Effect of Surge Current Testing on Reliability of Solid Tantalum Capacitors

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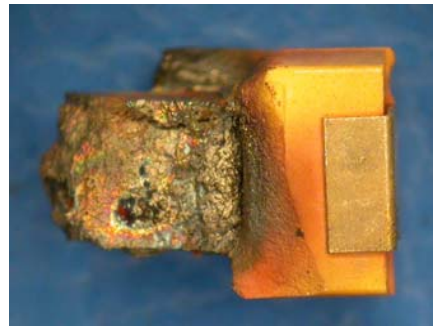
Outline



- Introduction.
- Experiment.
- Distributions of breakdown voltages.
- Effect of SCT on Characteristics of Tantalum Capacitors.

- Effect of SCT on life testing.
- Effect of life testing on SCT.
- Failures under multiple SCT cycling conditions.

- Modeling of SCT.
- Conclusions.

Introduction

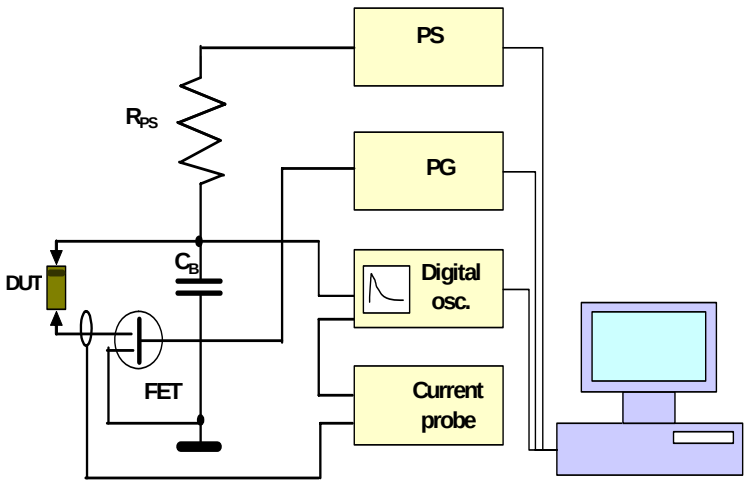
- Ta caps per MIL-PRF-55365 are established reliability components and have FR < 10 FIT (grades D or S).
- Risk of application = (FR) × (consequences).

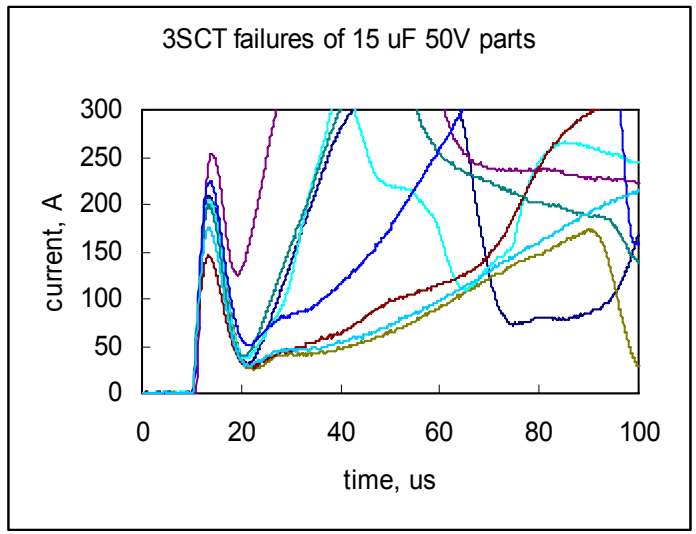
  ⇨ Ta caps are low FR parts with a high risk of application.

- Parts that have passed SCT screening might fail during applications. Possible reasons:
  - Defective capacitors might escape screening due to operator mistakes or equipment problems.
  - Non-adequate test conditions.
  - Environmentally-induced stresses and/or soldering might damage the dielectric.
  - Performing SCT before Weibull grading (option C per MIL-PRF-55365) might have degraded the parts. (is opt. B preferable?)
  - Does screening with SCT 10 cycles guarantee that the part will not fail during cycle 11 and higher?

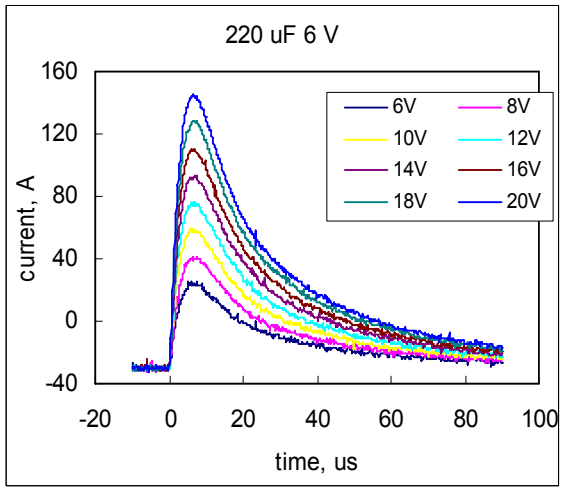
Experiment

- Ten different types of commercial high-CV parts (525 mF-V to 3300 mF-V) and CWR parts.
- Test set-up with MOS FET switches and no limiting resistors.
- Data acquisition system allowed recording current spike amplitudes.
- Life tests at 125 °C, 1.5VR and at RT, 2VR.

