Tech) & connectors (ADS, CSA/ABB) | 223K–333K | 233K–303K | N/A | N/A |

*Notes: (1) PLM safe mode case, as cold as the non-operating temperature. (2) Decontamination mode case, included in the PL design as a lesson learnt from past projects but not baselined operationally (only used if in-orbit data demonstrates it is necessary).*

From an initial list of more than 160 part types, the test candidates were selected considering the temperature values seen by each unit, the coverage of technologies and the representativeness of each candidate for its family. When a tested part covers other similar ones, the most stringent conditions of the family were retained. The candidates were then grouped into test runs in order to reduce cost and overall lead time. Table 2 lists the seven runs completed and reported in this paper.

*Table 2: Cryogenic test runs completed and test conditions*

| Run | Part type / description | Component number | Mfr. | Qty | Conditions |
|---|---|---|---|---|---|
| 1 | T6932 hermetic microswitch | ESCC 370100302B | Petercem | 3 | 37–323 K; 15,000 pulses @37 K |
| 2 | Junction cable for thermistors | ESCC 390101850 | Axon | 2 × 1 m | 37–323 K; 500h @37 K |
| | 4 × ESCC 3901/019 SPC wires + Kapton | P559699 | Axon | 1 × 2 m | |
| | CEH 2807 INOX, ePTFE/polyimide, AWG28 | P541327A | Axon | 2 × 1 m | |
| | Fluoropolymer wire, 600 V (CSWL var. 01) | ESCC 3901020401B | Axon | 3 × 1 m | |
| 3 | Heater 30×20 mm, single layer, PSA, 26AWG leads | ESCC 400900210R5789 | Zoppas (RICA) | 3 | 29–323 K; 500h @29 K |
| 4 | Nano-D 85 Titane FLEX pair | NM-225-085-225-JC00-D55 + NK-2G5-085-135-TH00-D56 | Airborn | 2 sets | 29–323 K; 500h @29 K |
| | Nano-D 85 FLEX / CFEE pair | NK-2G2-085-135-JC00-E1Q + NK-2F2-085-435-TH00-E1Q | Airborn | 2 sets | |
| 5 | PHR2010 7K98 0.1% 500 mW 25 ppm/°C | ESCC 4001023047981B2 | Vishay Sfernice | 5 | 29–323 K; 500h @29 K |
| | PT1000 QP1K0.232.2L73.B.0300 | ESCC 400601508040300 | IST | 5 | |
| 6 | 0805 2.2 nF NP0 10% 50 V | ESCC 3009003062201KC | AVX | 10 | 37–323 K; 1000 h @42 K |
| | 0805 100 nF BME X7R 10% 100 V | ESCC 300904103104KE | AVX | 10 | |
| | TAJ 2.2 µF tantalum 10% 16 V | 301200102225KC | AVX | 10 | |
| | SR1209 100 nF CRX 10% 25 V | SR1209CRX104Z1F | Presidio | 5 | |
| | CHPHR0805 4.7 Ω 2% thick film | ESCC 4001026024R70G6 | Vishay Sfernice | 5 | |
| 7 | MDM solder bucket 31 S/P | ESCC 340102902B31SFR164E + 31PFR164E | C&K | 2 sets | 29–323 K; 500h extended to 1000 h @29 K |
| | Space splice | ESCC 340109701B | C&K | 2 sets | |
| | HD Sub-D 26 pins M/F | ESCC 340100202BDAMA26PNMB + SNMB | C&K | 2 sets | |

*Qty excludes control and set-up samples. Conditions: 12 non-operating thermal cycles; extended cryogenic (life) test.*

## TEST FLOW AND EQUIPMENT

The test flow agreed with ESA and the users is shown in Figure 2 (left). The 12 thermal cycles between the maximum and minimum non-operating temperatures, performed unbiased, are intended to reproduce the thermal stress suffered by the parts just by being exposed to those temperatures. The extended cryogenic test (cryo life test) evaluates the fatigue of the parts when working biased at the minimum operating temperature. Its nominal duration of 1000 h was reduced to 500 h for thermistors, connectors and cables. For each component, dedicated calculations according to ESA-ARIEL-PL-TN-003 were used to define the applicable temperatures.

Unless otherwise stated, room temperature measurements were performed at 22 ± 3 °C and 45 ± 15% relative humidity, and a maximum drift of ±3% was used as acceptance criterion for the key parameters after each cryogenic step. No limits were specified for measurements at cryogenic temperature; these were recorded as reference values.

