Characterization of Tantalum Polymer Capacitors

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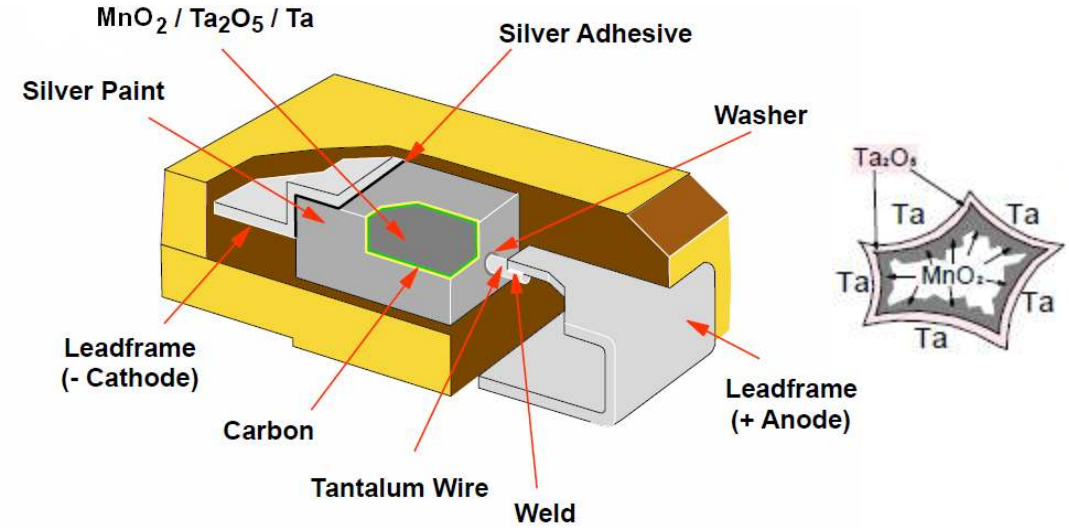
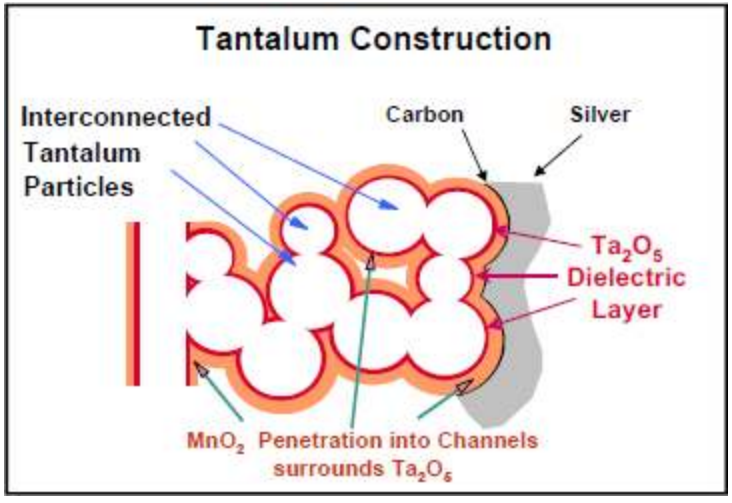
Agenda

- Overview
- Polymer Pros and Cons
- Data Gathered to Date
- Plan Moving Forward
- Summary and Conclusions

