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

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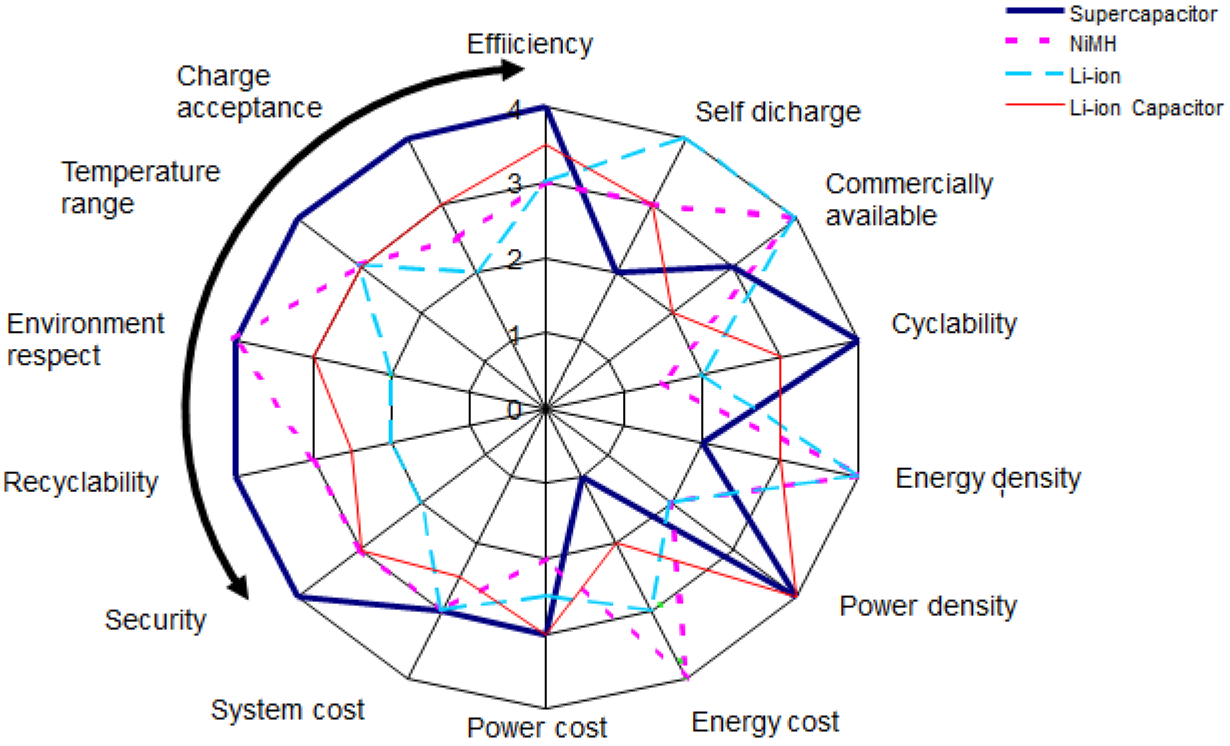
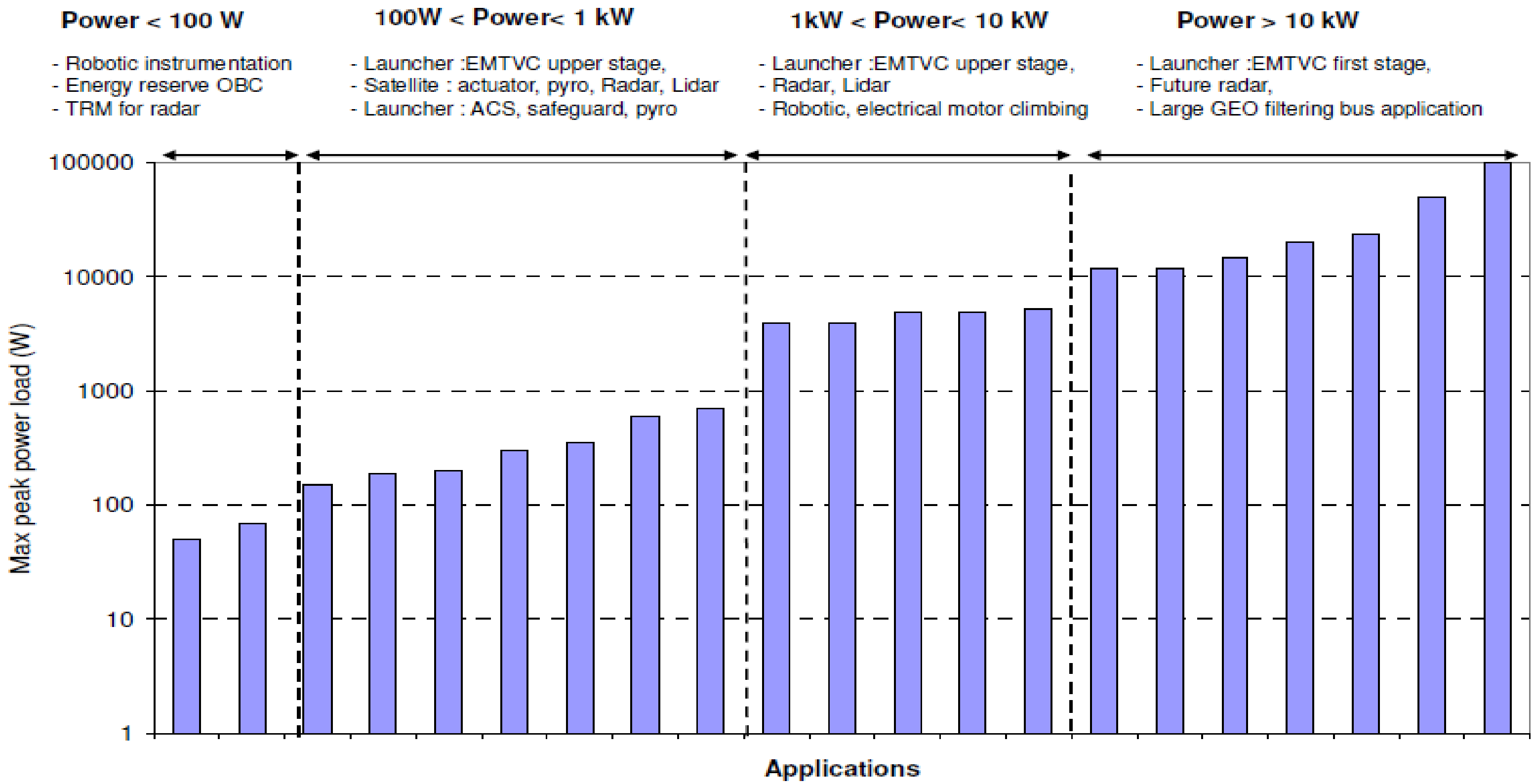
Supercapacitors for space applications

