Lessons Learned from Screening and Qualification of COTS Capacitors

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List of Acronyms

AEC	Automotive Electronics Council	**MSL**	moisture sensitivity level
BI	burn-in	**PST**	power surge test
DCL	direct current leakage	**PWB**	printed wiring board
DLA	Defense Logistics Agency	**RB**	reverse bias
EM	electrical measurements	**RVT**	random vibration test
ER	established reliability	**S&Q**	screening and qualification
ESA	European Space Agency	**SS**	sample size
ESR	equivalent series resistance	**TC**	temperature cycling
FR	failure rate	**TS**	thermal shock
IDC	inter-digitated capacitor	**TTF**	time to failure
LAT	lot acceptance test	**VR**	voltage rating
LT	life test		

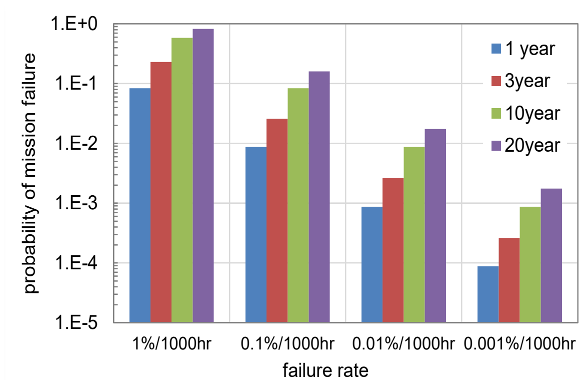
Abstract

A traditional approach to screening and qualification of hi-rel COTS capacitors and its limitations are analyzed. Results of testing of four types of COTS capacitors for L2 projects are summarized. The types include DLA drawing tantalum MnO2 capacitors, high-voltage hermetically sealed polymer tantalum capacitors, multianode COTS+ capacitors, and feedthrough BME ceramic capacitors. Lessons learned from this experience might accelerate processes and reduce risks of inclusion of COTS components in space projects.

Outline

- Traditional approach to screening and qualification of hi-rel COTS capacitors and its limitations
- Case 1: DLA drawing MnO2 capacitor
- Case 2: High-voltage hermetically sealed polymer tantalum capacitors
- Case 3: Multianode COTS+ tantalum capacitors
- Case 4: Feedthrough ceramic capacitors
- Lessons learned

COTS vs. MIL-Grade Capacitors



- Capacitors for different level space projects are selected based on reliability/FR grading.
- Risk of using a COTS capacitor:
  P_m × *(consequences of failure)*.

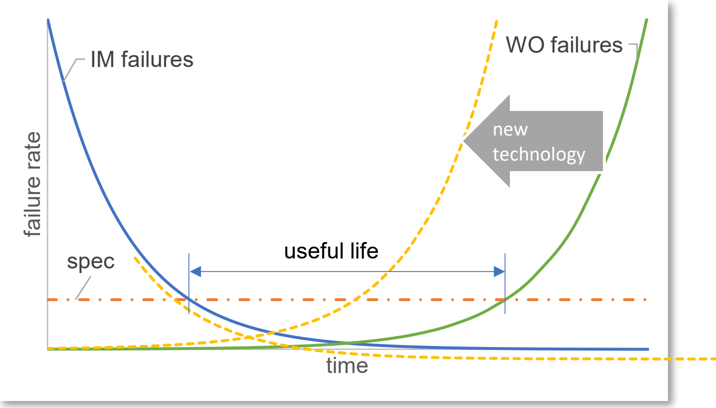
$$P_m = 1 - \exp(-\lambda_m t_m), \qquad \textbf{\textit{derating}} \rightarrow \lambda_m = \lambda/AF$$

- The major benefit of using ER MIL-grade parts is that they are assumed to be acceptable for most space projects if operating conditions are within the MIL range of temperatures and voltages.
- Lack of confidence in consistency of quality in different lots of COTS capacitors → difficulties in reliability assessments for a given part type.
- Contrary to MIL applications, space projects are often interested in a single lot of capacitors that are to be used at a relatively benign conditions → the need to assess reliability of a particular batch for a specific application.
- Existing guidelines for S&Q of COTS parts typically follow MIL-spec requirements developed for relatively old technologies.

Life Testing of COTS Capacitors

- Increasing risks of WO failures for new technology capacitors can be managed.
- If a COTS part can pass the relevant MIL spec requirements is it as good as a MIL part?
  - Due to a small SS during LT and low confidence/trust in quality consistency for COTS it is impossible to get acceptable FR without significant acceleration.
  - Test results cannot be generalized for a given part type → each lot should be tested.
  - Existing LT for COTS capacitors is a quality compliance, but not a reliability test.
  - LT conditions in the existing guidelines might be not applicable for advanced COTS.

