Anomalous Transients in Chip Polymer Tantalum Capacitors

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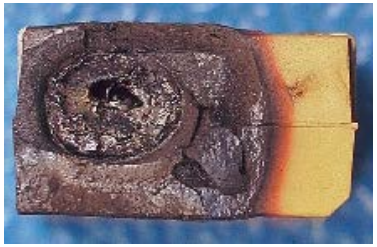
Outline

- Issues with chip polymer tantalum capacitors (CPTC)
- Experiment
- Factors affecting transient currents
  - Preconditioning
  - Temperature
  - Voltage
  - Vacuum
  - Operation at high temperature under bias
  - Part type
- Anomalies in AC characteristics
- Mechanisms of anomalous transients
- Summary

Issues with CPTCs

- Major benefits compared to MnO2 capacitors:
  - Better volumetric efficiency (smaller case sizes for the same CV);
  - Higher operating voltages (up to 125V);
  - Lower ESR (milliohm range);
  - A relatively safe failure mode (no ignition).



- Major drawbacks:
  - Insufficient or excessive amount of moisture might be detrimental;
  - Vacuum can be a benefit or a hazard;
  - Weibull grading test is not applicable;
  - ESR might degrade with time at high temperatures;
  - A new phenomena: **anomalous transients**.

Anomalous transients include a group of phenomena:

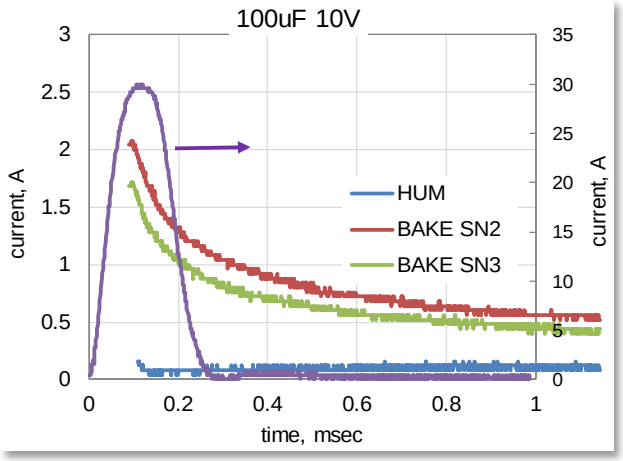
- ✓ A temporary short circuit without damaging the part;
- ✓ Increasing of C and DF with voltage;
- ✓ Substantial increasing of DCL at low temperatures.

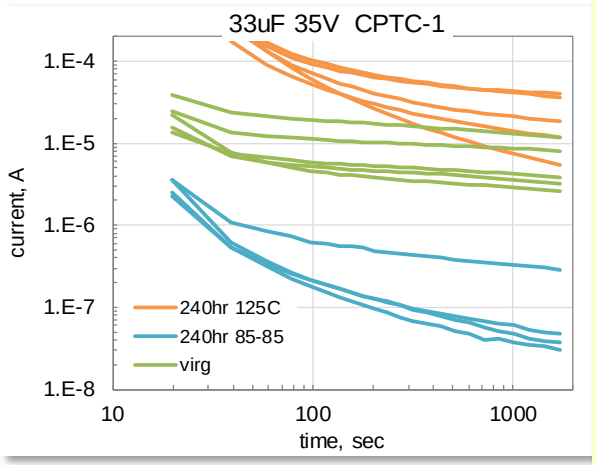
Experiment

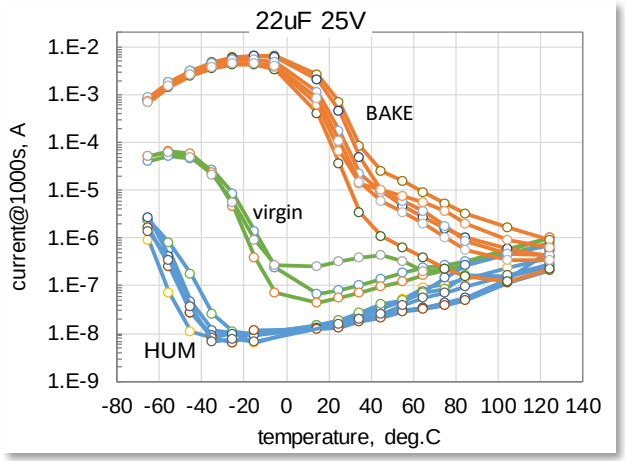
- Transient currents were monitored using three techniques:
  - From 1 μsec to 1 msec using a current probe and an oscilloscope using a set-up for surge current testing.
  - From 1 msec to 10 sec using a power SMU in Agilent Analyzer 4156A. The currents were clamped at 1 A at ≤ 20V and 0.5 A at ≤ 40V.
  - From 10 sec to hours using a PC-based system by scanning voltages across 1k to 10k limiting resistors.
- More than 20 types of CPTCs from three manufacturers rated from 6.3V to 35V were used. Most capacitors had case size D.
- The parts were used in “as is” (virgin) condition within a few days of removal from dry bags, and after soaking in humidity chamber at 85 ºC, 85% RH (hum), or after storing at 125 ºC (bake). Duration of soaking or storing was typically 10 days.
- Thirteen part types were tested after 2000 hr storage in vacuum at 3×10^{-6} torr.

