2013 NEPP Tasks Update for Ceramic and Tantalum Capacitors

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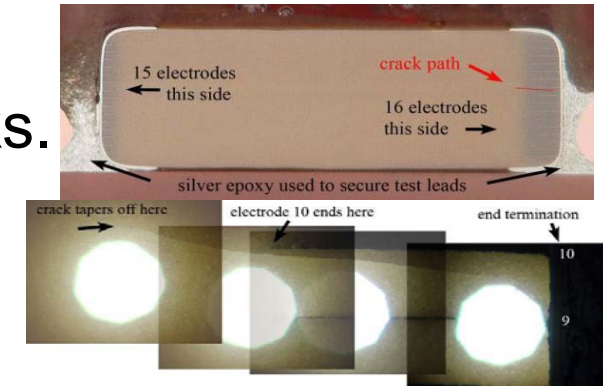
Reliability Assurance for Ceramic and Tantalum Capacitors Tasks

- Screening techniques for multilayer ceramic capacitors (MLCC) with cracks.
  - How to select robust parts and prevent cracking?
  - How cracking affects reliability and performance?
  - What testing would mitigate the risk of failure?

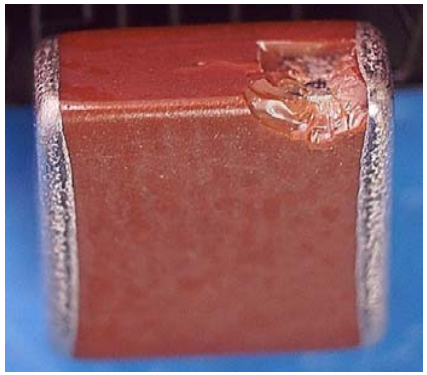


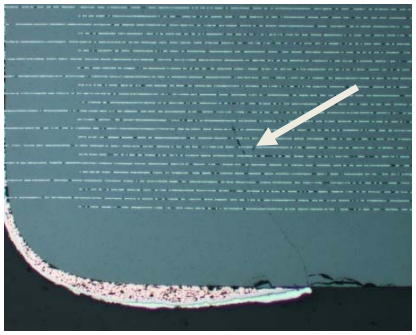
0.1uF 50V MLCC failed after 1.5y of the system operation and testing (FA by C. Greenwell)

- Reliability of advanced wet and solid tantalum capacitors.

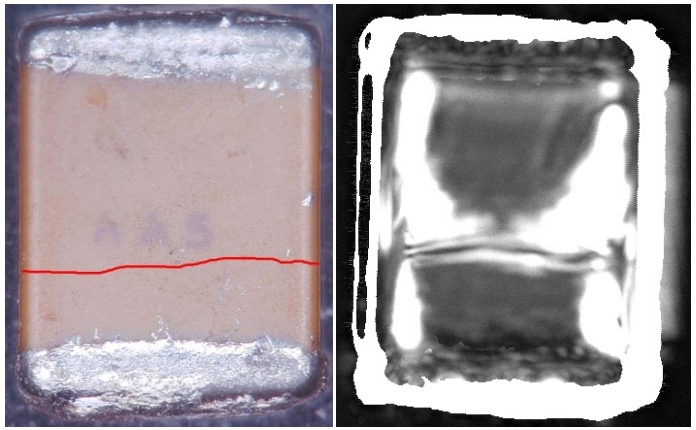
  Wet capacitors:
  - Effect of reverse bias and requirements for qualification testing.
  - Effect of random vibration and requirements for lot acceptance testing.
  - Effect of ripple currents and requirements for qualification testing.

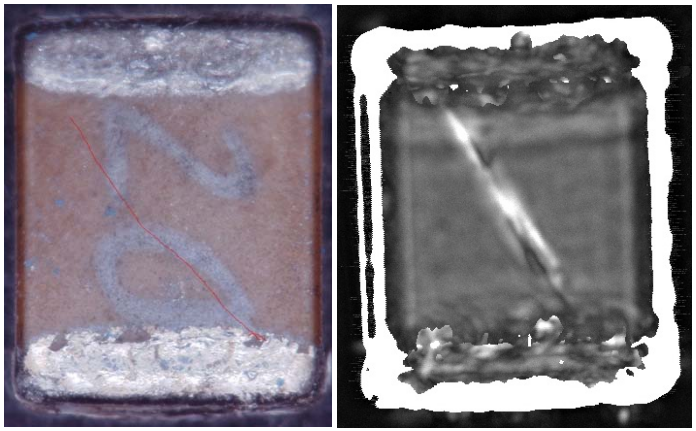
  Solid capacitors:
  - Surge current testing and requirements for surge-limiting resistors.
  - Weibull grading test and voltage derating requirements.