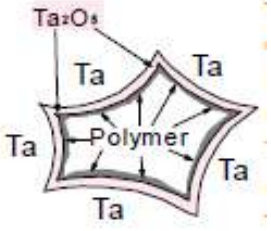
Overview

- MIL-PRF-55365 Tantalum MnO_2 Capacitors





- Tantalum Polymer Capacitors: MnO_2 cathode is replaced with polymer material



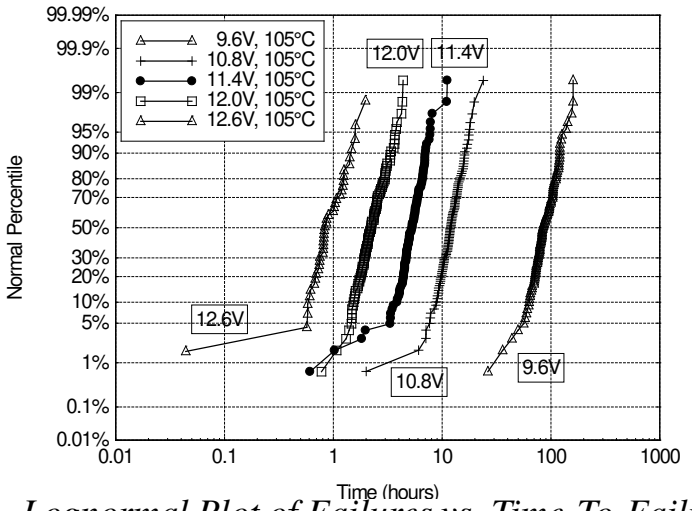
* "Replacing MnO_2 with Conductive Polymer in Tantalum Capacitors," CARTS Europe 1999
* "Capacitor Types, Construction, and Characteristics," KEMET KIT 2011

Polymer Pros and Cons

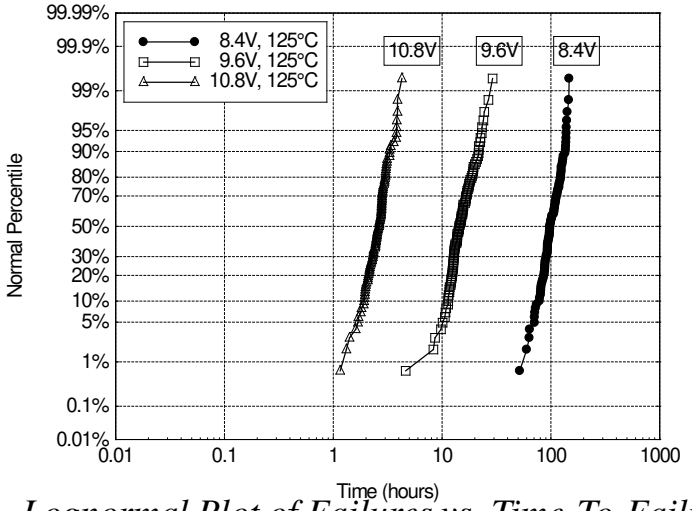
- Pros
  - No ignition problems
  - Lower ESR
  - Less stress during manufacturing (low-temperature deposition)

- Cons
  - Less thermally stable
  - Higher leakage current
  - Moisture Sensitivity Level 3 (168 hours $\leq$ 30°C / 60% RH)