The beauty of WO failures: PoF approach and modeling

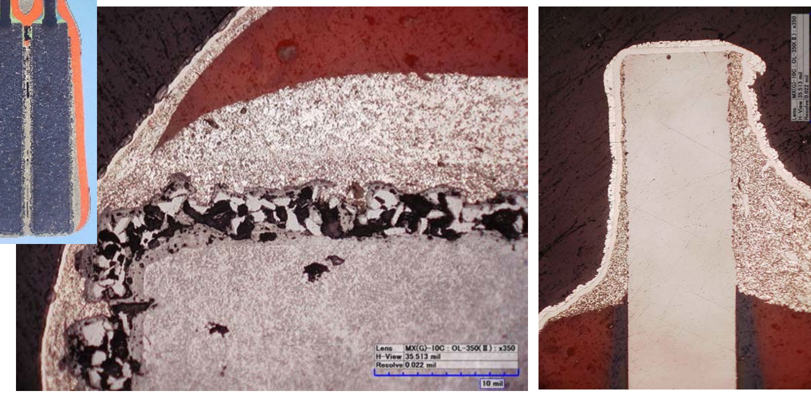


- If COTS capacitors fail MIL requirements for life testing, can it still be used? If not, but you wish to use the part very much, then should we:
  A. Relax the requirements in the MIL spec (IDC, hybrids)?
  B. Assess acceleration factors and prove reliability for the mission?

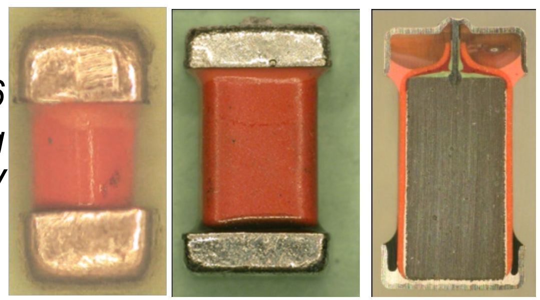
DLA #13008

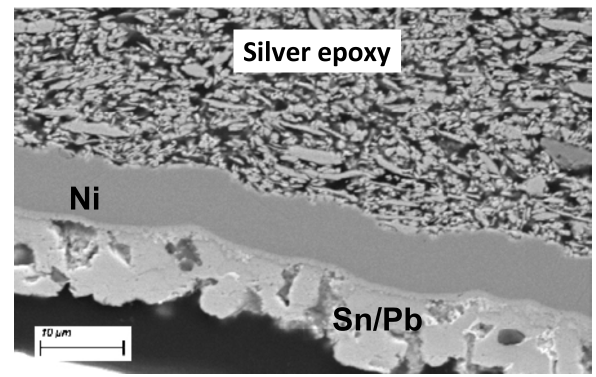
❑ Benefits of frameless design:
- Better polarity indication
- Elimination of wire welding
- Extended range
- The part has a good self-healing capability (10% of damage after scintillation breakdown)