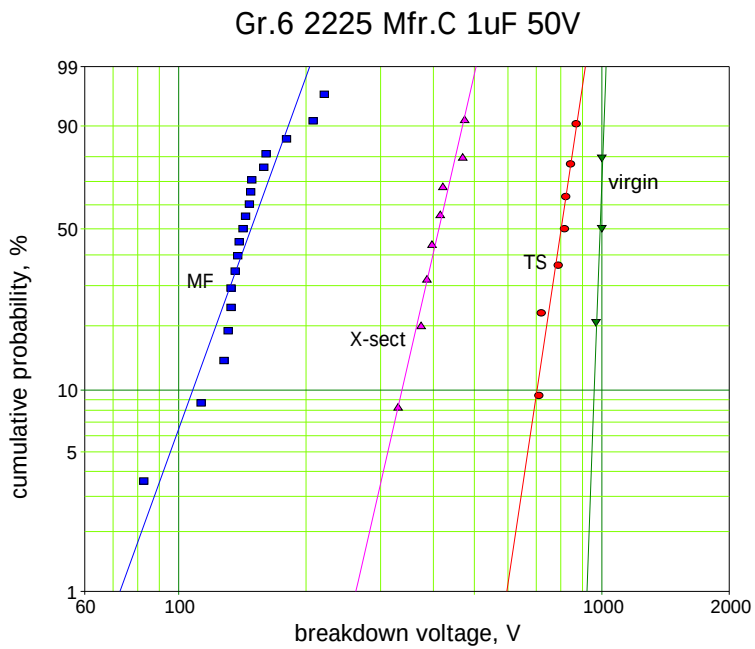


Testing Techniques for Low-Voltage Ceramic Capacitors with Cracks





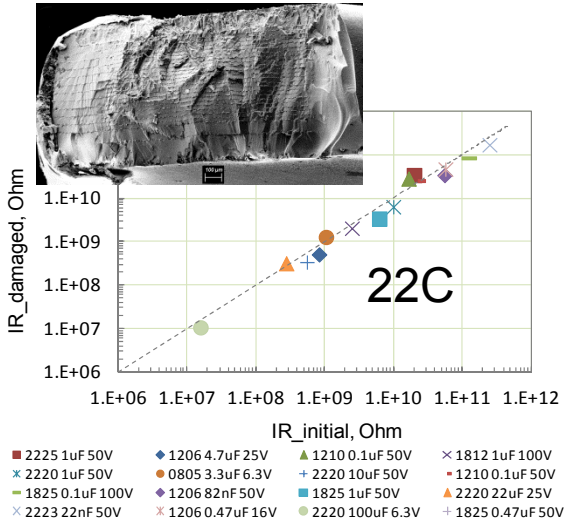
Effectiveness of DWV Test



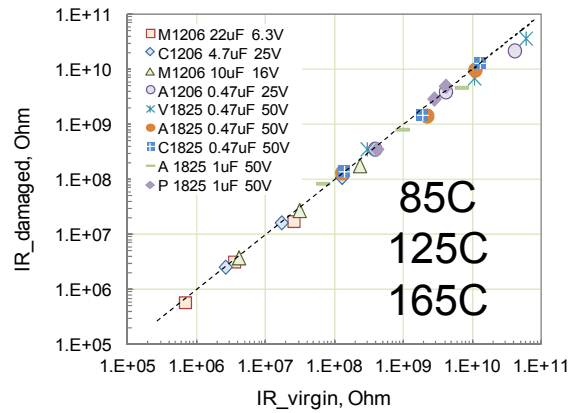
- Dielectric Withstanding Voltage (DWV) test requires application of 2.5 times rated voltage (VR).
- Only ~20% of parts with gross defects failed the test.
- 19 out of 30 (63%) lots of parts damaged by X-sectioning and thermal shock (TS) had the probability of DWV test failure <1%.

- ✓ Breakdown voltage (VBR) is sensitive to the presence of defects and reflects quality of the lot.
- ✓ The effectiveness of the existing DWV testing is low.
- ✓ Guidelines: $VBR_{cr} = 0.5 \times (VBR_{avr} - 2 \times \sigma)$ - (5% level)/2

Effectiveness of IR measurements

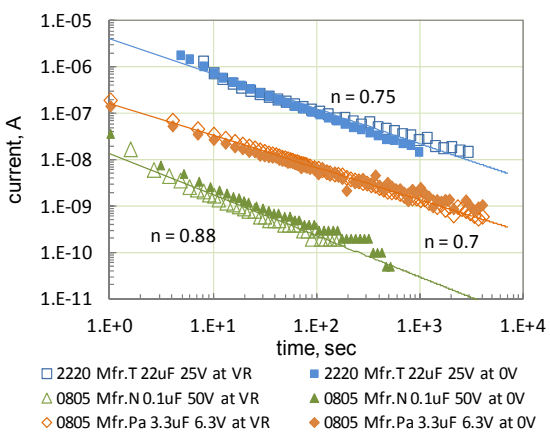


$$I(t,T,V) = I_{abs}(t,V) + I_{il}(T,V) + I_{dl}(T,V,RH)$$

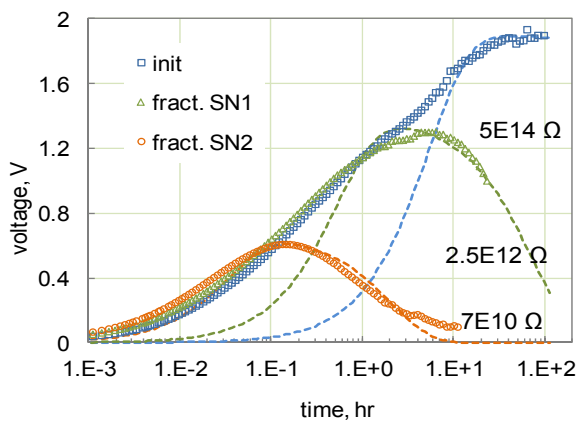


- ❑ Absorption currents prevail at room temp.
- ❑ Intrinsic leakage currents prevail at high temperatures, >85 °C.

Absorption currents



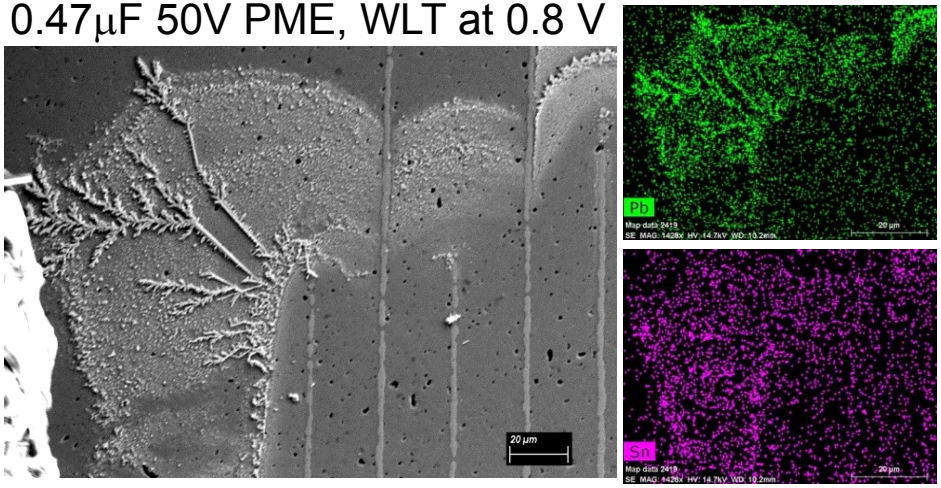
Absorption voltages



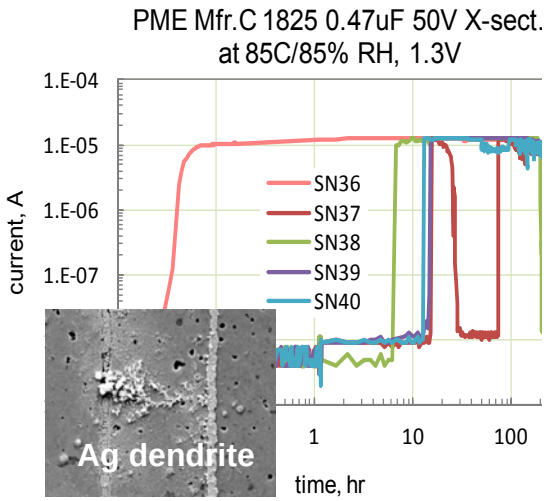
- ✓Standard IR measurements fail to reveal cracks in MLCCs.
- ✓Measurements of absorption voltages can expose the difference.