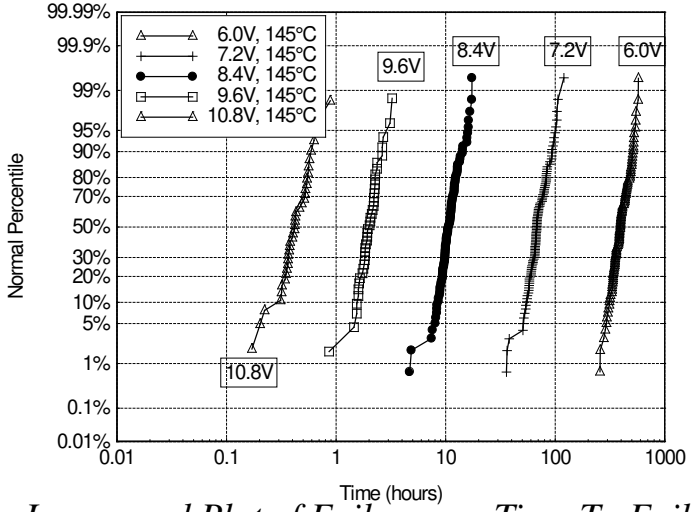
Failure Distribution of 6 V Capacitors



Lognormal Plot of Failures vs. Time-To-Failures, 6 V Tested at 105°C



Lognormal Plot of Failures vs. Time-To-Failures, 6 V Tested at 125°C

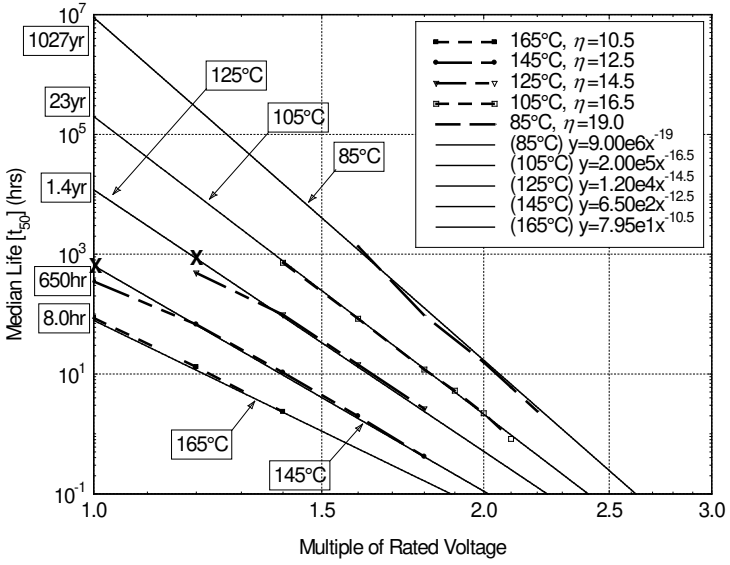


Lognormal Plot of Failures vs. Time-To-Failures, 6 V Tested at 145°C

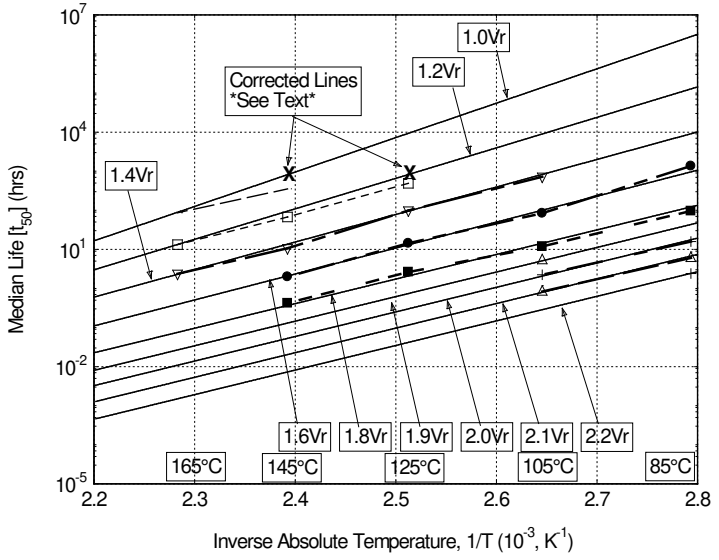
* "Reliability of Tantalum Polymer Capacitors," CARTS USA 2004

Characterization of 6 V Capacitors

- Characterized in 2004 by KEMET
- Voltage acceleration, t_{50} = 1027 years at 85°C and maximum rated voltage
- Temperature acceleration, t_{50} = 360 years at 85°C and maximum rated voltage