Testing was performed at ALTER facilities by means of two closed-loop helium cryostats with pumping system and electrical feed-through, operating in parallel on different runs (Figure 2, right). The second cryostat was acquired with dedicated support from the ESA ARIEL project in order to double the cryogenic capability and match the project needs and schedule. The main characteristics of the systems are:

- Temperature control on a large cold finger from 10 K, with sensors for control and monitoring.
- Load capacity of 22 cm diameter and 10 cm height; temperature rate below 2 K/min.
- Vacuum range from 1E-4 to 1E-7 mbar.
- Electrical feed-through for in-vacuum measurements; operation possible inside an ISO 8 clean area.




*Figure 2: Cryogenic validation test flow (left) and ALTER cryogenic laboratory with the two closed-loop He cryostats (right)*

## TEST RESULTS

### *Run 1: Microswitch T6932 (Petercem)*

Following the positive de-risking presented at SPCD 2024, four hermetically sealed microswitches with nitrogen internal atmosphere (ESCC 3701/003, date code 2402) were submitted to the full cryogenic validation sequence: three test samples and one control sample. The switches were fixed on a copper interface with their normal mounting means (2 × M2.5 screws), and each of the three contacts was wired with Kapton wires to the cryostat feed-through, allowing 4-wire contact resistance measurements in both switch positions. A linear motion feed-through and an aluminium wedge were used to actuate the plunger from outside the cryostat (Figure 3).

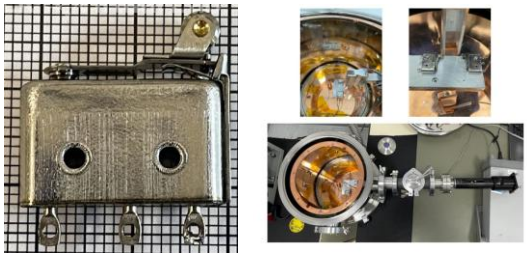


*Figure 3: T6932 microswitch (left) and actuation set-up through the linear motion feed-through (right)*

Contact resistance (C–NO and C–NC, I = 50 mA, ≤ 50 mΩ) and insulation resistance (500 Vdc, ≥ 1000 MΩ) were measured at room temperature and at 37 K, followed by 12 non-operating thermal cycles between 37 K and 323 K (30 min dwell, pressure below 1E-4 mbar). The operating life test consisted of 15,000 pulses at 37 K, one pulse being formed by a C–NC closed step and a C–NO closed step (Figure 4). Contact resistance was monitored during all pulses for the three samples.

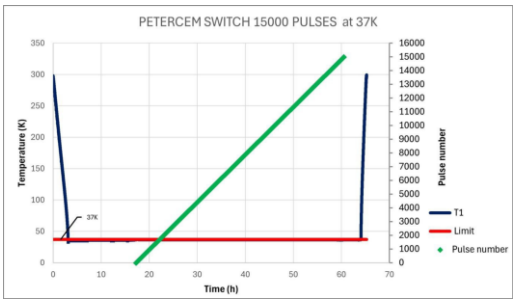



*Figure 4: Temperature and pulse count during the 15,000-pulse operating life test at 37 K*

*Table 3: T6932 contact resistance (mΩ) along the test sequence*

| Step | Contact | CTRL 2350207 | S/N 2350141 | S/N 2350142 | S/N 2350145 |
|---|---|---|---|---|---|
| Initial, RT (precision) | C–NO / C–NC | 11.5 / 13.8 | 11.7 / 11.4 | 12.1 / 11.5 | 12.4 / 13.3 |
| 37 K, after cycles (1) | C–NO / C–NC | n/a | 20.4 / 23.7 | 6.2 / 12.3 | 10.0 / 12.0 |
| 37 K, after 15,000 pulses (1) | C–NO / C–NC | n/a | 23.0 / 16.5 | 9.2 / 9.4 | 12.1 / 12.3 |
| Final, RT (precision) | C–NO / C–NC | 11.3 / 13.6 | 11.4 / 12.3 | 13.6 / 13.2 | 13.6 / 13.1 |

*(1) Measured with the samples inside the cryostat, including electrical feed-through and cables.*

All samples passed every step of the sequence, with no anomalies in visual inspection and insulation resistance. The final precision measurements at room temperature remain well below the 50 mΩ limit and close to the initial values, which confirms the de-risking results and supports the Petercem T6932 as a valid alternative to the long-lead-time microswitch initially considered.