- Satellite and launchers energy storage are based on batteries (State of the Art = Li-ion), source of energy.
- For some applications, oversizing of the battery on power peaks → embarked mass increase
- Supercapacitor 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).



Supercapacitors applications for space applications

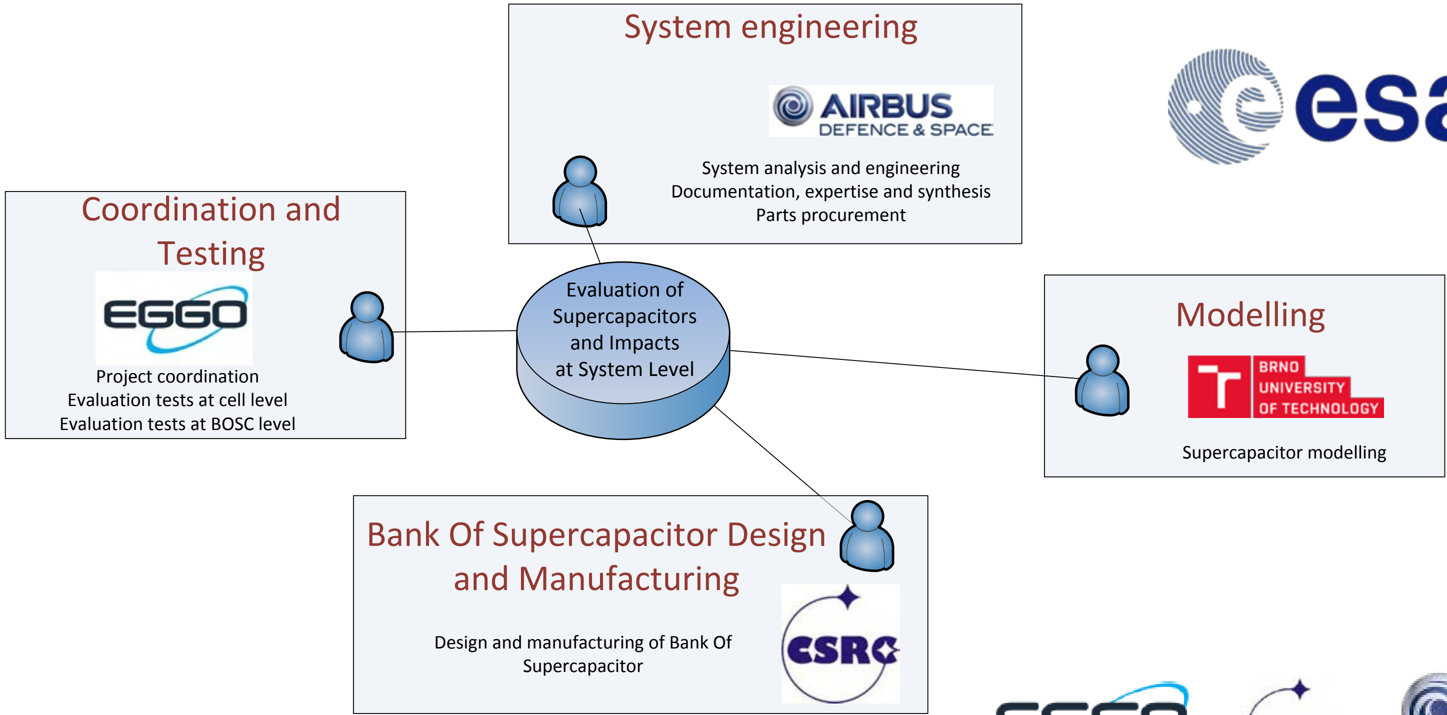
- ESA Study Contract No. 21814/08/NL/LvH entitled “High Power Battery Supercapacitor study” completed in 2010
- Potential space applications for supercapacitors:



- Supercapacitors have the potential for hybridization with batteries (power peaks < 10s)
- Other applications such as memory back-up
- From this activity, components with capacitance of tenth of Farad are identified to cope with the most promising applications.

Objectives of the project

- ESA funded activity under contract No. 4000105661/12/NL/NR “Evaluation of Supercapacitors and Impacts at System Level”.
- The main technical objective is to evaluate current state of the art in commercial supercapacitor technologies suitable for space grade capacitor that can increase the specific energy density beyond 6Wh/kg.
- Other objective is to choose the most suitable type of Supercapacitor for producing of the Bank of Supercapacitors in two models suitable for Space applications and to identify potential products for future qualification.



Choice of the components for space applications (2/3)

Cap XX®
HS130 (2.4 F)

Maxwell®
PC10 (10 F)

Nesscap®
EHSR 0010C0-002R7 (10 F)

