Random Vibration Testing of Advanced Wet Tantalum Capacitors

Alexander Teverovsky
AS&D, Inc.
Alexander.A.Teverovsky@nasa.gov

To be presented by Alexander Teverovsky at the Quality and Reliability Technical Symposium, Phoenix, AZ, March 23-25, 2015

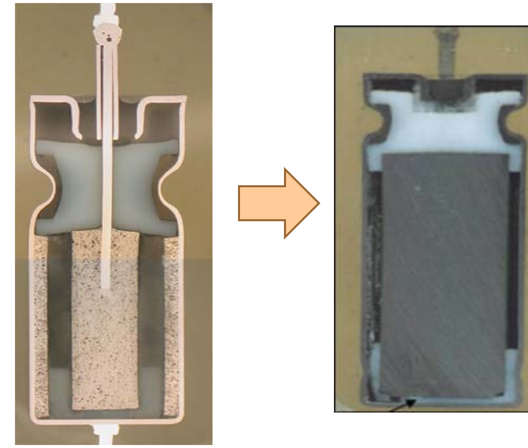
Outline

- Introduction.
- Existing requirements and practice.
- Simulation of current spiking.
- Experiment.
- Results of step stress random vibration testing (RVT).
- Post-testing leakage currents.
- Discussion.
  - Mechanisms of failure.
  - Can RVT be used as a screen?
  - Failures due to gas generation caused by excessive leakage currents.
- Recommendations.
- Conclusion.

Acronyms

AC	alternative current
DCL	direct current leakage
DLA	Defense Logistics Agency
DWG	drawing
GEVS	General Environmental Verification Specification
Mfr.	manufacturer
rms	root mean square
RT	room temperature
RVT	random vibration testing
TM	test method
VR	rated voltage

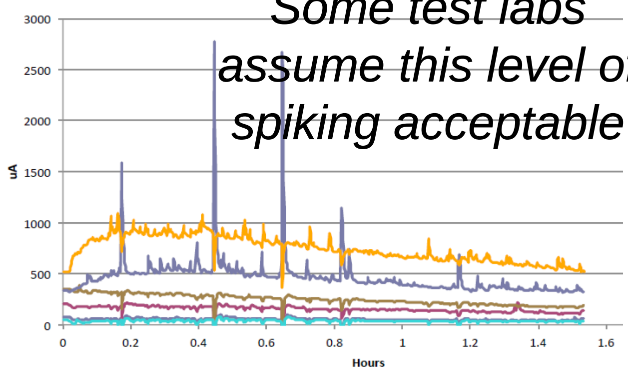
Introduction



- History of RVT for wet tantalum capacitors.
- Advanced wet Ta caps have different cathode materials, larger anodes compared to MIL capacitors, and are more susceptible to damage under RVT.
- Requirements for space modules: typical range of RVT is from 4.5 to 12.9 g rms.
- General Environmental Verification Specification (GEVS): an overall qualification level for testing is 14.1 g rms.
- Assuming a 3dB margin to the system-level, capacitors should sustain 19.64 g rms (condition II-E per MIL-STD-202, TM214).
- RVT cannot be replaced with sinusoidal testing. Peak accelerations during RVT are up to 4-5 times of the rms value.
- Capacitors per DLA DWG#93026 are not specified for RVT.

Existing Requirements and Practice

- MIL-PRF-39006: up to 53.8 g rms; 1.5hr in 3 directions; last 30 min by monitoring every 0.5 msec “to determine intermittent open-circuiting or short-circuiting”. $DCL_{post\ test}$= 125% of DCL_{init}.
- Test techniques and failure criteria are not specified allowing different test labs to carry out testing differently.
- Intermittent open circuit can be relatively easily detected during AC measurements.
- Intermittent shorts result in spiking during DC measurements and require establishing critical levels.

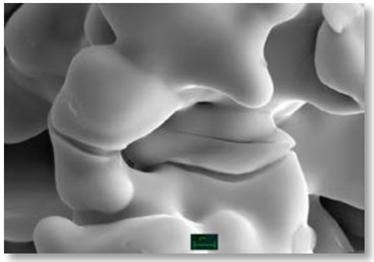


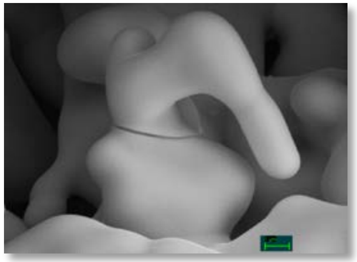
- Used circuits vary substantially, e.g limiting resistors from ohms to dozens of kohms, and failure criteria vary from 5% to 90% of VR.

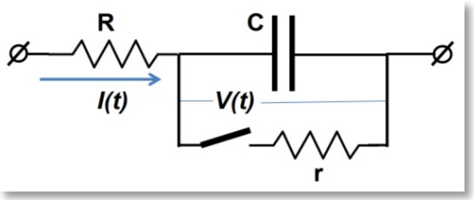
✓ Different set-ups have different sensitivity to short-circuiting.
✓ Different failure criteria cause inconsistency in test results.
✓ A single scintillation event is sufficient to cause lot failure.

Simulation of Current Spiking

- Spiking is due to combination of damaging (cracking) during RVT and fast self-healing. Duration of scintillations, Δt ~ msec.