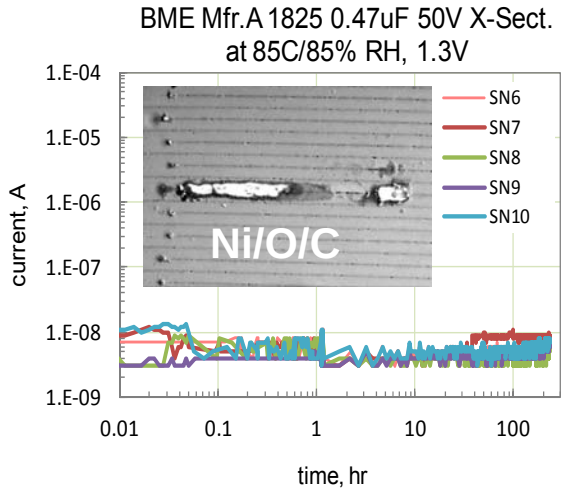
Effectiveness of Humidity Steady State Low Voltage (HSSLV) Testing

0.47μF 50V PME, WLT at 0.8 V



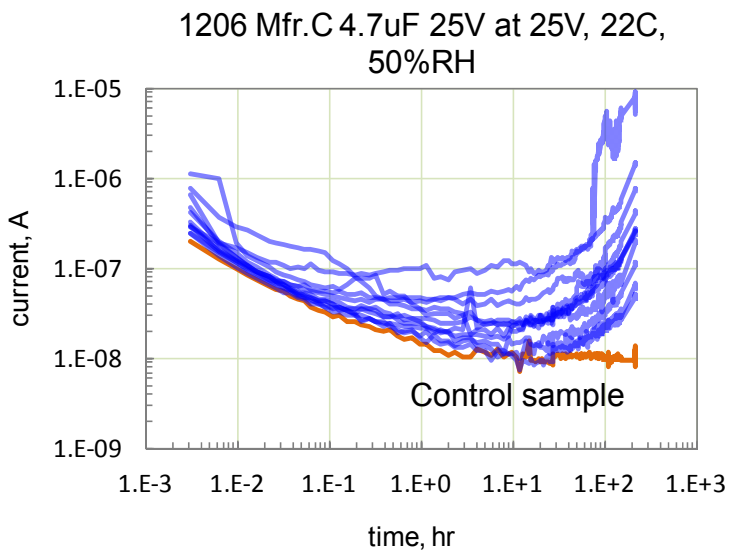
- Pb and Sn dendrites and deposits are formed near the edge cathode electrodes.
- HSSLV failures: 0/20 base metal electrode (BME), MLCCs and 17/20 precious metal electrode (PME), MLCCs.
  - Ag dendrites grow on PME and nickel carbonates on BME capacitors.

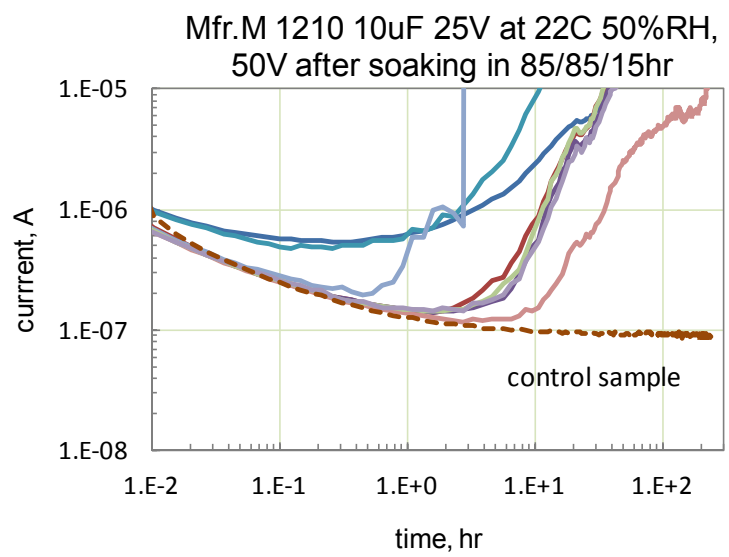




✓ HSSLV testing might be useful for PME capacitors but is much less effective for BME capacitors.

Degradation of Leakage Currents in MLCCs with Cracks

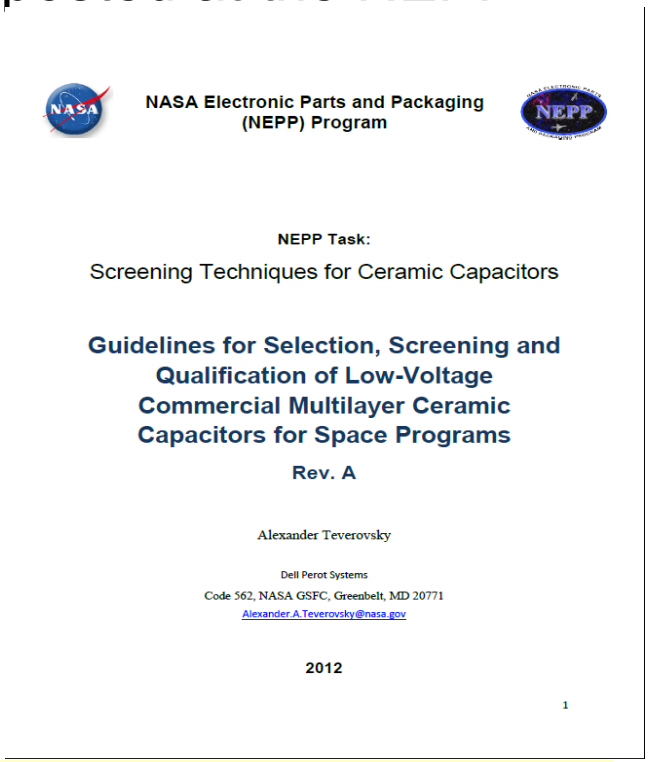




- ✓ Monitoring of leakage currents with time at VR to 2×VR during or after exposure to humid environments might be a useful technique to reveal capacitors with cracks.
- ✓ The effectiveness of the Resistance to Moisture Absorption Test (RMAT) is currently being evaluated.