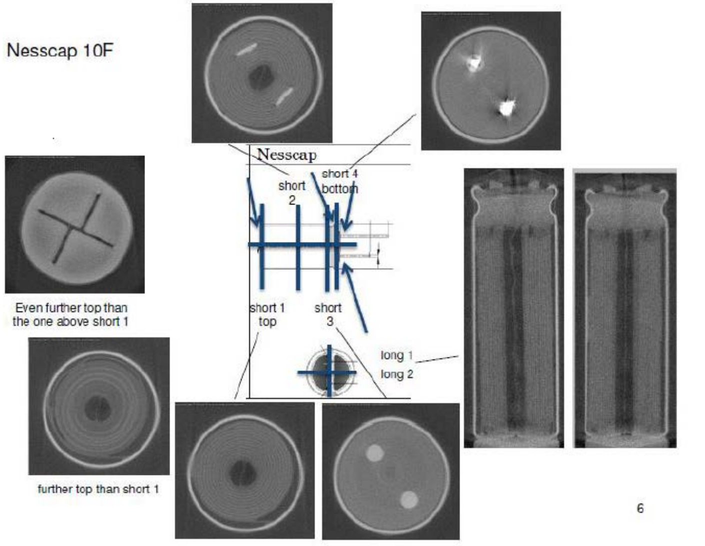
Maxwell®
BCAP0010 P270

	Cap XX® HS130	Maxwell ® PC10	Nesscap ® EHSR 0010C0-002R7	Maxwell ® BCAP0010 P270
Capacitance BoL	1.92F–2.88F	9F-12F	9F-12F	8F-12F
DC ESR BoL	< 31 mΩ	< 180 mΩ	< 34mOhms	< 80mOhms
AC ESR BoL	-	-	< 26mOhms	< 60mOhms
Rated voltage	2.75V	2.5V	2.7V	2.7V
Absolute Maximum Voltage	2.75V	2.7V	2.85V	2.85V
Maximum RMS Current	6A	-	-	-
Maximum Continuous Current @ $\Delta T = 15°C$	-	2.4A	3.4A	2.2A
Maximum Continuous Current @ $\Delta T = 40°C$	-	3.8A	5.6A	3.5A
Leakage Current	< 5µA	< 40µA	< 23µA	< 30µA

Components Evaluation - Construction analysis

■ Technology analysis assessment

• X –Ray inspection	MIL STD 202 method 209
• External inspection	ESCC2263000 issue2
• Dimensions	ESCC2263000 issue 2
• Resistance of the terminals	MIL STD 202 method 208
• Internal visual inspection	



X-Ray inspection on Nesscap EHSR 0010C0-002R7 (10 F)

■ Main conclusions
- Cap-XX® : pouch cells → packaging to be improved
- Good performances for Nesscap 10F
- Generally, an additional fixture when used at unit level will need to be designed to ensure a good mechanical strength.

Components Evaluation - Environment tests

- Environment tests
  - Fast temperature transients and vaccum exposure
    - Fast temperature transients — MIL STD 202 test method 107
    - Vaccum exposure
  - Radiation — ESCC 22900
  - Mechanical tests
    - Seal test — MIL STD 202 test method 112
    - Vibration — MIL STD 202 test method 204D
    - Shocks — MIL STD 202 test method 213

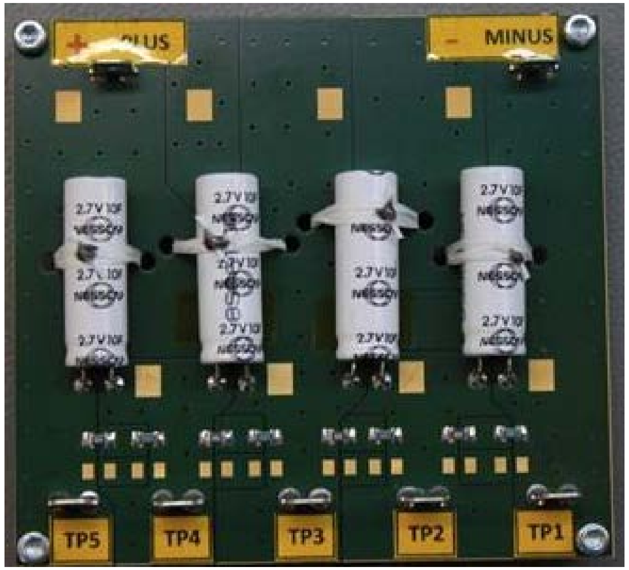
- Main conclusions
  - Good mechanical results for all parts
  - Gross leak and fine leak are non fully relevant for non-full hermetic packages
  - Non sensitivity to radiations up to 100krad
  - Thermal cycles and vacuum exposure
    - ESR increases of Maxwell® is unacceptable
    - Good results for Nesscap® and Cap-XX®
    - No leakage of electrolyte

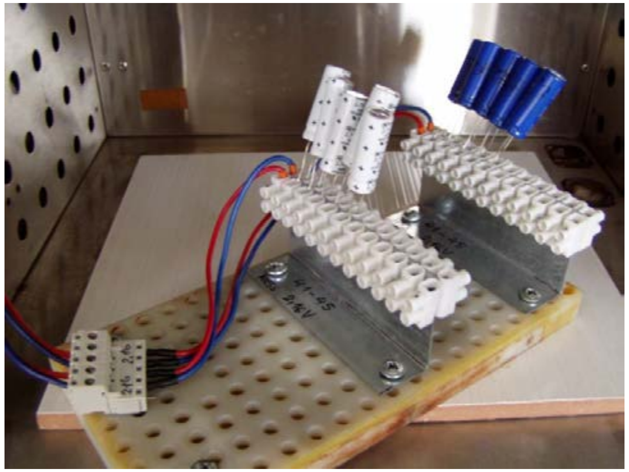
Components Evaluation – Electrical and Life Tests

- Initial electrical characterization

- Life test
  - Floating life tests
  - Cycle life tests

- Passive balancing validation for bank design





Components Evaluation – Electrical and Life Tests - Synthesis

- Passive balancing performances
  - For Cap-XX® and Nesscap®, 10mV drift between the highest and the lowest voltage (bank configuration).
  - For Maxwell® PC10, spread of voltage after 20 000 cycles (bank configuration).