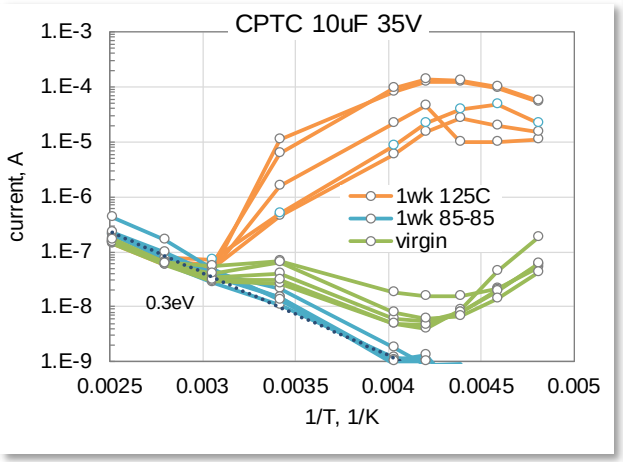
Effect of Preconditioning

Preconditioning: 7-10 days at 85C/85%RH or at 125C





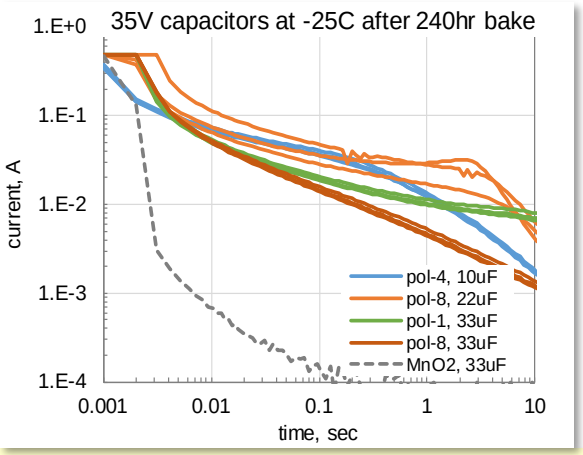


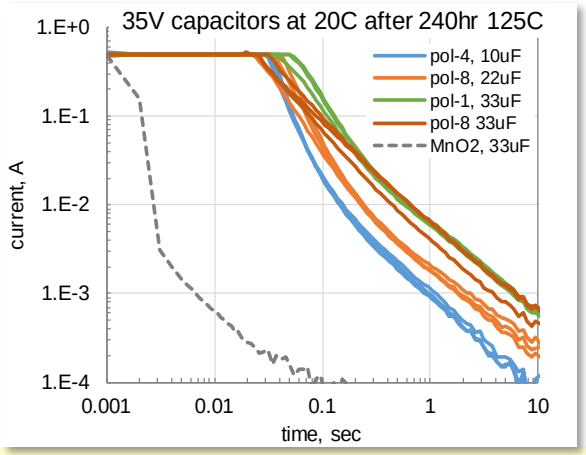


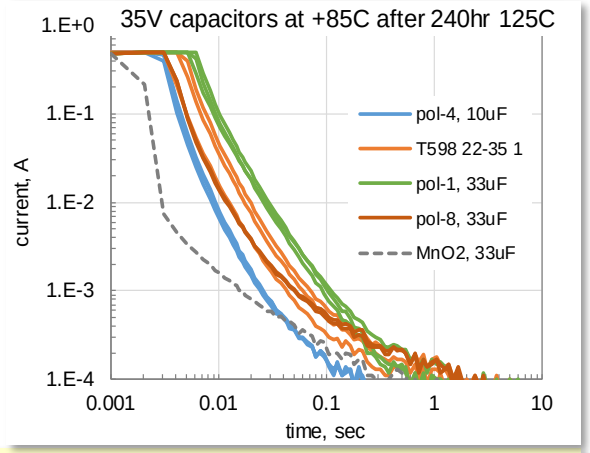
- ✓ Preconditioning affects transient currents from 0.1 millisec to hours.
- ✓ Behavior of CPTCs with moisture is similar to MnO2 caps.
- ✓ At RT dry CPTCs might have currents >10^3 times greater than humidified caps.
- ✓ Contrary to MnO2 capacitors, leakage currents at low temperatures in dry CPTCs might increase up to 10^6 times.

