Can Chip Polymer Tantalum Capacitors Manufactured to AEC-Q200 Requirements be used for Space Applications?

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List of Acronyms

AC	alternative current	HTS	high temperature storage
AEC	automotive electronic council	MC	molding compound
C	capacitance	NT	new technology
COTS	commercial off the shelf	OCM	original component manufacturer
CPTC	chip polymer tantalum capacitors	QA	quality assurance
DF	dissipation factor	RT	room temperature
ESR	equivalent series resistance	S&Q	screening and qualification
FPGA	field-programmable gate array	SCD	source control drawing
HALT	highly accelerated life testing	WGT	Weibull grading test

Abstract

This presentation analyses quality assurance approaches used by automotive industry and using polymer tantalum capacitors as an example, reviews possible ways of COTS insertion in space systems. Specifics of polymer tantalum capacitors in comparison with traditionally used MnO2 tantalum capacitors are discussed.

Outline

- Significance of COTS and automotive industry components for space applications.
- What are polymer tantalum capacitors?
- Specifics of CPTCs as compared to MnO2 capacitors.
  - How to assure reliability for parts with degrading parameters? (ESR degradation in CPTCs)
  - Anomalies in behavior of CPTCs.
- How to mitigate risks of using CPTCs for space?

Processes of AEC-Q Parts Insertion

- Are automotive parts COTS components?
  - COTS = non-MIL? or COTS = non-SCD?
  - Automotive parts = parts compliant with AEC-Q?
- Two approaches for COTS insertion:

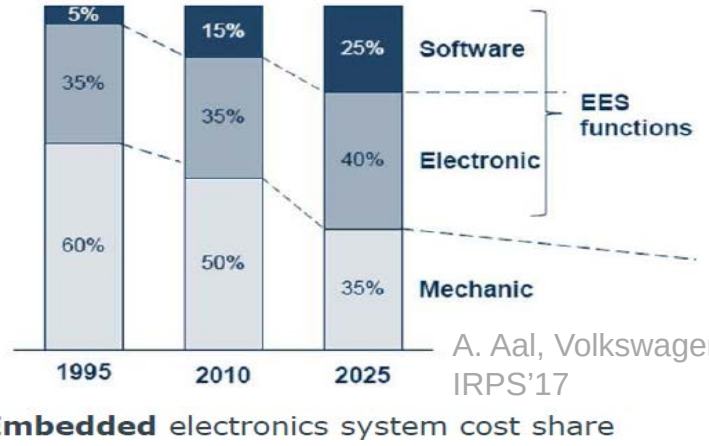
1. Reliability of COTS is inferior to MIL parts, and to qualify for space extensive testing per the existing requirements are necessary.
   - The major concern is cost and time of qualification rather than technical issues.
2. COTS are NT devices.
   - New mechanisms might require new testing techniques.
   - Existing procedures for S&Q have to be evaluated and adjusted.

✓ "COTS as NT" approach requires understanding of new degradation mechanisms, specific reliability issues, and development of adequate S&Q procedures.

✓ The consistency of COTS quality still remains a problem.

Components for Space are Coming from the COTS World

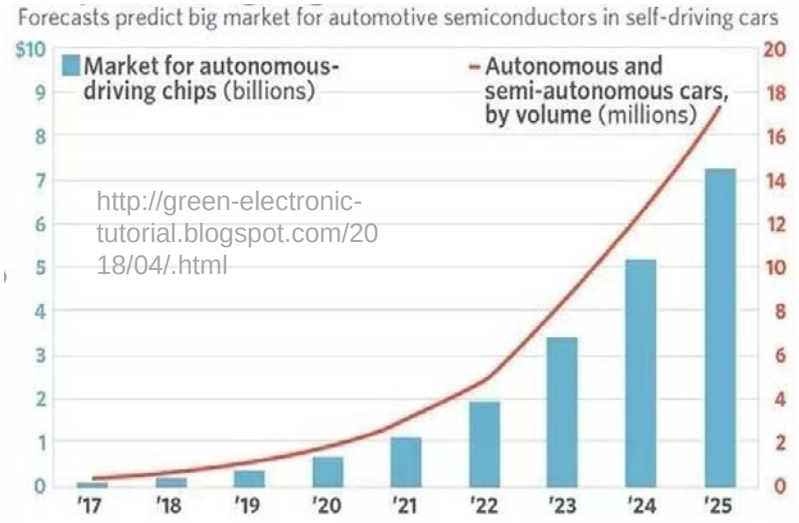
- Future cars will be sensors and computers on wheels.
- The cost of cars will be mostly due to electronics.
- Automotive components is the fastest growing market, ~10%/year.
  (→ Current shortage of components; OCMs are running at full capacity.)



A. Aal, Volkswagen, IRPS'17

Embedded electronics system cost share

- Requirements for automotive components are comparable to MIL and these parts are the first choice for selection for space.
  - Temp from -40 ºC to +165 ºC
  - Vibration 0-2000Hz
  - Acceleration up to 50g
  - Life time 10-15 years (mostly non-operational); self-driving cars: 1-2 years intensive operation



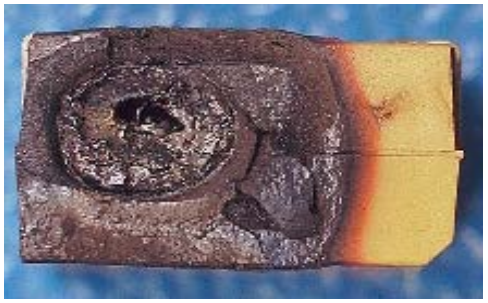
What Components are Used in Cars?

- B. Knoell, AEC chair: there is a need to use an appropriate mixture of qualification methodologies:
  - Stress Test per AEC-Q Specs. Step-stress testing. Application-Specific tests.
  - Physics-of-Failure approaches. Sequential Stress Tests. Board Level Reliability.
- A. Aal, Volkswagen: reliability issues should be resolved by working together with components' manufacturers.
  - AEC-Q is only one aspect of the **total quality management system**.
  - Detailed analysis of QA of manufacturing process.
  - 30-50% of failures were due to material/process changes (notification process).
  - Multi-mode stresses, rather than operation hours kill lifetime.
  - Assembly affects parameters of thin dielectric ICs.

