



NASA Electronic Parts and Packaging (NEPP) Program

Screening and Qualification of BME Feedthrough Capacitors for a Space Project

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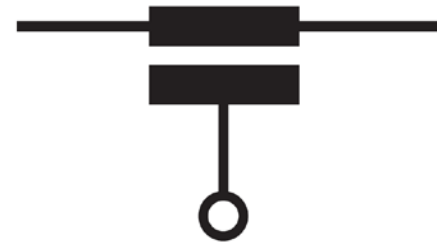
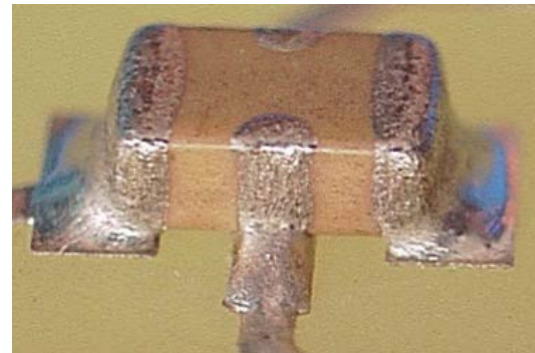
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List of Acronyms

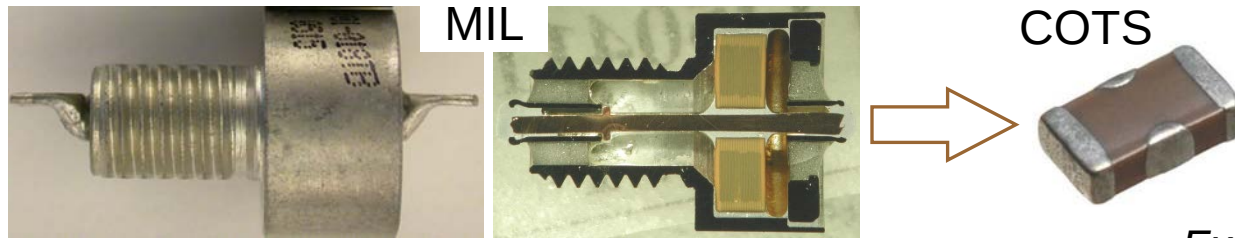
AC	alternating current	IM	infant mortality
AEC	Automotive Electronics Council	IR	insulation resistance
AF	acceleration factor	LT	life test
BI	burn-in	PWB	printed wiring board
BME	base metal electrode	RH	relative humidity
COTS	commercial off the shelf	RT	room temperature
COTS	capacitance	S&Q	screening and qualification
DC	direct current	TS	thermal shock
DCL	direct current leakage	TTF	time to failure
DF	dissipation factor	VR	voltage rating
HALT	highly accelerated life testing	WO	wear-out

Outline

- ❑ COTS feedthrough capacitors and approaches to QA.
- ❑ S&Q test plan.
- ❑ Results of screening.
- ❑ Results of qualification.
- ❑ Preliminary reliability prediction.
- ❑ Failure analysis.
- ❑ HALT.
- ❑ Reliability assessments.
- ❑ Conclusion.