Median Life vs. Test Voltage

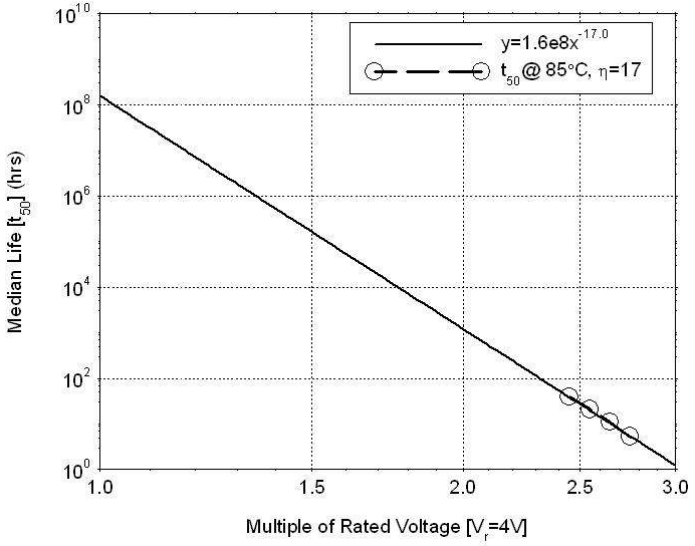


Median Life vs. Inverse Absolute Temperature

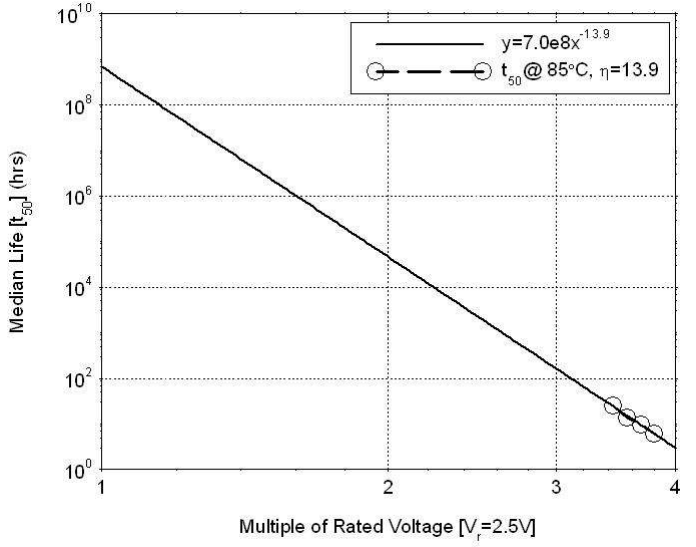
* "Reliability of Tantalum Polymer Capacitors," CARTS USA 2004

Voltage Acceleration of 4 V and 2.5 V Capacitors

- Partially characterized in 2005 by KEMET
- 4 V capacitors, t_{50} = 18,000 years at 85°C and maximum rated voltage
- 2.5 V capacitors, t_{50} = 80,000 years at 85°C and maximum rated voltage



Median Life vs. Test Voltage, 1000 µF, 4 V, Multiple-Anode



Median Life vs. Test Voltage , 680 µF, 2.5 V, Multiple-Anode

* "Reliability of Low-Voltage Tantalum Polymer Capacitors," CARTS USA 2005

JPL Characterization of 4 V Capacitors

- Main goal: Develop an accurate acceleration model by focusing on accelerated life tests using elevated voltage and temperature
- Secondary goal: Compare two different manufacturers, Manufacturer A and Manufacturer B, to determine if acceleration models are similar
- 220 µF, 4 V tantalum polymer capacitors

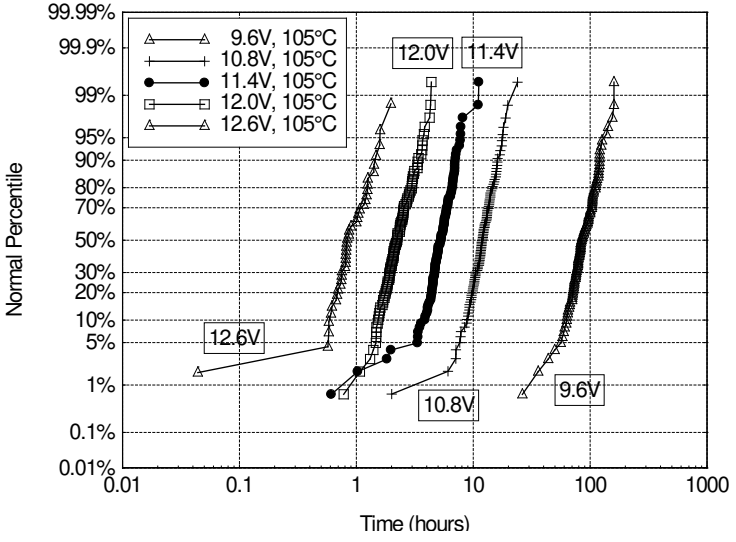
Test Matrix				
85 C		105 C		125 C
V_{Test} (V)		V_{Test} (V)		V_{Test} (V)
V_{low}		V_{low}		V_{low}
V_{medium}		V_{medium}		V_{medium}
V_{high}		V_{high}		V_{high}

JPL Characterization of 4 V Capacitors (A)

- Test matrix and resulting t_{50} times:

Manufacturer A: 220 µF, 4 V						
85 C			105 C		125 C	
V_{Test} (V)	t_{50} (hr)		V_{Test} (V)	t_{50} (hr)	V_{Test} (V)	t_{50} (hr)
10	169		8.8	105	8.8	13
10.8	46		9.6	33	9.2	8.6
11.6	18		10.4	11	9.6	4.5

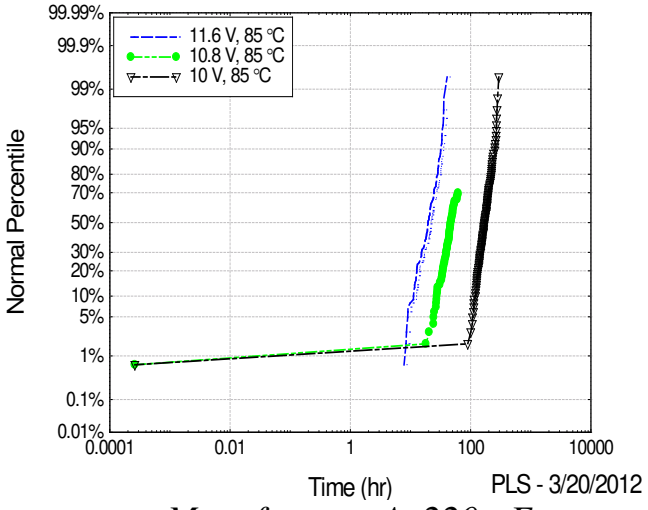
- Expected results:



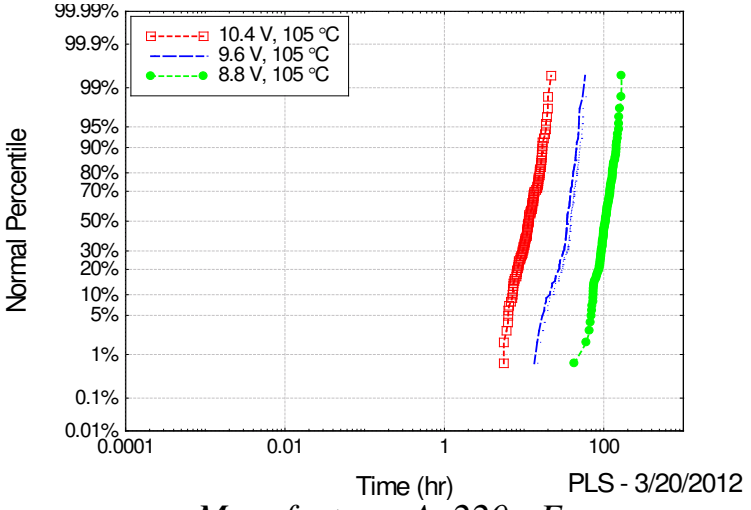
Lognormal Plot of Failures vs. Time-To-Failures, 6 V Tested at 105°C

* "Reliability of Tantalum Polymer Capacitors," CARTS USA 2004

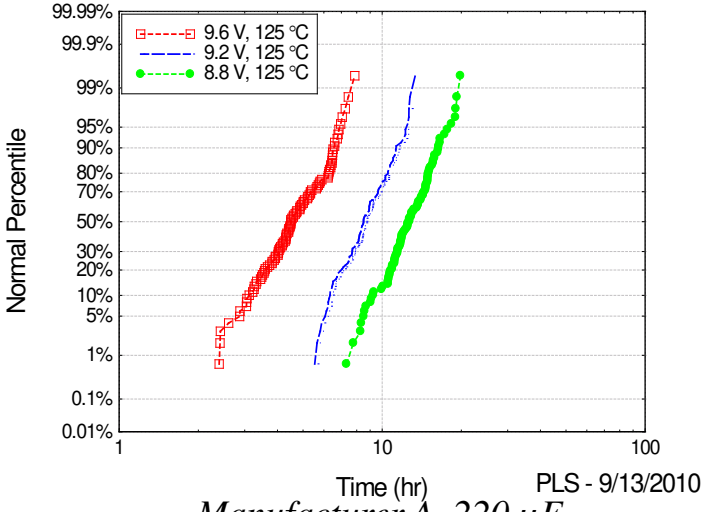
Failure Distributions for Manufacturer A



