



NASA Electronic Parts and Packaging (NEPP) Program



Effect of Surge Current Testing on Reliability of Solid Tantalum Capacitors

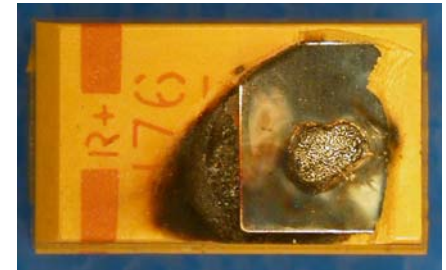
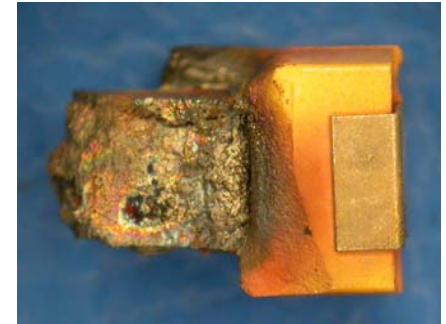
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Outline

- 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 = $(FR) \times (\text{consequences})$.

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

- Parts that have passed SCT screening might fail during applications. Possible reasons:

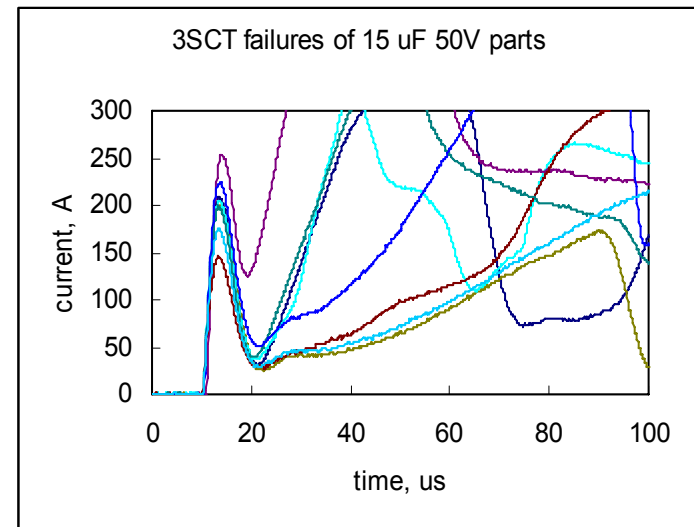
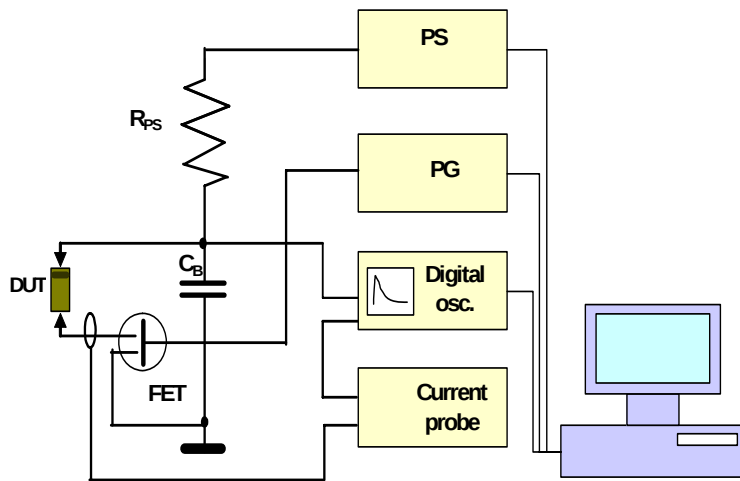
- Defective capacitors might escape screening due to operator mistakes or equipment problems.
- Non-adequate test conditions.
- Environmentally-induced stresses and/or soldering might damage the dielectric.



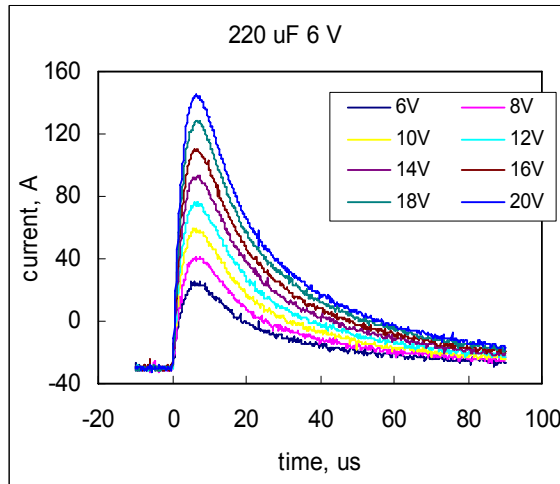
- Performing SCT before Weibull grading (option C per MIL-PRF-55365) might have degraded the parts. (is opt. B preferable?)
- Does screening with SCT 10 cycles guarantee that the part will not fail during cycle 11 and higher?