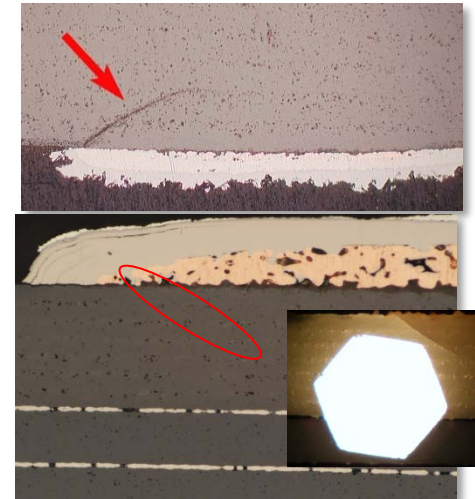


Feedthrough Capacitors



- ❑ Benefits: smaller size and weight, better performance.
- ❑ Drawback: COTS BME + possible cracking at terminals.
- ❑ A space project required AEC Q-200 BME 0805, X7R, 10nF, 50V, 1A feedthrough capacitors for use at 5V, 65°C and 250mA max.
- ❑ Two approaches for S&Q:
 - Testing to MIL-spec requirements.
 - Drawback: the relevance of test conditions (125C/2VR). 96hr for BI and 1000hr/45(1) for life test.
 - Existing guidelines for S&Q of COTS caps do not assess reliability of the parts.
 - Reliability assessment and BI selection based on HALT.
 - Problems: possible new failure mechanisms, models for reliability prediction.
- ❑ Both approaches were used in this work.

Examples of corner cracks at terminations



Screening and Qualification Test Plan

❑ Additional tests: sufficient margin for DC current limit.

❑ Screening (300pc.):

- Visual examination.
- R_DC using 1 sec pulses of 1.4A.
- Measurements of C, DF, and IR RT and 125C.
- Monitored Burn-In at 125C/100V/160hr.
- Final measurements of C, DF and IR.

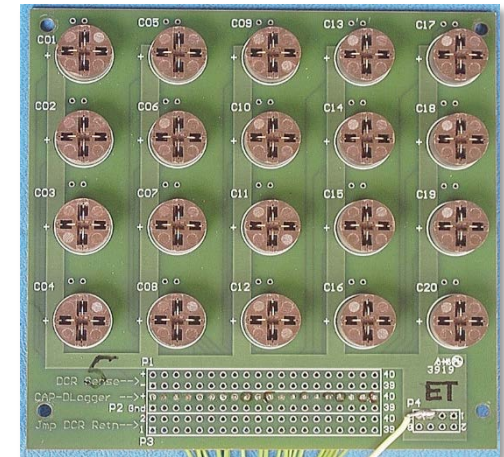
❑ Qualification (140 pcs. Soldered onto test PWBs):

- TS and humidity testing (80pcs.)
 - 100TS -55C to 125C.
 - Monitored THB at 85C/85% RH/10V for 160 hr.
- TS and life testing (60pcs.)
 - 10TS -55C to 125C.
 - Monitored LT at 125 °C/100V/2000hr

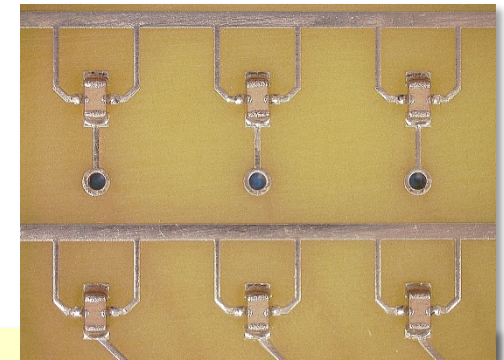
✓ Initial plan: BI and life testing per MIL requirements.

✓ Monitoring leakage currents during provides detailed information about behavior of the parts and allows for IR calculations.