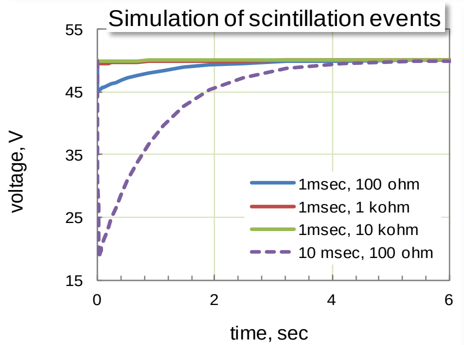


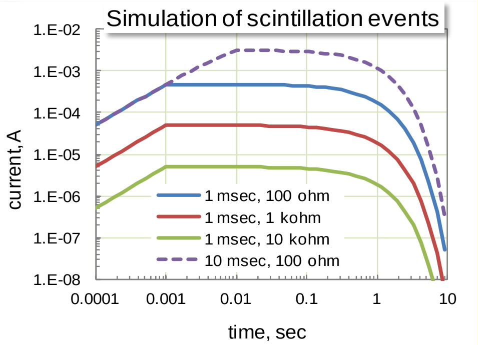




R – external;
r ~ ρ/L – internal resistors

At the resistance of electrolyte, ρ ~1 ohm×cm and size of cracks *L* from 1 to 100 µm, *r* is from 100 Ohm to 10 kOhm.





✓ The rate of *I* or *V* recovery is controlled by $\tau = R \times C$ and occurs relatively slowly => no need for sampling at 0.5 msec.

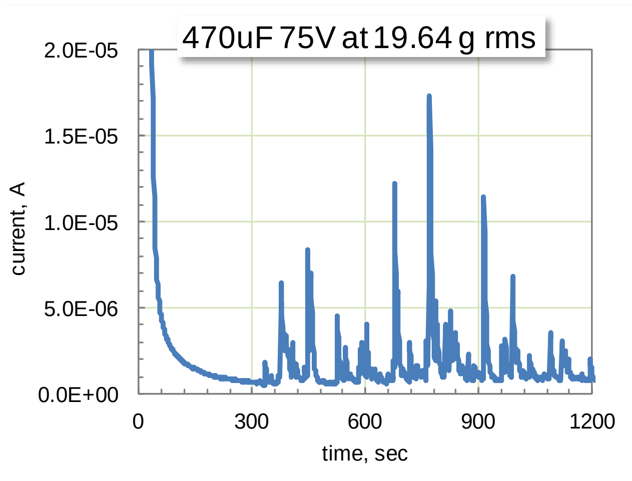
✓ At *R* =10 kohm, sampling at *f* = 10 Hz is sufficient.

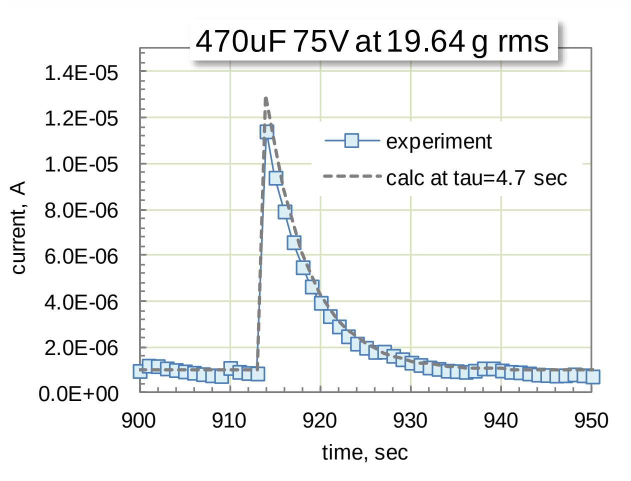
✓ At *R* = 10 kOhm, a 10% voltage drop occurs at rather significant scintillations events when Δt > 10 msec and the damage is large enough to reduce *r* below 100 Ohm.

Experiment

- Step stress RVT: from 10.76 g rms (Cond. II-C) to 53.79 g rms (Cond. II-K) consequentially for 15 min.
- DCL were monitored every 100 msec through 10k resistors.
- Vibration started after 5 min of electrification.
- 24 types of military and DLA DWG#93026 capacitors from 4 manufacturers. 4 to 5 samples in a group.

Typical results of RVT

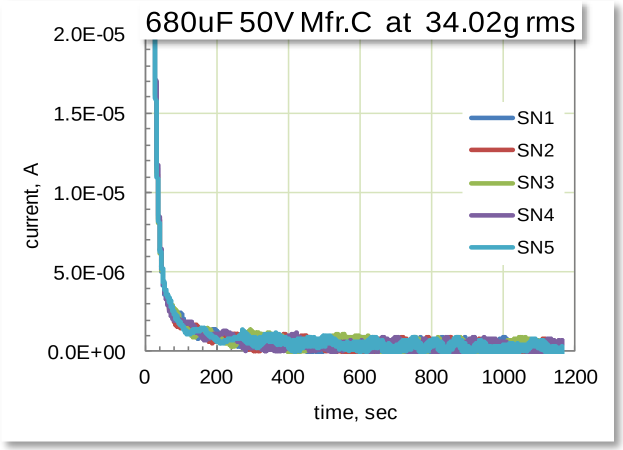


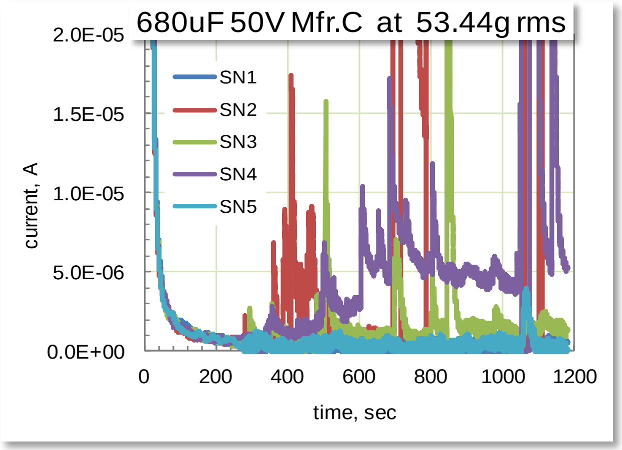


✓ The rise time is below 0.1 sec and the decay had a characteristic time of 4.7 sec (= 470 μF×10 kOhm) that corresponds to the model described above.

