Qualification of Commercial Off-The-Shelf Supercapacitors for Space Applications

3rd Space Passive Component Days (SPCD), International Symposium

9-12 October 2018
ESA/ESTEC, Noordwijk, The Netherlands

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INTRODUCTION

Supercapacitor is a product which fills the gap between batteries and capacitors, featuring very high power density (up to 100kW/kg) with lower stored energy than that of batteries (up to 7 Wh/kg).
This paper is focusing on small size supercapacitors enhancing power densities ≤ 15 kW/kg.
This technology is already widely used in various industrial, automotive and aeronautic applications.

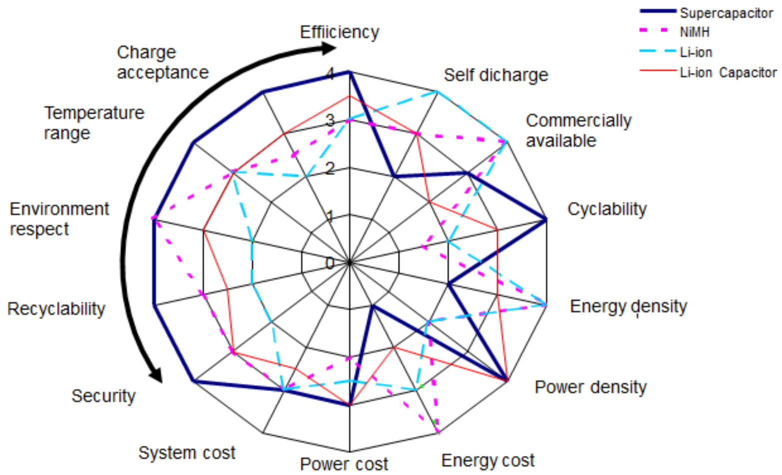

Fig. 1. Supercapacitor, a safe and efficient storage component compatible with large temperature ranges

Its fast charge and discharge time, its ability to withstand millions of charge / discharge cycles and its wide range of operational temperature (-40°C to +70°C) makes it a perfect candidate for several space applications (launchers and satellites) as demonstrated in ESA Study Contract No. 21814/08/NL/LvH entitled “High Power Battery Supercapacitor study” completed in 2010 by Airbus D&S. From the most promising ones, it can be quoted: optimization of pyrotechnical activation system, high power mechanisms, electrical thrust vector control, high power radar supply or even hybridization of Supercapacitor banks with Li-Ion batteries.
The number of known flight demonstration is very low. This is partially linked to the fact that there are currently no parts available at space grade.

TEST CAMPAIGN OF 10F NESSCAP® SUPERCAPACITORS FOR THE ENTRY IN EPPL II

Components selected and frame of the activity

A previous activity [1] has demonstrated the interest and suitability of COTS supercapacitors for space applications. In particular, this activity has highlighted the excellent performances of the 10F components from Nesscap® in terms of ageing when submitted to life test and space environments including vacuum at both cell and system levels and enabled to identify the part as a good candidate for future space qualification.

Nesscap® is a company based in Korea which has manufactured for more than 10 years a wide range of high performances supercapacitors used in several industrial domains.

Nesscap® has improved the 10F part to enhance its sealing performances including urethane coating around leads, anodization of the lead part attached to the electrode and improvement of the rubber bung. This improved XP product was released to the general public (available in mass production) in April 2016. Moreover, in case of any change in the material, process or design of the part, Nesscap® will submit a PCN for approval.

Fig. 2. Nesscap® EHSR 0010C0-002R7UC (10 F)

The current on-going activity under ESA Study Contract No. 4000115278/15/NL/GLC/fk entitled “Generic Space Qualification of 10F Nesscap Supercapacitors” consists in two main activities. First to perform an official test campaign on Nesscap ESHSR-0010C0-002R7UC parts in order to have the part introduced into ESA EPPL Part2. Second to develop and qualify the associated Bank Of SuperCapacitor, a generic and modular unit including components parallel/series arrangements compatible with several space systems.

In 2017, Maxwell acquired Nesscap. But former Nesscap products are going to be continued as before. Only the sleeve will change and both part numbers (Maxwell & Nesscap PN) will be printed. The products will stay in production in the Korea facility.

The new name of the component ESHSR-0010C0-002R7UC will become BCAP0010 P270 X01.