### *Run 2: Wires and cables (Axon)*

Eight cable samples from four types were tested: ESCC 390101850 two-core cable for thermistors (two cores per sample, 1 m), the P559699 microswitch bundle made of four

ESCC 3901/019 silver-plated copper wires with Kapton (2 m), the CEH 2807 stainless-steel (INOX) AWG28 wire with expanded PTFE and polyimide insulation P541327A (1 m), and the ESCC 3901/024 fluoropolymer insulated wire 390102401B (1 m). Five samples were exposed to the cryogenic sequence and three were kept as references. The cables were fixed to a copper base plate with Kapton tape at several points and each core was connected to the feed-through.

After the measurements at 37 K and 12 cycles between 37 K and 323 K, the cables were stored for 500 h at 37 K while the DC resistance of every core was monitored with a 4-wire method (Figure 5). Table 4 summarises the main values. The resistance of the copper conductors drops to roughly 20–45% of the room temperature value at 37 K, while the stainless-steel P541327A wire shows a much smaller reduction (about 72%), as expected from its alloy composition.

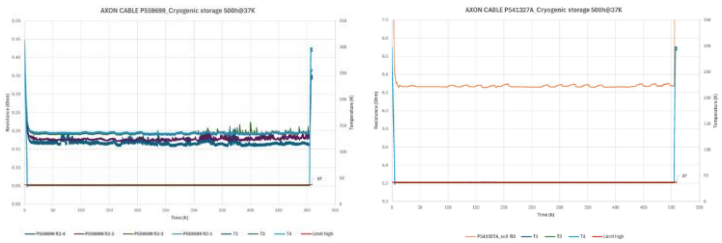


*Figure 5: Resistance during 500 h storage at 37 K: P559699 bundle (left) and P541327A INOX wire (right)*

*Table 4: Wires and cables: DC resistance (Ω, 1 m or 2 m length) and drift after the full sequence*

| Type | Initial RT | 37 K (after cycles) | 37 K (after 500 h) | Final RT | Max. drift |
|---|---|---|---|---|---|
| 390101850 (2 cores) | 0.231 | 0.087–0.138 | 0.093–0.101 | 0.229 | 1.0% |
| P559699 (4 cores, 2 m) | 0.447–0.450 | 0.172–0.200 | 0.195–0.225 | 0.443–0.447 | 1.0% |
| P541327A (INOX) | 8.304 | 5.992 | 6.273 | 8.233 | 0.9% |
| 390102401B | 0.323–0.325 | 0.049–0.113 | 0.070–0.134 | 0.322 | 0.8% |

All samples passed: drifts at room temperature remained below 1.3% at any step (limit ±3%), and no mechanical damage was detected in the final visual inspection.

### *Run 3: Flexible heaters (Zoppas Industries – RICA)*

Four ESCC 4009/002 single-layer polyimide heaters, 30 × 20 mm, with pressure-sensitive adhesive (PSA) and 26AWG leads (date code 2442A) were tested: three samples in the cryogenic sequence and one reference. Each heater was bonded with its own PSA to a 1 mm thick copper plate of the heater size. A thin layer of Apiezon® N vacuum grease was applied between the copper plate and the cryostat base plate, and heater body and leads were secured with Kapton tape (Figure 6, left). Resistance (V = 1 V, 564.48–587.52 Ω), insulation resistance (500 V, ≥ 1000 MΩ) and leakage current (500 Vrms, ≤ 2 mA) were measured.

During the 12 cycles between 29 K and 323 K (40 min dwell), the heaters were powered at 21 V (about 0.7 W) after 30 min of stabilisation at 29 K in every cycle, without anomalies. In the first cycles the ramp-down was slower due to a decrease of the helium pressure; the issue was solved and the cycles continued at the nominal rate. After cycling, one heater (SN3)

was found detached from the copper substrate due to failure of the PSA adhesive, while all electrical measurements passed.

The 500 h storage at 29 K was performed monitoring the resistance with 1 V in a 4-wire connection, with a daily switch-on at 21 V (21 switch-on events in total, no anomalies). When the Kapton tape was removed at the end of the test, the lead insulation add-on of SN4 was completely detached from the heater body, while SN2 and SN3 showed cracks and slight detachment on the periphery of the same material (Figure 6, centre and right). The solder joints did not show cracks. As shown in Table 5, the electrical behaviour was very stable: resistance at 29 K was 1.6–2.8% below the room temperature value and the final measurements passed, insulation resistance and voltage proof of SN4 being measured on the heater area only.