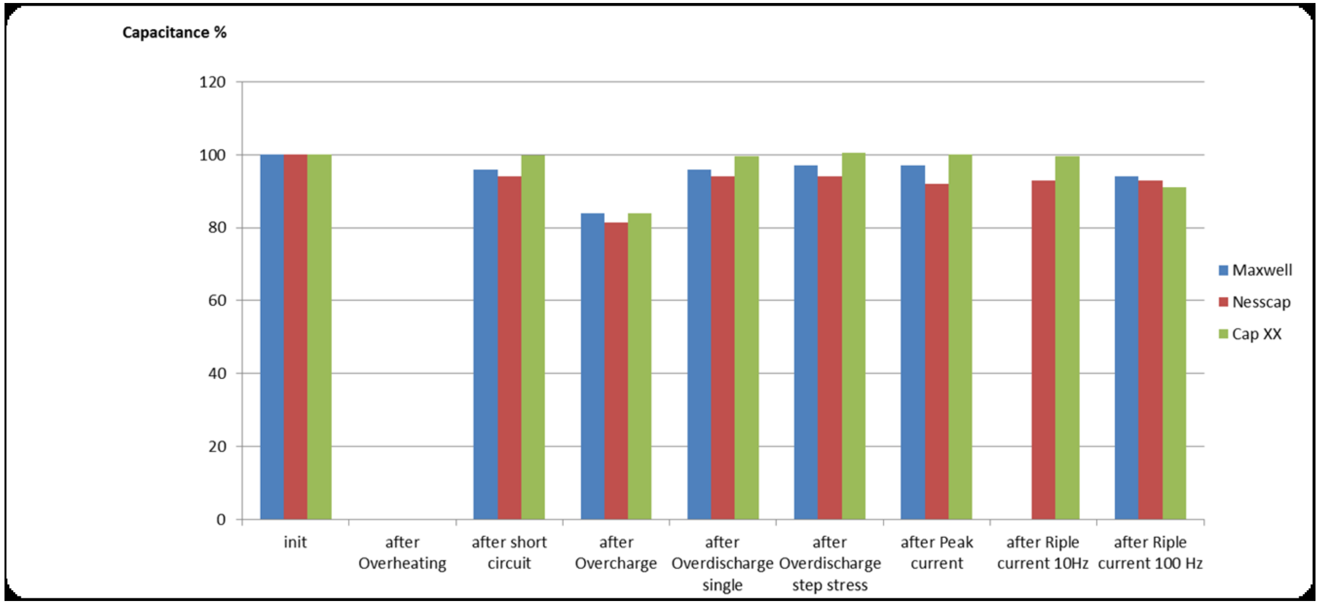
- Calendar and Cycling Tests under ambient pressure
  - Strong degradation is observed for:
    - Continuous cycling for 100% energy
    - Calendar test at 65°C with an operating voltage superior to 0.6 Vop
    - Calendar test at 20°C with an operating voltage superior to 1.2 Vop
  - Optimal conditions:
    - Optimal operating voltage is < 0.8 Vop
    - Optimal temperature range is between -35°C and 45°C
    - Optimal cycling condition is inferior to 75% energy

- Ageing models elaborated by Brno University

- Long duration vacuum life test on Nesscap® 10F
  - After 13 months, the ageing is similar to the one obtained at ambient pressure under the same temperature and voltage conditions.

Abusive tests

- Abusive tests
  - Overheating : all failed into open circuitry
  - Short circuit : no major sensitivity
  - Overcharge : overcharge test cause capacitance decrease by 10%,
  - Overdischarge : no major sensitivity
  - Peak current : higher impact on Maxwell® PC-10 regarding to higher ESR
  - It has to be noted that Maxwell® BCAP0010 P270 was not submitted abusive testing.



BOSC EM Features

- Supercapacitor selected: Nesscap® 10F because of electrical test results, packaging, mechanical – environmental test results.