Screening tests

In the frame of the activity, a batch of 3.000 parts of Nesscap® EHSR 0010C0-002R7UC has been procured.

The first step of the activity consists in parts screening.

- Visual inspection
- Initial characterisation
- Vacuum exposure
- Intermediate characterisation
- Burn-in
- Final characterisation

For that purpose, EGGO Space has developed specific test facilities so that to perform the screening of a 200 parts batch in one month.

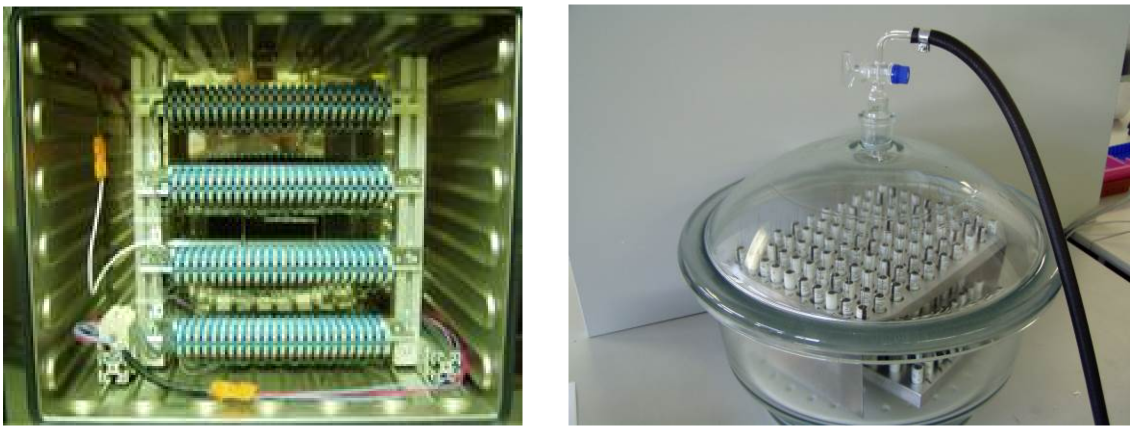

Fig. 3. EGGO supercapacitors screening facilities - burn-in (left) and vacuum (right)

<u>Screeening status :</u>
Screened 2400 pcs
Rejected Visual Inspection: 77 pcs
Rejected by screening : 3 pcs capacitance, 1pc ESR, 7 pcs mechanical defects

Test campaign for the entry in EPPL II

The test campaign including the tests listed hereunder are foreseen

- Initial and final electrical characterization (80 parts)
    - Capacity determination
    - ESR measurement (DC and AC impedance)
    - leakage current
- Technology analysis assessment (5 parts):
    - External inspection ESCC2263000 issue 2
    - X –Ray inspection MIL STD 202 method 209
    - Solderability MIL STD 202 test method 208
    - Dimensions ESCC2263000 issue 2
    - Resistance of the terminals MIL STD 202 method 208
    - Internal visual inspection
- Outgassing test (5 parts) : ECSS-Q-ST-70-02
- Mechanical and Thermal tests (10 parts)
    - X –Ray inspection MIL STD 202 method 209
    - Vibration MIL STD 202 test method 204D
    - Shock MIL STD 202 test method 213
    - Fast temperature transients MIL STD 202 test method 107
    - Seal test MIL STD 202 test method 112
    - Technology analysis assessment
- Life test (60 parts)
    - Calendar test (success criteria @ 2000h)
        - 20 parts at 0,9*Vop and @ 50°C
        - 20 parts at 0,9*Vop and @ 60°C
    - Cycle life tests
        - 20 parts at continuous 100% energy cycling
    - Vacuum life test
        - 800 parts to be tested during 18000 h in floating life test under vacuum at +55°C. at 0.85Vop

All the tests have successfully been passed. The only test that is on-going is the vacuum life test on 800 parts.