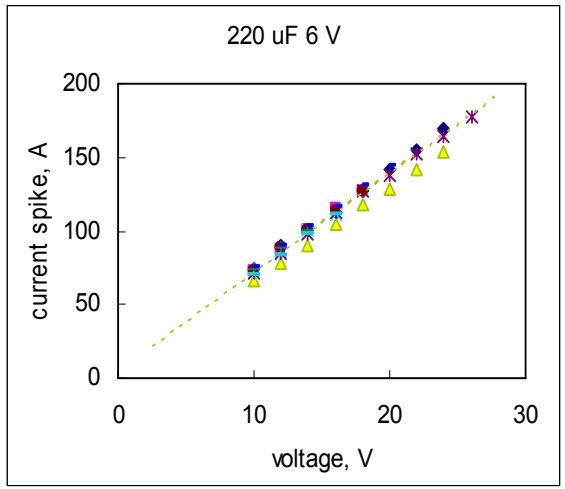




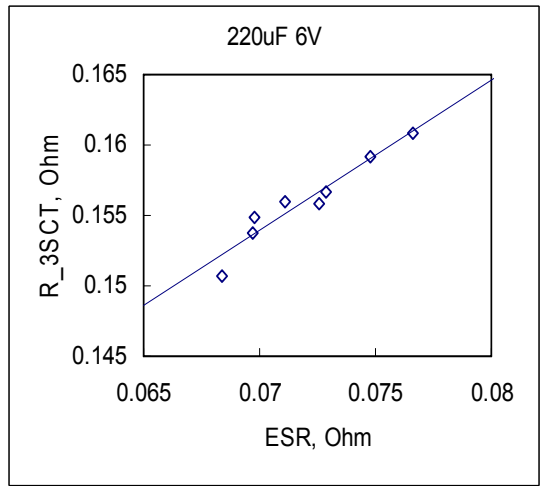
Step Stress Surge Current Testing



Typical current spikes during 3SCT at incrementally increasing voltages.



Variations of the spike amplitude with voltage.
R_{eff} = 1/(slope)

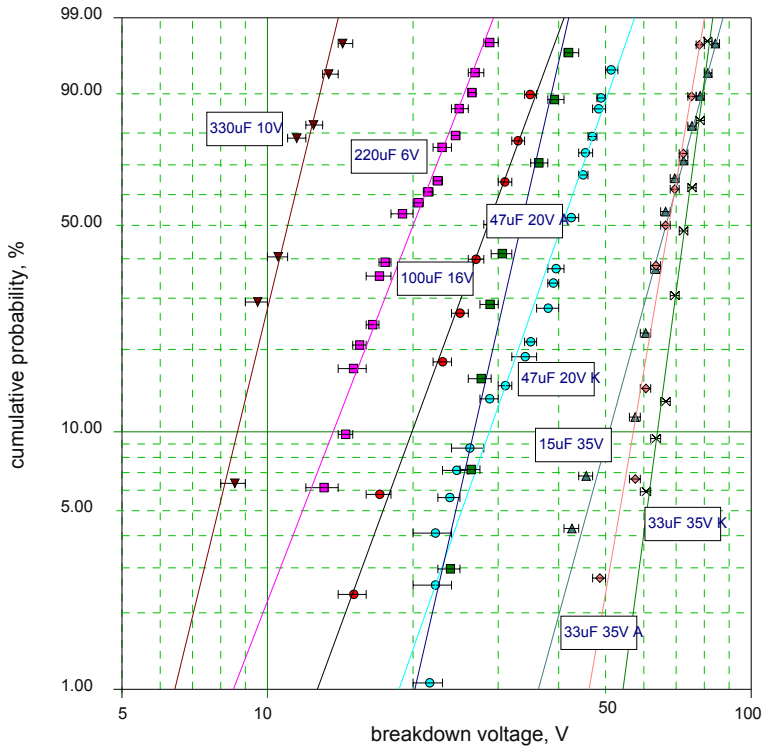


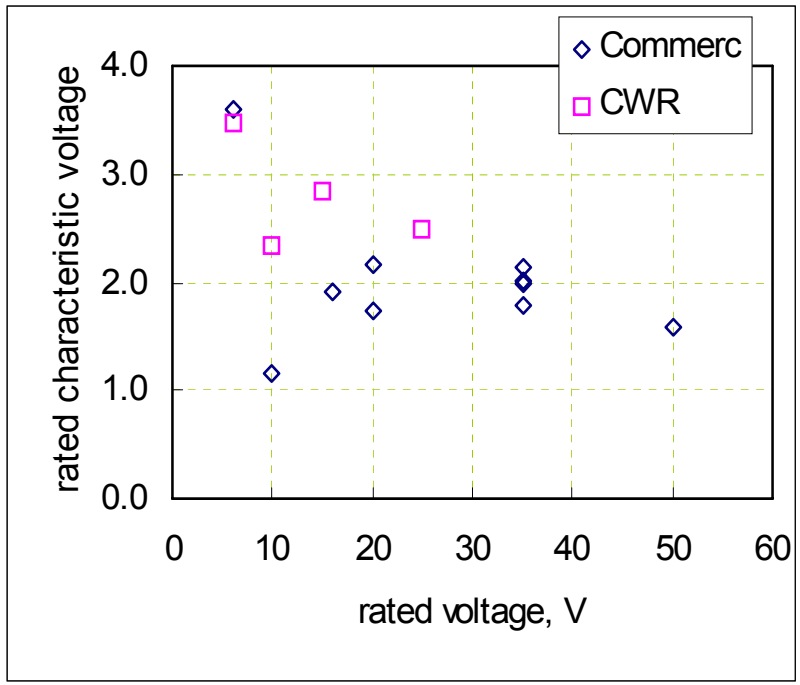
Correlation between ESR (measured at 100 kHz) and R_{eff}.