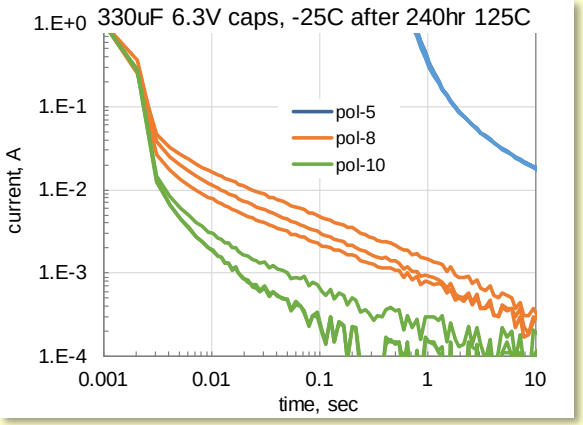
Effect of Temperature

Medium-term transients at -25, +20, and +85 ºC for different types of dry 35V and 6.3V capacitors





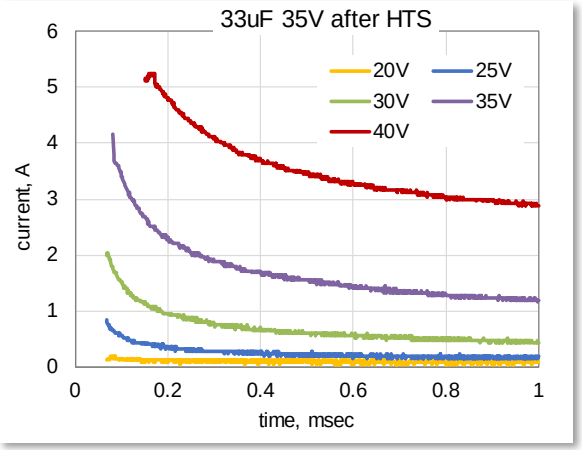


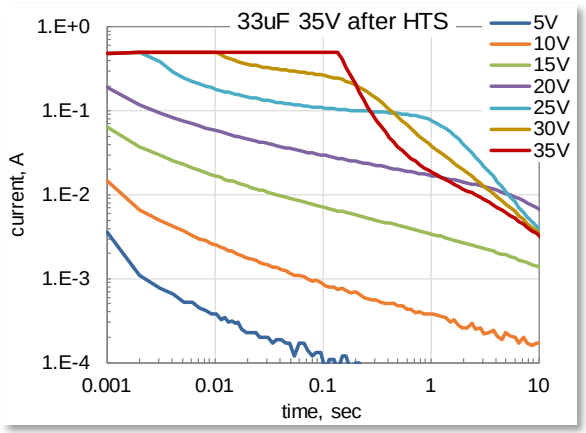


- ✓ Transient currents are increasing at low temperatures and might exceed 1A for up to 1 sec that might be interpreted as a short circuit failure during cold start-up of the system.
- ✓ Currents exceeding 1 A after 1 msec are currently considered a failure during surge current testing per MIL-PRF-55365.
- ✓ CPTCs with high-current transients can endure multiple surge cycling.

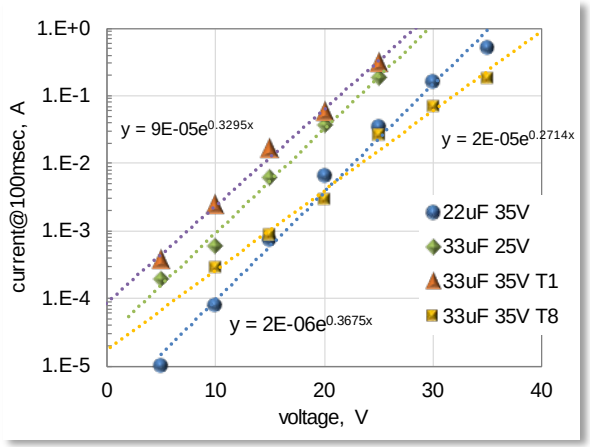
Effect of Voltage

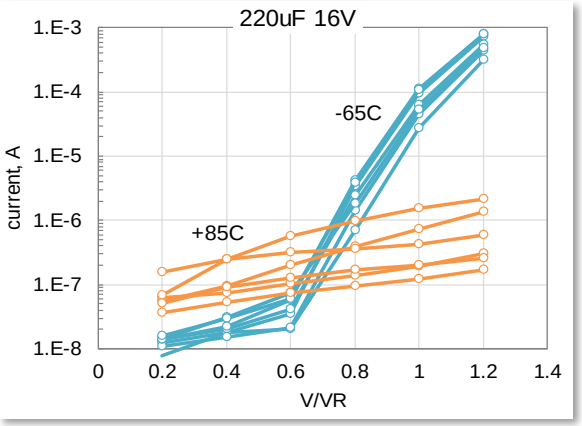
Short- and medium-term transients in 33 μF 35 V CPTCs after storage at 125 ºC