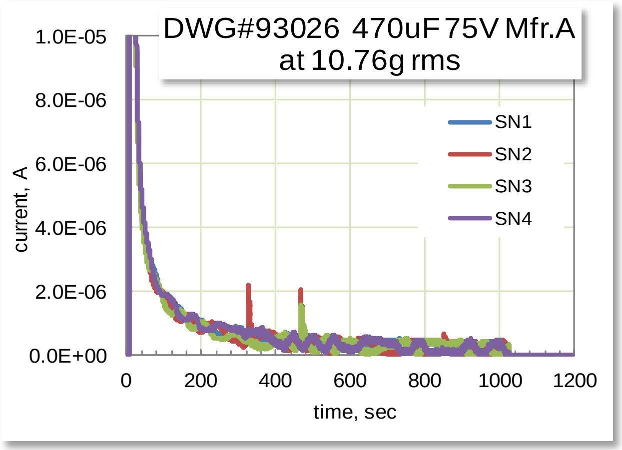
Results of Step Stress Testing

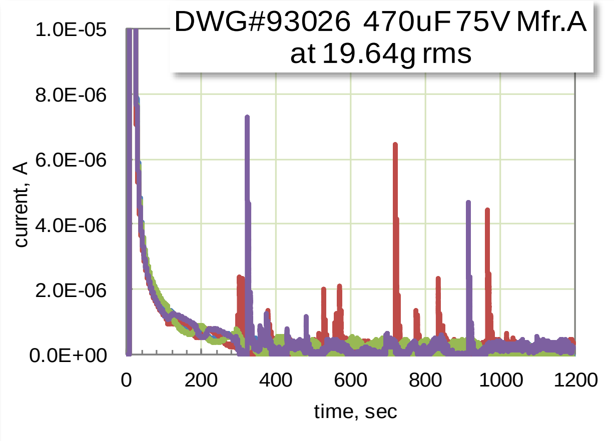
Example of a part passing RVT at 34 g rms and failing at 53.44 g rms





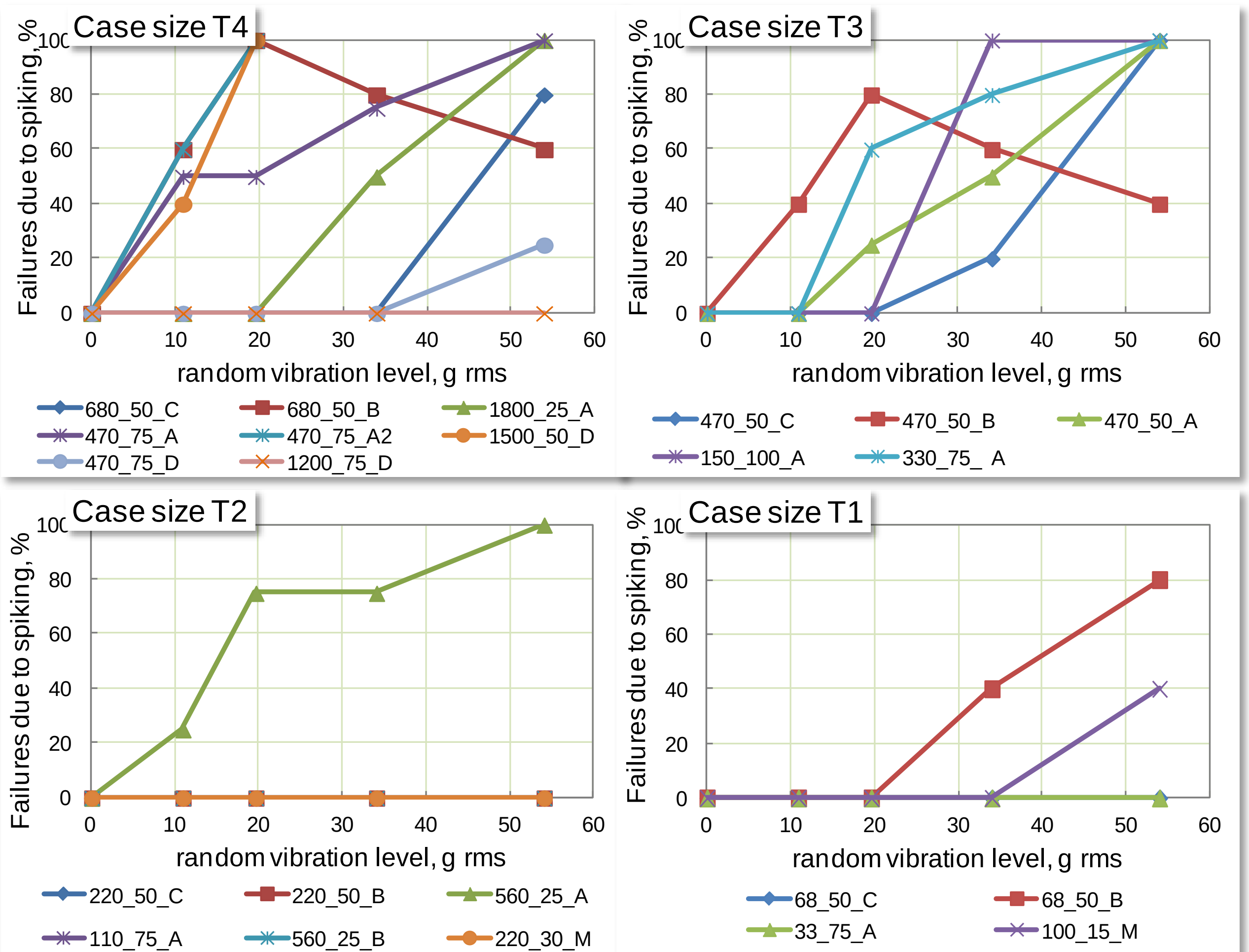
Did this part fail at 10.76 g rms, at 19.64 g rms?