Using AEC-Q Components for Space

- ✓ Automotive industry does not use AEC-Q parts without substantial additional testing and analysis working with OCMs.
- ✓ Car manufacturers have significant leverage, but require high reliability for low price.
- ✓ Space community might not have a similar leverage, but we do not have cost as a priority.
- ✓ We can benefit from AEC-Q by using compliant part as a baseline and developing a knowledge-based system for parts' selection, S&Q.

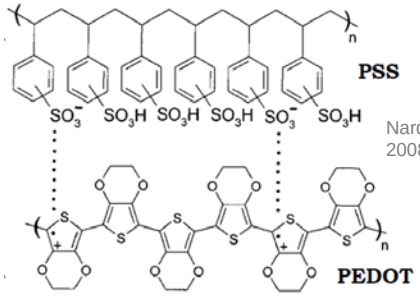
Why CPTCs?



Breakdown in MnO2 capacitors

- Major benefits:
  - Better volumetric efficiency (smaller case sizes);
  - Higher operating voltages (up to 125V);
  - Lower ESR (milliohm range);
  - A relatively safe failure mode (no ignition).
  - CPTCs are less likely to fail short circuit and are more likely to pass life testing per MIL-PRF-55365 compared to MnO2 COTS capacitors.
- Major drawbacks:
  - Effect of environments: both, excessive and insufficient amount of moisture might be detrimental; vacuum can be a benefit or a hazard.
  - The core element of S&Q for MnO2 capacitors, WGT, is not applicable.
  - ESR might degrade with time at high temperatures (HTS testing for QA).
  - New phenomena: anomalous transients.
- Substantial efforts have been made to demonstrate compliance of CPTCs with AEC-Q200.
  - Currently: $T_{storage}$ up to 150ºC and 85ºC/85% RH/1000hr biased.

What are CPTCs?



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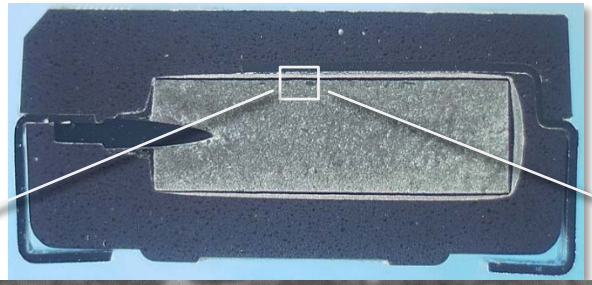
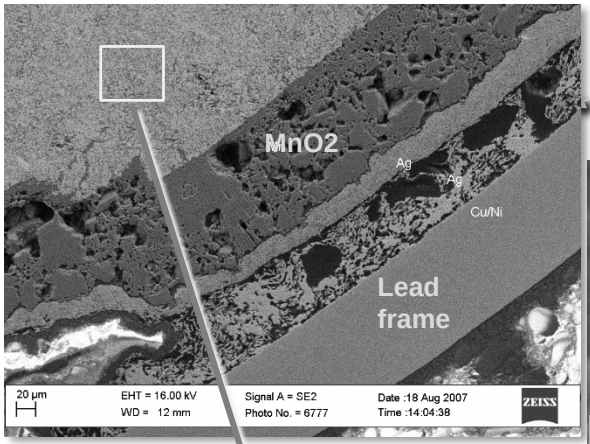
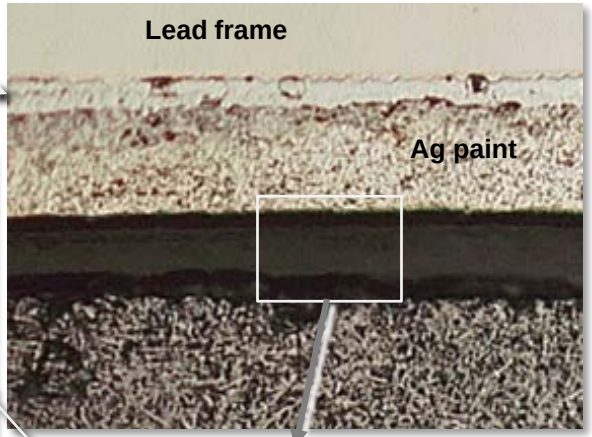
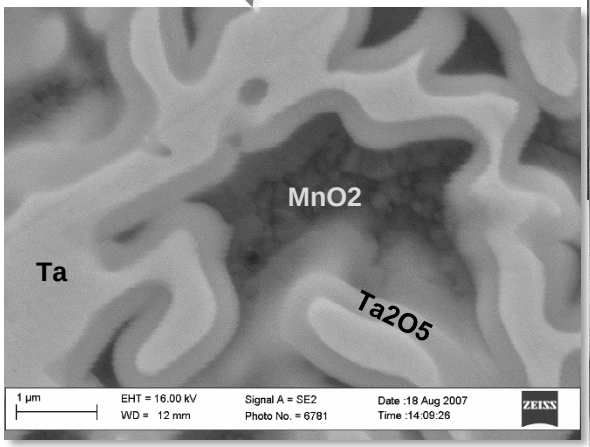
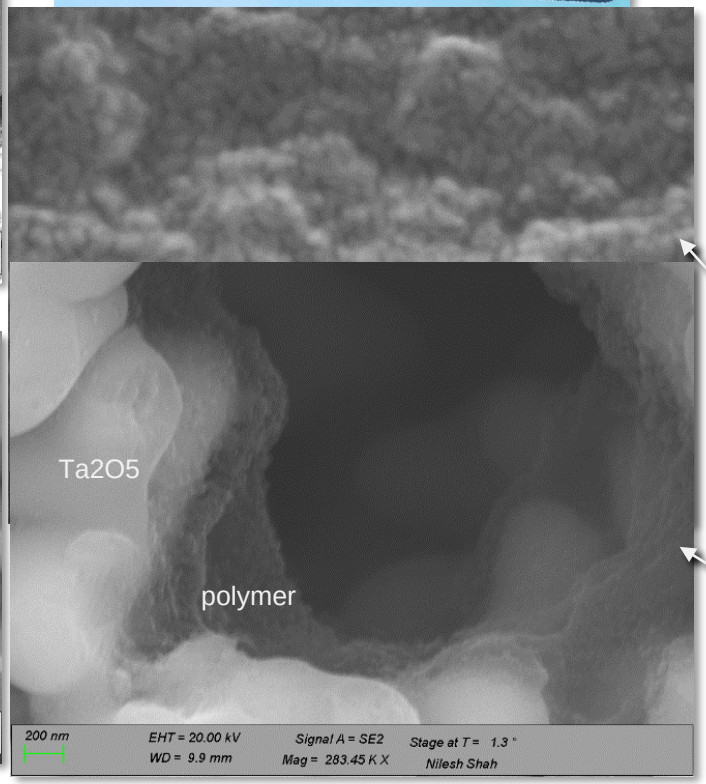
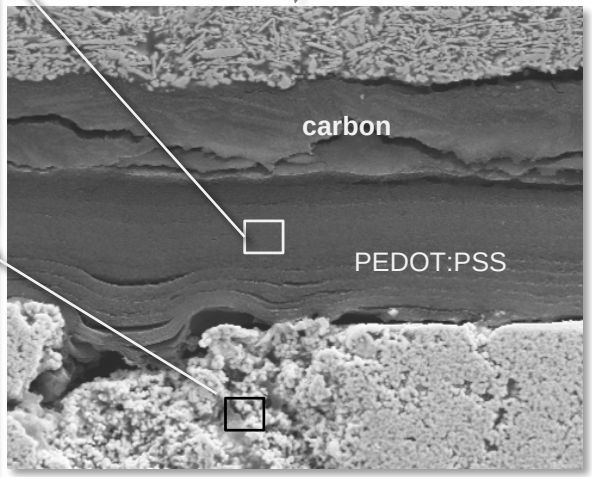