Vaccum life test and reliability

The curves below, gives an overview on the life tests results on the 800 after 15000 h in floating life test under vacuum at +55°C. at 0.85Vop :

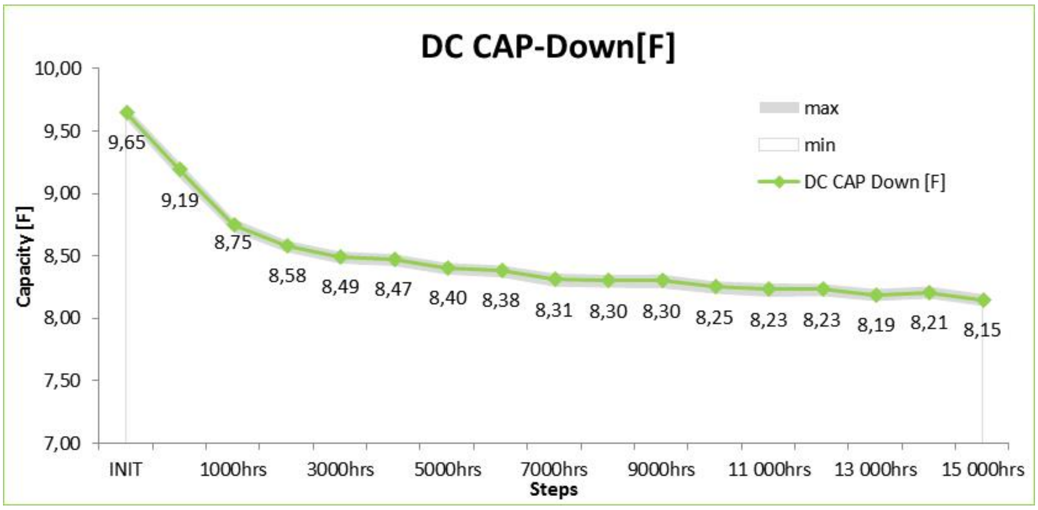

Fig. 4. Capacitance decrease during vacuum life test

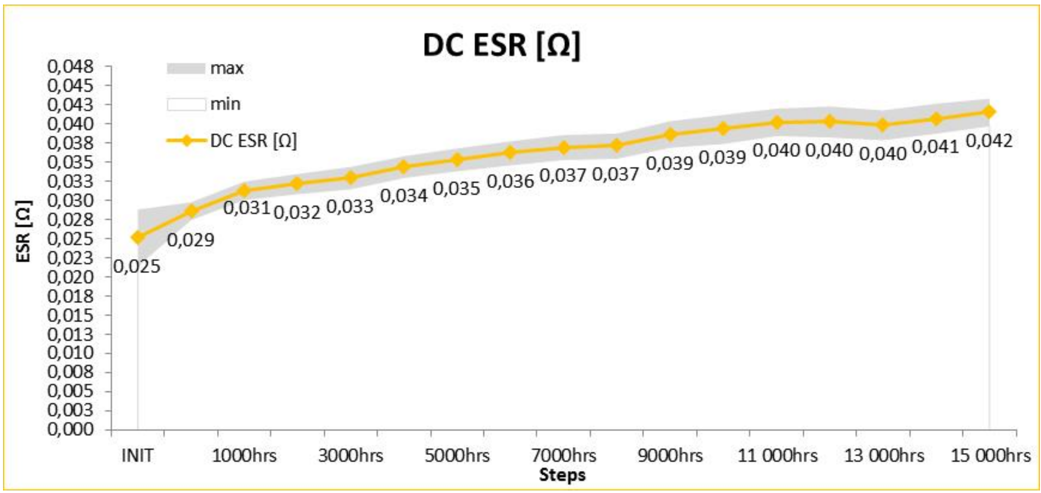

Fig. 5. DC ESR increase during vacuum life test

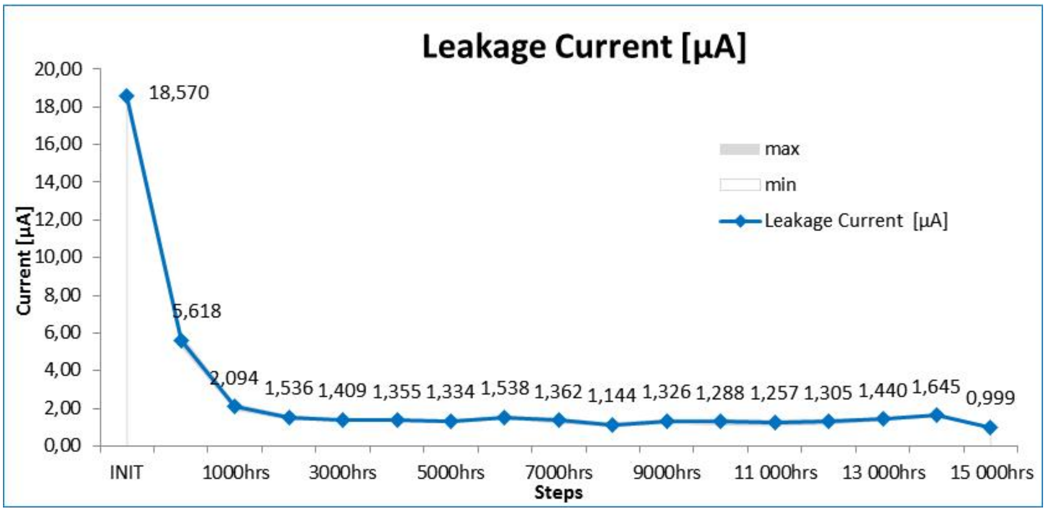

Fig. 6. Leakage current decrease during vacuum life test

After 11 000h of life test without failure, the reliability rate demonstrated is 32 FIT for one supercapacitor

Next steps

The vaccum testing for MTBF determination will continue up to 18000 hours.

Two specifications are being currently written at ESCC template :

- SUPERCAPACITORS, EDLC (Electric Double Layer Capacitor) - ESCC Generic Specification
- SUPERCAPACITORS, BASED ON TYPE ESHR-0010C0-002R7UC from NESSCAP (BCAP 0010 P270 X01 from Maxwell) upscreened for space application - ESCC Detail Specification

DESIGN AND QUALIFICATION OF A BOSC BASED ON 10F NESSCAP® SUPERCAPACITORS FOR SPACE APPLICATIONS

In the frame of the project entitled “Generic Space Qualification of 10F Nesscap Supercapacitors”, a development and qualification of associated BOSC based on Nesscap 10F is on-going. A generic and modular unit including components parallel/series arrangements compatible with several space systems has been designed.

Design status
The electrical and mechanical designs of the BOSC are completed.
Materials and process activities are on-going
The main BOSC performances are given in the table below:

Parameter	Performance
Maximum voltage in operational mode	72V
Minimum capacitance BoL	0.73F
Minimum capacitance EoL	0.62F
Maximum internal resistance BoL	377mΩ
Maximum internal resistance EoL	700mΩ
Weight	1.43kg
Dimensions	189m x 116mm x 57mm

Fig. 7. BOSC main characteristics

Electrical testing of EM BOSC
An EM BOSC has been manufactured and tested electrically.

Fig. 8. EM BOSC

The BOSC behaves as expected and the main testing conclusions are reported below:

- It was verified by the test, that NTC thermistors are functional.
- Total capacitance of the BOSC unit was measured and estimated to 0.878 F at ambient temperature.
- Balance and Serial resistances are correct values there’s no abnormal status observed.
- Capacity of each capacitors verified functionality of each capacitor separately. No problem with any cell was found.
- During inrush test, no voltage difference between each cell higher than 120 mV was recorded.
- Steady power consumption was estimated after one hour to 474,5mW at voltage level 72V.
- ESR of the BOSC was measured to 248 mΩ.

- Bonding tests verified all electrical connection between mechanical parts, maximum resistance was 1.8 mΩ at the position “Case of the connector JB3”.
- Isolation test verified that specified points have higher resistance than 100 MΩ. Capacity of the chassis to positive or negative pole was about 0.43 nF.

Materials and process activities - Background
Supercapacitors are quite sensitive components to mechanical stress, especially if applied to their leads. Some kind of mechanical fixing to the PCB had to be solved, to avoid any mechanical stress. It was quite challenging to take into account all the aspects of the specific requirements, manufacturability and repeatability of the manufacturing process, all in accordance with ECSS standards to obtain final product with maximum quality.
Potting was chosen as the only possible solution, especially due to limited physical dimensions, which were required. Potting ensures appropriate mechanical fixing of the supercapacitors and provides thermal interface to withdraw heat from the capacitors. Thermally conductive potting material can easily withdraw the supercapacitor’s heat and transfer it into the satellite structure. Heat transfer out of the BOSC unit was also crucial to consider as supercapacitors have limited operating temperature range (-40°C up to +65°C). Keeping the temperature as low as possible also extends life of the unit and slows down the supercapacitors ageing.