- Realization of two EM BOSC
  - 15S/2P configuration
  - Capacitance BoL : 1,2F
  - Series resistance BoL : 125mOhms
  - Max Operating Voltage : 30V

- Mechanical and thermal vacuum tests
  - No degradation observed

- Electrical life test cycling
  - 3 000 000 electrical cycles at 45°C.
  - Low degradation of the performance
  - Less than 12% loss of capacitance
  - Less than 25% increase in series resistance
  - 20mV drift between the highest and lowest voltage

Context of Nesscap Supercapacitors Qualification

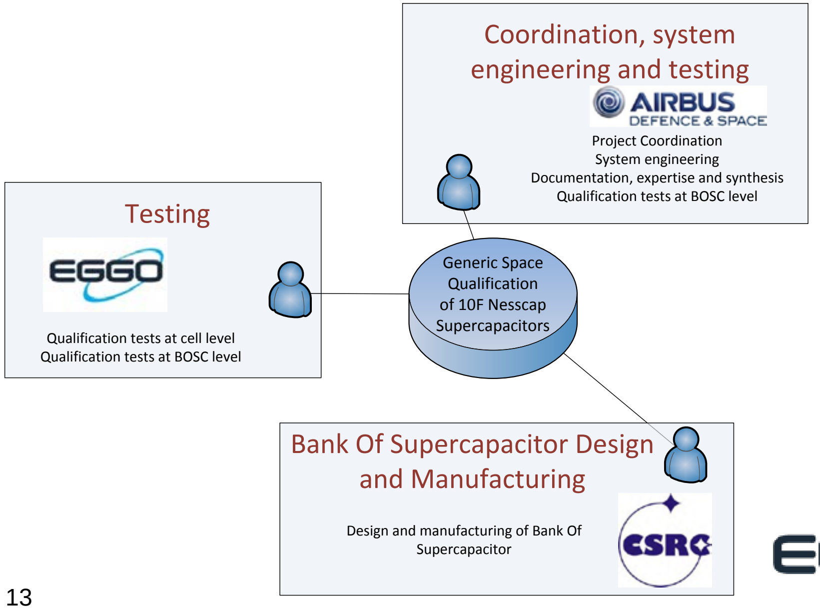
- The previous evaluation study has demonstrated the interest and suitability of COTS supercapacitors for space applications.

- 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.

- In 2015-2016, Nesscap® has improved the sealing performance of the 10F part (ESHSR-0010C0-002R7**UC** – XP products family**)**.
  This product is mass produced and commercially available since April 2016 and will be maintained in production at least up to 2021.
  Moreover, in case of any change in the material, process or design of the part, Nesscap® will submit a PCN for approval.