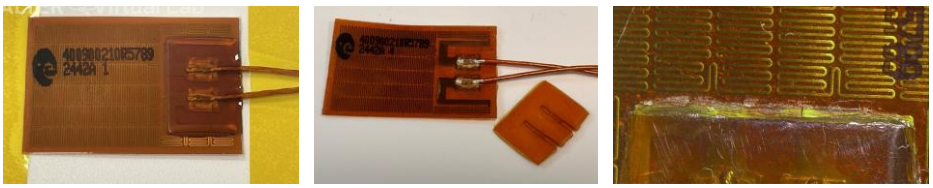


*Figure 6: Heater before test (left), SN4 lead insulation detached (centre) and peripheral cracks on the lead insulation add-on (right)*

*Table 5: Heater resistance (Ω) along the sequence*

| Step | SN1 (ref.) | SN2 | SN3 | SN4 |
|---|---|---|---|---|
| Initial, RT | 574.83 | 586.03 | 582.20 | 583.21 |
| 29 K, initial (drift vs RT) | – | 570.36 (−2.7%) | 573.11 (−1.6%) | 567.40 (−2.8%) |
| RT after 12 cycles | 575.14 | 586.13 | 582.25 | 583.16 |
| 29 K after 500 h (drift vs RT) | – | 573.31 (−2.2%) | 570.83 (−2.0%) | 572.26 (−1.9%) |
| Final, RT | 575.41 | 586.48 | 582.64 | 583.52 |

The functional performance at cryogenic temperature is therefore confirmed, but two mechanical weaknesses were identified: the PSA is not suitable to guarantee the heater attachment at these temperatures, and the lead insulation add-on is sensitive to long cryogenic exposure. As a result, the users will secure the heaters by mechanical means or potting, and a modified design using Kapton FEP and Teflon FEP film as lead insulation (ESCC 4009/002 variant 10, 42 × 20 mm) will be tested.

### *Run 4: Nano-D connectors (Airborn)*

Two pair types of 85-way Nano-D connectors were tested (two mated pairs each): the Titane FLEX pair NM-225-085-225-JC00-D55 + NK-2G5-085-135-TH00-D56 and the FLEX/CFEE pair NK-2G2-085-135-JC00-E1Q + NK-2F2-085-435-TH00-E1Q, procured to EEE-INST-002 Section C2. The connectors were soldered on individual PCBs, mated in pairs and all contacts were connected in one daisy chain, with 20 cm cables used to measure the chain resistance and the insulation resistance (100 Vdc, ≥ 1000 MΩ) between the chain and the chassis (Figure 7, left).

The pairs were measured at 29 K, cycled 12 times between 29 K and 323 K (30 min dwell) and stored for 500 h at 29 K (+0/−10 K) with continuous monitoring of the four chain resistances (Figure 7, right). All samples passed all the electrical measurements and visual inspections, and no anomalies were observed. It is noted that insulation resistance at 29 K could not be measured reliably, since the connector chassis was in physical contact with the

metallic base plate of the cryostat; this measurement was therefore only considered at room temperature.

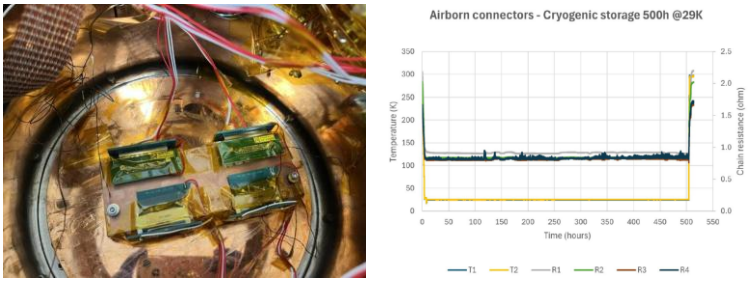



*Figure 7: Nano-D pairs installed in the cryostat (left) and daisy-chain resistance during 500 h at 29 K (right)*

### *Run 5: PHR2010 precision resistor and PT1000 platinum sensor*

The fifth run combined two part types used for temperature sensing and precision signal conditioning in the payload: five PHR2010 7.98 kΩ 0.1% 500 mW 25 ppm/°C precision chip resistors (Vishay Sfernice, ESCC 4001023047981B2) and five PT1000 platinum resistance sensors QP1K0.232.2L73.B.0300 (IST, ESCC 400601508040300). One additional sample of each type was kept as control. The test sequence was the same as for the rest of candidates, with 12 thermal cycles between 29 K and 323 K followed by a 500 h extended cryogenic test at 29 K, the reduced duration applicable to thermistors.