Manufacturer A, 220 µF, 4 V tested at 85°C



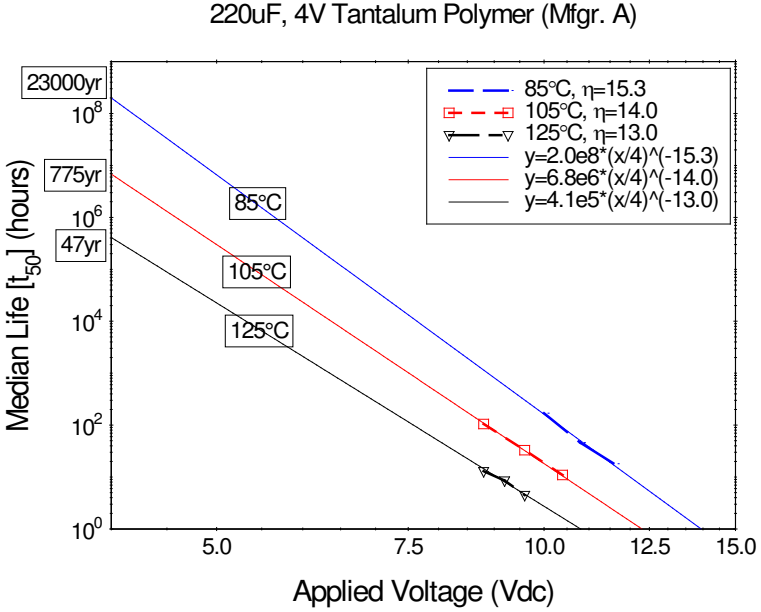
Manufacturer A, 220 µF, 4 V tested at 105°C



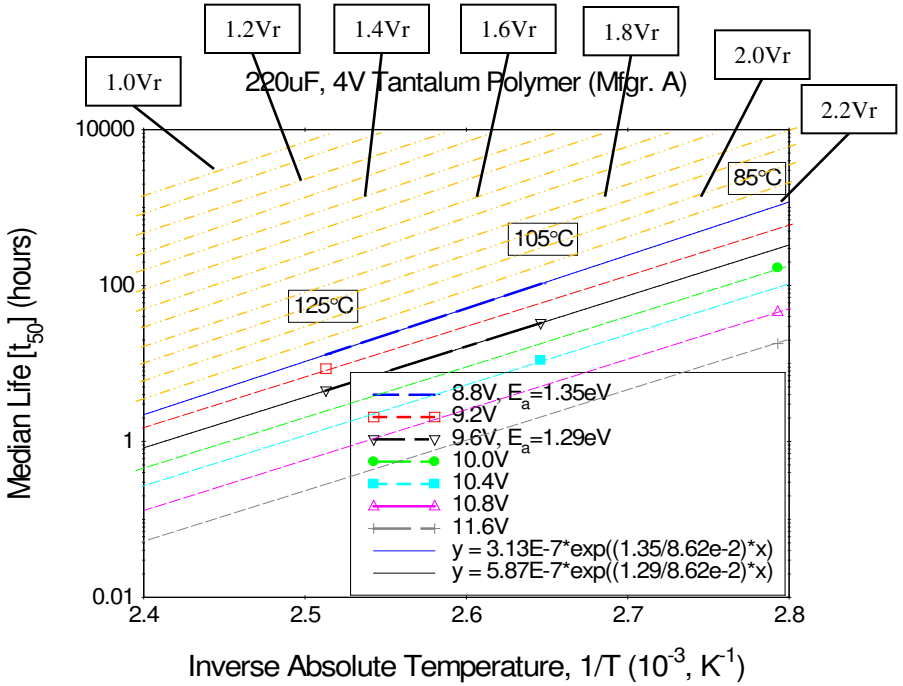
Manufacturer A, 220 µF, 4 V tested at 125°C

Acceleration Models of 4 V Capacitors (A)

- Voltage acceleration, t_{50} = 23,000 years at 85°C and maximum rated voltage
  - Comparable to KEMET's t_{50} of 18,000 years
- Temperature acceleration, t_{50} = 950 years at 85°C and maximum rated voltage