Guidelines for Commercial Ceramic Capacitors

- Guidelines, Rev.A, that addresses issues related to both, PME and BME capacitors, has been posted at the NEPP web site in 2012.
  - *I. Scope*
  - *II. Background*
  - *III. Parts selection and construction analysis/DPA*
  - *IV. Lot acceptance testing*
  - *V. Qualification testing*
  - *VI. Freshness policy*
  - *VII. Derating*
  - *VIII. Assembly*



NASA Electronic Parts and Packaging (NEPP) Program

NEPP Task:

Screening Techniques for Ceramic Capacitors

Guidelines for Selection, Screening and Qualification of Low-Voltage Commercial Multilayer Ceramic Capacitors for Space Programs

Rev. A

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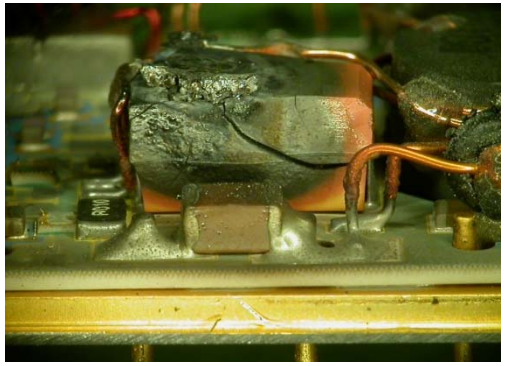
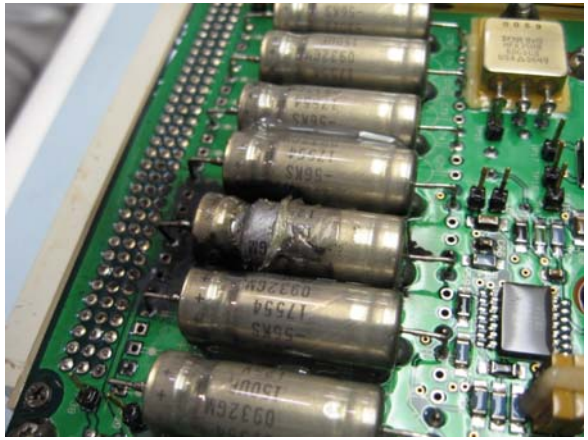
✓ Rev.B of the guidelines that addresses cracking-related issues in more details will be prepared in 2014.



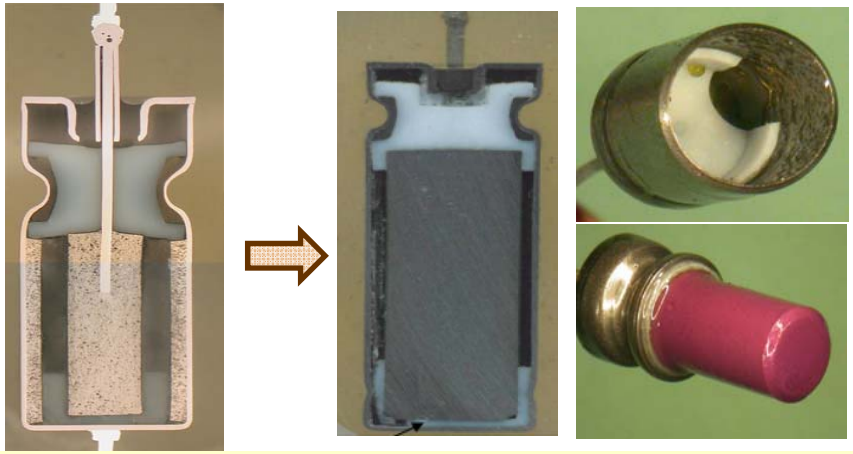
Reliability of Advanced Wet and Solid Tantalum Capacitors

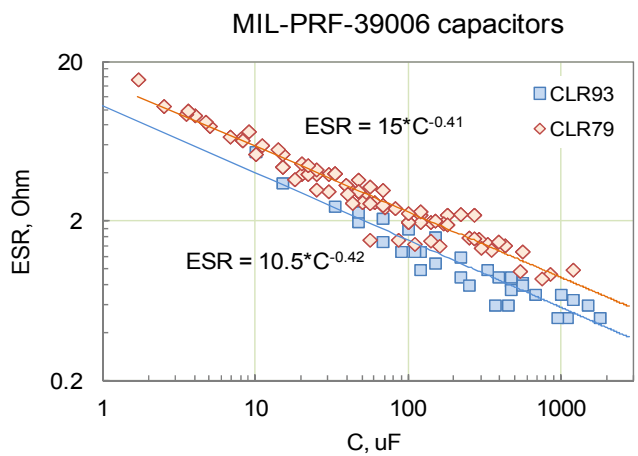


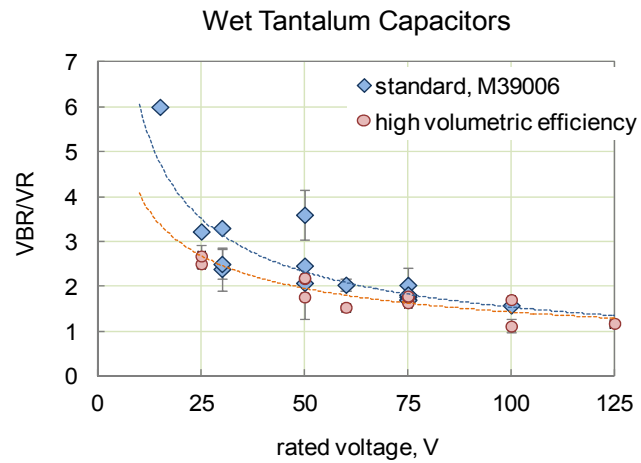
High Volumetric Efficiency Capacitors

- Volumetric efficiency is achieved by reducing the thickness of the cathode layer, increasing the size of the slug, and using high-CV powders.

M39006 DWG93026

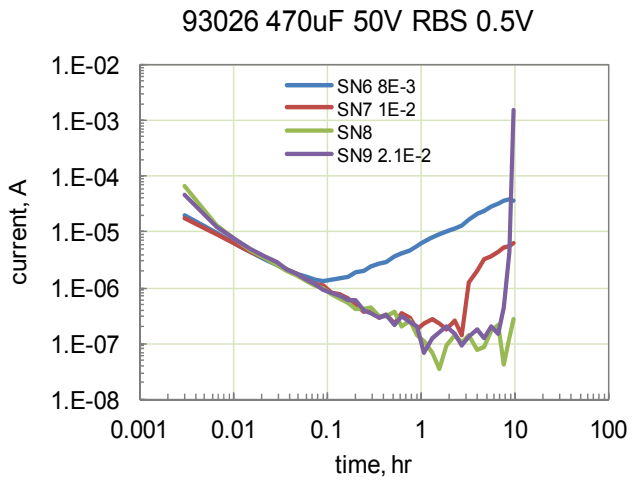






- ✓ Breakdown margin is similar for both types of capacitors.
- ✓ Anodic system remains the same => no effect on life testing.
- ✓ Better performance does not come free: effect of design on reliability at reverse bias and vibration.