The initial electrical measurements at room temperature are summarised in Table 6. The PHR2010 resistance was measured in 4-wire configuration, and the PT1000 resistance with a maximum measurement current of 0.3 mA in order to avoid self-heating. All six samples of each type, including the controls, were accepted.

*Table 6: PHR2010 and PT1000: room temperature electrical parameters*

| # | Test | Conditions | Min | Max | Unit | Accept | Reject |
|---|---|---|---|---|---|---|---|
| 1 | R (PHR2010) | 4-wire auto-ohm | 7972.02 | – | Ω | 6 | 0 |
| 2 | R (PT1000) | I max = 0.3 mA | 998.82 | 1001.17 | Ω | 6 | 0 |
| 3 | IR | 100 V (±10%) | 100 | – | MΩ | 6 | 0 |

The mounting of the sensors was one of the key aspects of this run (Figure 8). The PT1000 sensors were mounted on a thin copper interface (1 mm) following the user's request in order to reproduce the two mounting methods foreseen in flight: two samples were bonded with Stycast 2850 (catalyst 9) epoxy, and the remaining three samples were placed in direct contact with the copper plate and held with Kapton tape and vacuum grease. The copper interface carrying the samples was then screwed to the helium cryostat base, vacuum grease being added to improve the thermal conductivity between copper plate and chamber base plate. The PHR2010 resistors were soldered on a dedicated test PCB.

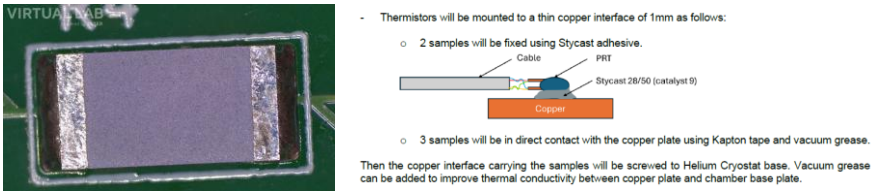



*Figure 8: PHR2010 resistor on the test PCB (left) and PT1000 mounting scheme agreed with the user (right)*

The 12 thermal cycles between 29 K and 323 K were completed in about 130 hours, with the samples unbiased. The parts were afterwards stored for 500 h at 29 K, with the electrical parameters measured in-situ. No electrical anomalies were reported on any of the samples during the whole sequence, either at cryogenic temperature or in the final measurements at room temperature, which confirms that both the PHR2010 resistor and the PT1000 sensor are electrically suitable for operation at the lowest ARIEL temperatures.

The relevant finding came from the final visual inspection. After the life test, and after cleaning the samples with IPA, a lack of adhesion was observed on the sensors mounted with Stycast (Figure 9, centre and right). Since the electrical behaviour of the sensors was not affected, the finding is attributed to the mounting process rather than to the components themselves. The lesson learnt is that the attachment method of a sensor must be qualified together with the part.

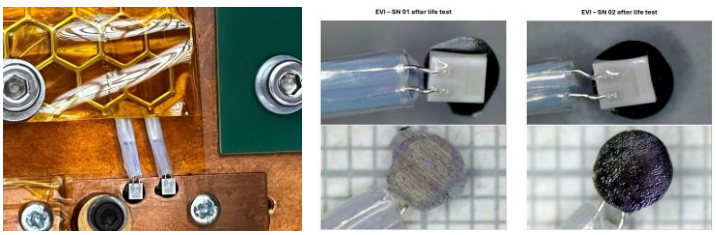



*Figure 9: PT1000 samples on the copper interface (left) and Stycast-mounted sensors SN01 and SN02 after the cryo life test (centre, right)*

### *Run 6: Ceramic and tantalum capacitors and thick-film resistors*

This run, the most populated of the campaign, gathered 44 samples of five part types (Table 2): ten 0805 2.2 nF NP0 capacitors (C1, ESCC 3009/003, date code 2336), ten 0805 100 nF BME X7R capacitors (C2, ESCC 3009/041, date code 2327), five SR1209 100 nF CRX cryogenic ceramic capacitors (C3, Presidio, MIL-PRF-123 based, date code 2323), ten TAJ 2.2 µF 16 V case B tantalum capacitors (C4, ESCC 3012/001, date code 2326) and five CHPHR0805 4.7 Ω thick-film resistors (R, ESCC 4001/026, date code 2449), plus one control sample per type except C3.