Experiment

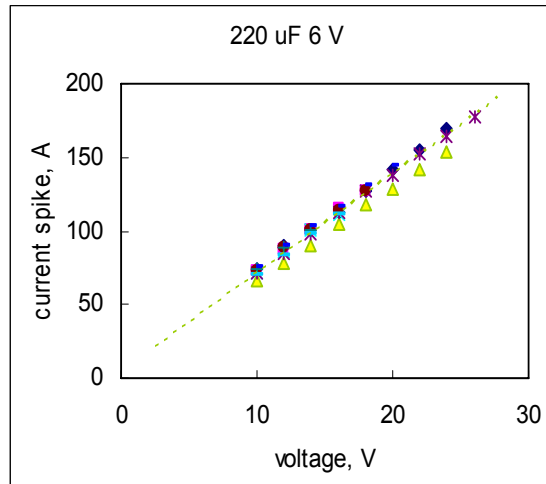
- Ten different types of commercial high-CV parts (525 mF-V to 3300 mF-V) and CWR parts.
- Test set-up with MOS FET switches and no limiting resistors.
- Data acquisition system allowed recording current spike amplitudes.
- Life tests at 125 °C, 1.5VR and at RT, 2VR.



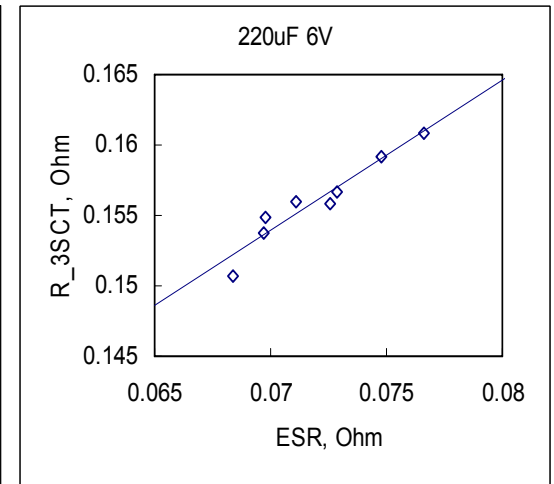
Step Stress Surge Current Testing



Typical current spikes during 3SCT at incrementally increasing voltages.



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

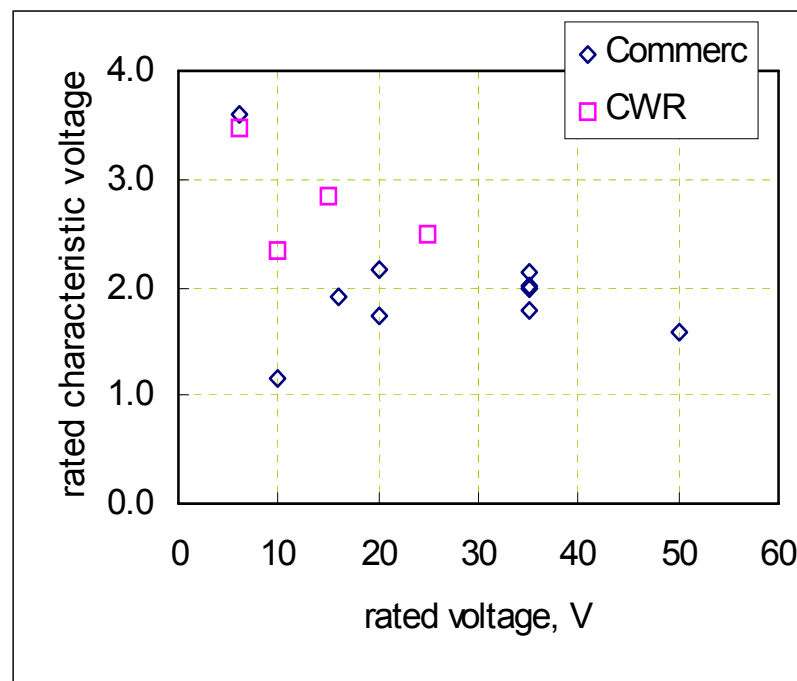
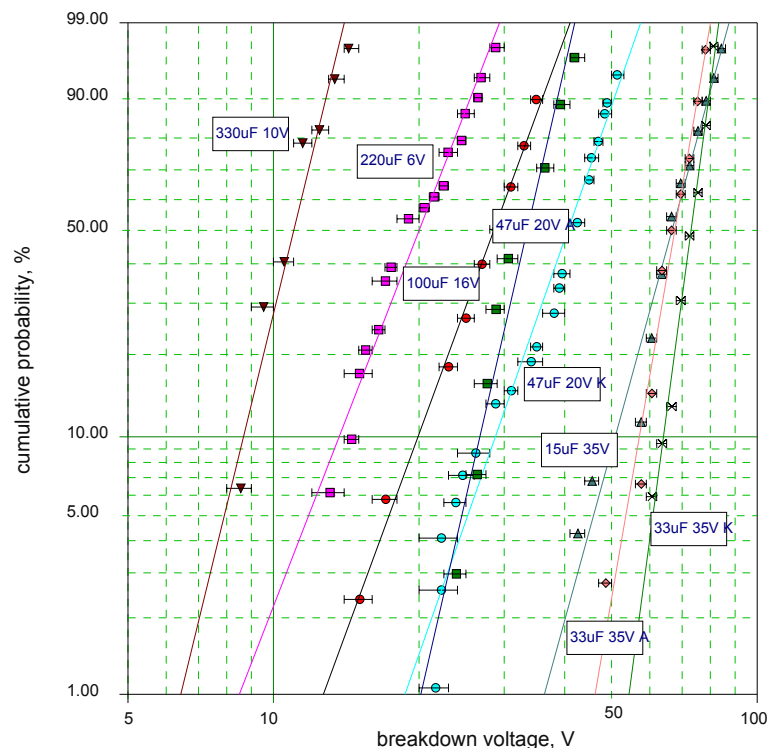