R_{eff} measurements are important to assure reproducible results and correctness of SCT.

Distributions of VBR_3SCT

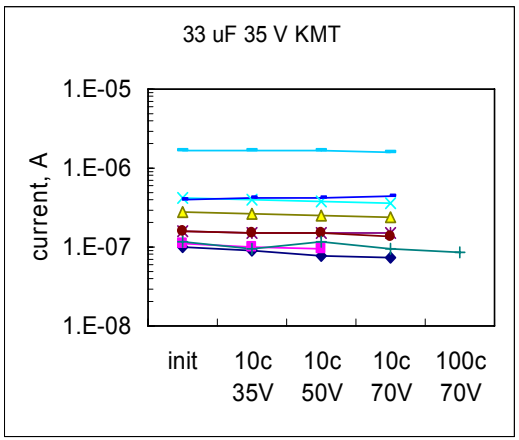
- Both, Weibull and Normal functions can be used to describe VBR_3SCT.
- In some cases bimodal distributions gave a better fit.
- The characteristic VBR ≈2*VR. However, the spread is large (1.2 to 3.6).

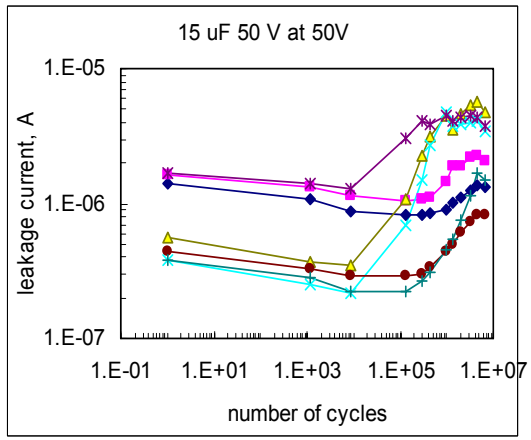


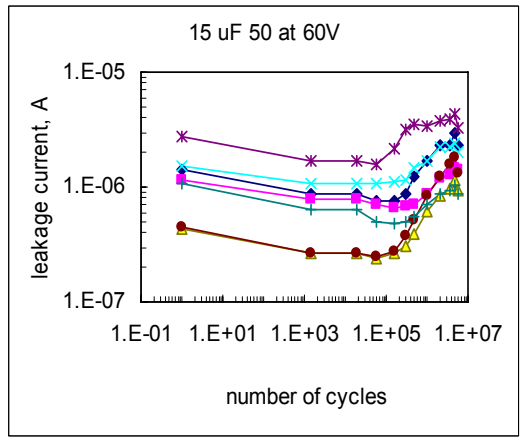


Rated voltage does not correlate with VBR_3SCT.