Initial Potting Solution
ECOBOND 285 was chosen for potting as it covered all the needed requirements. BDS/CSRC has a lot of experience and heritage with this adhesive, mainly used for thermal applications to heatsinks, frames, PCBs etc. In general, EC285 has very good thermal properties.
Justified concern was about the viscosity of the adhesive, viscosity is quite high to perform and establish potting process. In most cases, thermally conductive adhesives have higher viscosity than thermally non-conductive adhesives. Potting process was finally established using electronic dispenser. Although the potted layer was not consistent and smooth, it was sufficient for this application, see Fig. 1 and Fig. 2.

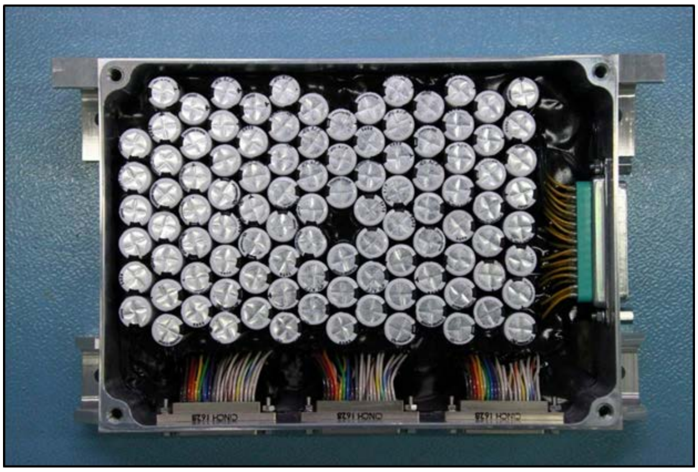

Figure 1 - Potted unit

Figure 2- Potted unit - detail.

First Qualification Test and Results

The BOSC unit was subjected to thermal cycling. After thermal cycling, tiny crack was found all around the perimeter of the BOSC housing, see Fig. 3 and Fig. 4. Paper sheet was unable to fit in, however, CT scan later revealed that the crack was going all long the housing of the potted layer, see Fig. 5, Fig. 6 and Fig. 7. Reason for the crack was probably different coefficients of thermal expansion. Elasticity of the adhesive should be also considered when selecting suitable candidate for potting as after the curing process, the adhesive becomes solid and not elastic at all.

Figure 3- Tiny crack along the housing wall.

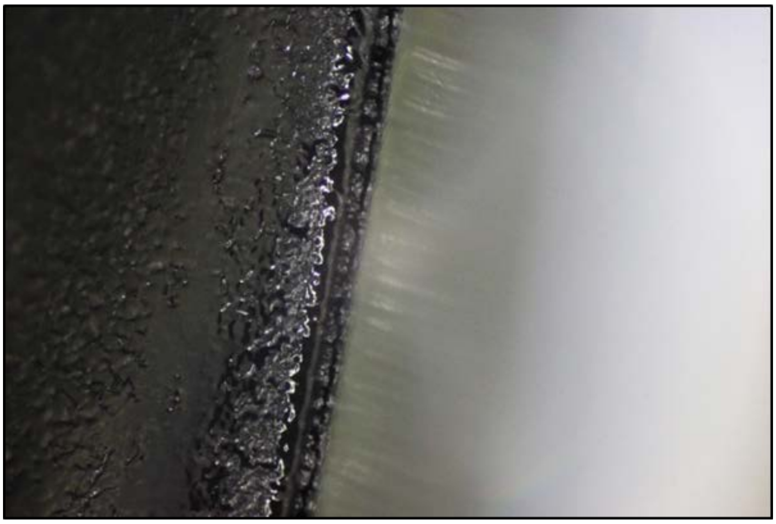

Figure 4- Tiny crack - detail.

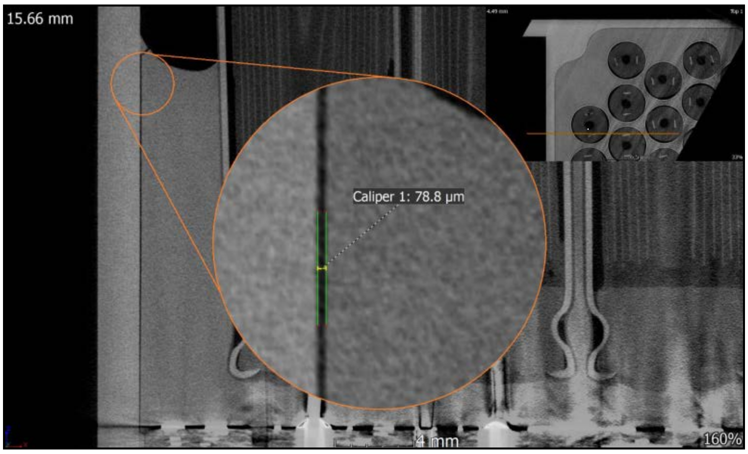

Figure 5- CT scan showing dark line (the crack) between the housing wall and the potting (top of the unit)