Correlation between ESR (measured at 100 kHz) and R_{eff} .

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

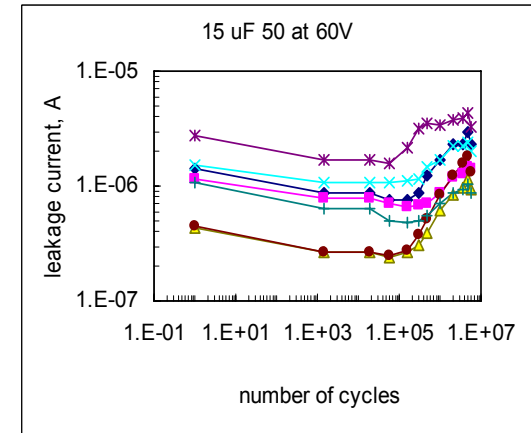
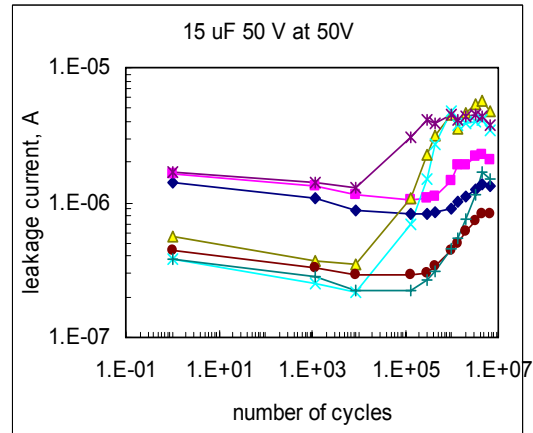
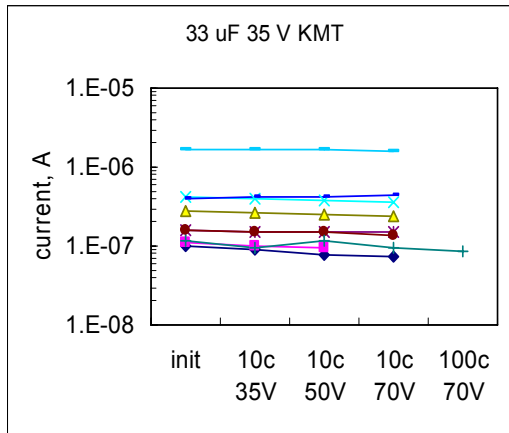
Distributions of VBR_3SCT

- Both, Weibull and Normal functions can be used to describe VBR_3SCT.
- In some cases bimodal distributions gave a better fit.
- The characteristic VBR $\approx 2 \cdot VR$. 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