Results of Step Stress Testing, Cont'd

Proportion of failures detected by current spiking for different case sizes

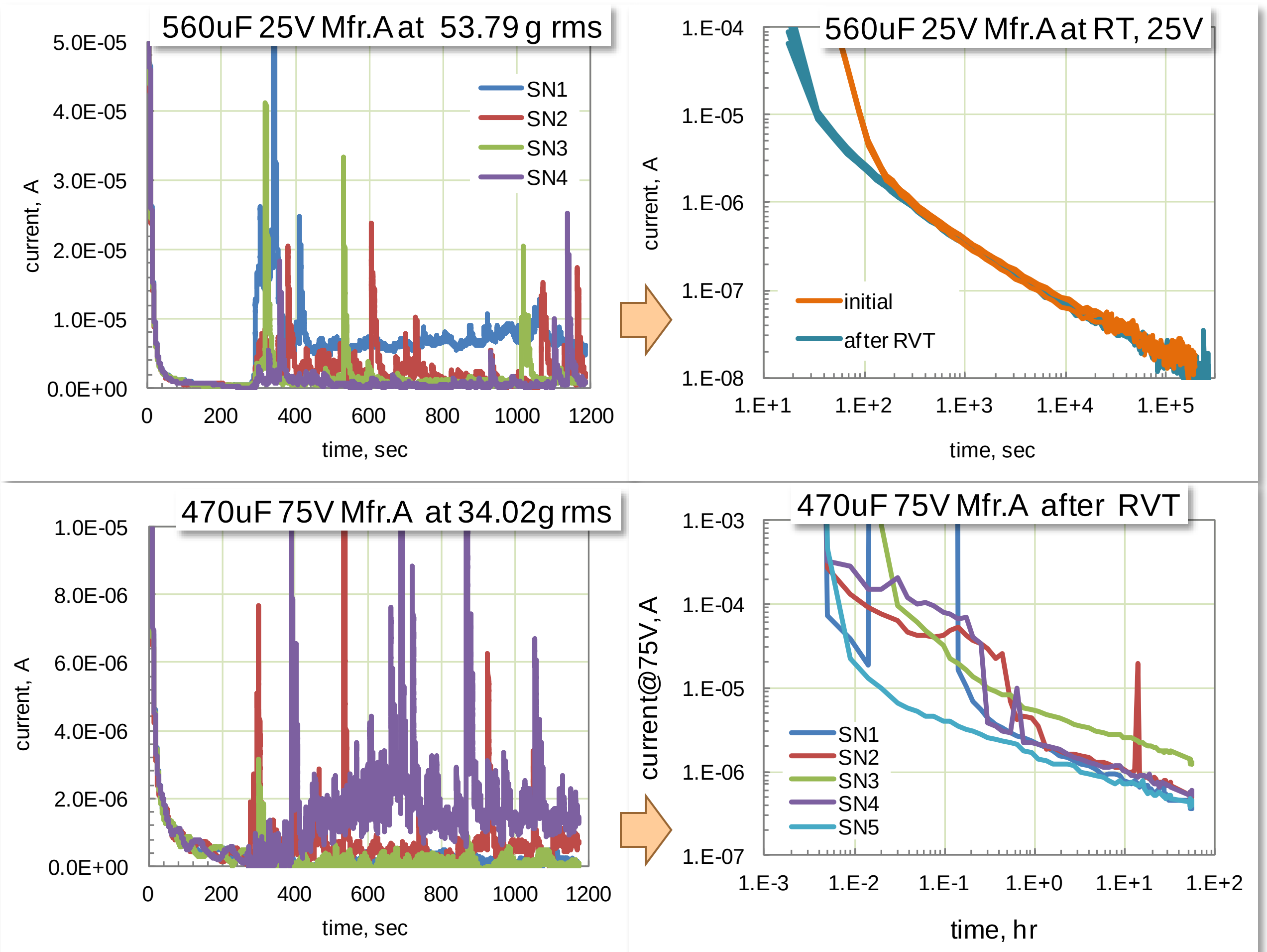


- ✓Capacitors can fail at low stress levels (~10 g rms)
- ✓Failures increase with the level of stress.
- ✓Some parts are recovering at greater stresses.
- ✓The probability of failure is greater for larger size capacitors.

Post-RVT Leakage Currents

- Leakage currents were monitored with time after RVT.