Fixtures for BI



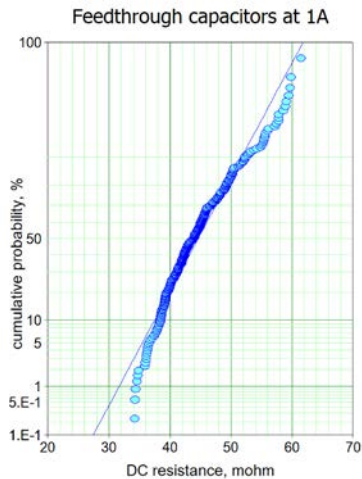
Parts for life testing



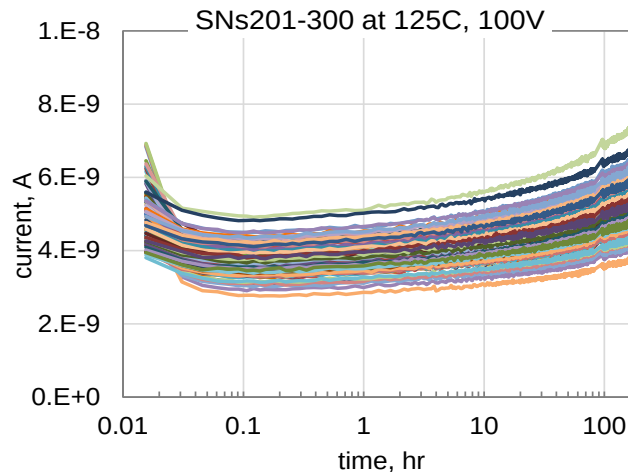
Results of Screening

- ❑ All AC and DC characteristics of the parts were within the specified limits.
- ❑ No anomalies during BI.

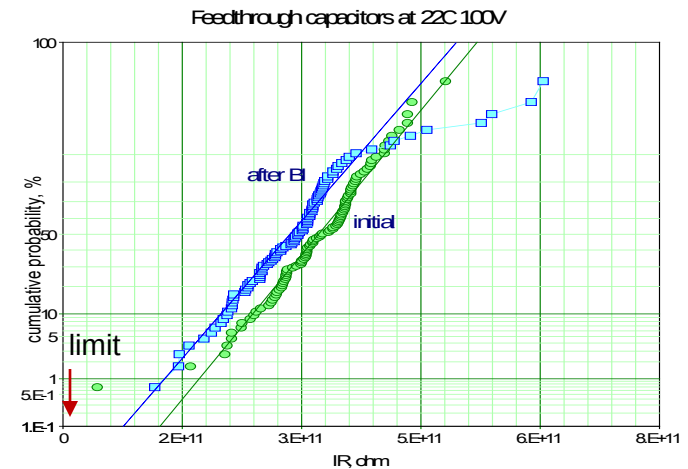
*DC resistance at 1A
pulses (150 mohm max)*



*Typical variations of leakage
currents during BI*



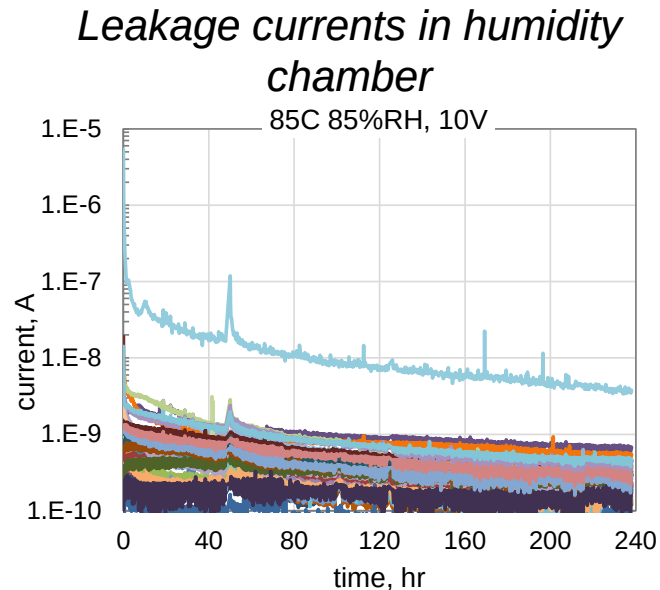
*Distributions of IR measured before
and after BI*



- ✓ No failures or anomalous behavior of currents during AC and DC measurements of 300 samples.
- ✓ Currents during BI remained in the nanoampere range and increasing with time was not significant.
- ✓ No IR degradation after burn-in.

Results of TS and Humidity Testing

- ❑ 80 samples reflow soldered on test PWBs.
- ❑ All samples passed 100TS -55C to 125C. 40 samples passed additional 300 TS cycles.
- ❑ Leakage currents in 40 samples after TS were monitored in humidity chamber at 85C 85% RH, 10V for 160 hours.
- ❑ IR after humidity testing were below the specified limit.