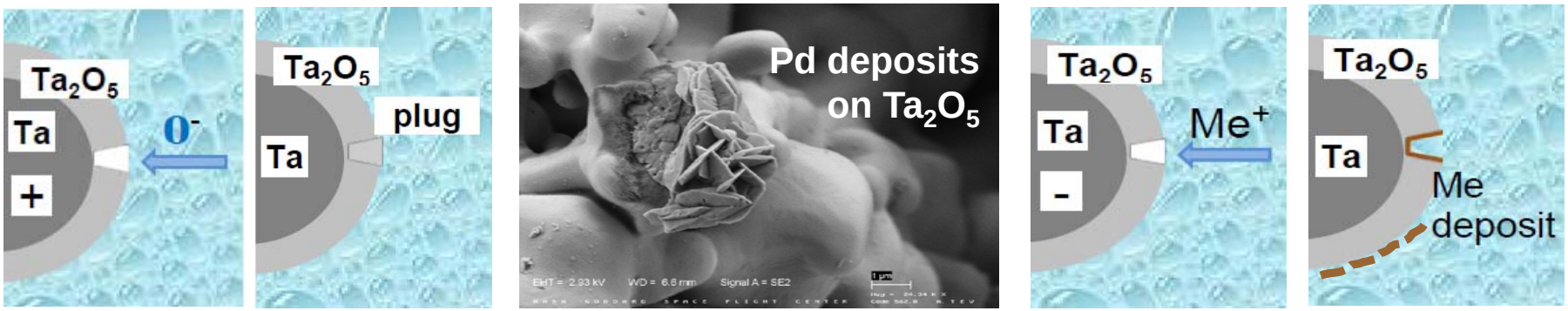
Effect of Reverse Bias (RB)



- The transfer charge to failure is below the specified value of 0.05C.
- Failures result in increasing leakage currents, bulging of the case, electrolyte leak, and corrosion.
- Failures might occur at RB < 0.5 V.
- Some part types can withstand long-term reverse bias at 1.5V.

Forward bias: Oxidation

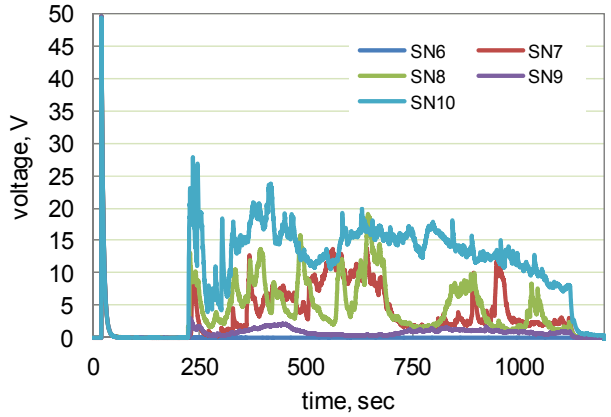
Reverse bias: Electrodeposition of cathode Me



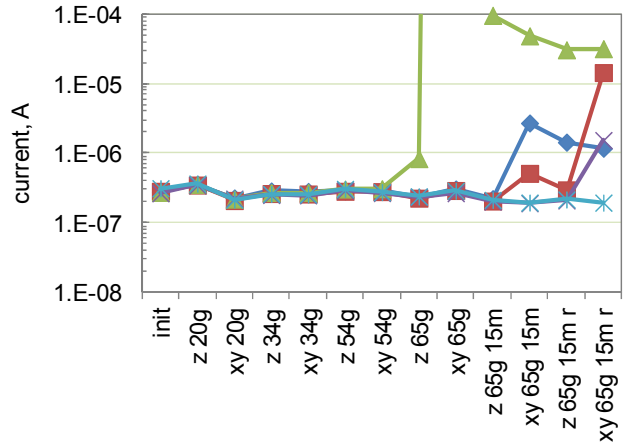
Effect of Vibration

- Capacitors are qualified to 20 g sin high frequency vibration only.