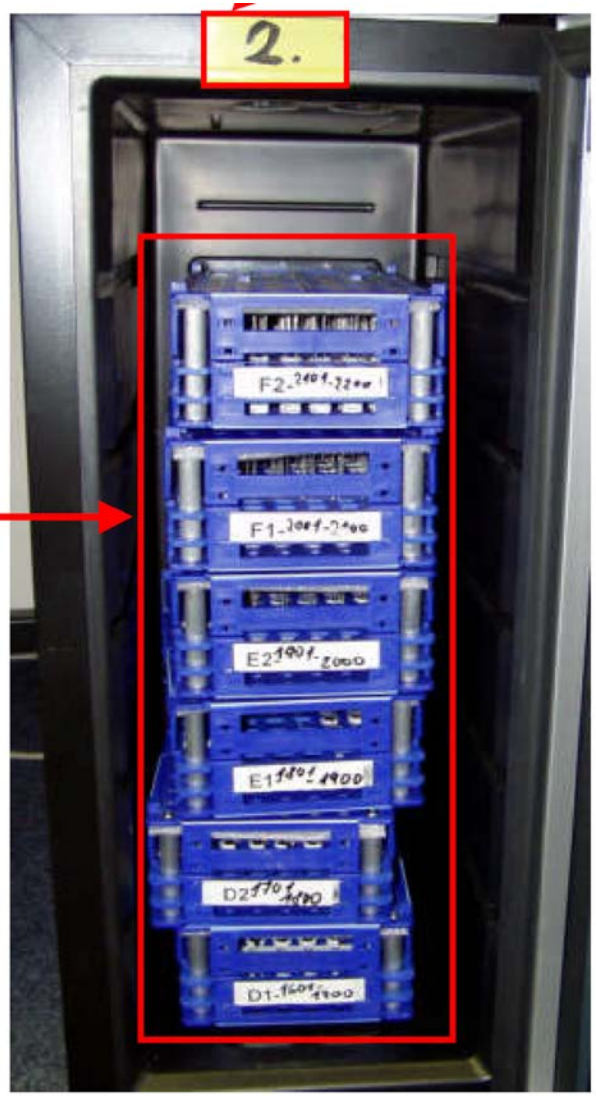
Objectives of the Project

- ESA funded activity under contract No. 4000115278/15/NL/GLC/fk “Generic Space Qualification of 10F Nesscap Supercapacitors”.
- The project has started in October 2015 and will be completed mid-2017.
- Two main activities
  - Performing an official test campaign on Nesscap® ESHSR-0010C0-002R7UC in order to have the part introduced into ESA EPPL Part2.
    → Once the activity completed, EGGO Space company will take over CPPA responsibility for those parts, being responsible of the parts procurement from Nesscap, screening according to the procurement specification agreed in the frame of the study, Lot Acceptance Tests and part sales at space grade to all potential users.