Effect of SCT on Characteristics of Tantalum Capacitors



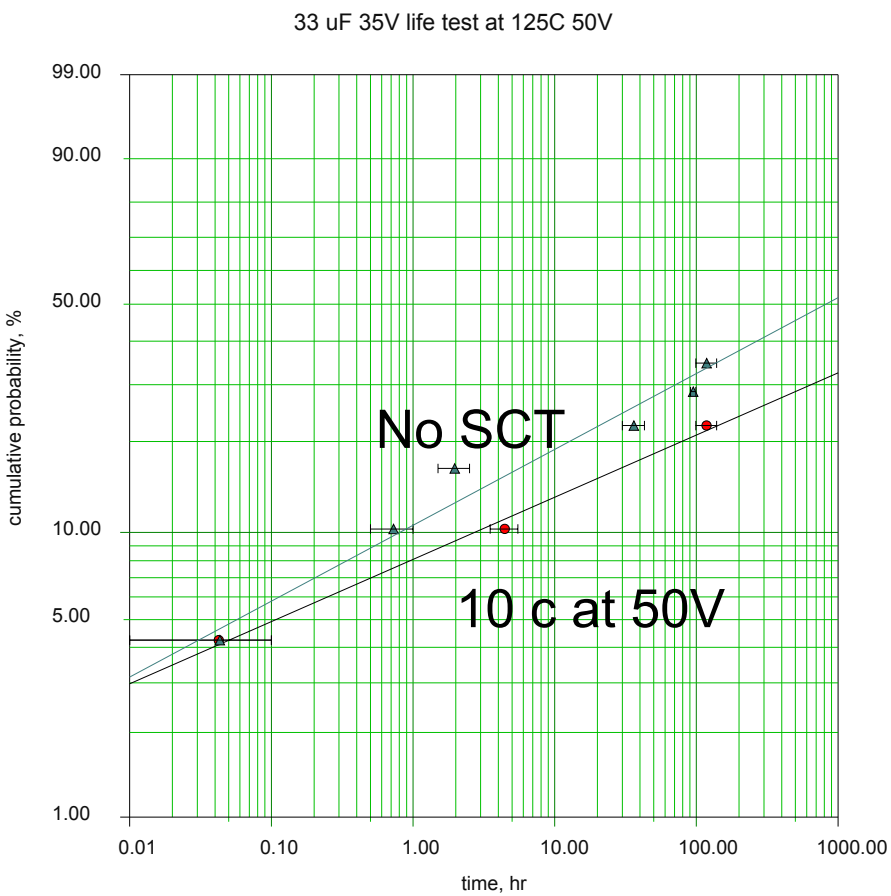


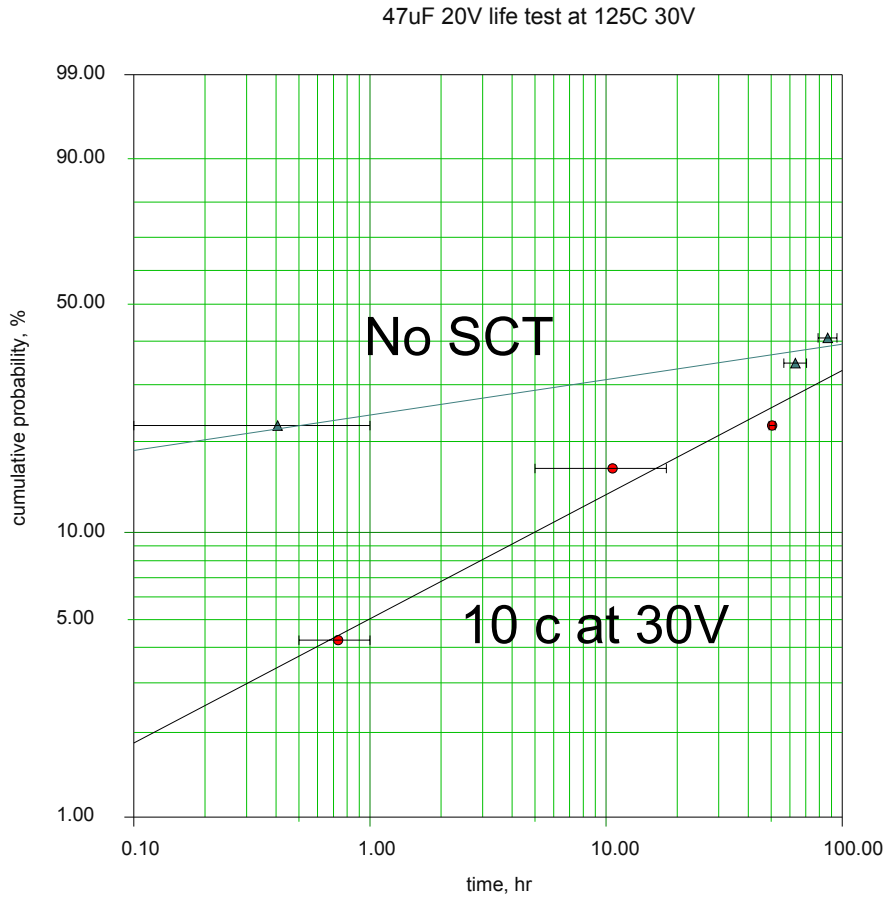


- Multiple SCT at stress voltages up to 2VR and N_c up to 100.
- Only minor variations of the AC and DC characteristics.
- Increased currents after ~ 10^5 cycles are not related to SCT.

Tantalum capacitors can withstand practically unlimited number of high current spikes without degradation.

Effect of SCT on Reliability under Steady-State Conditions



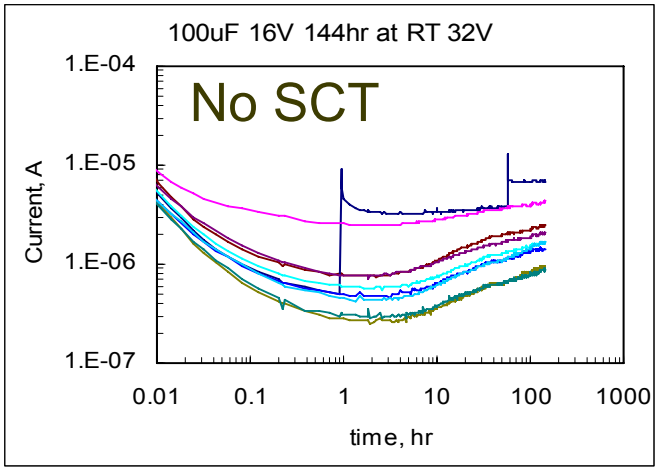


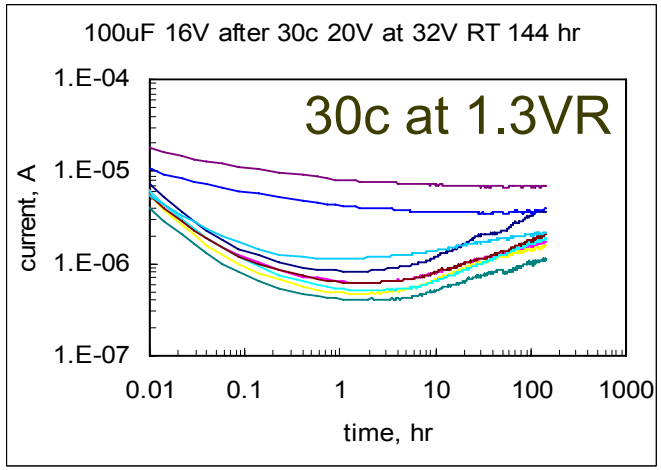
Effect of SCT on Life Test at 125 °C under Steady-State Conditions

Part	Life Test Condition	Precondition	QTY	Failures	Fisher Exact
100 µF/16 V	24V, 72 hr	w/o SCT	25	16	0.82
		SCT 16 V, 10c	25	19	
220 µF/6 V	9V, 168 hr	w/o SCT	16	0	1
		SCT 9 V, 10c	16	1	
47 µF/20 V Mfr. K	30V, 168 hr	w/o SCT	16	7	0.74
		SCT 30 V, 10c	16	5	
33 uF/35 V Mfr. A	50V, 250 hr	w/o SCT	16	10	0.54
		SCT 50 V, 10c	16	6	
33 µF/35 V Mfr. K	50V, 168 hr	w/o SCT	16	6	0.72
		SCT 50 V, 10c	16	4	