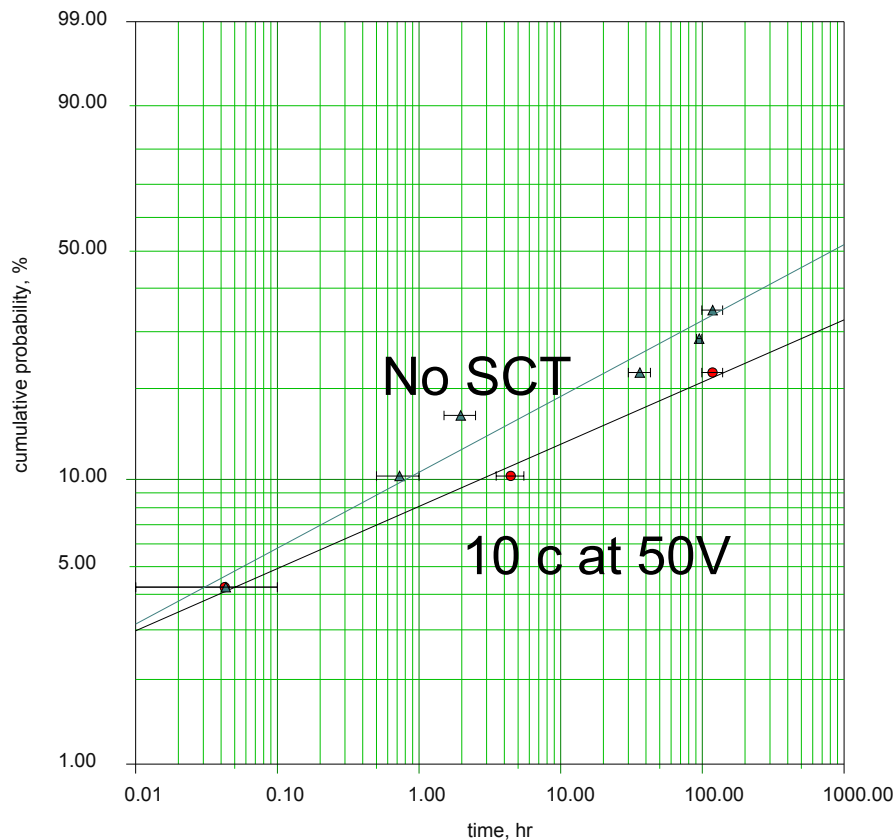


- Multiple SCT at stress voltages up to 2VR and N_c up to 100.
- Only minor variations of the AC and DC characteristics.
- Increased currents after $\sim 10^5$ cycles are not related to SCT.

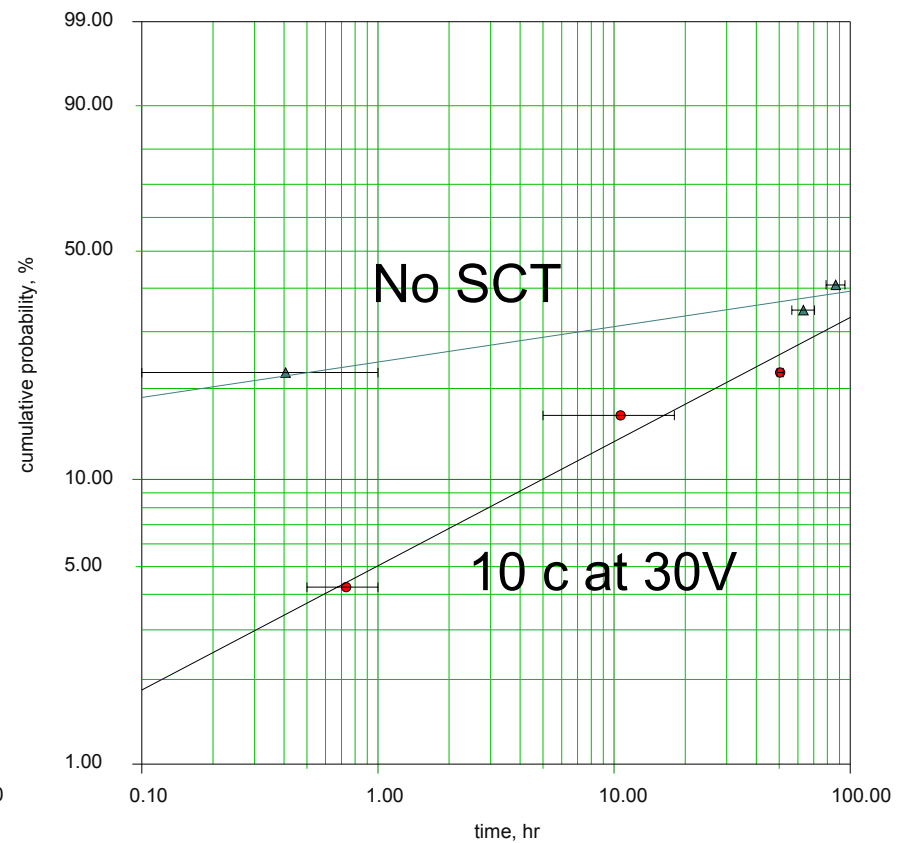
Tantalum capacitors can withstand practically unlimited number of high current spikes without degradation.