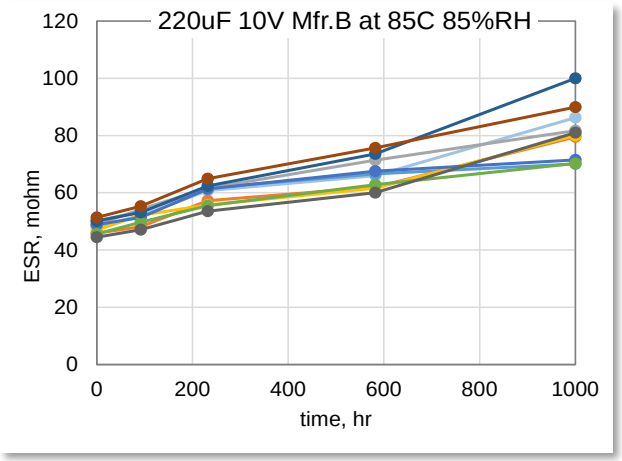


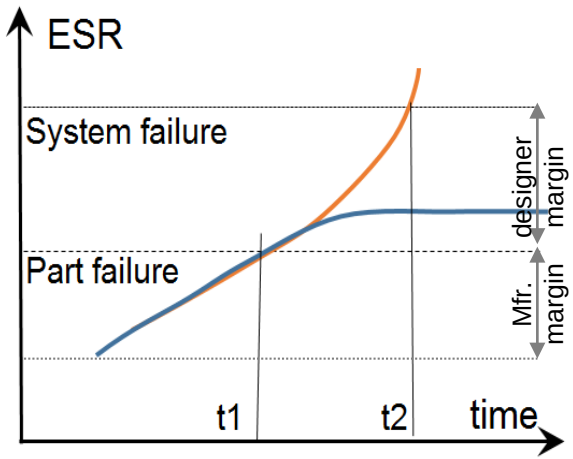


✓ No significant differences in design except for cathode materials.