- **SCT even at 1.5VR does not cause additional failures during 125 °C life testing.**
- **SCT screening does not affect Weibull grading.**

Life Test at Room Temperature

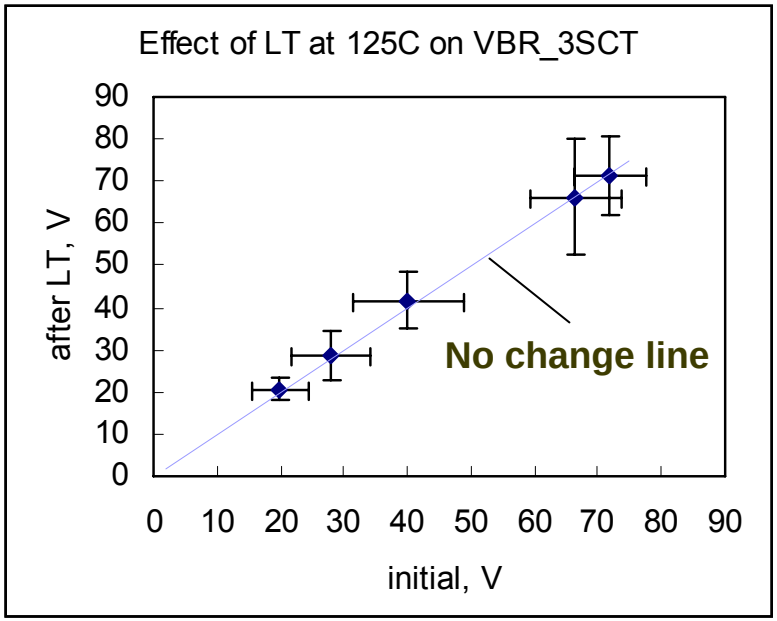


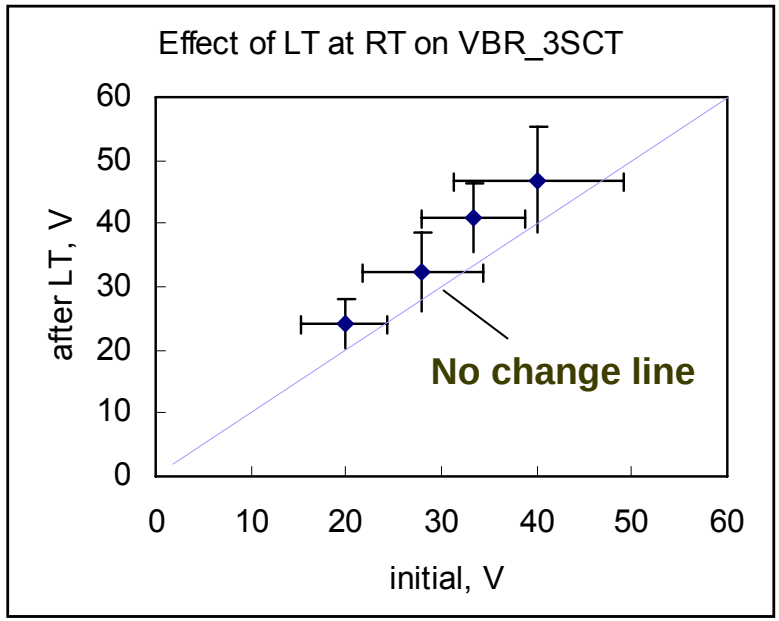


Part	Life Test Condition	Precondition	QTY	Failures
100 µF/16 V	32 V, 144 hr	w/o SCT	9	1
		SCT 20 V, 30c	9	0
220 µF/6 V	12 V, 200 hr	w/o SCT	18	2
		SCT 12 V, 10c	18	3
47 µF/20 V KEMET	40 V, 200 hr	w/o SCT	18	6
		SCT 40 V, 10c	9	3
47 µF/20 V AVX	40 V, 200 hr	w/o SCT	9	1
		SCT 30 V, 10c	9	0

SCT does not affect results of life test at RT

Effect of Life Testing on 3SCT





- Testing at 125 °C did not change results of 3SCT.
- Long-term bias at RT and 1.5VR to 2VR increases VBR.

Weibull testing does not degrade results of SCT.

3SCT after Life Testing

- Life test failures had VBR_3SCT similar to virgin parts.

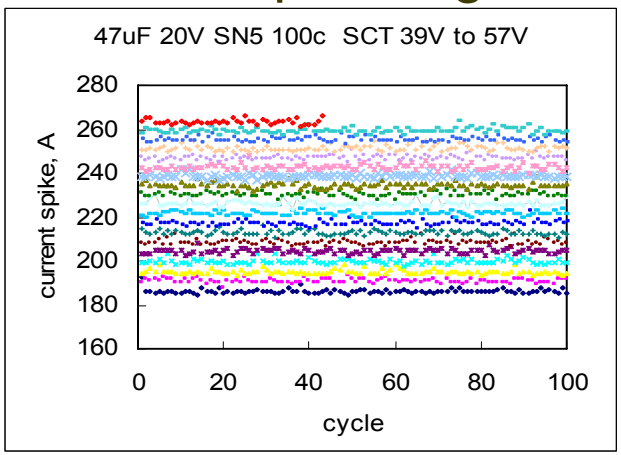
⇨ Self-healed scintillations do not degrade the capability of capacitors to withstand surge current conditions.