The 40 test parts were soldered on a single round test board fitted to the cryostat cold plate. The design of this set-up was complex: the use of the same materials and representative processes as the users was considered of utmost importance, which required several iterations with the users, and the boards were assembled by an ECSS-Q-ST-70-61C qualified assembly house.

Room temperature limits and conditions were those of the applicable ESCC specifications (e.g. 90–110 nF at 1 kHz for C2). For C3, no room temperature capacitance limit is defined, since its 100 nF value is specified at 77 K. All 44 parts passed the initial inspection and measurements.

At 42 K, two behaviours stood out (Figure 10). The BME X7R capacitors (C2) dropped to a mean of 24.0 nF, about 25% of their room temperature value, with individual values between 19.4 and 30.5 nF. This is the expected behaviour of the Class II X7R dielectric, whose permittivity is strongly temperature dependent and only characterised down to 218 K. Conversely, the CRX capacitors (C3), which measure about 20.3 nF at room temperature, rose to 123–223 nF at 42 K. NP0, tantalum capacitors and thick-film resistors showed no remarkable behaviour.

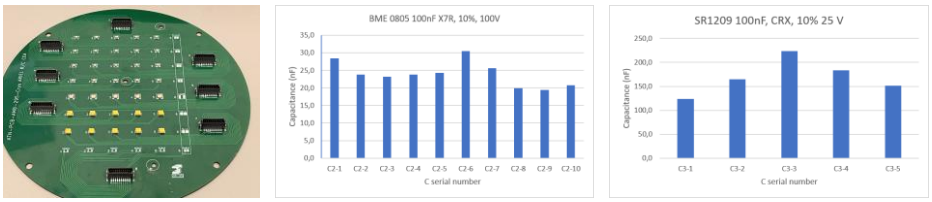



*Figure 10: Test board before assembly (left) and capacitance at 42 K of C2 BME X7R (centre) and C3 SR1209 CRX (right)*

The CRX behaviour is consistent with the design intent of this dielectric, optimised for cryogenic operation: as shown in the manufacturer curve of Figure 11 (left), its capacitance increases steeply as temperature decreases below 100 K and peaks around 20–30 K.

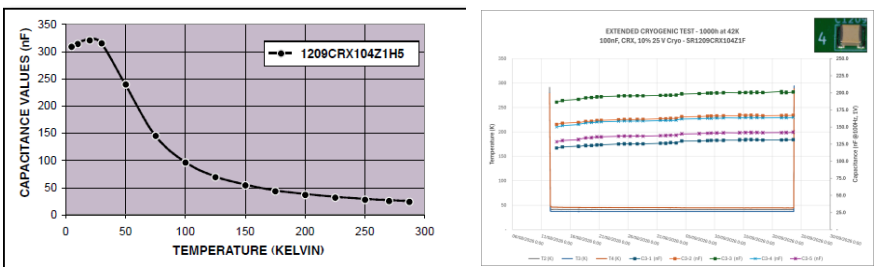



*Figure 11: Capacitance vs temperature of the CRX dielectric (left) and C3 capacitance during the 1000 h life test at 42 K (right)*

After the 12 unbiased cycles between 37 K and 323 K, the C2 capacitance at room temperature showed a drift larger than 3% in nine out of ten samples, and three of them (89.4, 89.7 and 89.9 nF) fell slightly below the 90 nF lower limit, while the control sample measured 98.0 nF. The remaining part types passed both the limits and the drift criterion; C3 returned to its usual value of about 20 nF. No anomalies, and in particular no cracks in the ceramic bodies or the solder joints, were observed in the visual inspection.

The 1000 h extended cryogenic test at 42 K was performed with capacitance and resistance measured each working day. No failure was detected. A slight decrease of capacitance was observed on all ten C2 samples, while all five C3 parts showed a significant and steady increase of capacitance over the test duration (Figure 11, right). At the end of the test, the values at 42 K were similar to those recorded before the thermal cycles for all part types. Table 7 summarises the evolution of the two capacitor types showing a remarkable behaviour.