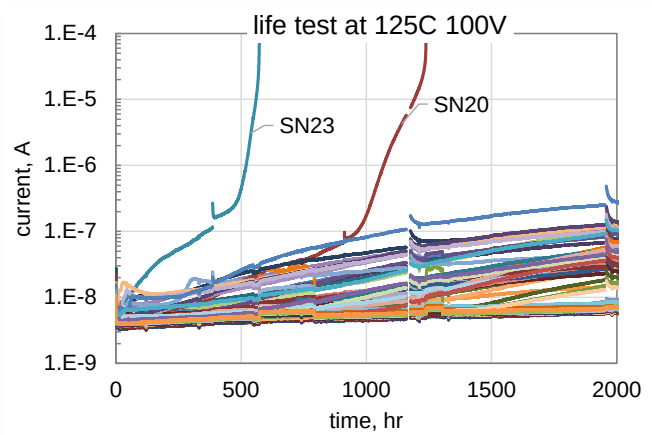


✓ Test results indicate absence of cracks that could have been associated with soldering and thermal shock stresses in the parts.

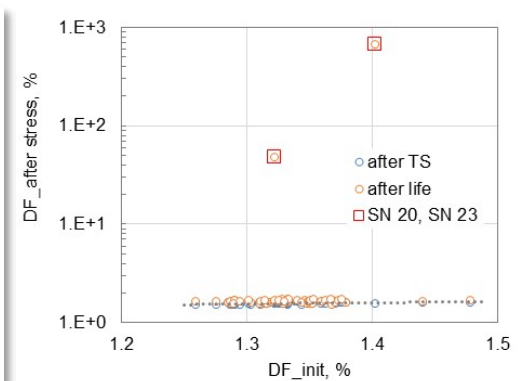
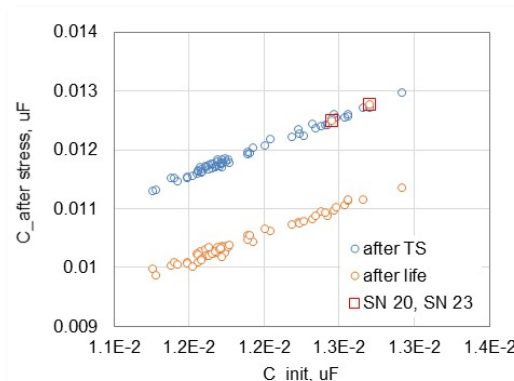
Results of Life Testing

- ❑ 60 samples reflow soldered on test PWBs.
- ❑ 10TS -55C to 125C before life testing.
- ❑ Leakage currents were monitored at 125C 2VR for 2000 hours.

Leakage currents during life testing



Correlations between initial and post-life-testing values of capacitance and DF



- ✓ Two samples failed after 570 hours and 1240 hours.
- ✓ Failed capacitors had substantially increased DF values, but acceptable, although out-of-family, values of capacitance.
- ✓ If life testing is carried out per the existing guidelines, 45(1), the probability of passing the test would be 56% (binomial probability of success at $p = 0.033$).
- ✓ Can this lot be used for the project?

Reliability Assessments

- Considering that during applications the parts will be operating at $V_{op} = 5V$ and maximum temperature of $T_{op} = 65\text{ }^{\circ}\text{C}$, the life expectancy increases substantially.