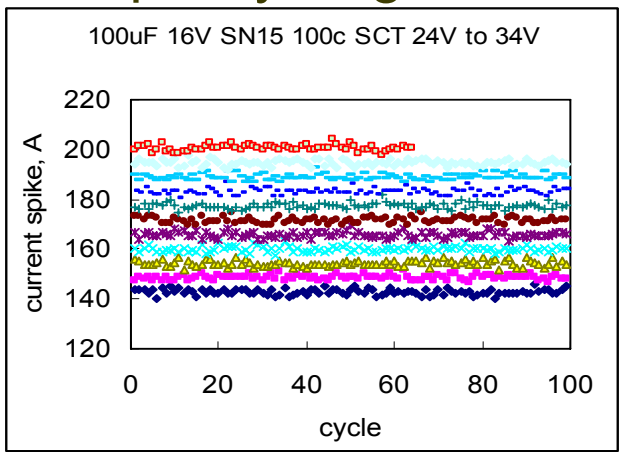
- Parts that withstood hundreds of hours during steady-state testing at 2VR, failed 3SCT at voltages much lower than 2VR.

⇨ Scintillation and surge current breakdowns have likely different mechanisms, and “proofing” of the parts might not guarantee reliability under surge current conditions.

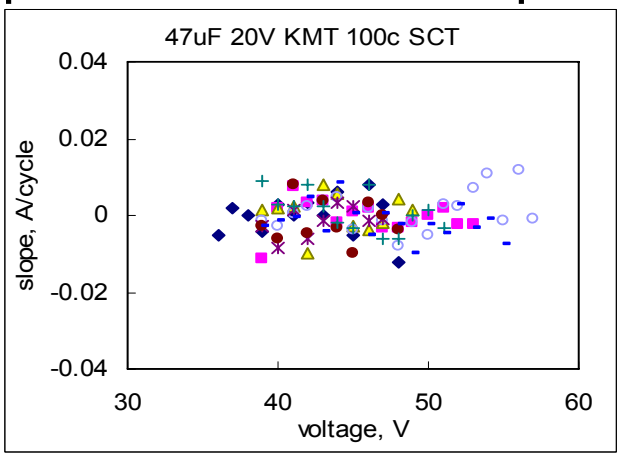
Effect of Multiple Cycling during SCT

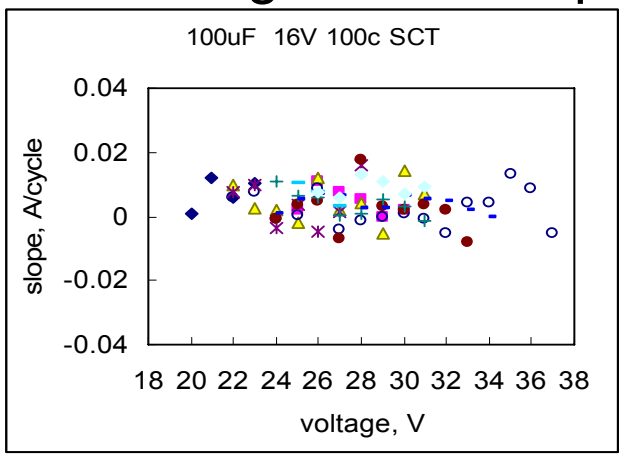
Variations of Isp during 3SCT at multiple cycling at each step



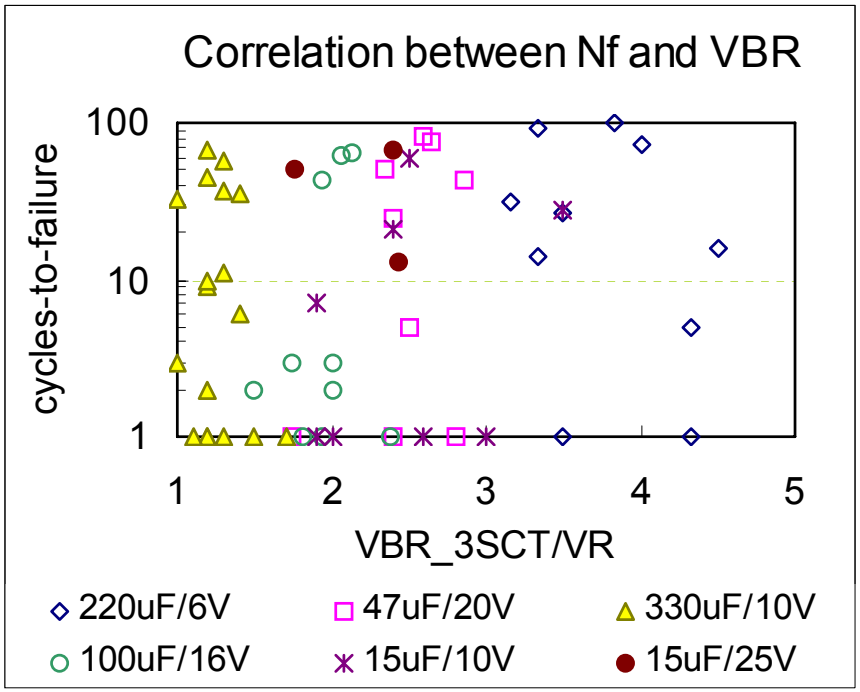


Dependence of the slope on stress voltage for 9 samples





Failures during Multiple 3SCT Cycling



- 3SCT on 6 lots at 100 cycles per step in 1 V increments.
- 56% of the parts failed after 10 cycles.
- There is no correlation between N_f and VBR_3SCT.