*Table 7: Evolution of C2 (BME X7R) and C3 (CRX) capacitance along the test sequence (nF; ≈ values read from charts)*

| Step | C2 BME X7R (10 pcs) | C3 CRX (5 pcs) | Remarks |
|---|---|---|---|
| RT, initial | Within 90–110 | ≈ 20.3 | All parts pass |
| 42 K, initial | 19.4–30.5 (mean 24.0) | 123.3–223.4 | C2 ≈ 25% of RT value |

| Step | C2 BME X7R (10 pcs) | C3 CRX (5 pcs) | Remarks |
|---|---|---|---|
| RT, after 12 cycles | 89.4–94.5 | ≈ 20 | C2: 3 pcs < 90 nF, 9 pcs drift > 3% |
| 42 K, after 1000 h | ≈ 20.8–28.2 | ≈ 132–201 | Similar to initial 42 K values |
| RT, final | ≈ 88.4–93.5 | 20.03–20.62 | C2: 4 pcs < 90 nF, 10 pcs drift > 3% |

In the final measurements at room temperature, all parts were within their limits except four C2 capacitors slightly below 90 nF (Figure 12, right), and all ten C2 samples exceeded the 3% drift with respect to the initial values. C1, C3, C4 and R passed all parameters and drift criteria, and the final visual inspection of the 44 parts showed no anomalies.

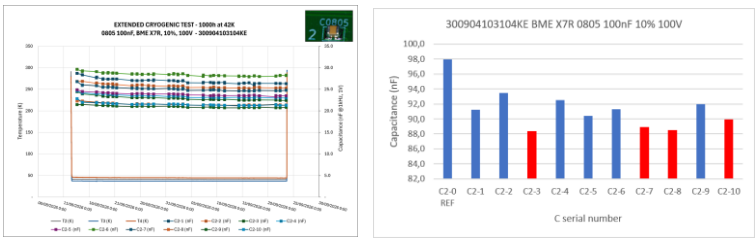



*Figure 12: C2 capacitance during the 1000 h life test at 42 K (left) and C2 capacitance at RT after the life test, out-of-limit values in red (right)*

The permanent decrease of a few percent of the BME X7R capacitance at room temperature, together with the 75% loss at 42 K, confirms that these capacitors can only be used at cryogenic temperatures where the circuit tolerates a large capacitance variation, whereas NP0 and CRX dielectrics are preferred for stable or cryogenic-optimised applications, respectively.

### *Run 7: Sub-D, Micro-D connectors and splices (C&K)*

The last run included three interconnection items from C&K, two sets each (Figure 13): MDM 31-way solder-bucket Micro-D connectors (ESCC 340102902B31SFR164E socket + 340102902B31PFR164E pin), high-density 26-way Sub-D connectors (ESCC 340100202BDAMA26PNMB male + 340100202BDAMA26SNMB female) and space splices (ESCC 340109701B).



*Figure 13: Micro-D 31 S/P solder bucket pair (left), HD Sub-D 26 male (centre) and connectors and splices installed in the cryostat (right)*

The set-up was not complex but laborious. The solder-bucket Micro-Ds were wired by a qualified assembly house, and all connectors were mated and prepared with cables so as to connect all pins in one daisy chain per mated pair. The daisy-chain resistance was measured with a precision ohmmeter in a 4-wire connection (I = 20 mA) through the helium cryostat electrical feed-through, and the insulation resistance between contact chain and chassis at 100 Vdc for 60 s (≥ 1000 MΩ). As the chain resistance is expected to be in the range of ohms,

no limits were specified: initial values were recorded as reference for the subsequent measurements. A copper L-shaped piece was used to mount the connectors as on a panel, reproducing their flight mounting, and the splices were fixed to the copper plate with Kapton tape (Figure 13, right).

All connectors met their specifications at room temperature and at 29 K. As shown in Table 8, the behaviour of the chain resistance at 29 K differed between technologies. It increased with respect to room temperature for the Sub-D connectors and for the splices, while it decreased for the Micro-D connectors. A reduction is expected from the lower resistivity of the conductors; the increase on Sub-Ds and splices suggests that the contact interface resistance dominates for these items. In all cases the values remain below 0.5 Ω for the complete chain.

*Table 8: Daisy-chain contact resistance at room temperature and 29 K (Ω, values read from test chart)*

| Item | Room temperature | 29 K | Variation |
|---|---|---|---|
| Micro-D 31, set 1 | ≈ 0.45 | ≈ 0.35 | ≈ −22% |
| Micro-D 31, set 2 | ≈ 0.46 | ≈ 0.37 | ≈ −20% |
| HD Sub-D 26, set 1 | ≈ 0.22 | ≈ 0.31 | ≈ +40% |
| HD Sub-D 26, set 2 | ≈ 0.23 | ≈ 0.26 | ≈ +13% |
| Splice | ≈ 0.06 | ≈ 0.11 | ≈ +80% |

The 12 thermal cycles were completed in about 75 hours. After cycling, the Sub-Ds and splices passed the visual inspection and the electrical measurements at room temperature. Both Micro-D socket connectors, however, showed cracks in the pink fluorosilicone elastomer interfacial seal, while still passing the electrical measurements (Figure 14). The cracking is most likely related to the stiffening of the elastomer at cryogenic temperature combined with the repeated thermal excursions.