T97 max rating 22uF, 250 mΩ, 63V

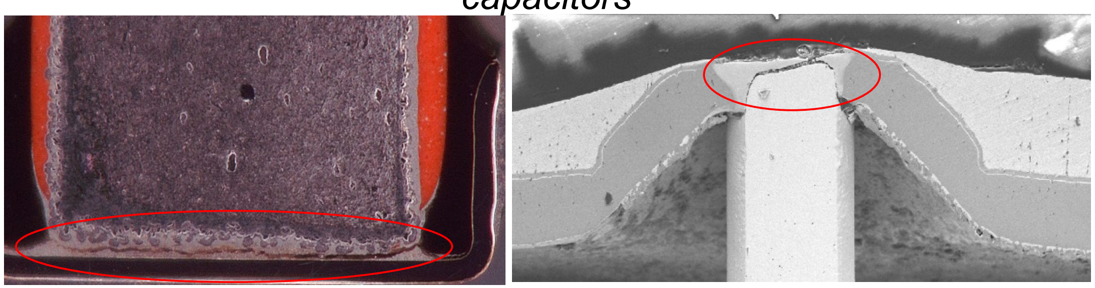


CWR06 max rating 4.7uF, 1.5Ω, 50V





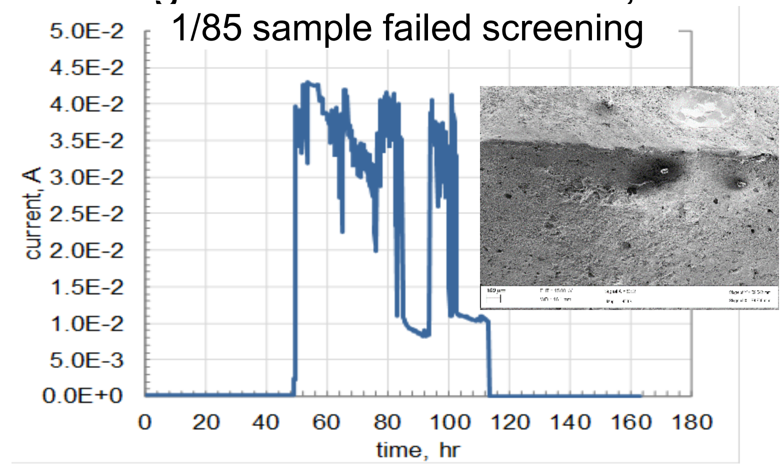
Examples of cracking at the anode and cathode in CWR06 capacitors



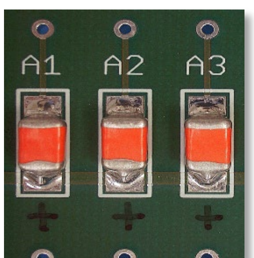
❑ Potential problems:
- Integrity after soldering
- Insufficient screening (85C/40hr/VR)
- Life test is optional (85C/2000hr/VR)

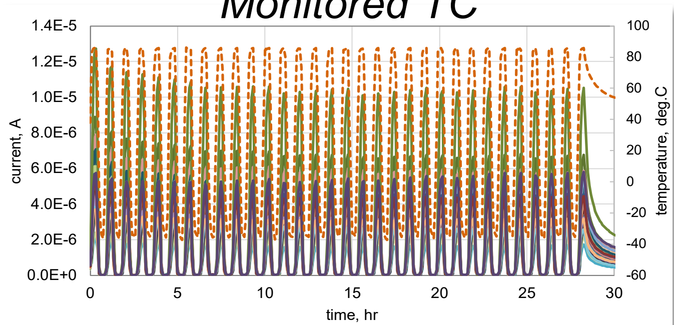
DLA #13008 10uF 63V S&Q

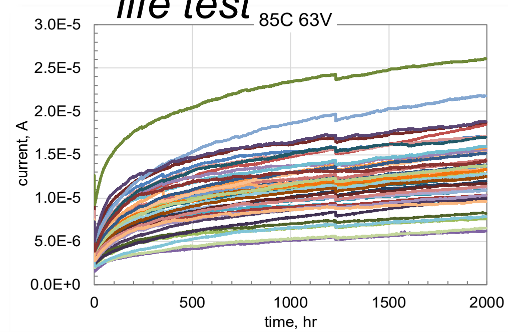
- ❑ Application conditions for a project: 28V, survival T range from -25ºC to 65ºC; possible transients during power-up 2-5 ms.
- ❑ Screening verification included monitored BI at 85C 63V for 160hr.
  One out of 85 samples failed after 50 hours. The appearance of the failure site suggested scintillation breakdown.



- ❑ Qualification tests using 45 samples reflow soldered onto test PWB: monitored cycling (30 TC -35 to +85C), power surge, and life test (2000hr, 85C).



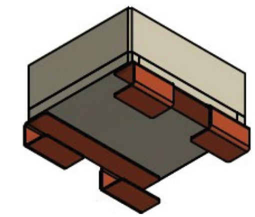


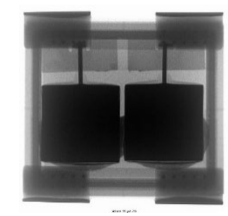


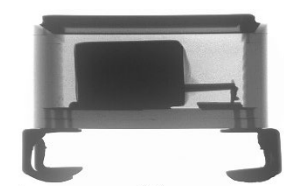
- ✓ The frameless technology improves performance and quality of the parts.
- ✓ DLA drawing parts might require BI verification.
- ✓ Life test at 85C 63V for 2khr corresponds to >1000yr during the mission.