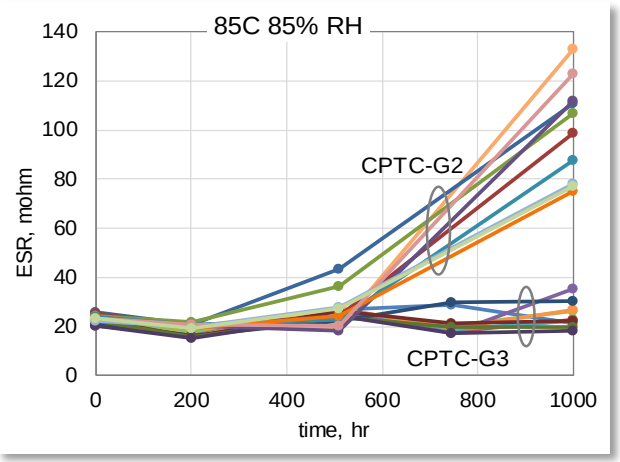
Specific of CPTCs: ESR Degradation

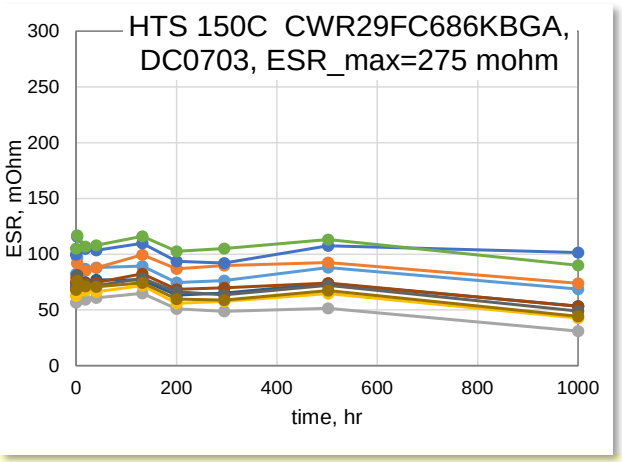
MnO2

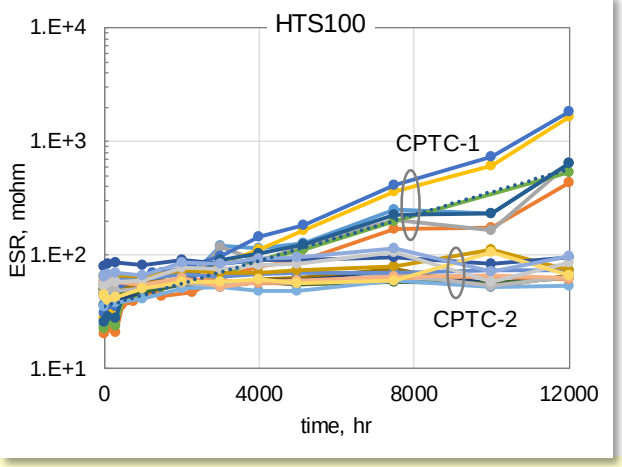


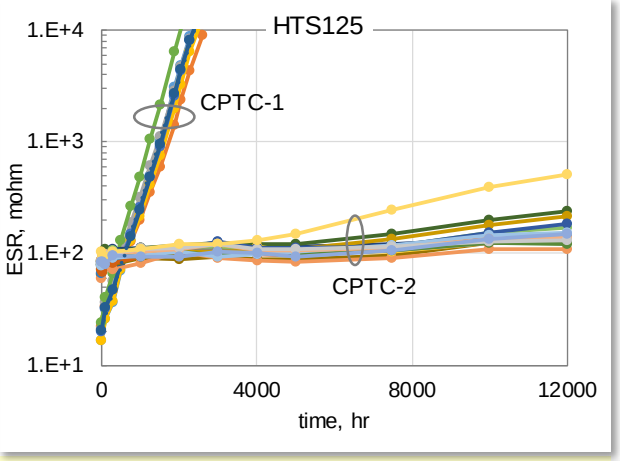


polymer









- ✓ Contrary to MnO2, CPTCs might degrade substantially during HTS.
- ✓ Can compliance to AEC-Q200 guarantee end-of-life ESR values?

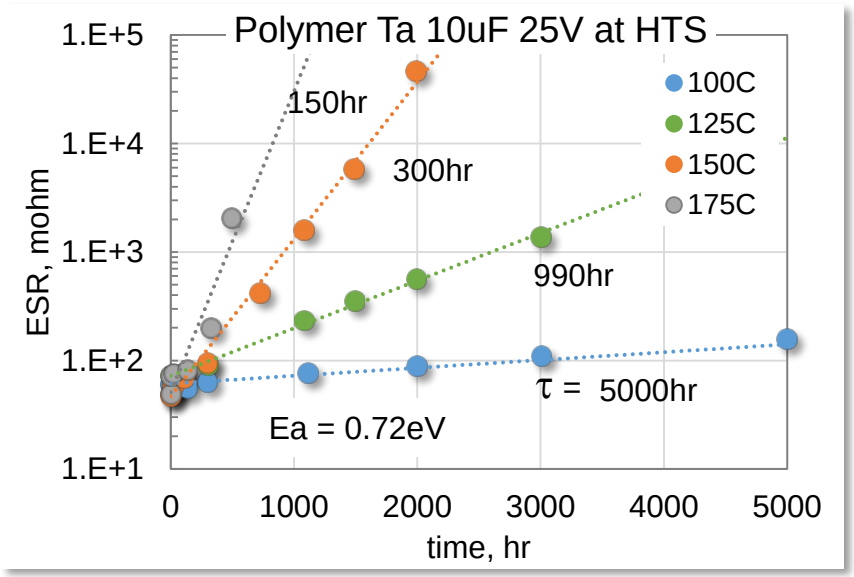
Modeling of ESR Degradation

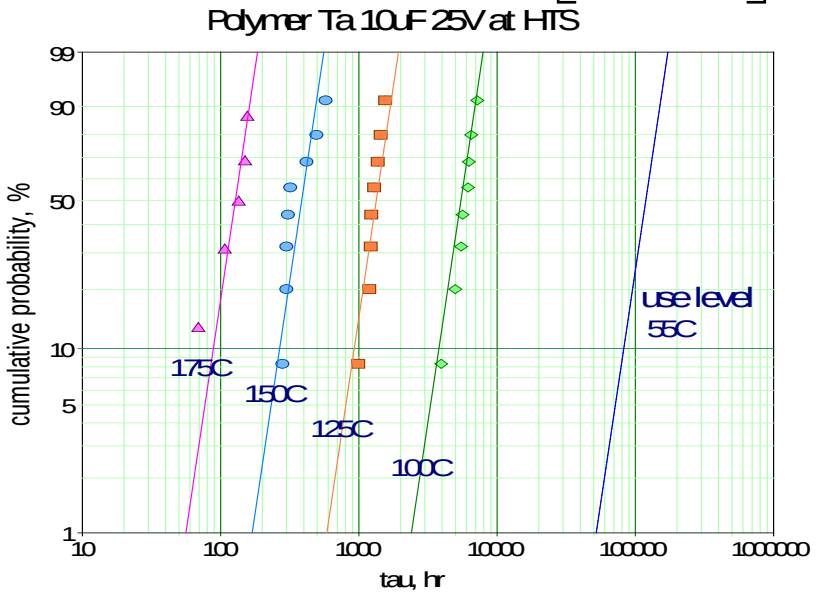
Approximations:

$$ESR = ESR_0 \times \exp\left(t/\tau\right)$$

$$\tau = \tau_0 \times exp\left(E_a/kT\right)$$

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



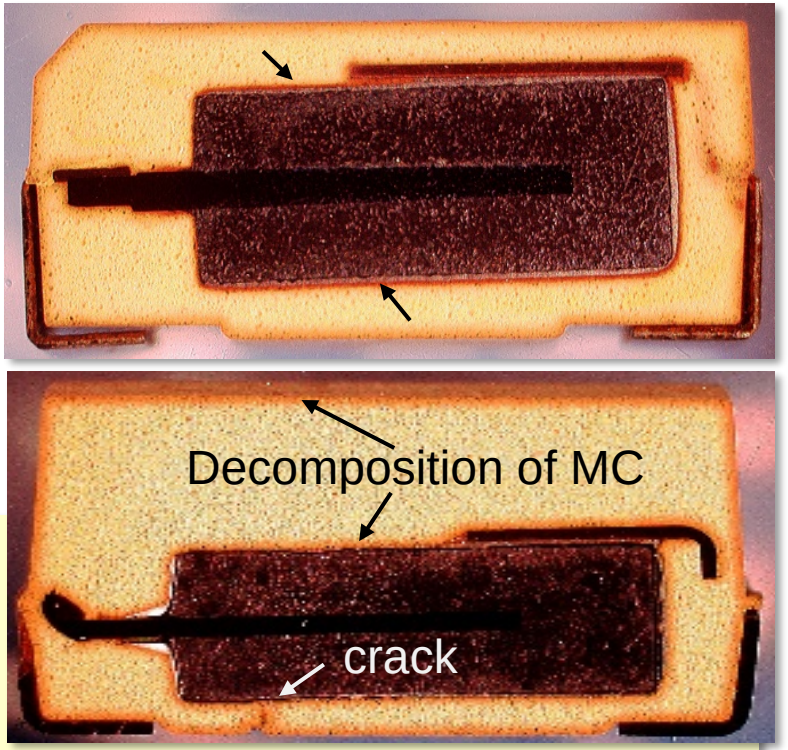


- ✓ Simulations allow for the end-of-life predictions.
- ✓ More complex models might be necessary for lots having different degradation inception times.