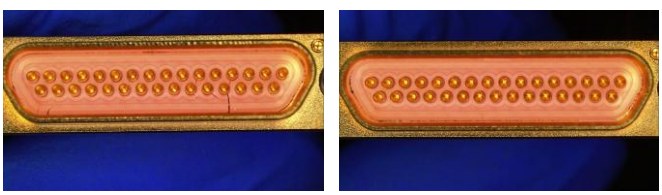


*Figure 14: Cracks in the fluorosilicone interfacial seal of the two Micro-D socket connectors after thermal cycling*

The Nonconformance Review Board (NRB) analysed the finding and decided to continue with the cryogenic life test, and to extend it from 500 h to 1000 h. The rationale was that the isolation at contact level is ensured by the LCP (liquid crystal polymer) insulator of the pin connector, so the seal cracking is not expected to compromise the electrical function. The 1000 h test at 29 K was completed without anomalies in the continuous monitoring of the contact resistance. The final visual inspection is the last pending step.

As lessons learnt, the polymeric and elastomeric materials of connectors, rather than their contacts, are the most sensitive elements at cryogenic temperatures.

## SUMMARY OF RESULTS

*Table 9: Summary of the cryogenic validation results*

| Run | Parts | Conditions | Result |
|---|---|---|---|
| 1 | Petercem T6932 microswitch | 37K–323K; 15,000 pulses @37K | PASS. No anomalies. |
| 2 | Axon wires and cables (4 types) | 37K–323K; 500 h @37K | PASS. Drift < 1.3%. |
| 3 | RICA flexible heater, PSA | 29K–323K; 500 h @29K | Electrical PASS. PSA detachment (1 pc) after cycles; cracks / detachment of lead insulation add-on after life test. |
| 4 | Airborn Nano-D 85 (2 pair types) | 29K–323K; 500 h @29K | PASS. No anomalies. |
| 5 | PHR2010 resistor and PT1000 sensor | 29K–323K; 500 h @29K | No electrical anomalies. Lack of adhesion of Stycast-mounted parts. |
| 6 | NP0, BME X7R, CRX, tantalum capacitors and thick-film resistors | 37K–323K; 1000 h @42K | PASS except BME X7R: ~25% of RT value at 42 K, > 3% drift and 4 pcs slightly < 90 nF at RT. No cracks. |
| 7 | C&K Micro-D, HD Sub-D, splice | 29K–323K; 1000 h @29K | Electrical PASS. Cracks in Micro-D socket interfacial seal after cycles. |

## CONCLUSIONS AND FURTHER STEPS

The ARIEL cryogenic validation campaign has produced a significant set of results for passive components widely used in space missions, for which data at temperatures down to 29 K were scarce compared with the classical [−55 °C, +125 °C] range. Most of the tested families showed a stable electrical behaviour, and the most relevant findings were related to materials and assembly rather than to the electrical function of the parts. The main lessons learnt are:

- Cryogenic effects on passive (and active) devices should not be underestimated, in particular on adhesives, elastomers and insulation add-ons.
- Temperature-dependent dielectrics must be considered at design level: BME X7R capacitors lose about 75% of their capacitance at 42 K, while CRX capacitors increase their value.
- Representative test conditions must be agreed early with ESA and the users, and the test set-up must use the users' materials and processes: "test as you fly, fly as you test".
- Planning is key: set-ups, assembly and the availability of cryostats drive the schedule of such campaigns.
- When extreme temperature testing is not within one's field of expertise, support from specialised laboratories should be sought.

The activity continues in 2026–2027 with the testing of Axon ND2SA15 Nano-D 15-way connectors (500 h at 29 K), the modified RICA heater with Teflon FEP lead insulation (ESCC 400900210R6186, 500 h at 29 K) and the Texas Instruments OPA2192ID precision operational amplifier (cycles 37–323 K and 1000 h at 47 K). Together, these results are building a first database of European passive EEE parts characterised at extreme low temperatures, providing valuable heritage for future missions.

## REFERENCES

[1] M. Morales, M. Sánchez, L. A. Farhat, “Qualification Challenges and Approaches for Cryogenic Temperature Testing of EEE Components in the ESA ARIEL Science Mission”, SPCD 2024.

## ACKNOWLEDGEMENTS

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