100 msec currents in different 35 V capacitors

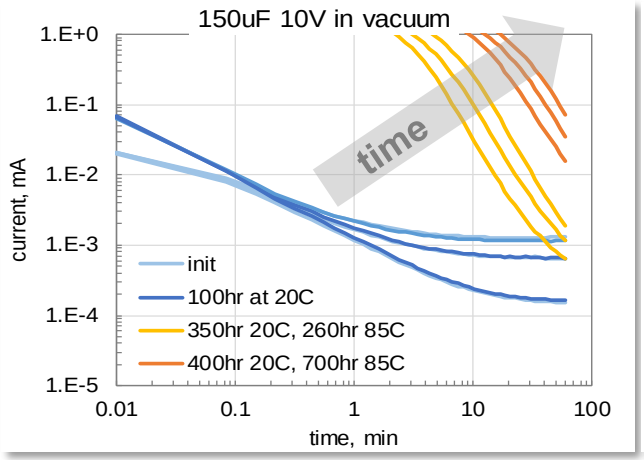


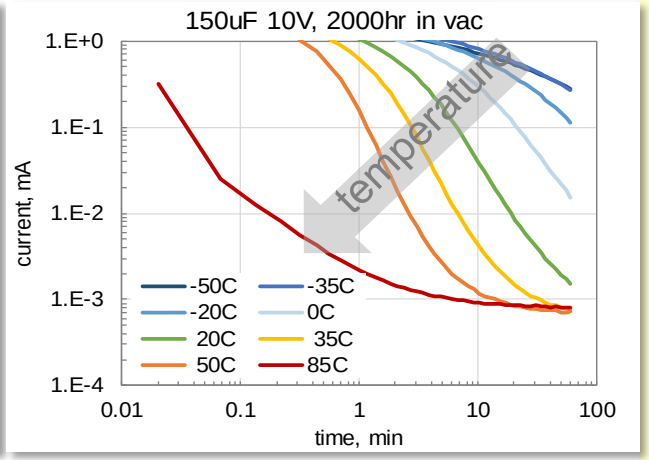


- ✓ Near exponential *I(V)* dependence.
- ✓ The rate of voltage variations at low temperatures is changing at ~0.5VR
- ✓ At RT *I(0.5VR) ≈ 0.01×I(VR)*
- ✓ Voltage derating is an effective means to constrain anomalous transients.

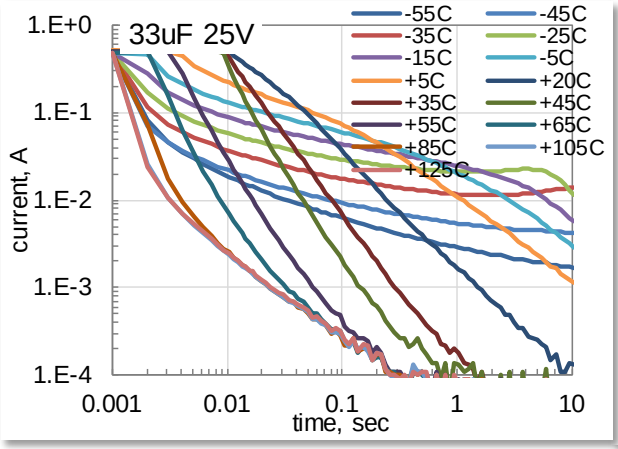
Effect of Vacuum

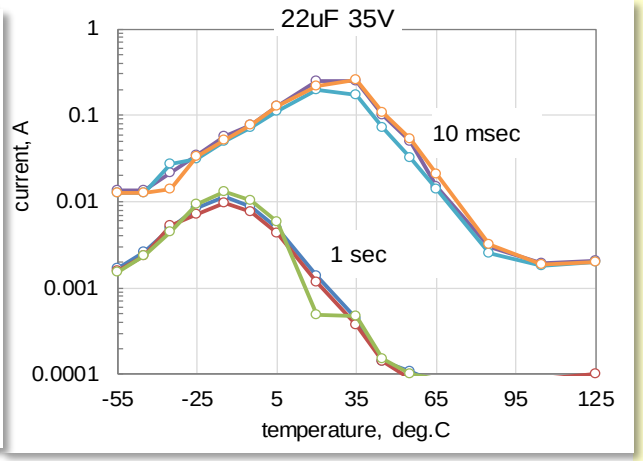
Long-term transients were measured with time of storage in vacuum