Mechanism of ESR Degradation

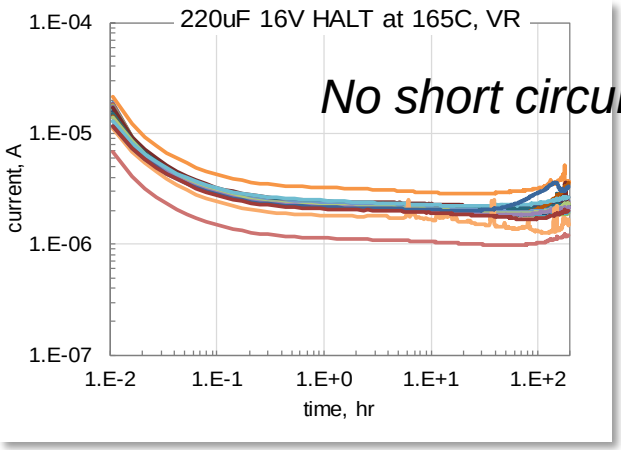
- Discoloration of MC indicates the pass of O_2 causing decomposition.
- Oxygen penetrates along the lead frame-MC interface.
- Parts with less decomposition around Ta slug have less degradation.
- Cracks accelerate ESR degradation.

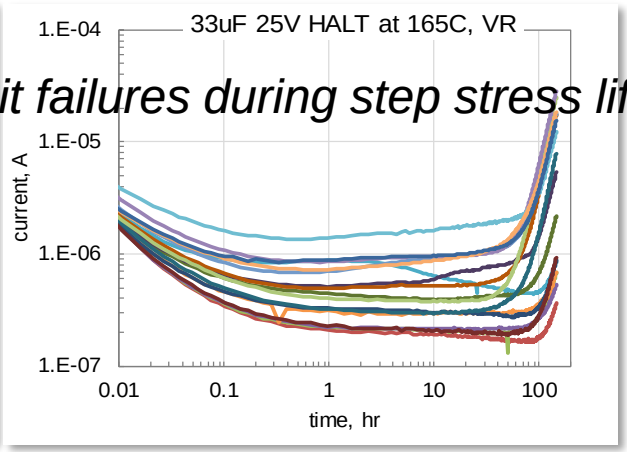
CPTCs after HTS

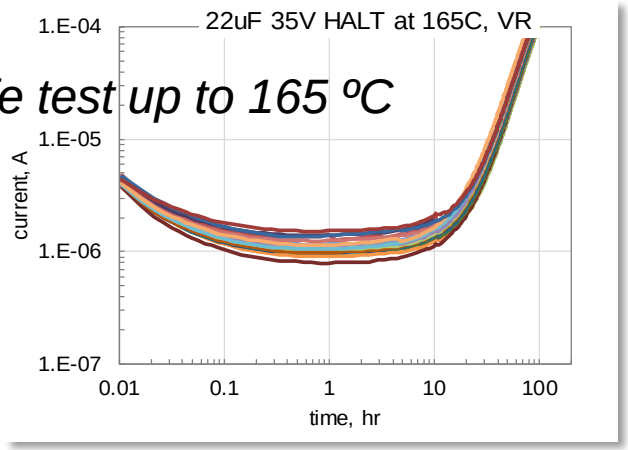


- ✓ESR degradation is due to thermo-oxidative processes in conductive polymers → better stability in vacuum.
- ✓Contrary to MnO2 capacitors, cracks in CPTCs are more likely to cause ESR failures.
- ✓Quality of packaging is critical for reduction of ESR degradation.
- ✓Parts manufactured to AEC-Q200 have a better packaging control.