Effect of SCT on Reliability under Steady-State Conditions

33 uF 35V life test at 125C 50V



47uF 20V life test at 125C 30V

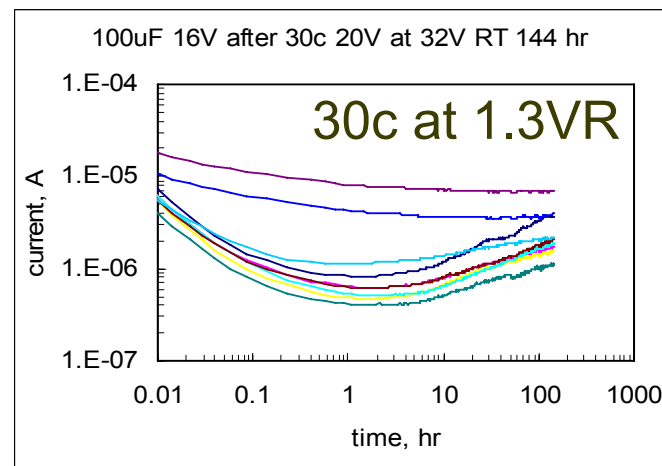
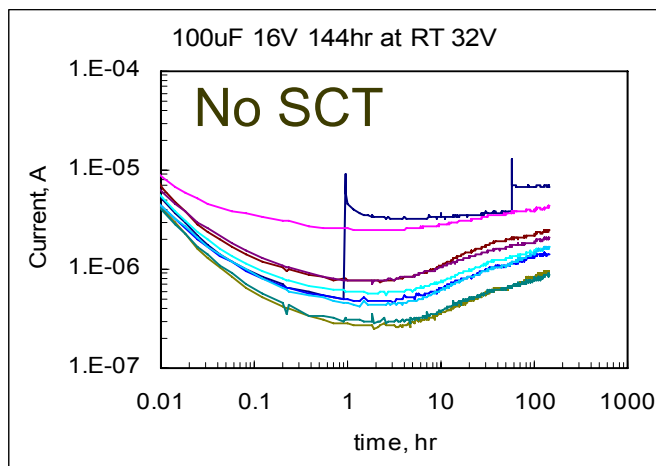


Effect of SCT on Life Test at 125 °C under Steady-State Conditions

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

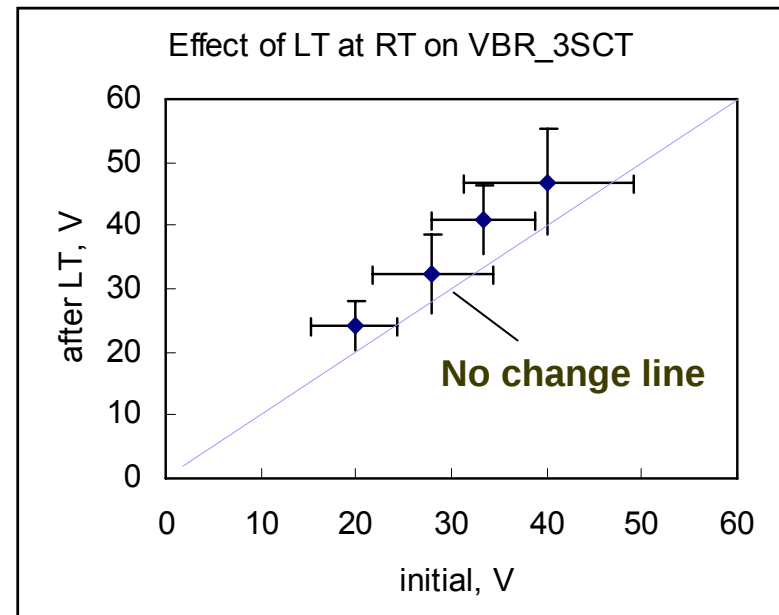
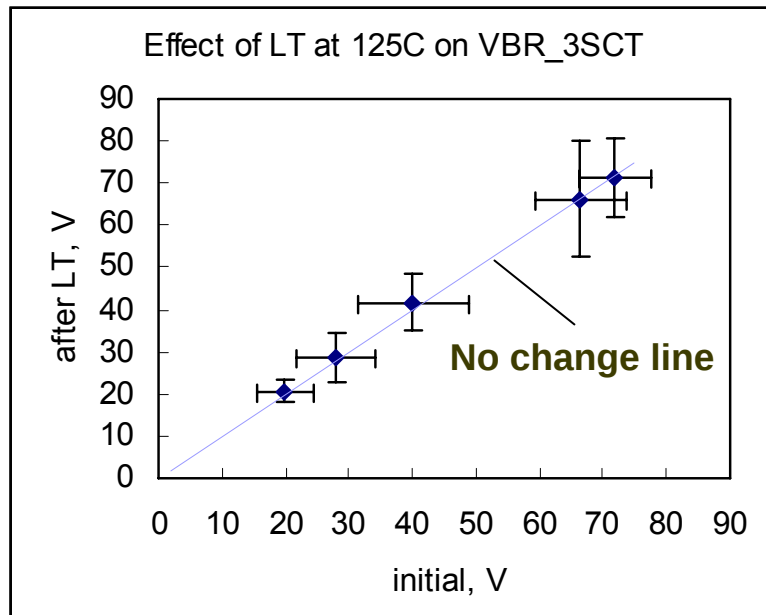
Life Test at Room Temperature