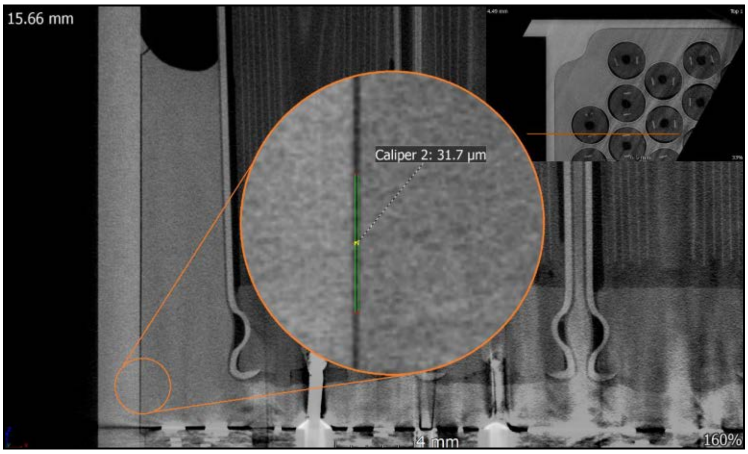

Figure 6 - CT scan showing dark line (the crack) between the housing wall and the potting (bottom of the unit)

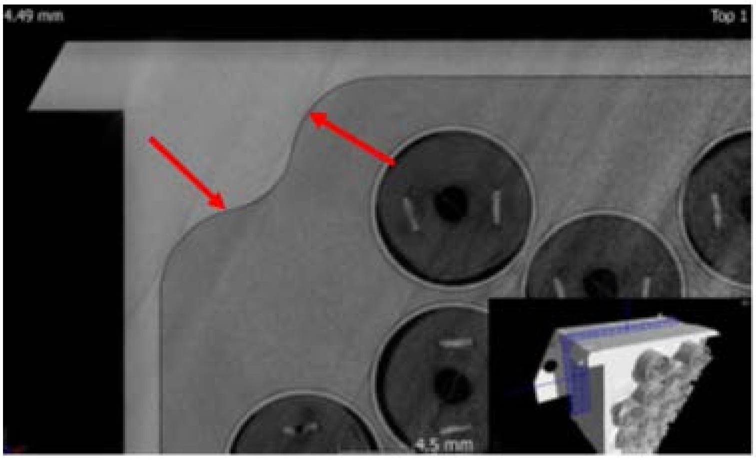

Figure 7- CT scan showing dark line between the wall and the potting all around the housing (top view)

New Work on the Potting

Several new potting materials were tested for their suitable viscosity and curing time. 2 out of 6 materials were selected - QS1123, EP37 – for their suitable properties. Materials EC2216, CV2946 and EP21 were found unsuitable for their high viscosity during potting process, and material CV1152 was found unsuitable for its too long curing time.

It was decided to create mock-up samples with the selected pottings and subject them to thermal cycling to select the most suitable potting. One mock up sample consisted of small mechanical housing, PCB, several capacitors to test spreading in between the capacitors, and 1 thermocouple to control the temperature during the thermal cycling, see Fig. 8. The internal surface of the mock-up samples was roughened to improve adhesivity of the potting. There was total of

4 mock-up samples. Each mock-up sample was potted with one selected potting material, including 2 reference samples with Loctite Ablestic 285 (Ecobond 285) - one with roughened and one without roughened internal surface.

Figure 8- Mock-up samples before potting

Thermal Cycling and CT Scan Results

Visual inspections after thermal cycling showed tiny cracks along the unit wall in both samples of Loctite Ablestic 285, same as for EM1, see Figure 9. No cracks or bubbles we found in potting QS1123 - potting is transparent and visual inspection was sufficient, see Figure 10. No cracks were found in EP37. CT scan showed that also no major bubbles were present in the potting. Few bubbles appeared, however, all smaller then 2mm. See Figure 11, Figure 12.