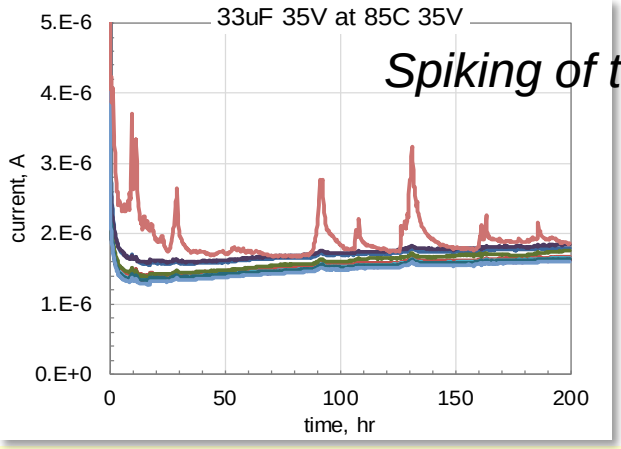
Specific of CPTCs: Life Testing

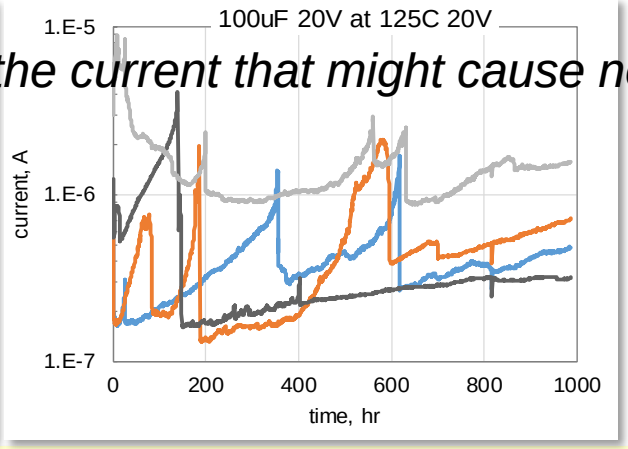


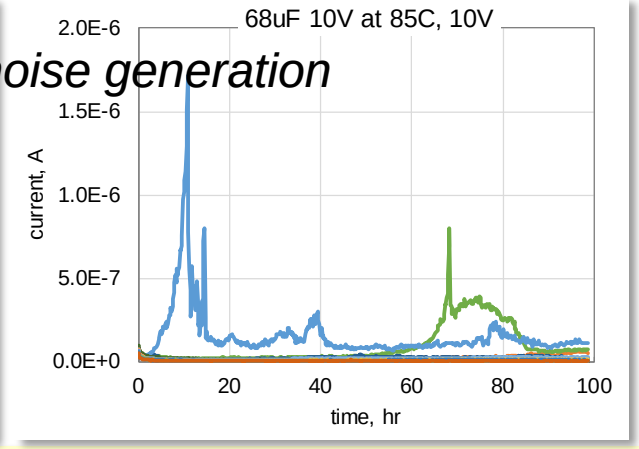




No short circuit failures during step stress life test up to 165 ºC



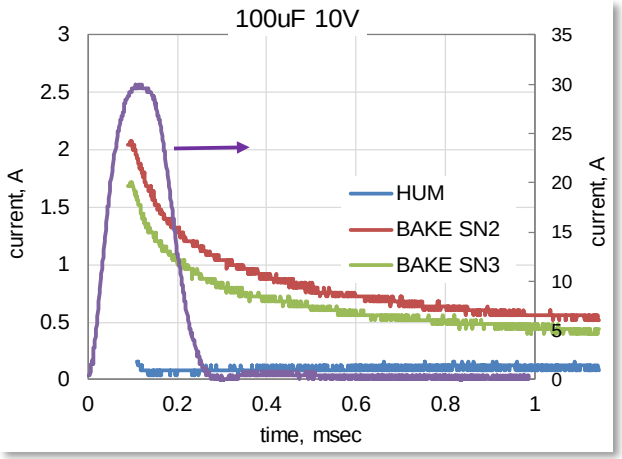


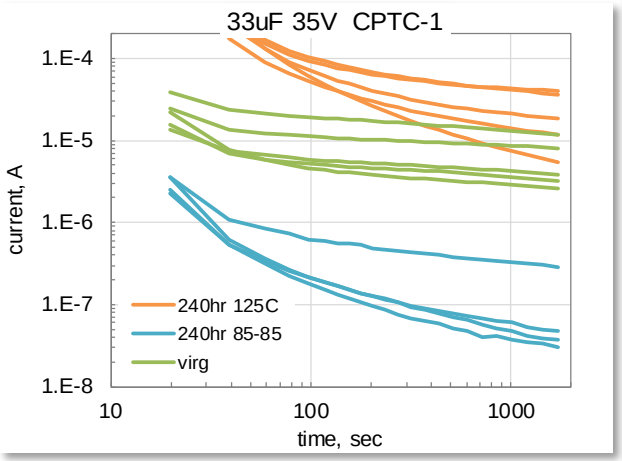


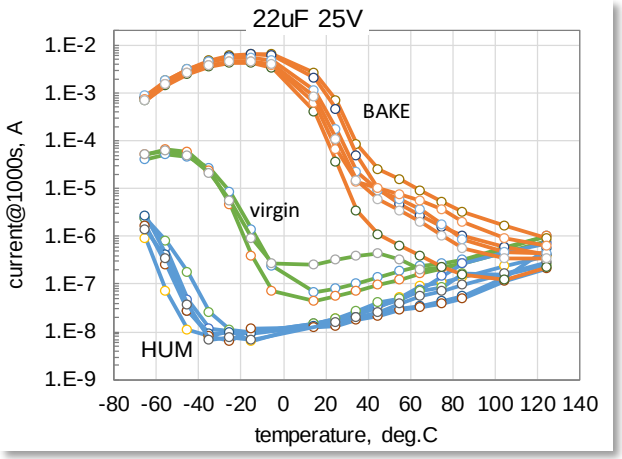
Spiking of the current that might cause noise generation

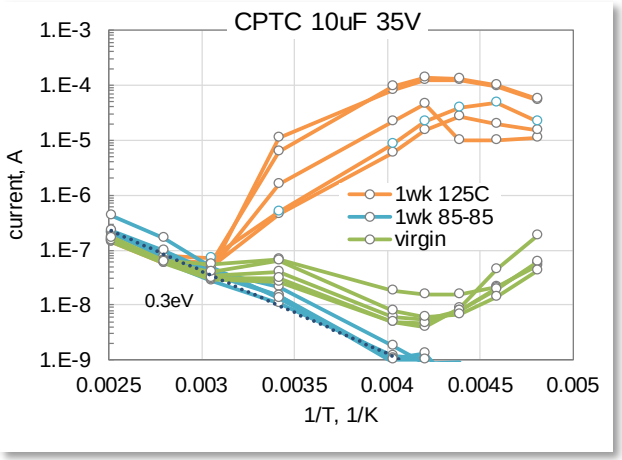
- ✓ Reliability of CPTCs during life testing is comparable or better than for MnO2 parts.
- ✓ Contrary to MnO2 caps that might fail short circuit, CPTCs are more likely to cause current spiking (not addressed by the existing S&Q).