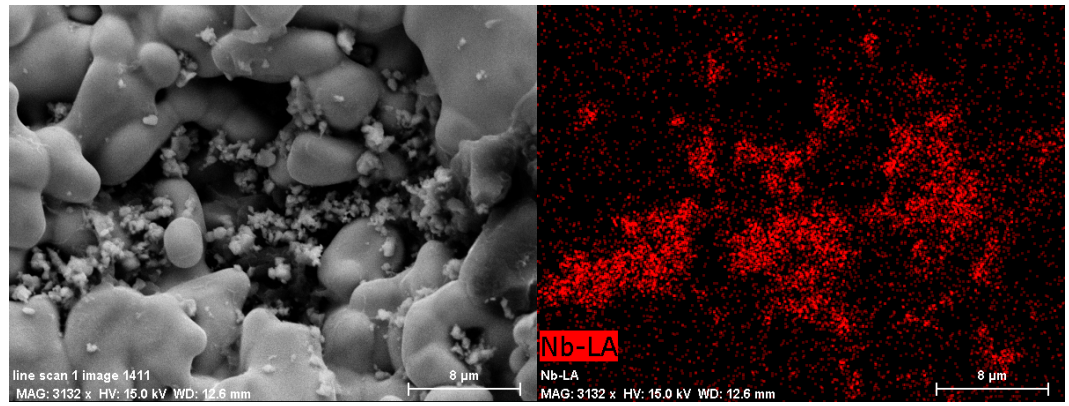
DWG93026 470uF 75V at 10.7 rms g



Mfr.B 470uF 50V DC0524



Failures due to NbO particles inside the slug

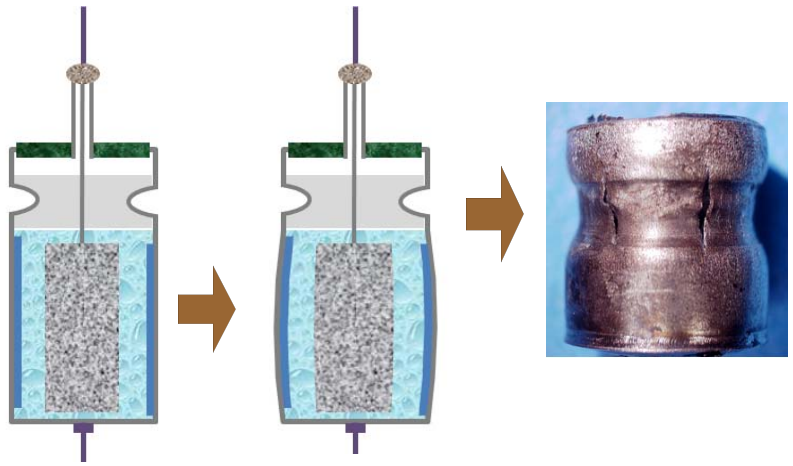


- ✓ Different part types have failures from 10 g_{rms} to > 65 g_{rms}.
- ✓ Some DWG93026 parts can fail at vibration levels that are below the mission assurance requirements.
- ✓ New design capacitors are qualified to random vibration at 20 g_{rms}.

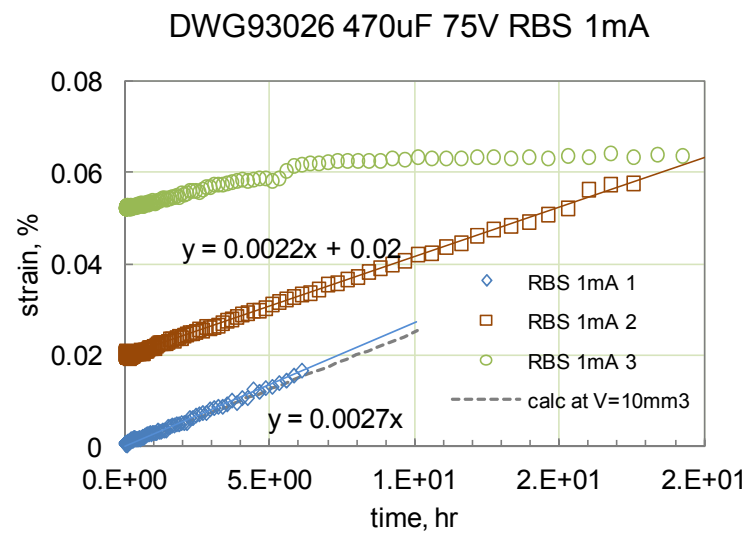
Mechanism of Failures

H_2 generation at cathode:

$2e^- + 2H_2O(L) \Rightarrow H_2(g) + 2OH^-(aq)$



Case deformation measured by flexible gages



$$n = \frac{I \times t}{z \times F} \qquad P = n \times \frac{RT}{V} \qquad \varepsilon = \frac{P \times r}{E \times h}$$

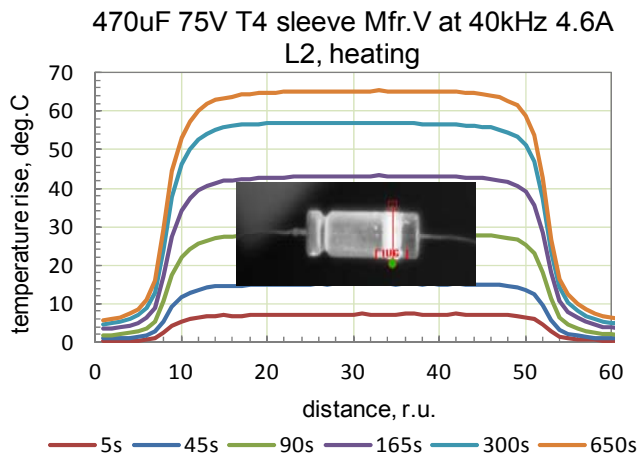
- ❑ Gas pressure can be calculated using Faraday and gas laws.
- ❑ Strain ~0.07% corresponds to a pressure of dozens of atm.
- ❑ Gas pressure => H_2 embrittlement at cold work areas => fracture.

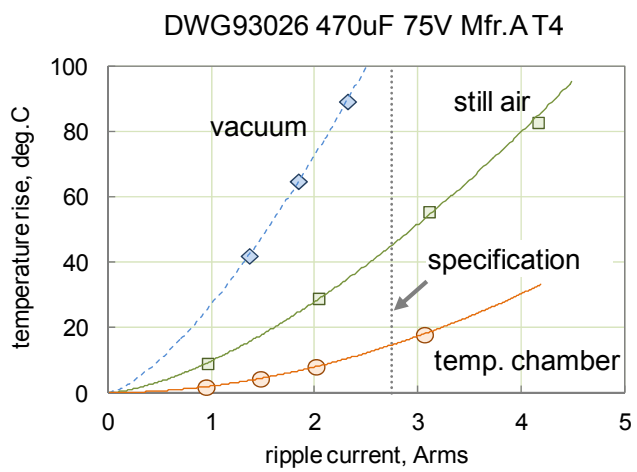
✓ Guidelines testing requirements: random vibration at 20 g_{rms}, and reverse bias at 85C, 1.5V.

Ripple Current Testing and Derating

Questions to be addressed:

- How maximum ripple current is determined?
- Is life ripple current testing more stressful compared to the DC bias only life test?
- How vacuum affects temperature rise?
- What ripple currents can be applied at low temperatures, frequencies?
- Do we need to derate ripple currents?





Preliminary results:

- Derating is necessary.
- At $f < 1$ kHz thermal run-away is possible.
- Ripple life testing is less stressful than regular life testing at 85°C and VR.