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

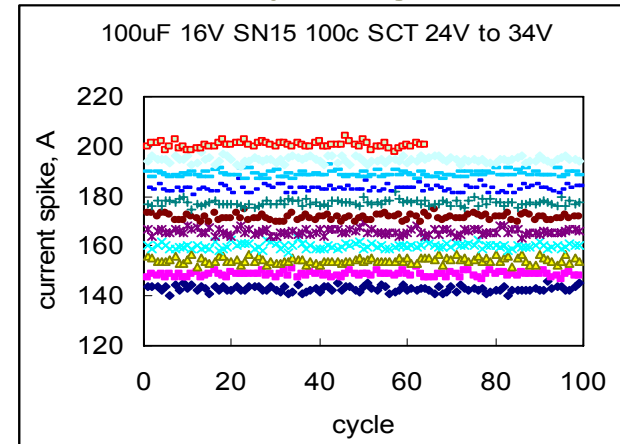
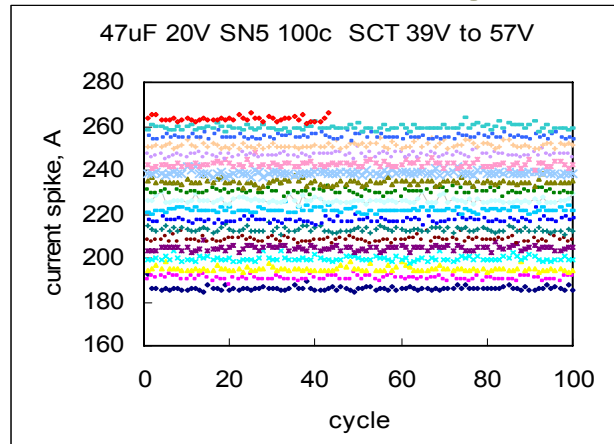
⇒ Self-healed scintillations do not degrade the capability of capacitors to withstand surge current conditions.

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

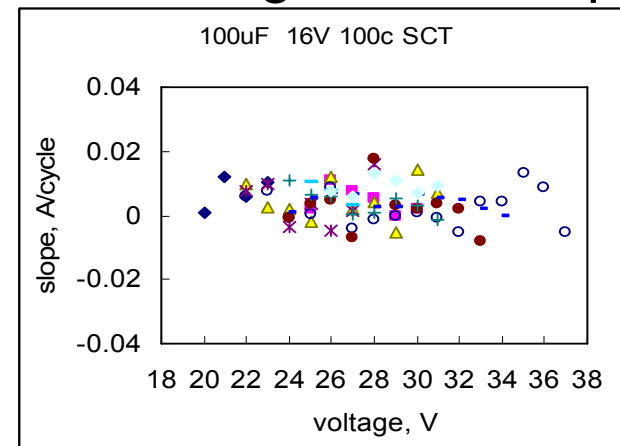
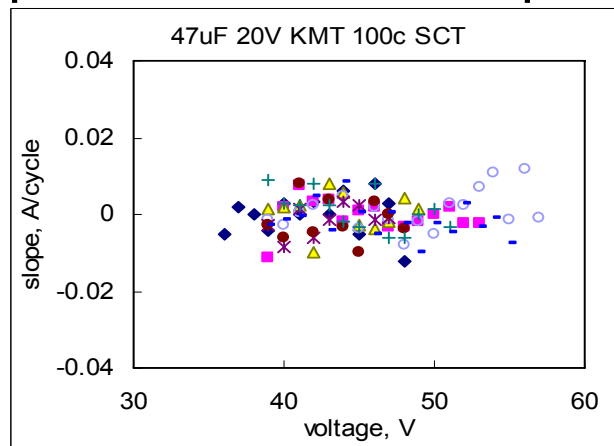
⇒ Scintillation and surge current breakdowns have likely different mechanisms, and “proofing” of the parts might not guarantee reliability under surge current conditions.