TCH Capacitors

- A project selected 22uF 100V Ta caps to be used in 35V power lines with possible transient spikes up to 43V. Turn ON/OF cycles are relatively slow, ~300 µsec. Operational T~ 25 ºC and possible variations -20 to +30 ºC. Ripple currents below 20 mA, which is ~10 times below the specified limit.
- TCH series are hermetically sealed polymer Ta caps developed for space applications per ESA requirements.
- C-shape terminals were selected to reduce stresses from PWB.
- Screening of 420 samples included:
  5 TC (-55C to +125C), power surge, hermeticity, and monitored BI (85C/100V/168hr).
- LAT was carried out for 3 groups after reflow soldering onto test PWB or soldering simulation.
  - Gr.I (20pcs): 100TC -55 to +125C -> EM -> humidity (85C/85% RH/2wk) -> EM -> power surge cycling.
  - Gr.II (20pcs): reflow soldering -> EM -> stability at HT and LT -> RVT.
  - Gr.III (60pcs): reflow soldering ->EM -> monitored life test (85C/100V/2000hr)



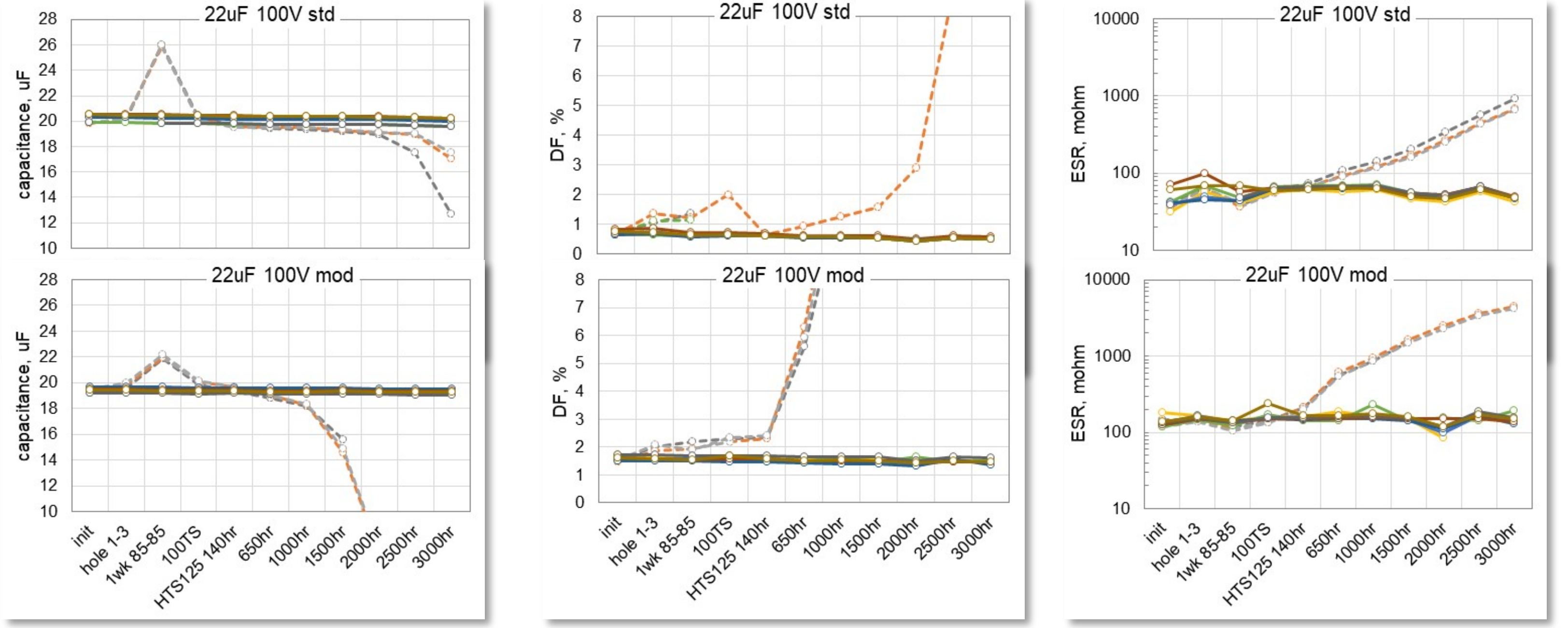




✓ Potential problems:
- Dehermetization or excessive leak
- Reverse bias pulses
- Reliability at operating conditions

Effect of Dehermetization

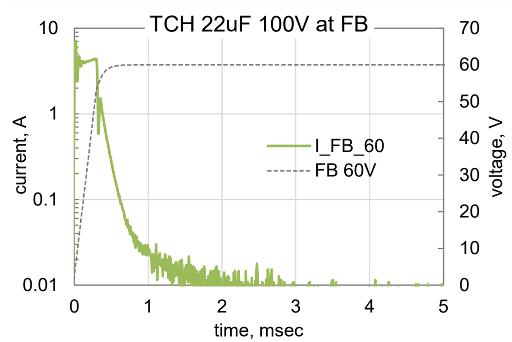
- Small holes were drilled in several engineering samples of the part.
- AC characteristics were measured after dehermetization, exposure to moisture, 100 TS, and HTS125 up to 3000 hours.