Screening might consume resources and increase the probability of failure for parts failing at VR.

Modeling of the Number of Cycles to Failure

Assumptions:

1. Parts fail the first SCT cycle at $V \geq V_{cr}$.
2. There is a certain threshold voltage, V_{th}, below which the part would never fail.
3. At $V_{th} < V < V_{cr}$ the part might fail at any number of cycles.
4. Failures at $N_f > 1$ are due to accumulated damage according to Miner's rule:

$$N_f \times D = 1$$

5. The value of damage depends on how mach the applied voltage exceeds V_{th} :

$$D = A\left(V - V_{th}\right)^n$$

Considering that at $V = V_{cr}$, $N_f = 1$:

$$N_f = \left(\frac{V_{cr} - V_{th}}{V - V_{th}}\right)^n$$

6. $V_{th} = \alpha V_{cr}$, where $\alpha < 1$

Modeling of the Number of Cycles to Failure, cont.

At $V > V_{cr}$ $N_f = 1$.

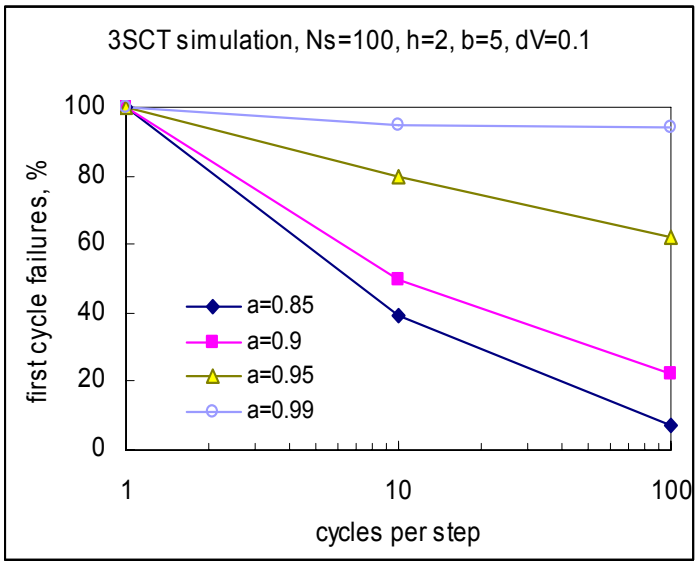
At $V_{th} < V < V_{cr}$:

$$N_f = \left(\frac{1-\alpha}{V/V_{cr} - \alpha} \right)^n \quad \text{where} \quad V_{cr} = \eta \times \left[-\ln(1-p) \right]^{1/\beta}$$

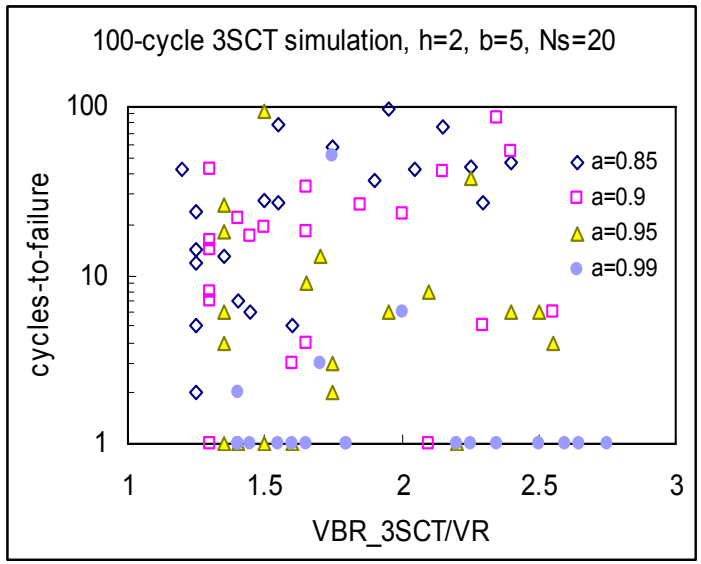
At $V_{th} < V$ $N_f = \infty$.

SCT screening at $V > VR/\alpha$ can eliminate post-screening failures.

3SCT Simulation



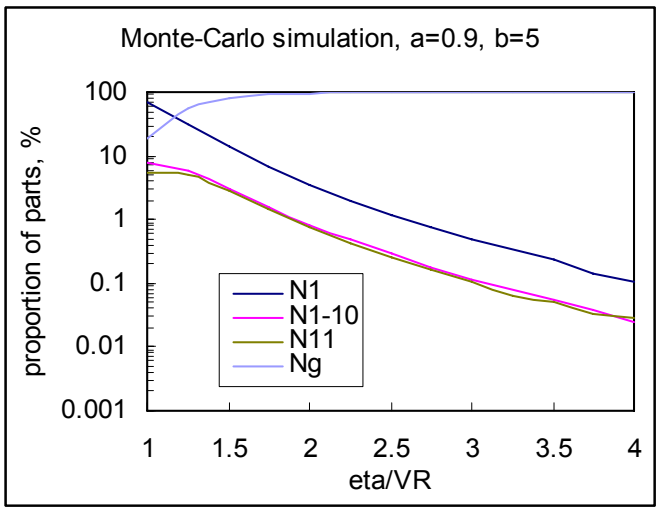
Proportion of parts failing the first SCT cycle at different number of cycles per step.