- AF can be calculated based on the Prokopowicz-Vaskas model:

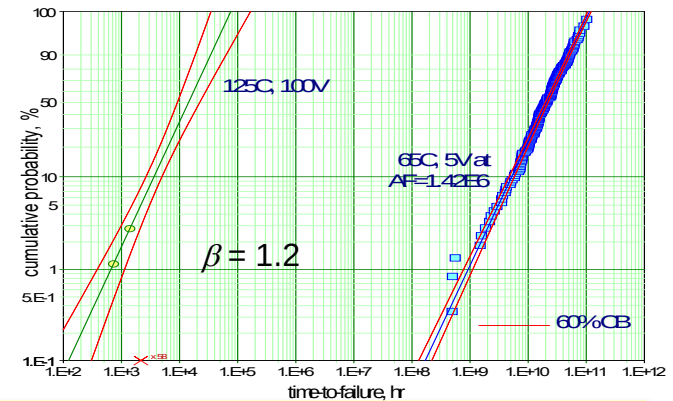
$$AF = AF_T \times AF_V, \quad AF_T = \exp \left[\frac{E_a}{k} \left(\frac{1}{T_{op}} - \frac{1}{T_{test}} \right) \right] \quad \text{and} \quad AF_V = \left(\frac{V_{test}}{V_{op}} \right)^n,$$

Life Test

E_a is from 1 to 1.6 eV and n is varying from 3 to 9.

$T_{test} = 125\text{C}$	$V_{test} = 100\text{V}$	
$T_{op} = 65\text{C}$	$V_{op} = 5\text{V}$	
$AF_{T_min} = 177$	$AF_{V_min} = 8\text{E}3$	$AF_{min} = 1.4\text{E}+06$
$AF_{T_max} = 3951$	$AF_{V_max} = 5.1\text{E}+11$	$AF_{max} = 2.0\text{E}+15$

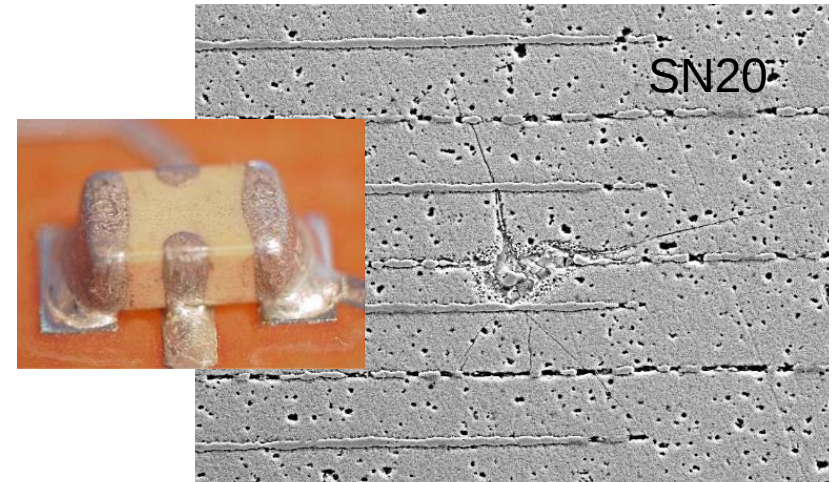
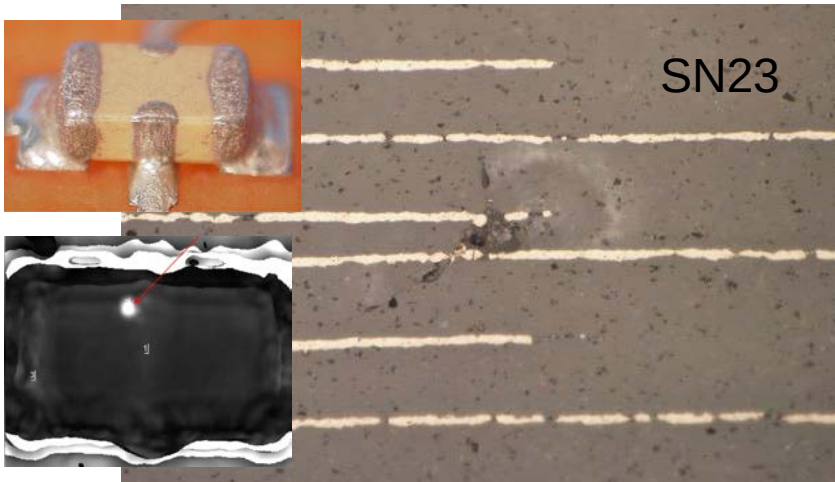
For conservative estimations, $AF = 1.4\text{E}6$