Specifics of CPTCs: Anomalous Transients



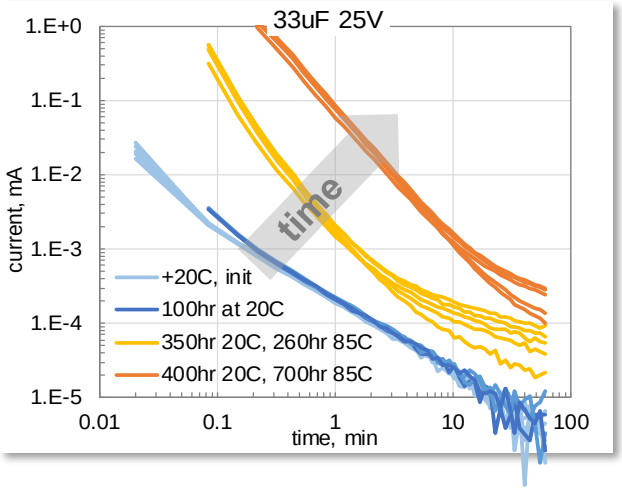


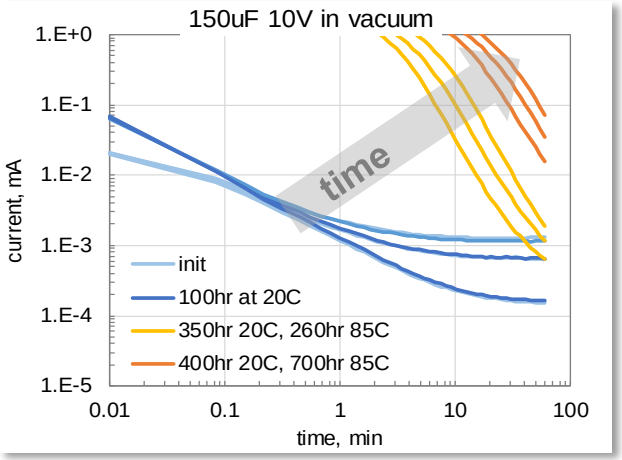


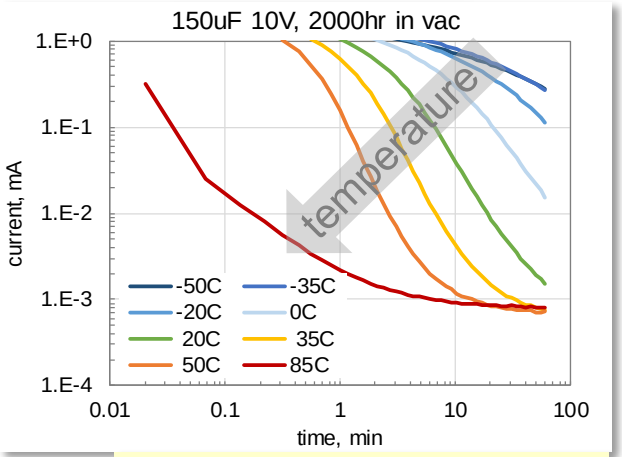


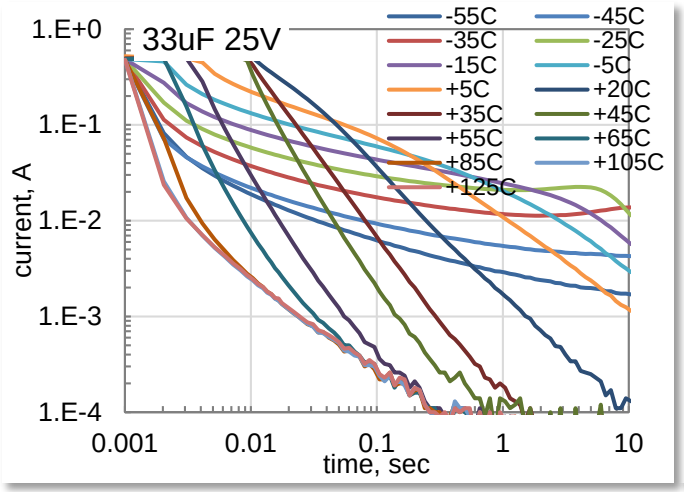
- ✓ Preconditioning affects transient currents from milliseconds to hours.
- ✓ Behavior of CPTCs with moisture is similar to MnO2 caps.
- ✓ At RT dry CPTCs might have currents >10^3 times greater than humidified caps.
- ✓ Contrary to MnO2 capacitors, leakage currents at low temperatures in dry CPTCs might increase up to 10^6 times.