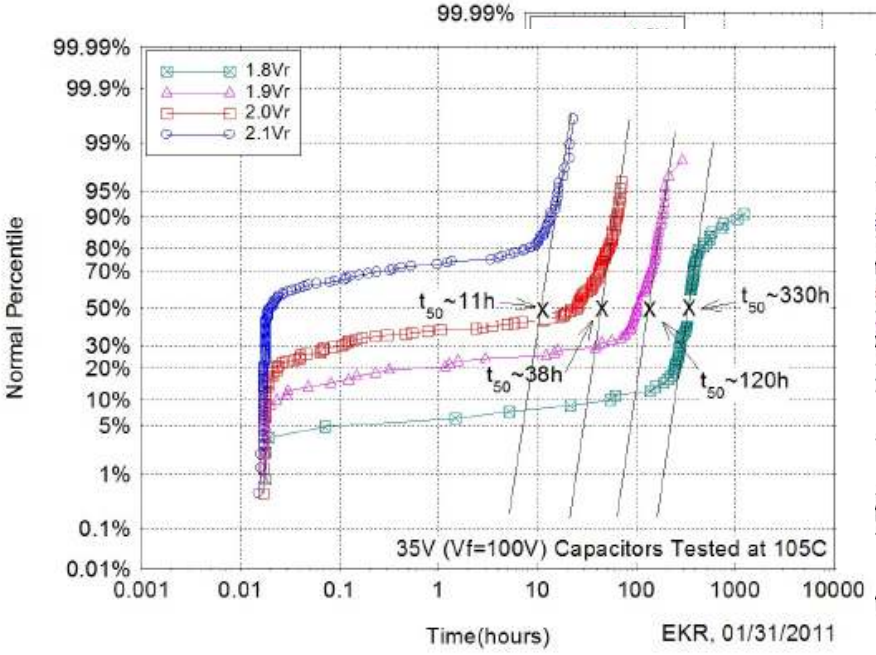


Median Life vs. Test Voltage

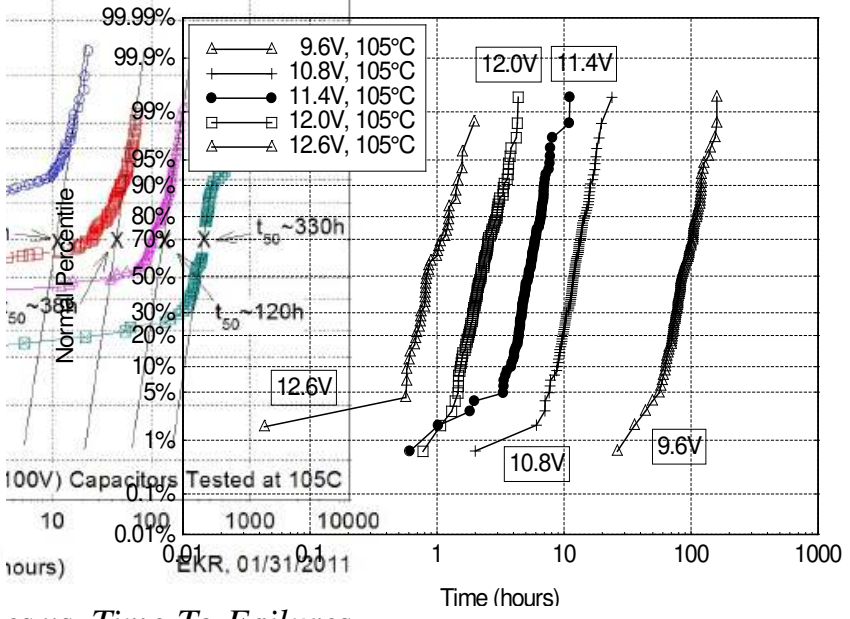


Median Life vs. Inverse Absolute Temperature

Failure Distribution of 35 V Capacitors



Lognormal Plot of Failures vs. Time-To-Failures, 35 V Tested at 105°C



Lognormal Plot of Failures vs. Time-To-Failures, 6 V Tested at 105°C

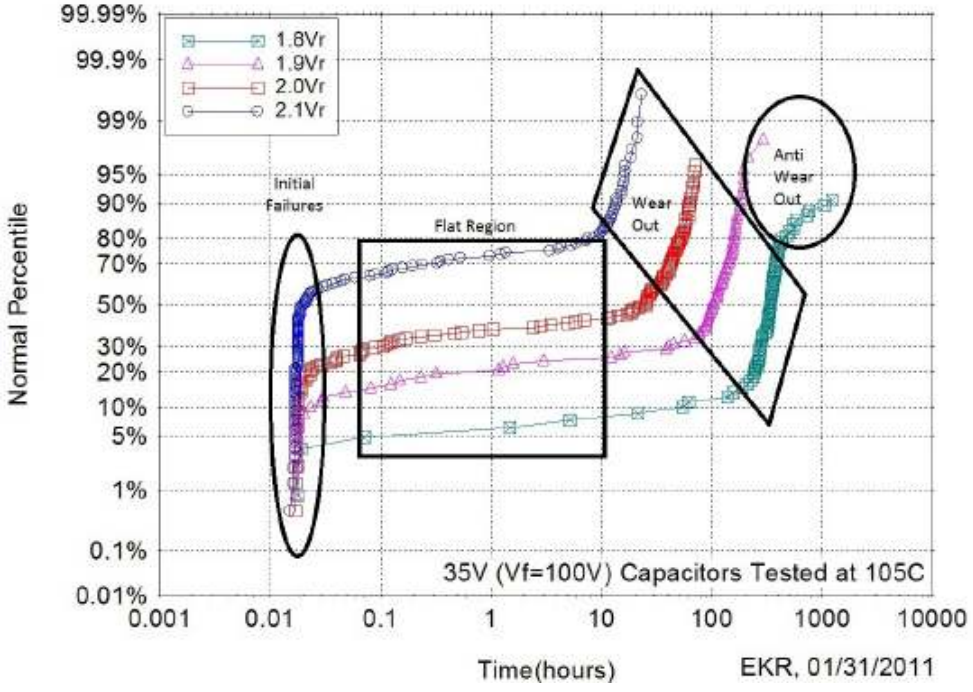
Lognormal Plot of Failures vs. Time-To-Failures, 35 V Tested at 105°C

- 35 V capacitors do not behave as expected