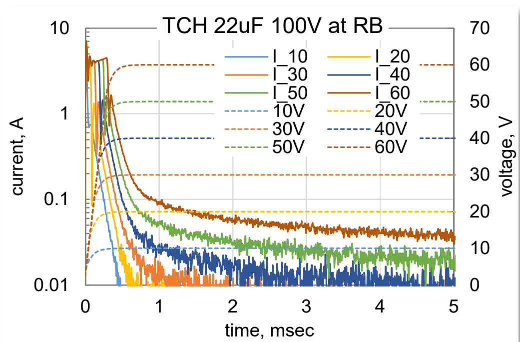


- ✓ Significant capacitance variations in non-hermetic parts indicate moisture presence.
- ✓ Epoxy foam inside the package does not substantially delay moisture penetration.
- ✓ The level of moisture corresponding to RC does not degrade the parts.
- ✓ Hermetically sealed parts can withstand > 3000hr of HTS125, whereas non-hermetic parts can fail even after 1000hr due to thermo-oxidative degradation of PEDOT/PSS.

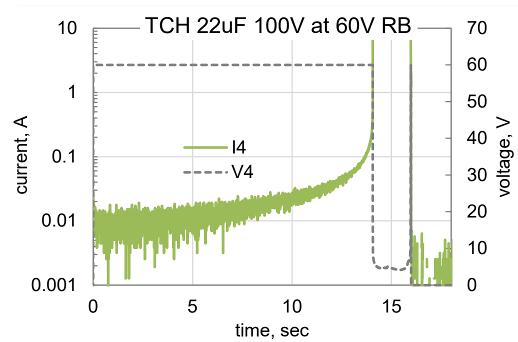
Effect of Reverse Bias Pulses

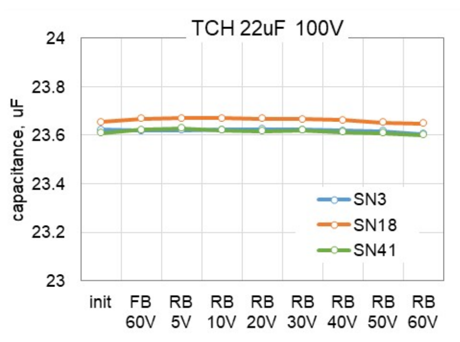
- During PST, the parts were stressed by 60V 0.5 sec pulses with a ramp time < 0.3msec.
- Similar pulses in reverse polarity were applied at increasing voltages.
- The currents were also monitored at 60V RB.