Guidelines for Wet Tantalum Capacitors

- Guidelines, Rev.A, that addresses reverse bias and vibration testing issues has been posted at the NEPP web site in 2012.
  - *I. Scope*
  - *II. Background*
  - *III. Failure rate*
  - *IV. Construction analysis/DPA*
  - *V. Lot acceptance testing*
  - *VI. Qualification testing*
  - *VII. Freshness policy*
  - *VIII. Derating*

NASA Electronic Parts and Packaging (NEPP) Program

NEPP Task:

Quality and Reliability of Advanced Wet and Solid Tantalum Capacitors

Guidelines for Selection, Screening and Qualification of Advanced Wet Tantalum Capacitors Used for Space Programs

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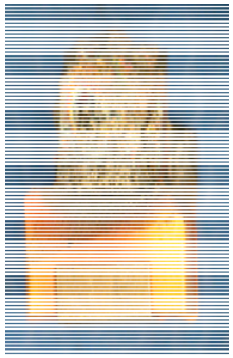
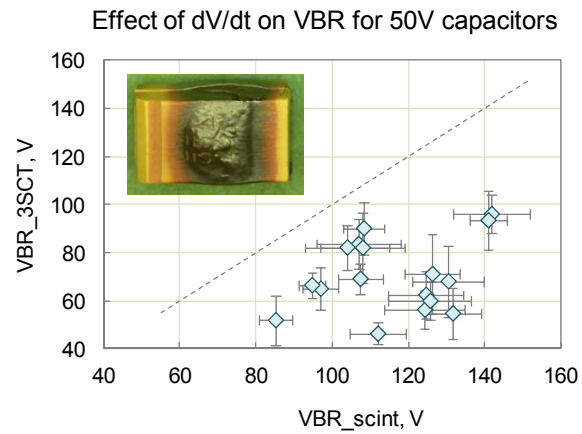
✓ Rev.B of the guidelines that includes requirements for ripple current testing is currently being developed.

Surge Current Testing (SCT) and Derating for Solid Tantalum Capacitors

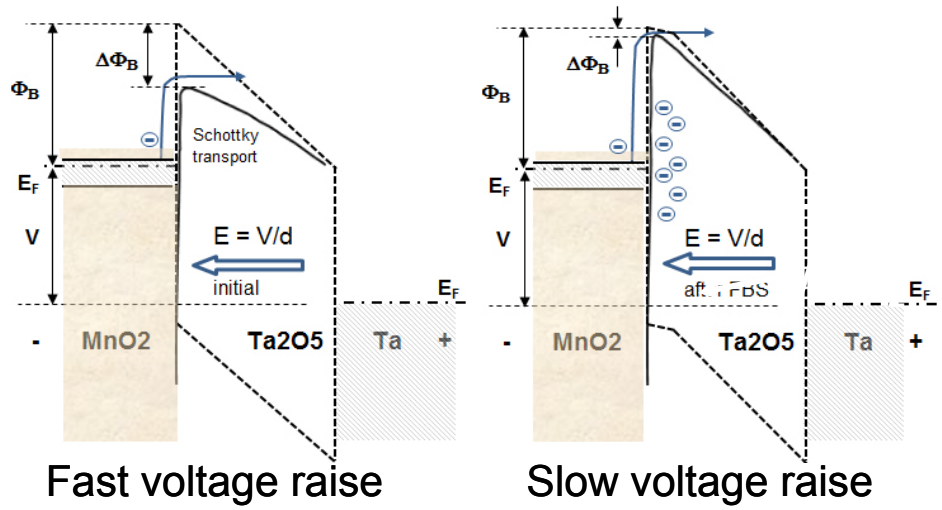


Effect of *dV/dt* on Breakdown Voltage

- Scintillation breakdown voltage, VBR_{scint} (*dV/dt* ~ 1 to 5 V/sec) is always greater than the surge current breakdown voltage, VBR_{surge} (*dV/dt* ~ 10^5 to 10^6 V/sec)
- The rate of voltage increase changes charges and electrical field at the interface.



Accumulation of electrons on traps at the MnO_2-Ta_2O_5 interface with time increases the barrier, the level of electron injection, and the probability of avalanching.



Fast voltage raise

Slow voltage raise

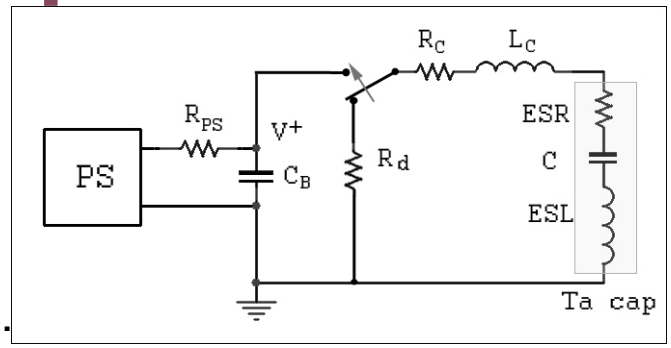
- ✓ The rate of voltage increase is critical for breakdown.
- ✓ A resistor in series with a capacitor reduces *dV/dt* and failures.

Surge Current Derating Requirements

- History of requirements for circuit resistance (R_{ac}):
  - In the 1960s: 3 Ω per each volt of operating voltage.
  - By the 1980s: 1 Ω per each volt.
  - From the 1990s: 0.1 Ω per volt or 1 ohm, whichever is greater.
- Manufacturers consider surge current failures as the major reason for voltage derating.
- Do we need derating of currents in addition to voltage?
- The limit for acceptable surge currents is set by the SCT conditions: <u>the current during applications should not exceed the current during testing</u>: $I_{appl.} < I_{test}$ *"use as tested"*

- ✓ Improvements in reliability and the need to increase the efficiency of power supply systems resulted in reduction of R_{ac}.
- ✓ At what conditions we can allow circuit designs without R_{ac}?
- ✓ Need a closer look at how the I_{test} is specified.

MIL-PRF 55365 SCT Requirements



- SCT per MIL-PRF-55365H:
  - Number of cycles: N_c = 4 surge cycles.
  - Energy storage capacitor: $C_B = 20 \times C_{DUT}$
  - Test voltage: VR
  - Charge time, t_{ch}, and discharge time, t_{disch}, ≥ 1sec.
  - Total DC resistance of the test circuit, R_{tc}, including the wiring, fixturing, and output impedance of the power supply should not exceed 1 Ω.
  - Measurements after SCT: DCL, C, DF (still no requirements for equivalent series resistance (ESR))
  - The minimum surge peak current shall be: $I_{test} \geq VR/(R_{tc} + ESR_{spec})$, R_{tc} = 1 Ω.
  - Failure condition: current = 1A after 1ms for $C \leq 330$ μF; 10ms for $C \leq 3.3$ mF, and 100ms for $C > 3.3$
- Before 12/1/2012:
  - N_c = 10.
  - $t_{disch} = t_{ch}$ = 4 sec.
  - $R_c \leq 1.2$ Ohms.
  - $C_B \geq 50$ mF.
  - No I_{test} requirements.

✓ New specification recognizes the role of the *ESR* as a limiting factor for surge currents. However, no specifics for I_{test} verification are given.

✓ The specification does not guarantee reliable operation at VR: $V_{test} = V_{C_MAX} = 0.95 \times VR$, => the need for voltage derating.