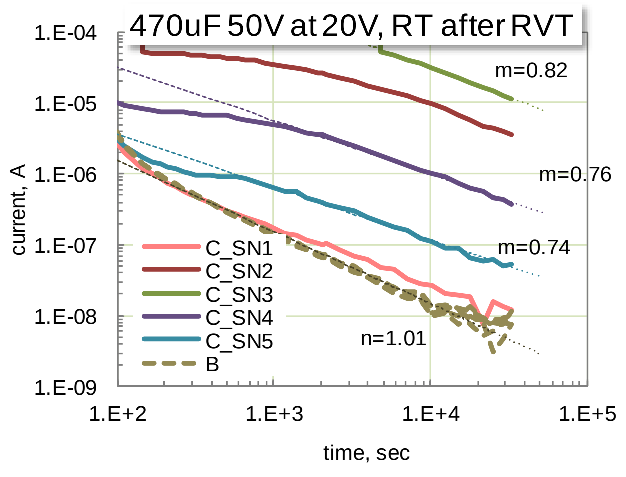
Currents during RVT *Currents after RVT*

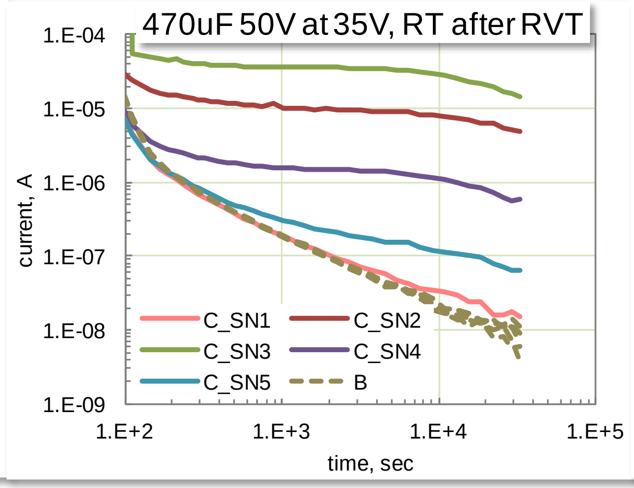


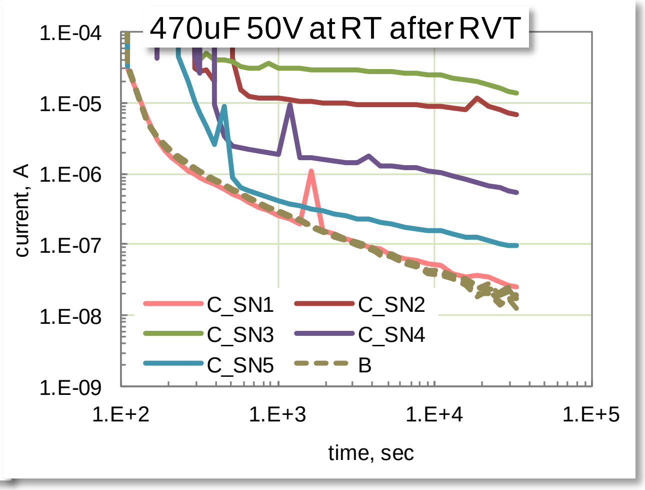
- ✓ Spiking during RVT might not result in DCL failures after the testing.
- ✓ 560 µF 25 V capacitors passed HALT after RVT at 53.8 g rms.
- ✓ Parts with excessive currents are recovering with time under bias.

Post-RVT Leakage Currents, Cont'd

Variations of leakage currents with time for capacitors from Mfr.B and Mfr.C at different voltages



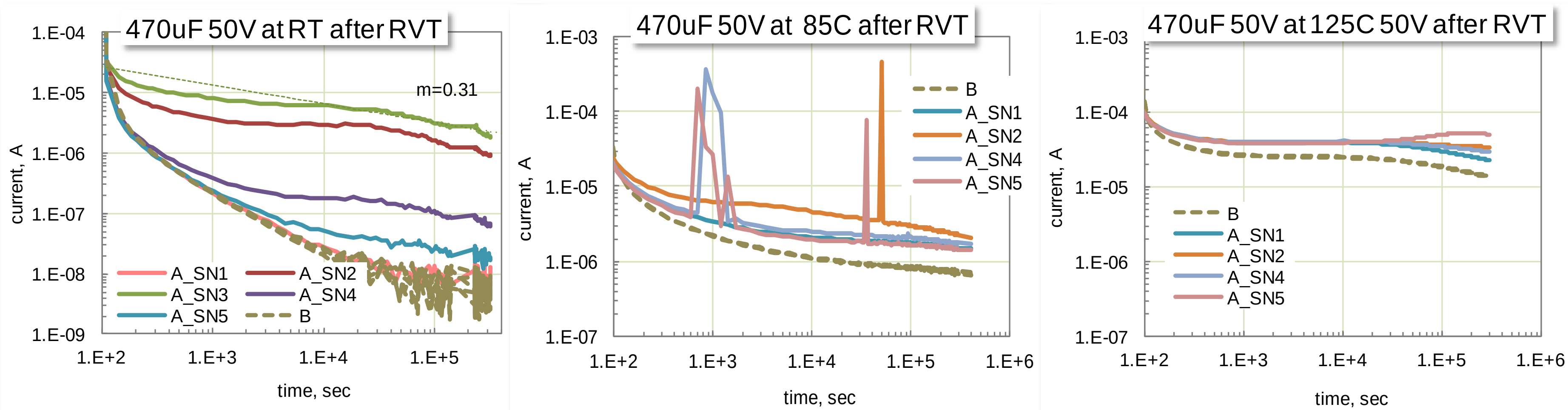




- ✓ At low voltages currents decrease according to a power law.
- ✓ Slow recovery in severely damaged capacitors.
- ✓ Damaged, but partially recovered capacitors are prone to scintillations at rated voltages.
- ✓ No changes in *I-t* characteristics for parts from Mfr.B.