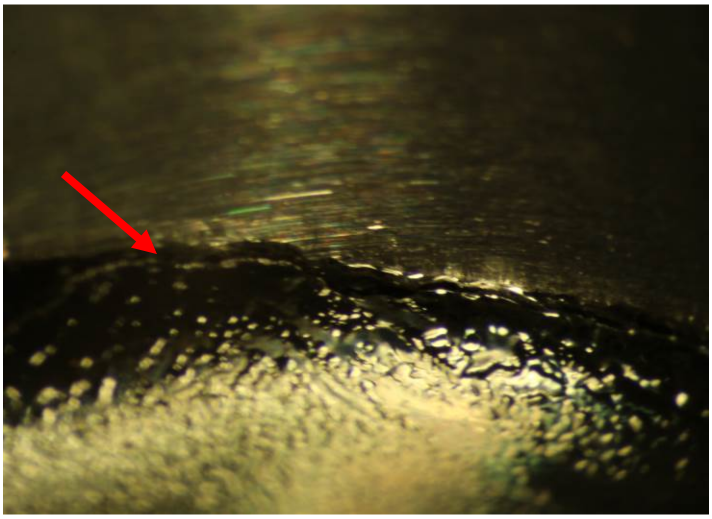

Figure 9 - Crack along the unit wall – Loctite Ablestic 285

Figure 10 - No cracks, no bubbles – QS1123

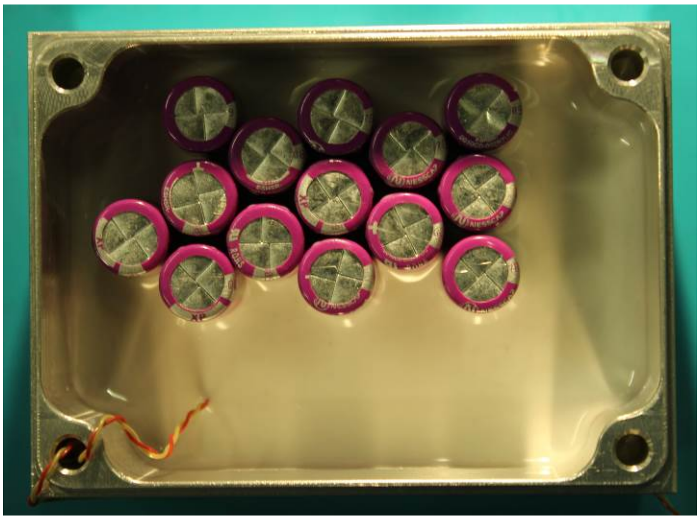

Figure 11 - No cracks – EP37

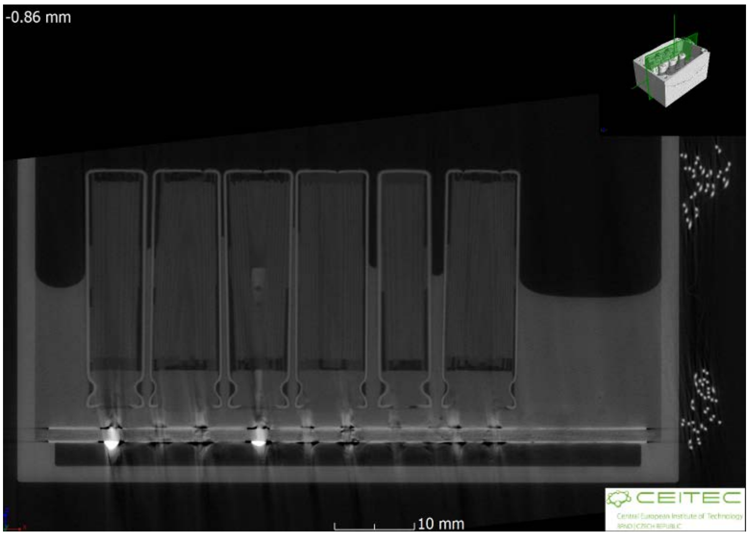

Figure 12 – CT scan showing no cracks, no bubbles - EP37 (length side view)