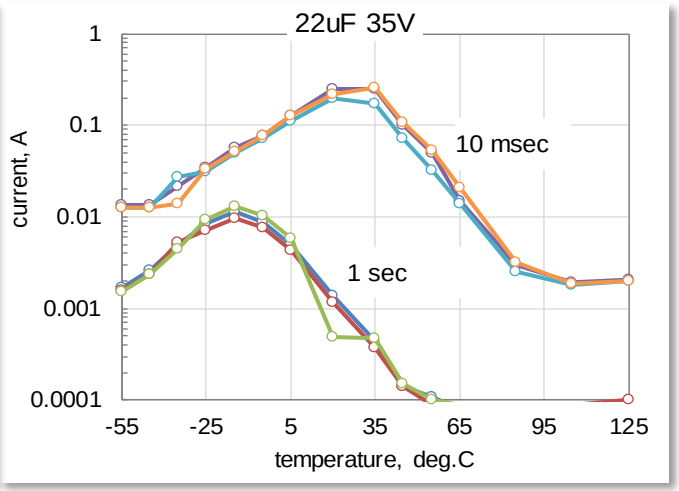
Effect of Vacuum







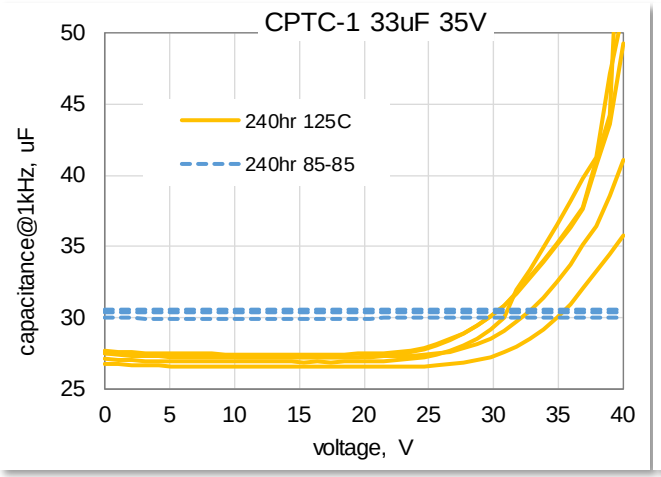


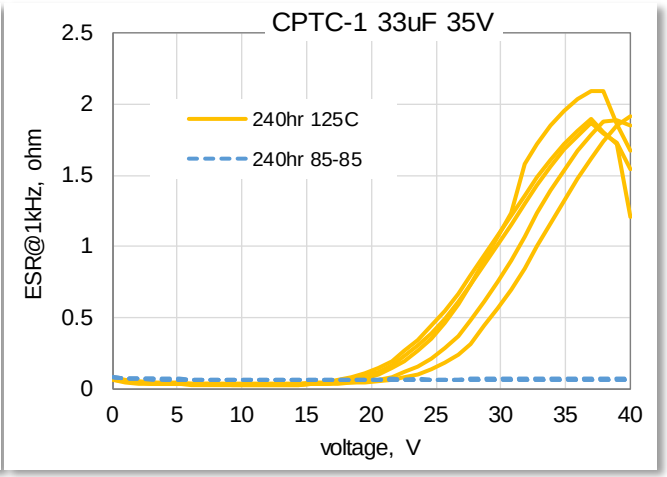


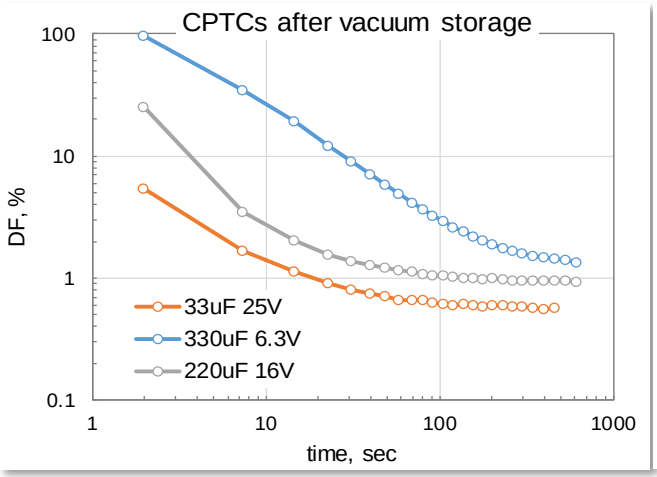
- ✓ Anomalous transients appear with time in vacuum.
- ✓ Inverse temperature dependence of leakage currents.

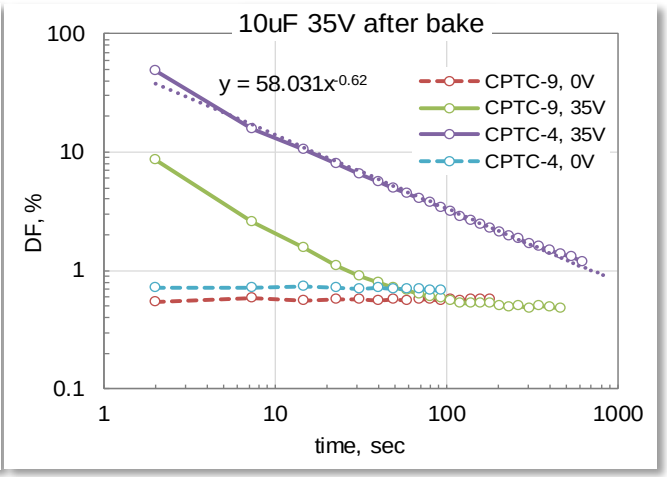
✓ Short- and long-term transients might have different mechanisms.

Anomalies in AC Characteristics



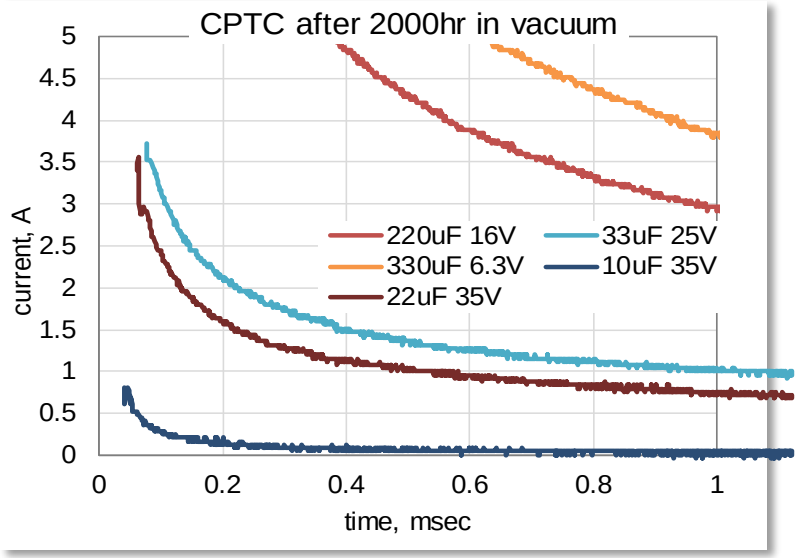


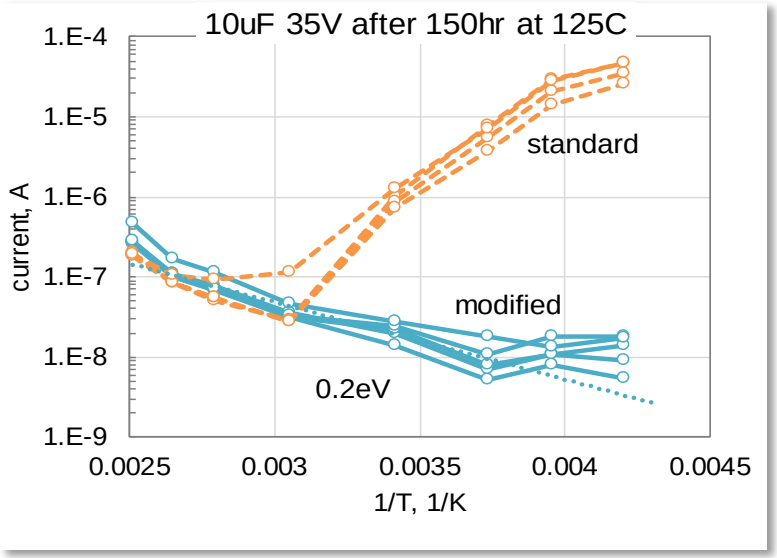




- ✓ Similar to MnO2 caps, wet CPTCs have stable AC characteristics.
- ✓C, ESR, and DF are increasing with voltage in dry CPTCs.
- ✓ DF in CPTCs after drying can increase well above 10% and then decrease gradually with time.

Anomalous Transients: Effect of Part Type





- ✓ Different part types have substantially different levels of transient currents.
- ✓ Currently, no specific tests evaluate the level of transients.
- ✓ Modification of polymers can practically eliminate anomalies in behavior of CPTCs.

Conclusions and Future Work

- To use CPTCs that are compliant with AEC-Q200 for space:
  - Designers should be aware of possible degradation and anomalies in the parts and determine acceptable levels.
  - The level of degradation, current spiking and anomalous transients is limited by adequate S&Q procedures.
  - Voltage derating should be 50% instead of 80% suggested by manufacturers.
- Future work on CPTCs:
  - Kinetics of moisture sorption and desorption at different temperatures;
  - Modeling of ESR degradation;
  - Effect of long-term exposure to vacuum and HTS on current spiking and anomalous transients;
  - Radiation hardness.
  - Guidelines for applications and parts' selection.