Mid-term transients after storage in vacuum

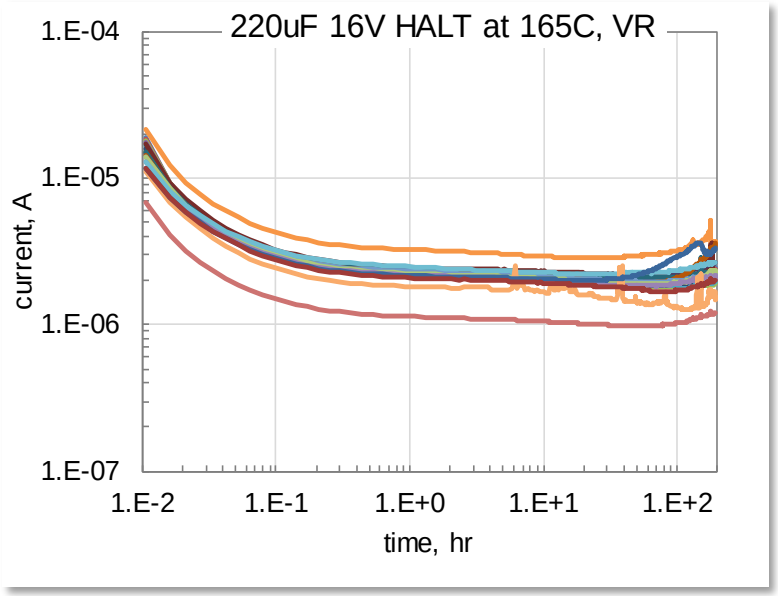




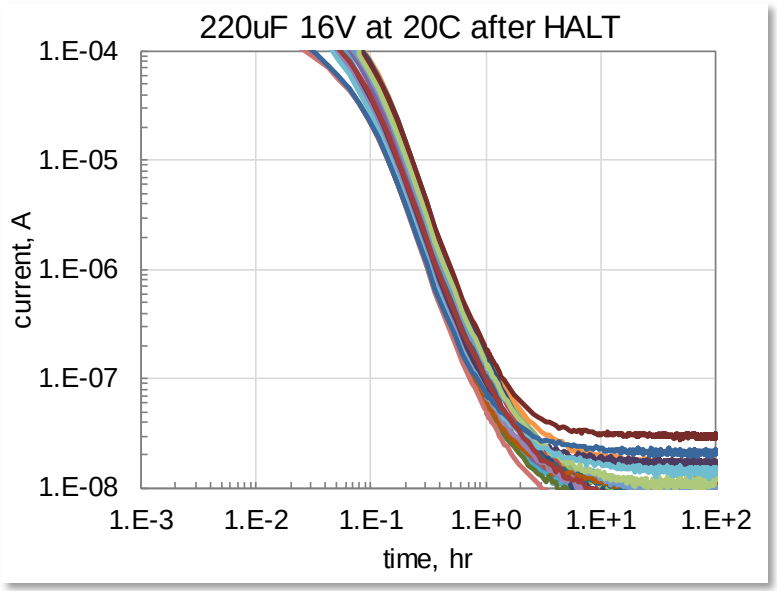
- ✓ Anomalous transients appear in vacuum after ~100hr.
- ✓ Currents might exceed 1 mA for more than 5 min.
- ✓ Inverse temp. dependence of leakage currents.
- ✓ Short- and long-term transients have different extremal dependencies on temperature and might be due to different mechanisms.

Operation at HT under Bias

Currents in 220 μF 16 V CPTCs during HALT at 165 ºC, 16 V for 200 hr



Currents at 22 ºC, 16 V after HALT and 1 hour depolarization

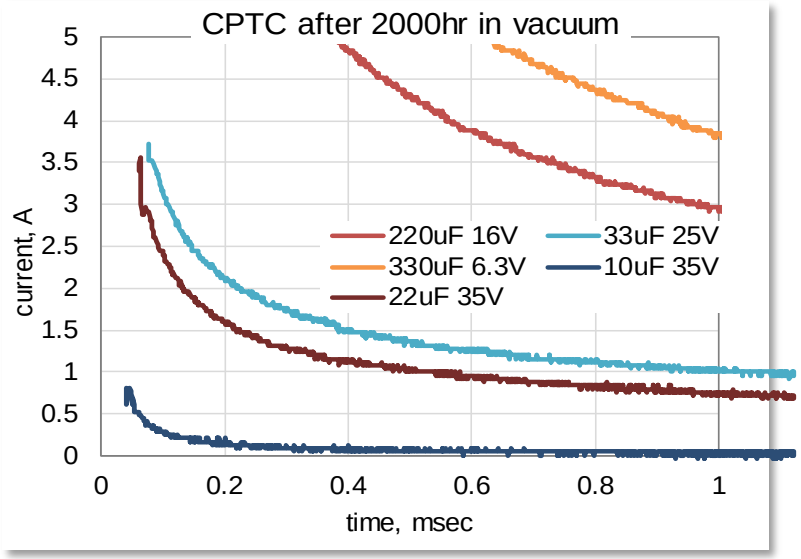


✓ Currents at RT after HALT during first few minutes exceeded currents at 165 ºC by orders of magnitude and then decreased more than 10^4 times after 10 hours.