Post-RVT Leakage Currents, Cont'd

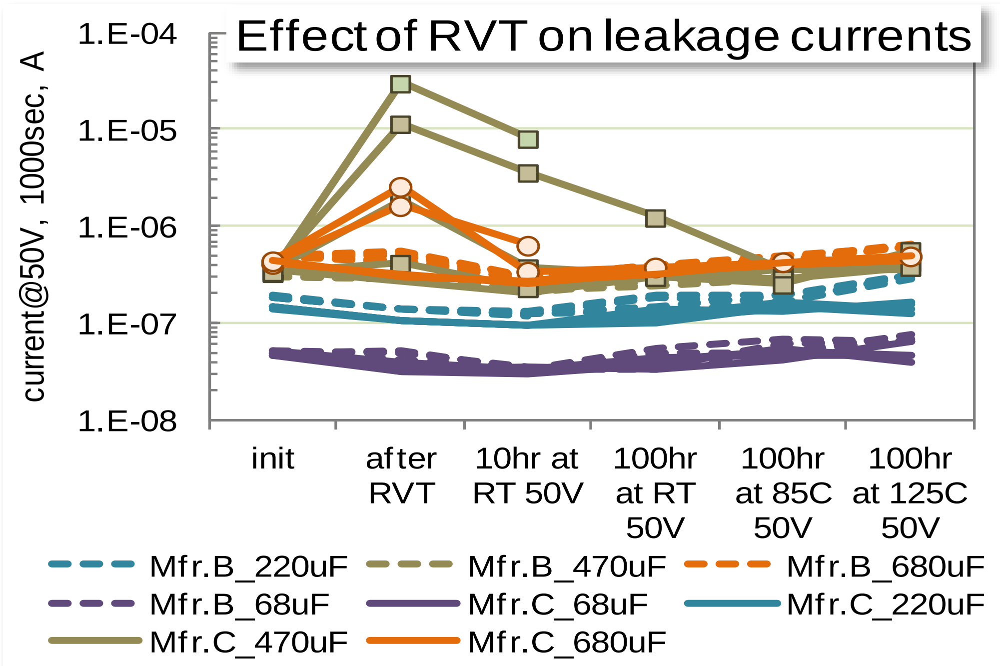
Variations of leakage currents during 100 hr testing for capacitors from Mfr.B and Mfr.C at 22 ºC, 85 ºC, and 125 ºC



- ✓ At RT, testing during 100 hr at VR is not sufficient for full recovery.
- ✓ The difference between damaged and not damaged capacitors decreases after 100 hr testing at 85 ºC.
- ✓ Recovery is almost complete after 100 hr at 125 ºC, 50V.

Post-RVT Leakage Currents, Cont'd

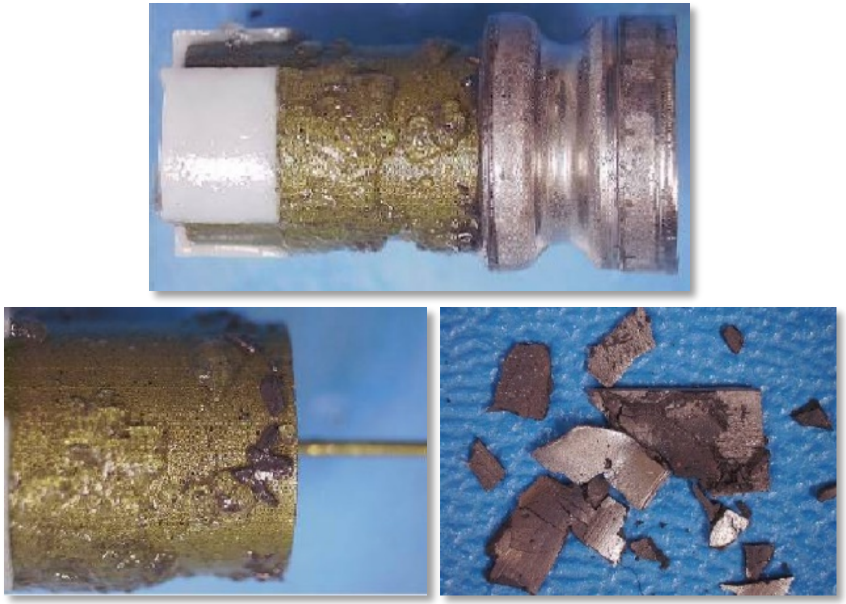
Variations of leakage currents at RT through the testing



- ✓ Intrinsic DCL have a stronger temperature dependence compared to currents in damaged areas => RT measurements might be more effective in revealing damage compared to high temperature measurements.

Discussion: Mechanisms of Failure

- Failure mechanism is likely related to the presence of particles in the electrolyte.
- Particles might be generated by scrubbing during assembly or by cramping.