Effect of Multiple Cycling during SCT

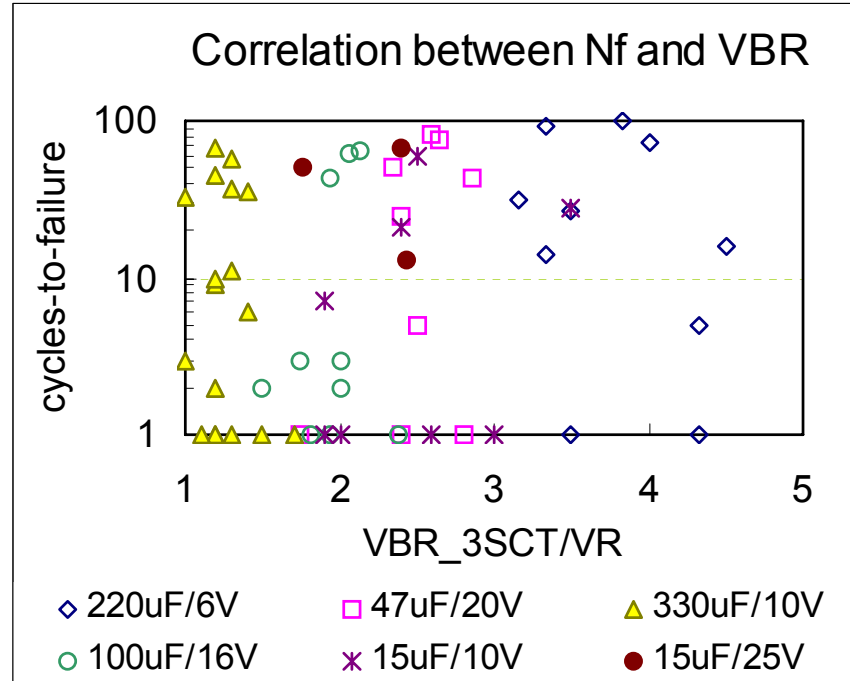
Variations of I_{sp} during 3SCT at multiple cycling at each step



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 much the applied voltage exceeds V_{th} :

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

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

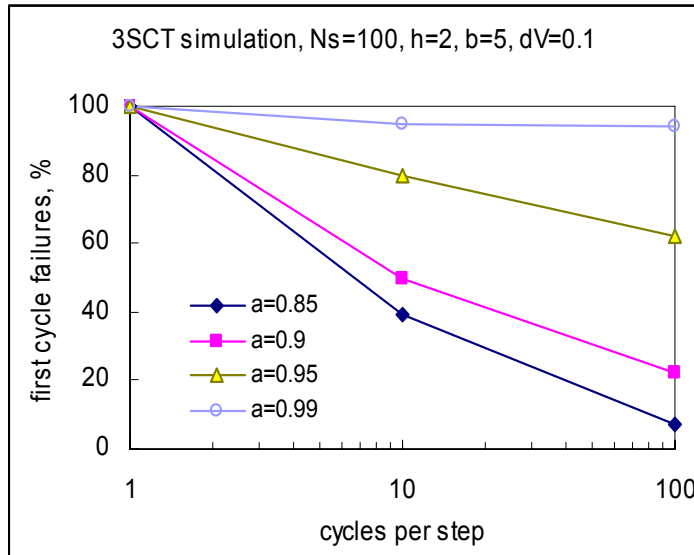
At $V_{th} < V < V_{cr}$:

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

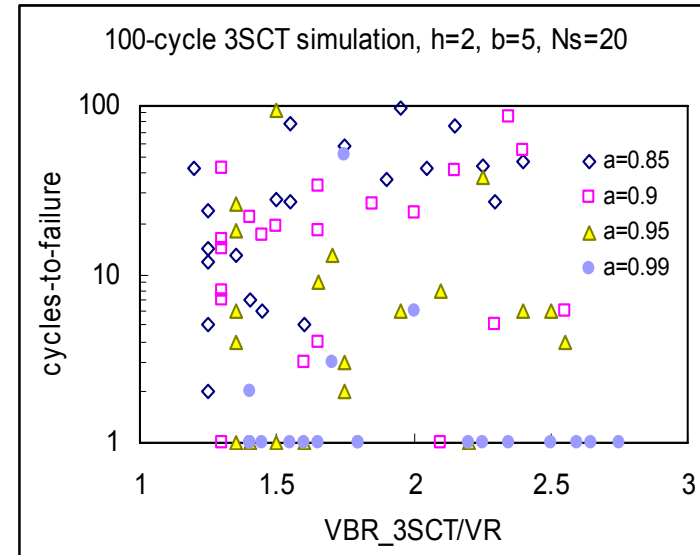
At $V_{th} < V$ $N_f = \infty$.