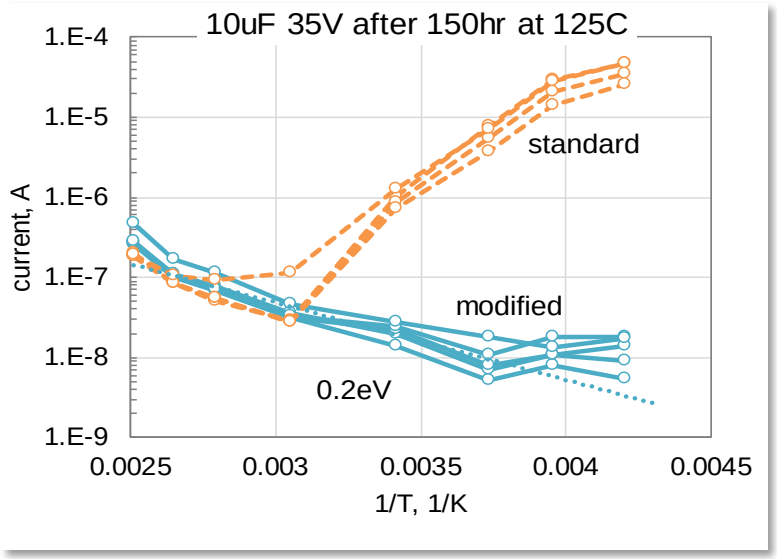
✓ HT biased operation results in anomalies similar to HT storage.

Effect of Part Type

Transient currents in different types of capacitors after 2000 hr in vacuum

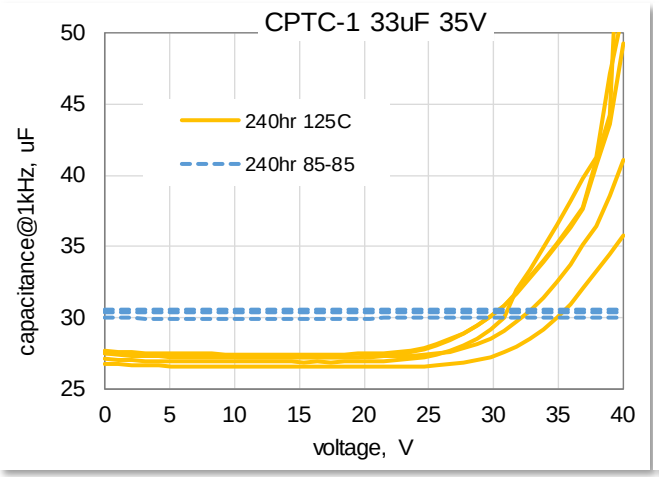


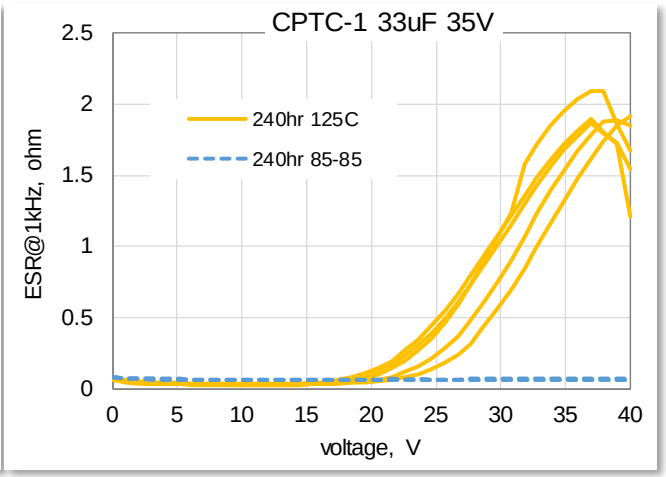
I(T) measured at 1000 sec for CPTCs having different conductive polymers