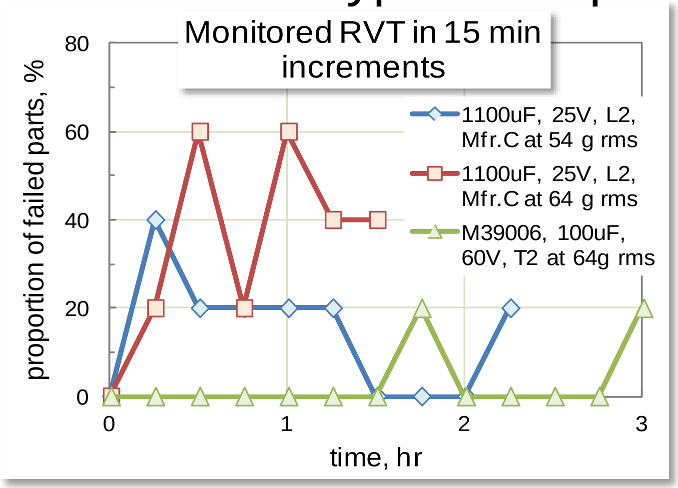
Example of cathode particles

- ✓ Development of a more resistant cathode materials and optimization of the assembly process to reduce the possibility of shifting the slug inside the case might improve performance of capacitors under mechanical stresses.

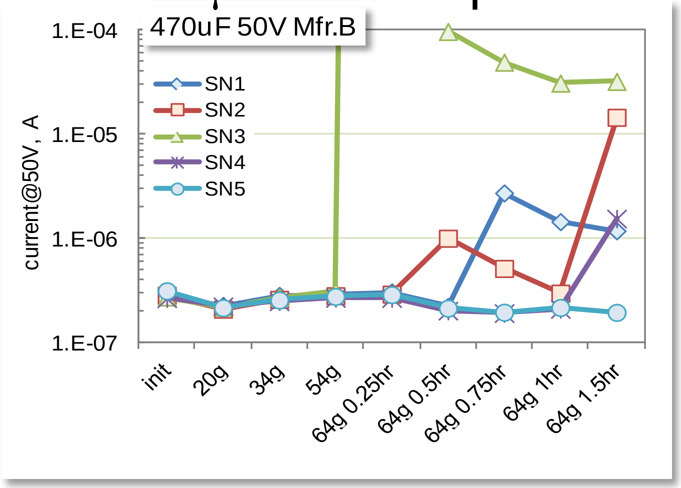
Discussion: Can RVT be used as a Screen?

- If failures are due to manufacturing defects, can they be screened out?

Proportion of failures with duration of RVT for three types of capacitors



Leakage currents in five samples of 470 μF 50 V capacitors



- ✓ There is a possibility of wear-out failures caused by increased duration of the stress.
- ✓ Attempts to evaluate the effectiveness of screening by RVT failed to produce conclusive results.

Gas Generation and Criterion for Current Spiking

The amount of H_2 that causes additional pressure ΔP: $$n_g = \frac{\Delta P \times V_g}{R \times T}$$

H_2 dissolved in the electrolyte: $$n_{el} = k_H \times V_{el} \times \Delta P$$

k_H is a constant that for H_2/water system is 7.8×10^7 mol/cc_atm.

Total amount of H_2: $$n = n_g + n_{el} = \Delta P \times V_f \times \left[\frac{\varphi}{RT} + k_H \times (1-\varphi)\right]$$

φ is a portion of the available free volume of the capacitor, V_f.

Amount of H_2 is determined by the Faraday's law: $$Q = \int_0^{t_{RVT}} i(t) \times dt = z \times F \times n$$

A critical charge, Q_{cr}, can be defined by the critical pressure ΔP_{cr}=0.1 atm

Critical charge for wet tantalum capacitors with different case size

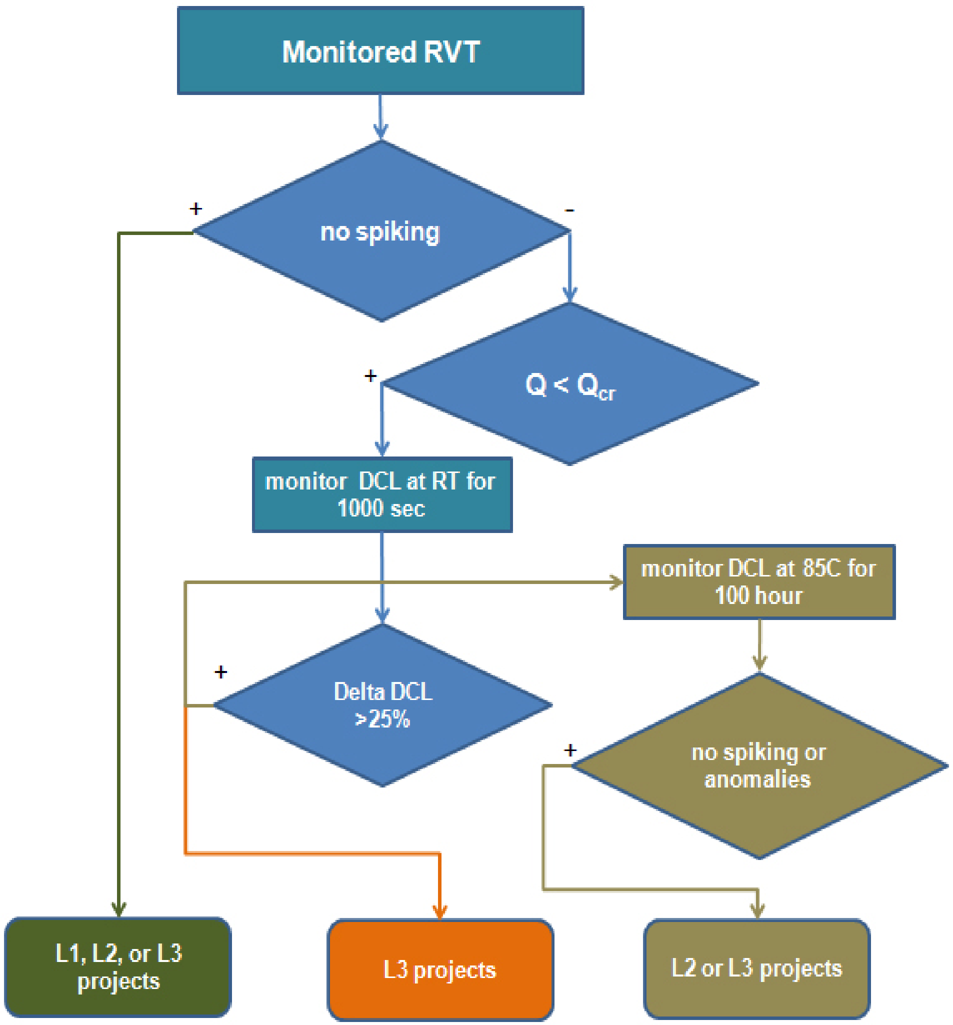
Case size:	T1	T2	T3	T4	L2
L, mm	11.5	16.3	19.5	27	25.6
R, mm	2.4	3.6	4.8	4.8	3.6
V_{case}, cm^3	0.21	0.66	1.41	1.95	1.04
V_f, cm^3	0.075	0.23	0.45	0.65	0.34
Q_{cr}, C	4.3E-03	1.3E-02	2.6E-02	3.7E-02	1.9E-02