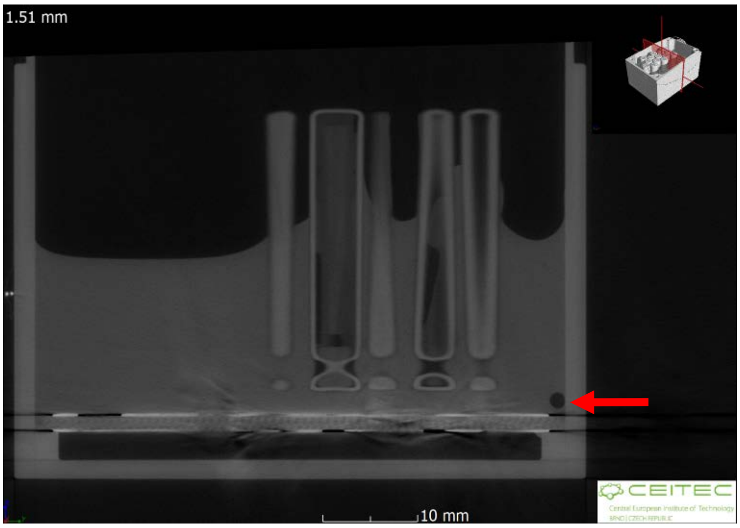

Figure 13 – CT scan showing no cracks, tiny bubble < 2mm (width side view)

Next Steps

The most suitable potting material will be selected considering all the criteria (thermal properties, viscosity, adhesivity, etc.). Potting will be then applied and qualified on EM2 model. After that, EQM models will be manufactured and qualified. After qualification, manufacturing of FM models can take place.

CONCLUSION AND FUTURE WORKS

The test campaign on 10F NESSCAP® supercapacitors for the entry in EPPL II is successful.

The bank Of Supercapacitors based on Nesscap® is under development and will be submitted to qualifications tests.

If successful, this study will allow having the Nesscap® 10F product space qualified and available on the shelf at both component and unit levels with a TRL level of 7. The completion of the proposed study will enable new applications or developments involving supercapacitors. The proposed study appears then to be of great interest for European space industry.

The targeted customers are prime contractors or equipment manufacturers that need either a complete BOSC (from CSRC) or only screened supercapacitors components (from EGGO).

This project will put into place a European industrial supply chain for supercapacitors products at space grade that will enable its utilization for space. It will also develop skills and facilities in space developments at both CSRC and EGGO Space levels, useful for this product and for future ones.

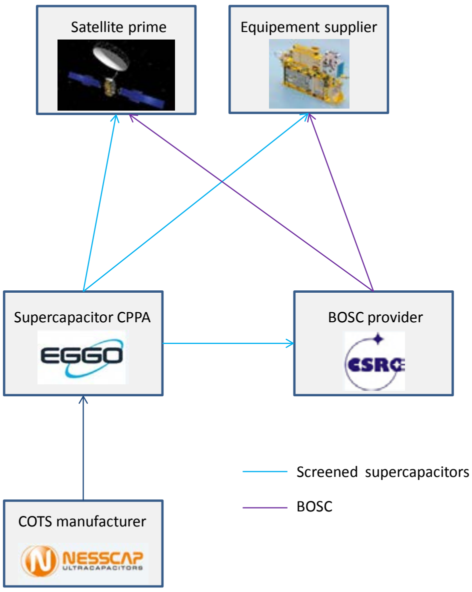

Fig. 13. Future industrial organization for Nesscap and BOSC procurement for space applications

In this paper it is aimed at providing an overview of what was and will be done in these programs for qualifying supercapacitors for the use in space applications.

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AUTHORS

Bertrand Faure received his diploma in Electrical Engineering at ENSEEIHT, Toulouse in 2006. He joined Airbus Defence and Space where he worked successively as electrical and power study engineer, electrical architect on sub-systems and energy storage engineer and project manager.

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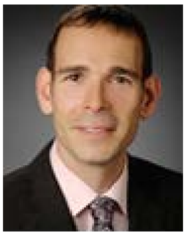
David Latif received his diploma from the Economy school in Lanškroun. He completed a NASA project management course in 2014. He joined the Company EGGO Space in 2012 and is currently project manager. Ha has been involved in several projects such as Evaluation of Supercapacitors and Impact at system level as a prime. He is currently working on High Density Connectors suitability to Space application ARTES 5.1 as prime.



Dr. Brandon Bürgler received his diploma in Material Engineering at the Federal Institute of Technology Zurich in 2002. After obtaining his PhD in Electrochemistry in 2006 he joined BMW Group where he worked on Fuel Cells, Supercapacitors and Batteries. He joined the European Space Agency in 2012 where he is working as Energy Storage Engineer.

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