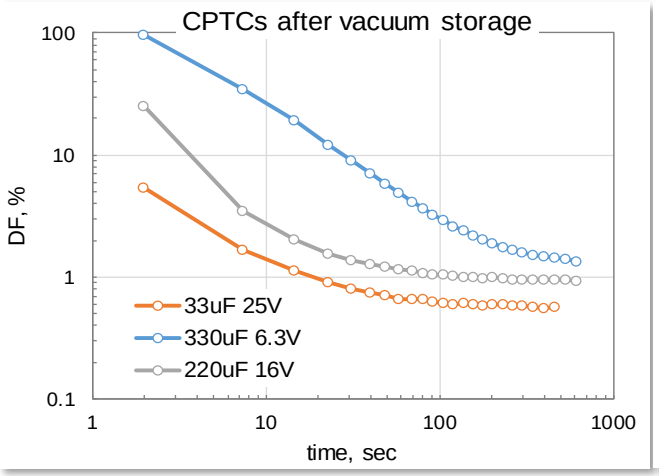


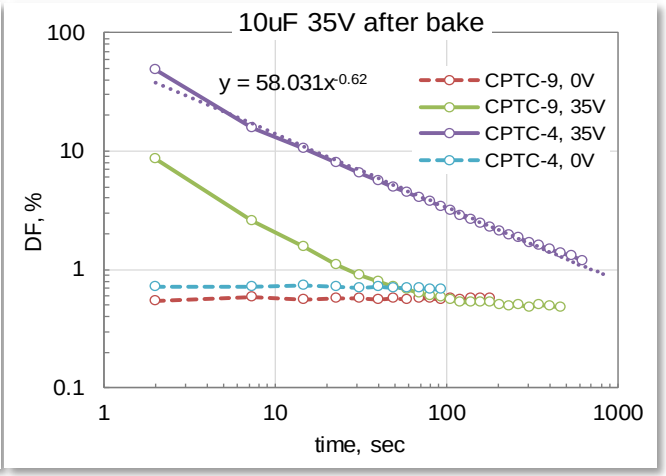
- ✓ After vacuum storage currents might exceed 3 A after 1 msec.
- ✓ Different part types have substantially different levels of transient currents.
- ✓ Modification of polymers can practically eliminate anomalies in behavior of CPTCs.

Anomalies in AC Characteristics







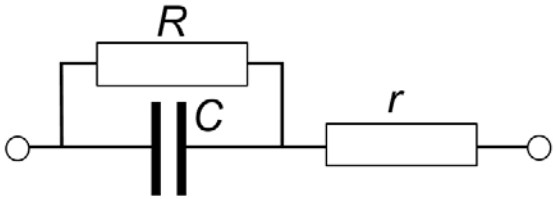


- ✓ In the presence of moisture AC characteristics are stable.
- ✓ C, ESR, and DF are increasing substantially with voltage.
- ✓ DF in dry CPTCs can increase well above 10% and then decrease gradually with time.

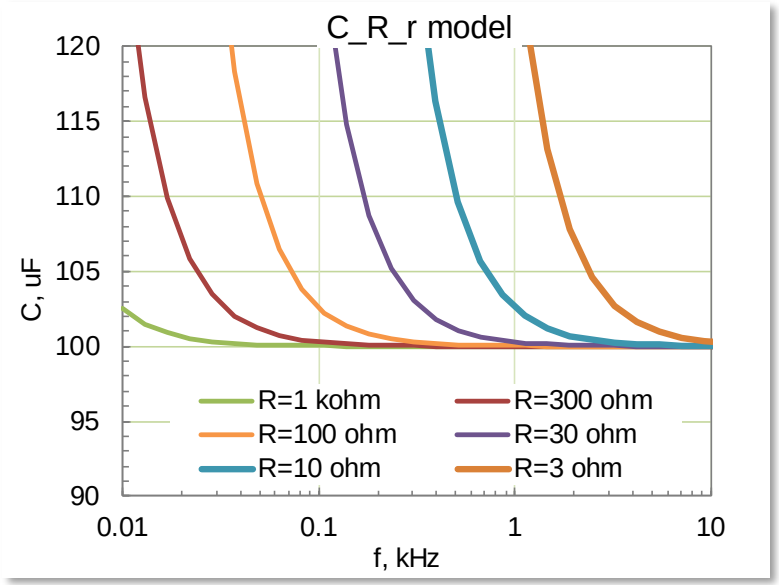
✓ Anomalous behavior is most evident at low frequencies and become negligible at f > 10 kHz.