- ✓ The time to failure inceptions (0.1%) increases from 120 hours for life test conditions to 19,000 years for use conditions.
- ✓ The probability of failure during a 20-year mission is $8.7\text{E}-8$, so the risk of failures during operation is small.
- ✓ What was the reason of failures for parts the passed BI?
- ✓ Uncertainty in failure predictions required additional analysis.

Failure Analysis

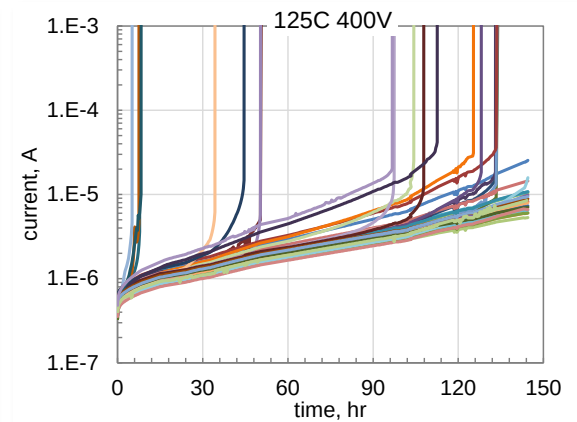
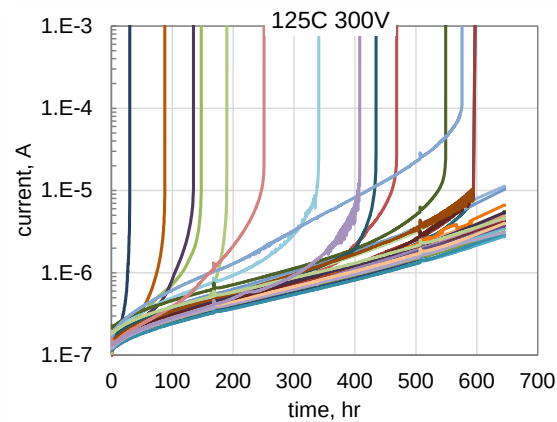
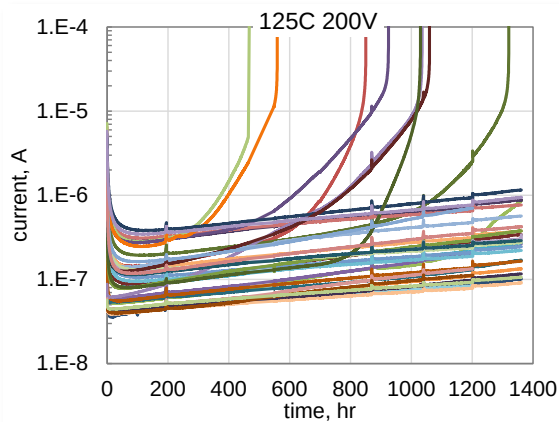
- ❑ Failed samples had resistances of 28k for SN20 and 2k for SN23.
- ❑ No defects during external visual examinations.
- ❑ Acoustic microscopy and cross-sectioning were used to reveal damage.