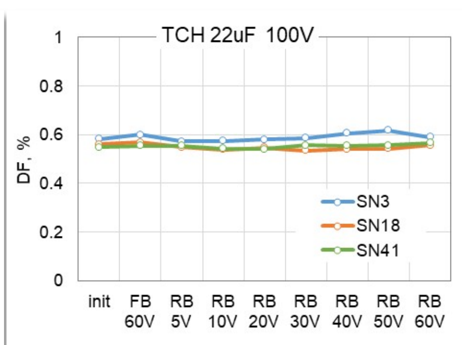


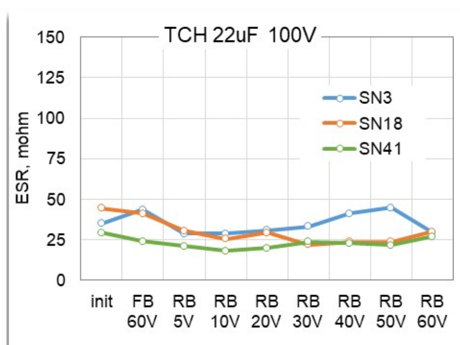


RB failure at 60V





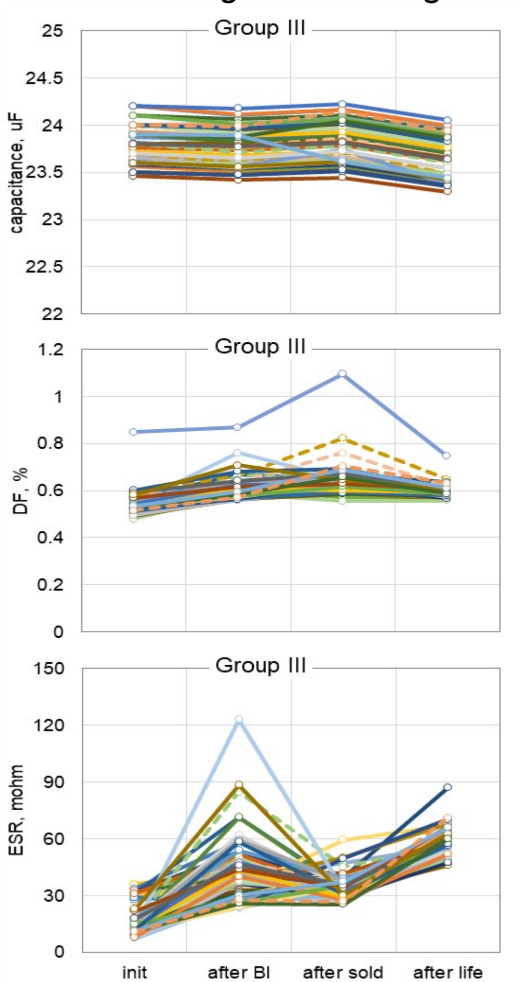


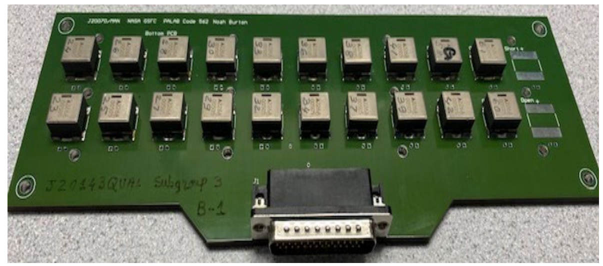


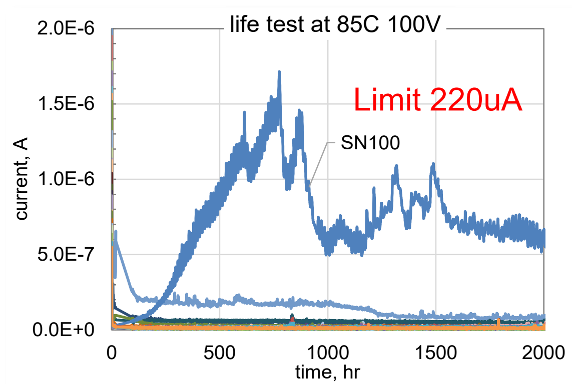
- ✓ Reverse bias during PST does not damage the part.
- ✓ At 60V, failures at reverse bias can be observed after 10 sec.
- ✓ RB failures result in charring of polymer around the whole surface of the slug.

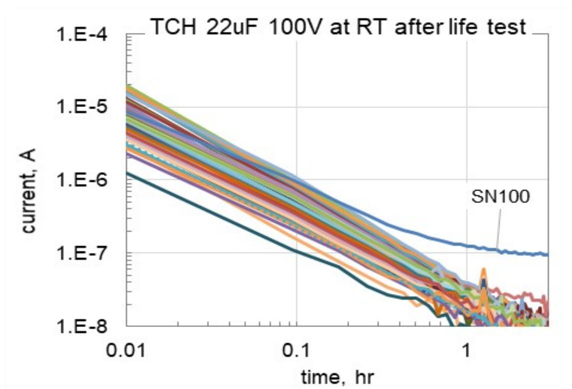
Results of Life Testing (Gr. III, 60 pcs)

Variations of AC characteristics through the testing





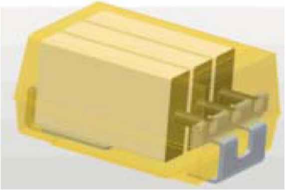


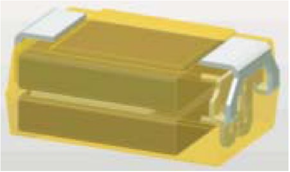


- Screening:
  4.3% of 420 pcs failed DCL before BI and 0.7% failed during BI.
- Life test:
  - No failures or significant anomalies during monitored life testing.
  - No parametric degradation or failures after life testing.

✓ Conservative estimations show that 2khr life test at 85C, 100V corresponds to more than 1000 years during the mission.

Evaluation of Multianode TBM Capacitors



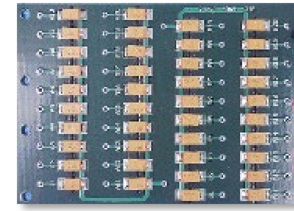


- Multianode capacitors allow for a substantial reduction of ESR that can be reduced to 35-70 mohms for MnO_2 capacitors.
- Available with Weibull Grade "B" reliability (0.1%/1000hr).
- Potential reliability problems:
  - Greater risk of popcorning due to increased number of edges.
  - Greater risk of breakdown due to a larger surface.