  - Developing and qualifying the associated Bank Of SuperCapacitor, a generic and modular unit including components parallel/series arrangements compatible with several space systems.
    → Once the activity completed, this module will be available as a space qualified product by CSRC to be sold to all potential users.



Test screening on Nesscap ESHSR-0010C0-002R7UC

- Procurement of a 3000 parts batch
- Screening test facilities development / improvements for batches of 200 parts
  - Vacuum testing
  - Burn-in
  - Visual inspection



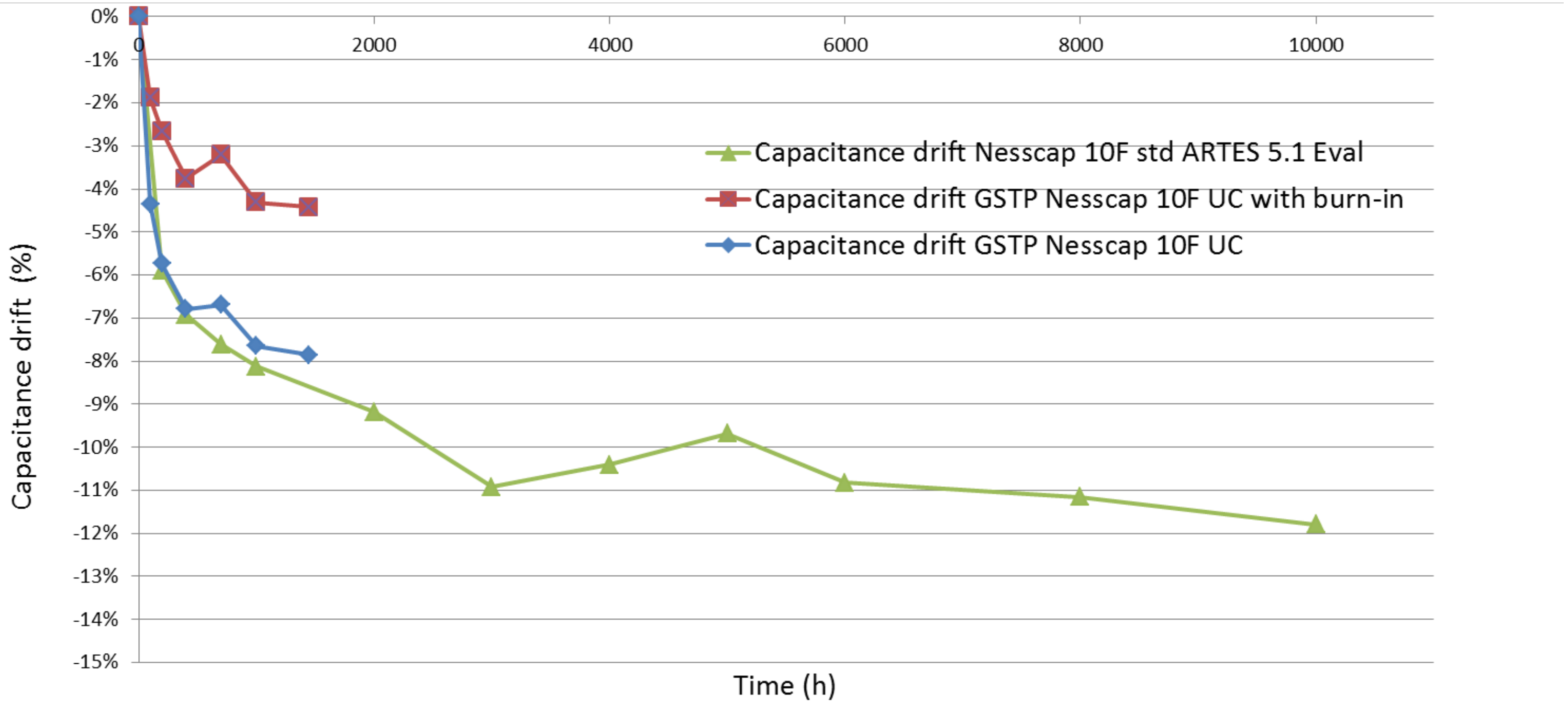
- Screening synthesis
  - 1000 pcs fully screened in total
  - 2200 pcs visually inspected with 177 rejected (8%)
  - 3 pcs were rejected after the full screening sequence