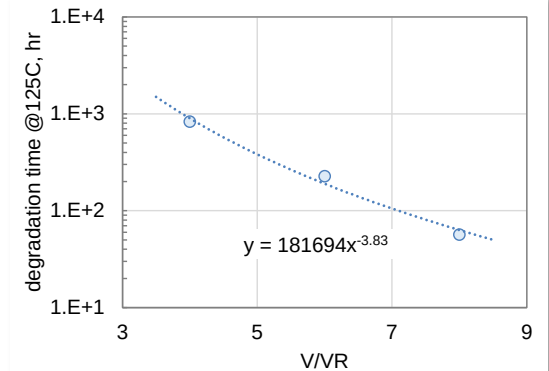
- ✓ In both cases, the damage was due to a local breakdown.
- ✓ Failure sites were associated with areas of thinning of the dielectric from 13 μm in normal areas down to 5-7 μm at the failed sites.
- ✓ The thinning is a manufacturing defect that typically causes IM failures and supposed to be screened out during burn-in of the parts.
- ✓ HALT was used for additional analysis of this type of failures.

HALT

- Leakage currents in three groups of the feedthrough caps with 40 samples each were monitored at 125 °C and voltages of 200V, 300V, and 400V.

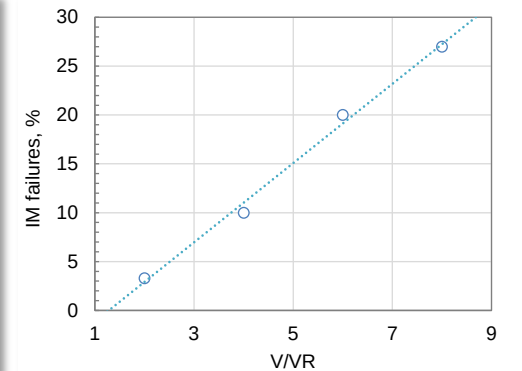
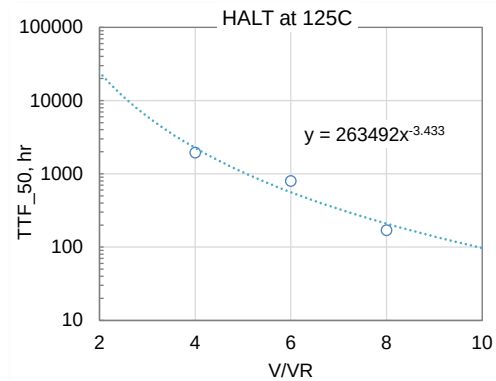
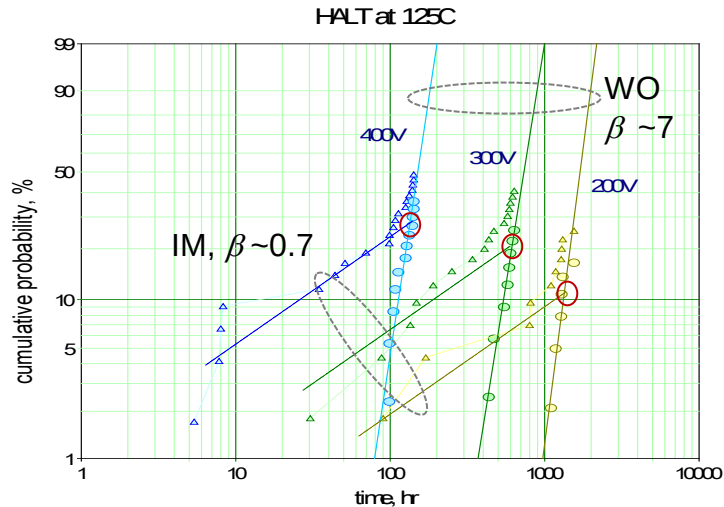


- ✓ DCL degradation is due to migration of V_O^{++} .
- ✓ DCL increases exponentially with time: $I \sim \exp(t/\tau)$.
- ✓ The characteristic time of DCL degradation increases with voltage:
 $\tau \sim (V/VR)^{-m}$, where $m = 3.84$.



HALT, Cont'd

- ❑ The shape of distributions suggests the presence of IM and WO failures.
- ❑ By treating these two groups separately, distributions of IM and WO failures can be characterized independently.