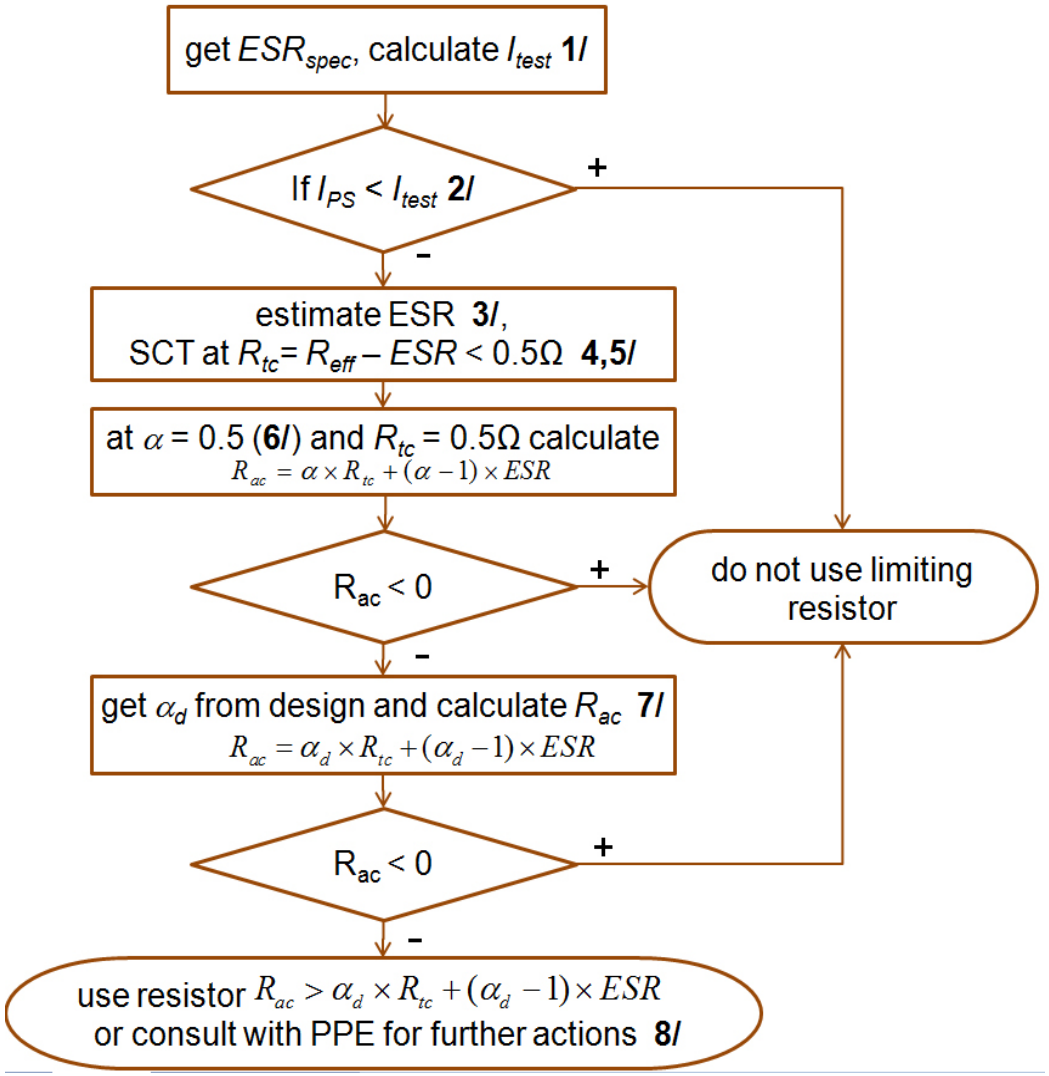
Application vs. Testing Conditions

- Typical application conditions:
  - No limiting resistors, minimal inductance.
  - Minimal contact resistance.
- ➢ Resistance of the circuit, R_{ac}, is minimal and the current is limited mostly by ESR.
- Surge Current Test conditions:
  - Unspecified contact resistance of fixtures.
  - Limiting resistor can be up to 1 Ω.
  - Relatively long wires and inductance.
  - No clear requirements for I_{test} verification (when, how?).
- ➢ Parts with poor contacts in the fixture can pass the testing.

Example:
- A 15μF 10V CWR06 capacitor with specified ESR=2.5Ω and real ESR = 0.5Ω is used in a 5V line.
- During application the part can experience a spike:
  I_{appl} = 5/0.5 = 10 A.
- During the testing it will be verified to the current:
  I_{test} =10/(1+2.5) = 2.8 A

✓Application conditions might be more severe than test conditions.
✓There is a need in tightening test requirements.

Algorithm for Surge Current Derating



1/ $I_{test} = \dfrac{VR}{R_{tc} + ESR_{spec}}$, R_{tc} = 1 Ω

2/ In case of using power supplies (PS) with current compliance, make sure that the clamping time $\tau \leq$ 10us. $I_{PS} = I_{max}$ PS.

3/ Estimate *ESR* as ESR_{spec}/N, where N=7, 3, 2 for CWR06/11/29 respectively.

4/ $R_{eff} = VR/I_{sp}$, where I_{sp} is the surge current spike amplitude.

5/ SCT should be carried out at a min. wire length, no limiting resistors, and I_{sp} should be verified to be greater than

$$I_{sp} > VR/(0.5 + ESR)$$

6/ Standard voltage derating: α = 0.5

7/ Actual derating: $\alpha_d = V_{app}/VR$

8/ Suggestions for further actions:
- get experimental data for ESR,
- calculate actual $R_{tc} = R_{eff} - ESR$,
- SCT at greater voltage levels, …

Conclusion

- Testing techniques for ceramic capacitors with cracks:
  - The effectiveness of acoustic microscopy, breakdown voltage and insulation resistance measurements, and humidity steady-state low voltage testing to reveal capacitors with cracks has been evaluated and improvements suggested.
  - Mechanisms of degradation of leakage currents in capacitors with cracks are being studied and rev.B of the guidelines for selection and testing of commercial MLCCs is planned for 2014.
- Reliability of advanced wet and solid tantalum capacitors.

  Wet capacitors:
  - Mechanisms of failures under reverse bias conditions and vibration have been studied and the relevant qualification and lot acceptance tests are suggested.
  - There is a need for ripple current testing and derating. A new version of the guidelines will be developed in 2013.

  Solid capacitors:
  - Tantalum capacitors manufactured per M55365 might fail in applications due to non-adequate surge current test requirements.
  - An algorithm for additional testing that are necessary to assure reliable operation of capacitors without limiting resistors is suggested.