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

3SCT Simulation



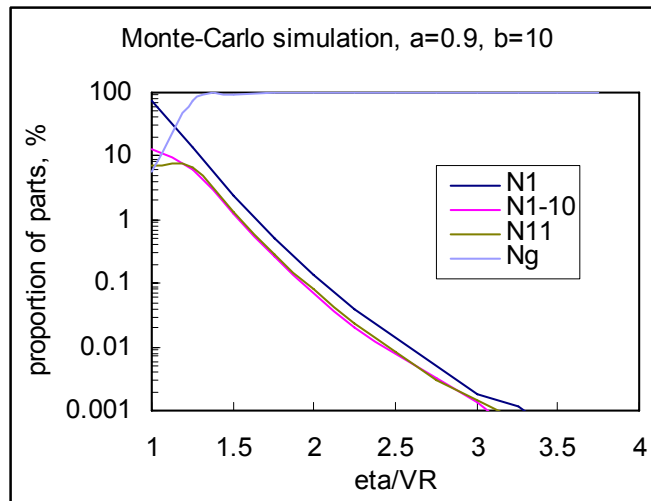
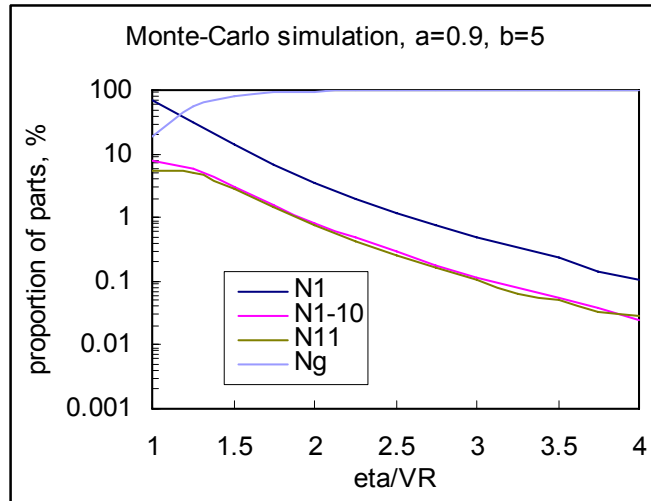
Proportion of parts failing the first SCT cycle at different number of cycles per step.



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

For $0.85 < \alpha < 0.95$ 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;

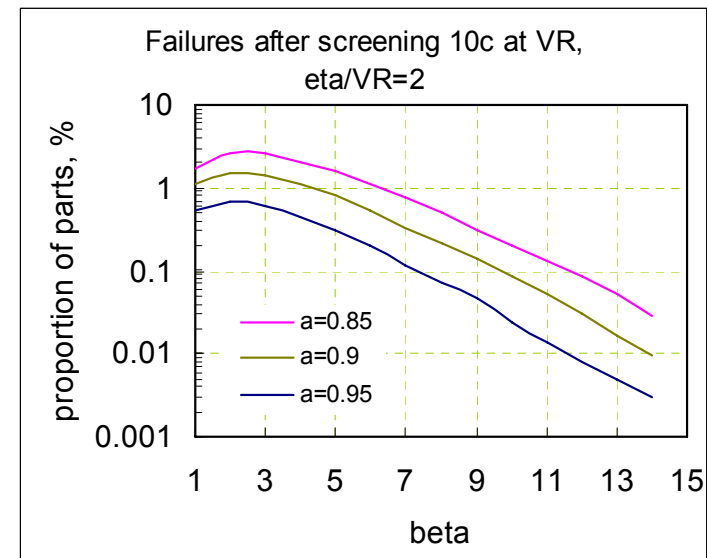
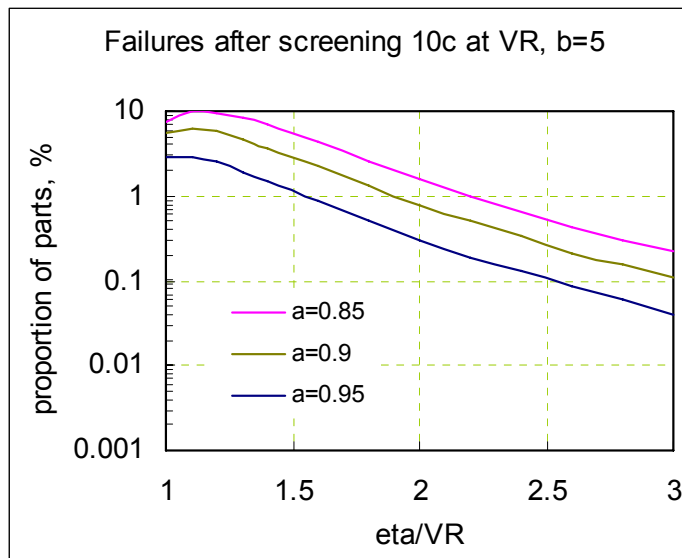
N_g - “never fail” parts.

- The probability of SC failures sharply decreases at $\eta/VR > 1.5$.
- 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 $V > V_R$, 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 $1.1V_R$ to $1.15V_R$.