Test campaign on Nesscap ESHSR-0010C0-002R7UC (1/3)

- 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

Test campaign on Nesscap ESHSR-0010C0-002R7UC (2/3)

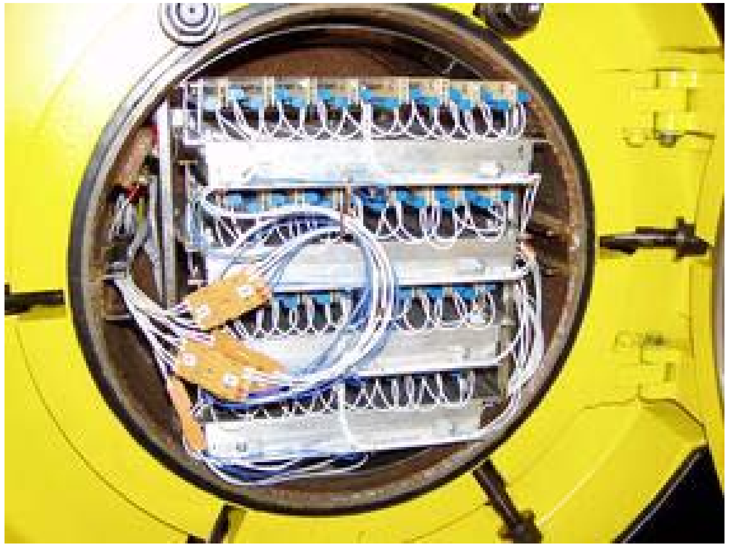
- Life test (60 parts)
  - Floating life test (1450h completed)
    - 20 parts at 0,9*Vop and @ 50°C (success criteria @ 2000h)
    - 20 parts at 0,9*Vop and @ 60°C (success criteria @ 2000h)



Comparison between ARTES 5.1 life test (45°C / 0,85Vop) and GSTP (50°C / 0,9Vop)

Test campaign on Nesscap ESHSR-0010C0-002R7UC (3/3)

- Cycle life tests (completed)
  - – 20 parts at continuous 100% energy cycling completed 240.000 cycles
- Vacuum life test (on-going – 1000h completed)
  - – 800 parts to be tested up to 9000 h in floating life test under vacuum at 30mbar at +55°C



Conclusion and next steps

- Timeline for COTS supercapacitors

2000
Achievement of ESA study Survey of Required Characteristics for Super Capacitors in Space applications

2000-2010
Internal survey of supercapacitors

2010
Achievement of ESA study High Power Battery Supercapacitor study.
Identification of best candidates.

2014
Achievement of ESA study under the lead of EGGO (Czech republic) “Evaluation of supercapacitor and impacts at system level” (**COTS approach)**
BOSC EM manufacturing and test

2015 - 2016
Test campaign of **Nesscap 10F** components under **vacuum**

2015-2017
ESA Study
Test campaign on **Nesscap 10F** for the entry in ESA **EPPL** Part II
Qualification of BOSC unit

2018 - …
Space applications.

timeline

- Next steps :
  - Completion of Nesscap® ESHSR-0010C0-002R7UC qualification by mid-2017
  - A procurement specification at ESCC format will be estabilished
  - Ready for flight from 2018 !

Thank you for your attention !

The view expressed herein can in no way be taken to reflect the official opinion of the European Space Agency.