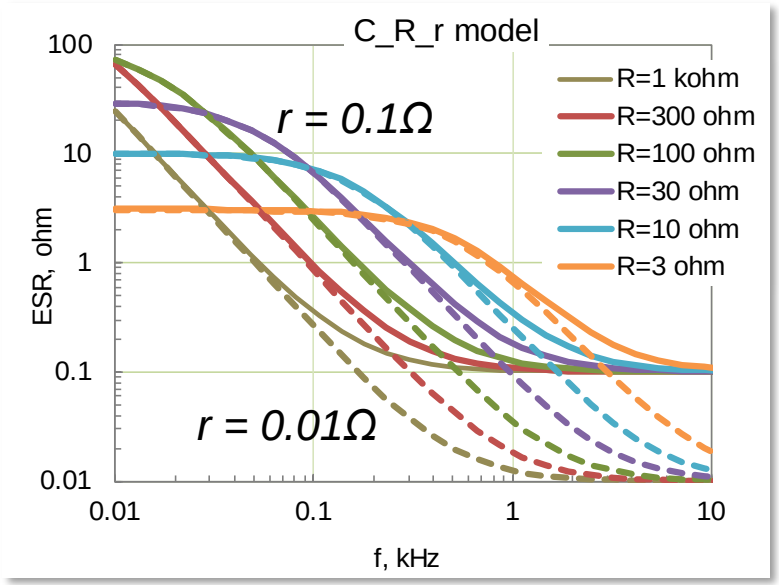
Mechanism of Anomalies in C and DF

A simple C-R-r model of a capacitor with leakage can be used to explain the effect of voltage on *C*, *ESR*, and $DF = \omega \times C \times ESR$



$$C = C_0 \times \left[1 + \frac{1}{(R\omega C_0)^2}\right] \qquad ESR = r + \frac{R}{1 + (\omega CR)^2}$$

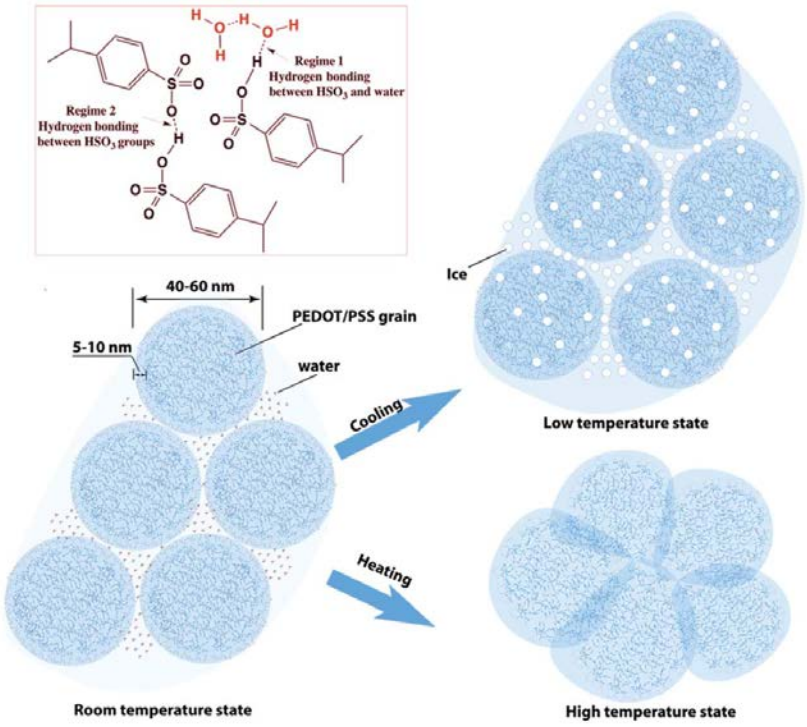




- ✓ The effect is due to increased conductivity of Ta2O5 that increases sharply with voltage.

Mechanism of Anomalous Transients

- The existing model for anomalous charging currents does not explain long-term transient effects.
- Variations in the moisture content and temperature affect the core-shell morphology of the polymer and might change its electronic band structure.
- Shifting positions of the molecular orbitals might change currents in CPTCs by changing the barrier height at the interface polymer/Ta2O5.



Changes in morphology of PEDOT/PSS with moisture content and temperature, Zhou et al. 2014

Summary

- Anomalous transients include a group of phenomena:
  - temporary shorting of the part;
  - increasing currents at low temperatures;
  - increasing C and DF with voltage at low frequencies.
- Anomalous transients can be observed in all types of CPTCs in dry conditions. In the presence of moisture the parts behave similar to MnO2 capacitors.
- The level of transients depends on the type of capacitors. A proper selection of polymers might reduce anomalies substantially.
- Mechanism: changes in the core-shell structure of dry PEDOT:PSS that affect the barrier height at the polymer/Ta2O5 interface. Oxidation/reduction reactions with time under bias result in decreasing of leakage.

Summary, Cont'd

- CPTCs can be used in space applications at the following conditions:
  - The sensitivity of the systems and circuits to the effect of possible anomalies is evaluated by circuit designers.
  - A 50% voltage derating is applied.
  - The level of anomalous transients is limited by special screening and qualification procedures.