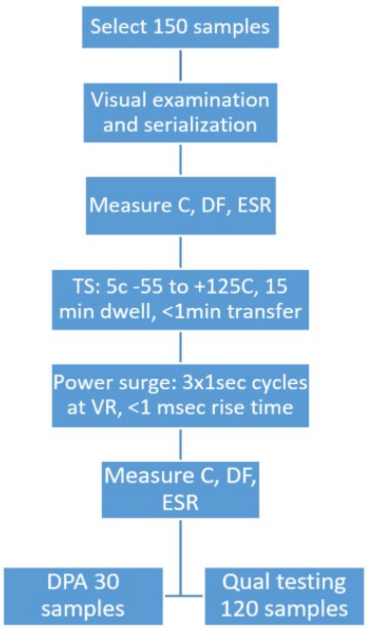
Preliminary tests showed that multianode capacitors preconditioned per MSL1 have cracks after reflow soldering

✓ Soldering of 6 types of TBM capacitors (720 pcs) shows that with proper baking the parts can be safely soldered onto PWBs.

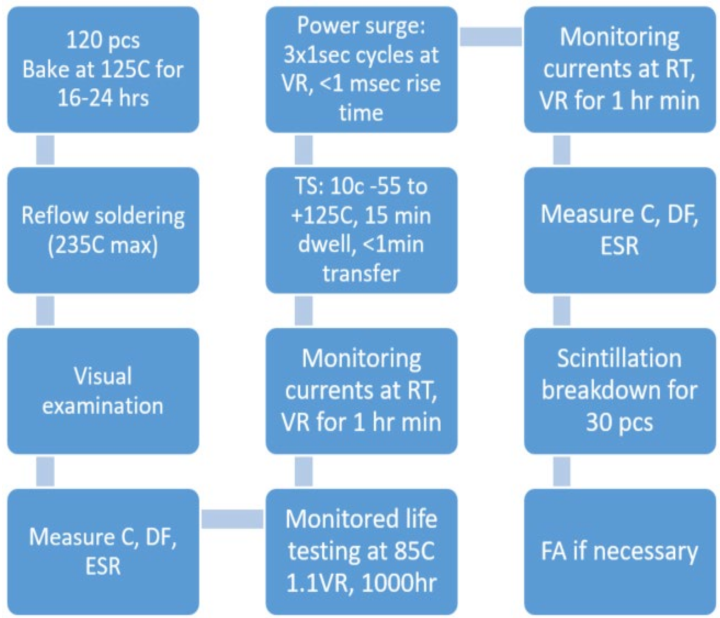
LAT of Multianode Capacitors



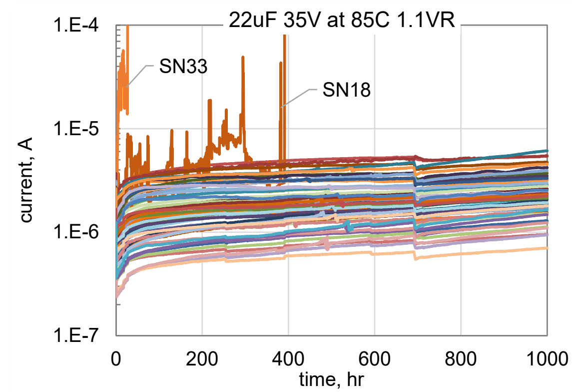
Test flow

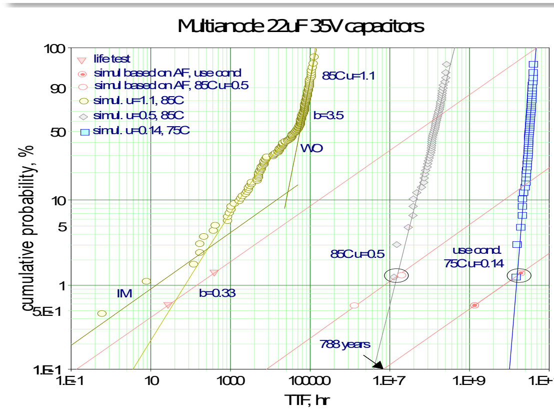


Qualification tests



Life Test for a Failed Lot

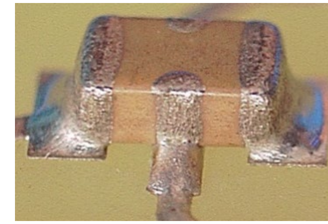




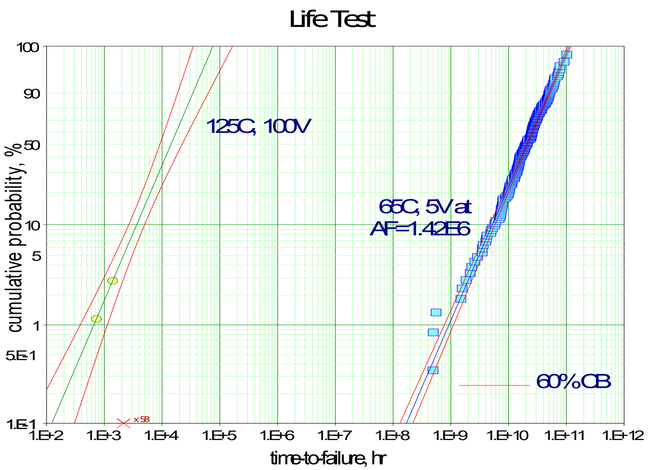
- No failures in 5 lots of capacitors.
- In one lot, 2 out of 120 samples failed life test.

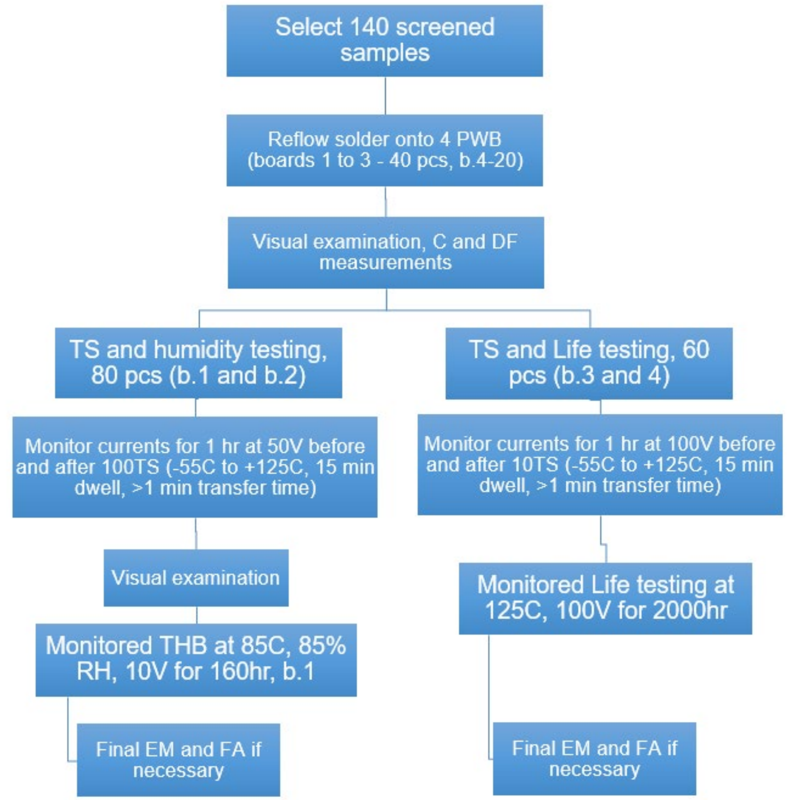
- ✓ Additional screening (BI) might be necessary in one of 6 tested lots.
- ✓ Using a 45(1) criterion per the guidelines, would have 83% chance of passing life test.
- ✓ Parts that passed the life test 120(0) at 1.1VR will have the probability of failure during a 20 year mission < 0.01%.

Feedthrough BME Capacitors



- AEC Q-200 feedthrough BME 0805, X7R, 10nF, 50V for use in 5V lines at 65 ºC max.
- 300 samples passed monitored BI at 125 ºC/100V/160hr with zero failures.
- Monitored LT of 60 soldered samples at 125 ºC/100V/2000hr resulted in 2 failures.





- ✓ For some AEC-Q200 parts BI is not necessary.
- ✓ Conservative estimations showed that at the mission conditions TTF > 10,000 years.
- ✓ Parts failing MIL life test requirements can be used for a space mission at substantially derated conditions.

Lessons Learned

- Instead of qualifying a COTS capacitor “for space”, we need to ensure that a given batch of parts has an acceptable probability of failure at specific application conditions for the required mission time.
- Paradigm shift: reliability for the mission instead of compliance with MIL-spec (relaxed?) requirements.
- Development of S&Q plans for COTS capacitors should include:
  - Analysis of potential reliability concerns specific to the design.
  - Qualification testing using sufficiently large SS of soldered capacitors.
  - Analysis of application conditions.
  - Assessments of reliability acceleration factors.
- COTS+ capacitors require BI, unless opposite is proven statistically.