Failures due to Spiking, Critical Charge, and Post-RVT Leakage Current

Part Number	10.8 g rms		19.6 g rms		34 g rms		54 g rms		Post RVT leakage
	spikes	Q_t, C	spikes	Q_t, C	spikes	Q_t, C	spikes	Q_t, C	
68_50_T1_C	0/5		0/5		0/5		0/5		0/5
220_50_T2_C	0/5		0/5		0/5		0/5		0/5
470_50_T3_C	0/5		0/5		1/5	3.4E-5	5/5	4.6E-1	4/5
680_50_T4_C	0/5		0/5		0/5		4/5	4E-2	2/5
68_50_T1_B	0/5		0/5		2/5	3.8E-3	4/5	8.6E-3	0/5
220_50_T2_B	0/5		0/5		0/5		0/5		0/5
470_50_T3_B	2/5	6.1E-5	4/5	1.2E-4	3/5	1.4E-2	2/5	8.9E-3	0/5
680_50_T4_B	3/5	7E-5	5/5	3.3E-4	4/5	1.4E-2	3/5	3.2E-2	0/5
250_75_L2_C	0/5		0/5		0/5		0/5		0/5
33_75_T1_A	0/5		0/5		0/5		0/5		0/5
110_75_T2_A	0/5		0/5		0/5		0/5		0/5
330_75_T3_A	0/5		3/5	1.6E-4	4/5	6.3e-4	5/5	7.7e-3	
470_75_T4_A 1	2/5	5E-4	3/5	4.1E-2	5/5	0.12			4/5
1500_50_T4_D	0/5		2/5	4.5E-2	5/5	0.1			3/5
470_75_T4_D	0/4		0/4		0/4		1/4	3.4E-4	
1200_75_T4_D	0/3		0/3		0/3		0/3		0/3
560_25_T2_B	0/5		0/5		0/5		0/5		0/5
100_15_T1_M	0/5		0/5		0/5		2/5	5E-4	0/4
220_30_T2_M	0/5		0/5		0/5		0/5		0/4
560_25_T2_A	1/4	1E-5	3/4	4.2E-4	3/4	5E-4	4/4	1.1E-3	0/4
1800_25_T4_A	0/4		0/4		2/4	1.3E-3	4/4	3.7E-3	0/4
470_75_T4_A 2	2/4	2E-5	2/4	5.3E-5	3/4	1.8E-4	4/4	1.4E-4	0/4
470_50_T3_A	0/4		1/4	1.1E-4	2/4	4.5E-4	4/4	2.7E-3	0/4
150_100_T3_A	0/4		0/4		4/4	9.3E-2	4/4	8.9E-2	2/4

- ✓Out of 96 tests 40% had failures due to the presence of current spikes.
- ✓Out of 38 failures due to spiking only 16% failed Q_{cr}.
- ✓All lots that failed Q_{cr} also failed post-RVT leakage measurements.

Recommendations



- ✓ Different tests for different risk levels.
- ✓ Each lot should be tested.
- ✓ Typical testing:
  - 19.6 g rms , 6 samples.
  - 15 min in each direction.
  - DCL is monitored (10k, 0.1sec sampling).
  - Criterion I: $I_{sp} > 3\times I_{300}$
  - Criterion II: $Q > Q_{cr}$
  - Criterion III: $I_{300\_RVT} > 1.25\times I_{300\_init}$
- ✓ Lots older than 5 years should be retested.

Conclusion

- Existing requirements for RVT of wet tantalum capacitors need clarification and revision.
- Damage to capacitors during RVT can increase leakage currents and noise in the system. It also poses risks of mechanical rupture due to gas generation.
- The probability of intermittent shorting is greater for larger size capacitors, depends on the design and is lot-related.
- Capacitors with minor spiking can self-heal and restore their performance and reliability.
- Testing procedures and requirements for capacitors used in different level space projects are suggested.