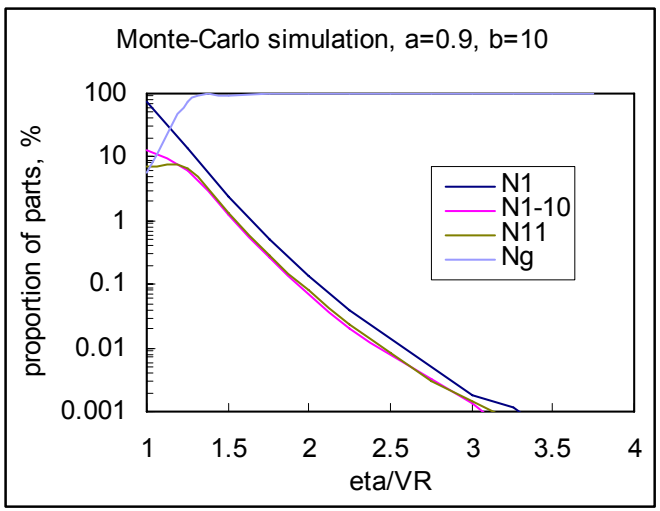


Correlation between the simulated VBR_3SCT and number of cycles to failure.

For 0.85 < α < 0.95 the results of simulations are in reasonable agreement with experiment.

Screening Simulation





Monte Carlo simulation of SCT screening at different η/VR and β.

N_f1 - first-cycle failures;
N_f1_10 - failures between 1st and 10th cycle;
N_f11 - failures after 10 cycles;
N_g - "never fail" parts.

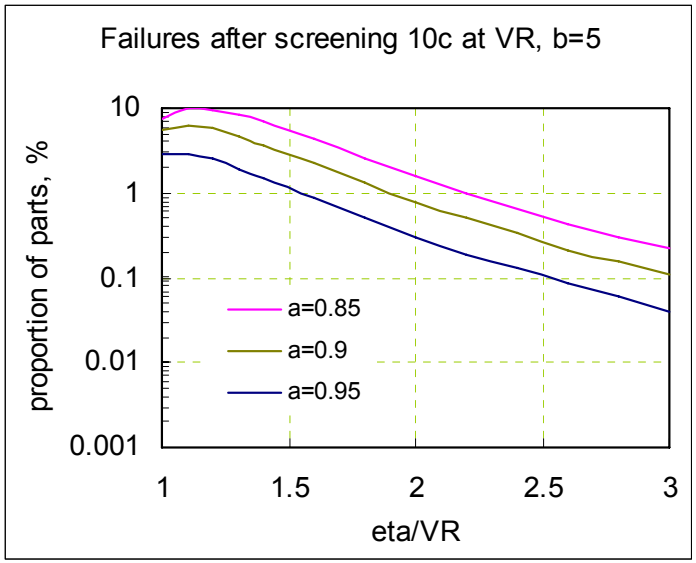
- The probability of SC failures sharply decreases at η/VR > 1.5.
- The first-cycle failures are the majority of screening failures.
- Proportion of post-screening failures is ~5 to 400 times less than of screening.

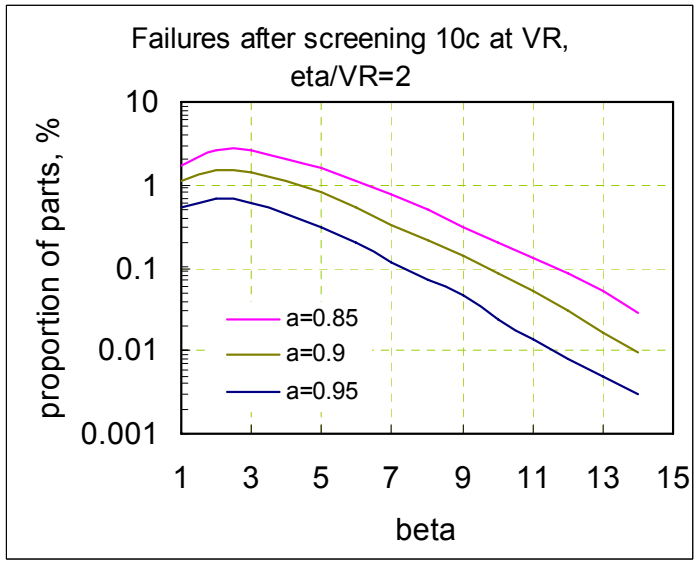
A low probability of post-screening failures explains the presumption that if a part does not fail first few cycles, it never fails.

Probability of Post-Screening Failures

Post-screening failures at different parameters of the model

Screening simulation: 10 cycles at VR.





- At $\beta < 5$, and $\eta/VR < 2$ the probability of post-screening failures exceeds 0.2%.
- For a typical case, $\eta/VR = 2$ and $\beta = 8$, the model predicts that more than 0.07% parts might fail at VR after screening.

Conclusion

- SCT screening does not affect life testing and life testing does not degrade SCT breakdown voltages.
  ⇨ Options B and C per MIL-PRF-55365 are equivalent.
- Multiple SCT, even at V > VR, do not cause degradation of parameters of the parts.
- More than 50% of parts failed 3SCT after 10 cycles and there is no correlation between N_f and V_{BR}.
- A model allowing calculations of N_f for a given distribution of V_{cr} has been developed.
- To reduce the probability of failures during applications, SCT screening should be performed at voltages from 1.1VR to 1.15VR.