- ✓ $TTF_{50} \sim (V/VR)^{-n}$, where $n = 3.43$, which is close to m and indicates similar mechanisms of DCL degradation and failures ($E_a \sim 1$ eV).
- ✓ The proportion of IM failures decreases linearly with test voltage.
- ✓ Considering the effect of temperature, the risk of having IM failures at operating conditions is negligibly small.
- ✓ According to the thermal run-away model for capacitors with defects, some parts that fail catastrophically HALT might never fail at low voltages.

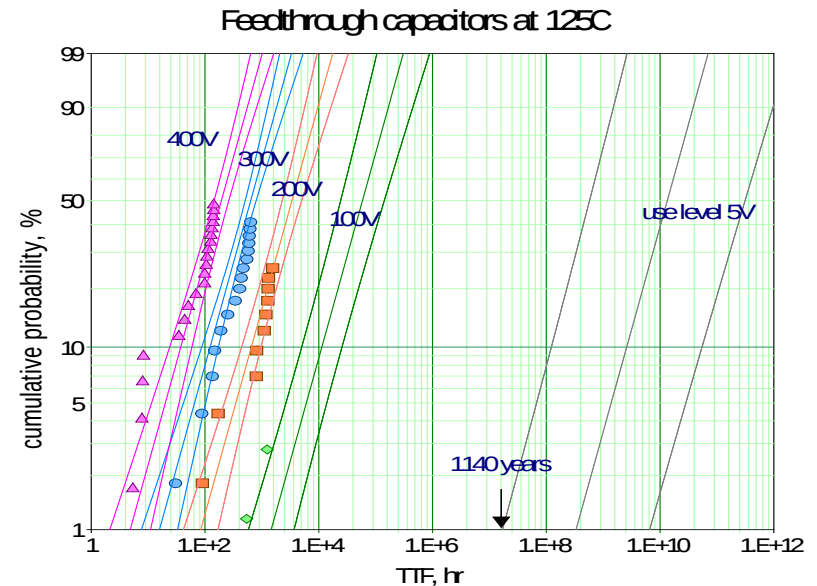
Reliability Assessments

- For conservative assessments, all failures, including IM, were assumed to follow the log-linear model.

$$P(t) = 1 - \exp \left[- \left(\frac{t}{\eta(V)} \right)^\beta \right]$$

$$\eta(V) = A \times V^{-n}$$

- Voltage acceleration constant $n = 4.1$



- ✓ Calculations at $V = 5V$ indicate the time to failure inception (0.1%) exceeding 5000 years at 125 °C.
- ✓ The probability of failures at BI conditions (125 °C/100V/160hr) ~ 0.08% (corresponds to no failures in 300 samples).
- ✓ WO failures at BI condition (125 °C, 2VR) occur after 1000hr, so BI for 160 hrs does not reduce substantially the use life.

Conclusion

- BI of 300 samples per MIL requirements (125°C/2×VR/160hr) did not result in failures.
- No anomalies in behavior of 40 samples soldered onto PWBs after 300 TS +125 to -55 °C. Post-TS samples passed humidity testing at 85%RH/85°C/10V for 240 hrs.
- Two out of 60 capacitors failed life testing at military-level conditions, 125°C/2VR/2000hrs. The failures were due to a local thinning of the dielectric that resulted in accelerated degradation and breakdown at the defect area.
- HALT at 125°C and 200, 300, and 400V was used to assess AF_V and the probability of failure at the use conditions. Based on conservative estimations, the risk of failure for a 20-year mission at 5V and 65°C is negligibly small, below $1E-7$.
- Distributions of TTF during HALT indicate the presence of IM and WO failures, and the proportion of IM failures increases at higher voltages. IM failures that can be revealed at high voltages might never happen at normal operating conditions.
- The used BI conditions do not reduce the resource of the part and are adequate for screening of the capacitors.
- A traditional approach for life testing that is based on MIL standard requirements does not allow for the assessments of the risk of failures for COTS capacitors susceptible to WO failures. A more effective approach is using HALT and reliability modeling for specific application conditions.