* "Reliability of High-Voltage Tantalum Polymer Capacitors," CARTS USA 2011

Unexpected Behavior of High Voltage Polymers

- Initial Failures: Increase proportionally to voltage
- Flat Region: Failures occurring slowly over time
- Wear-Out: Region of interest
- Anti-Wear-Out: De-doping of polymer material



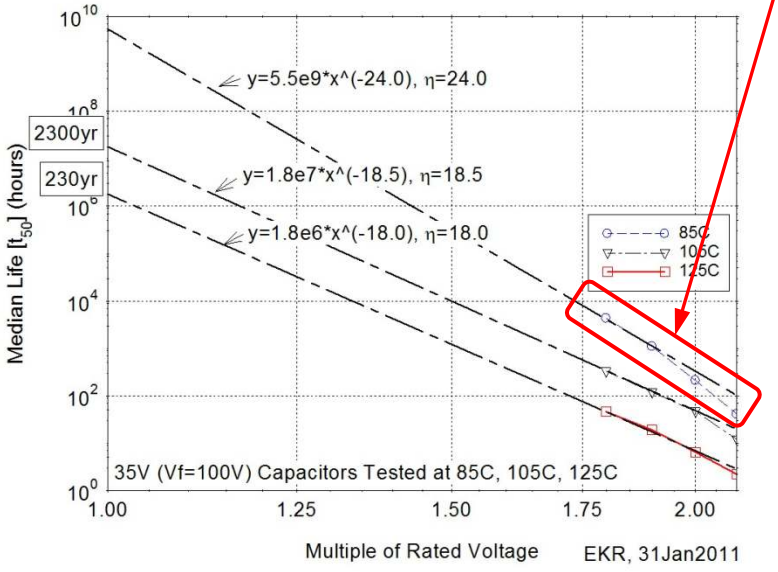
Lognormal Plot of Failures vs. Time-To-Failures, 35 V Tested at 105°C

* "Reliability of High-Voltage Tantalum Polymer Capacitors," CARTS USA 2011

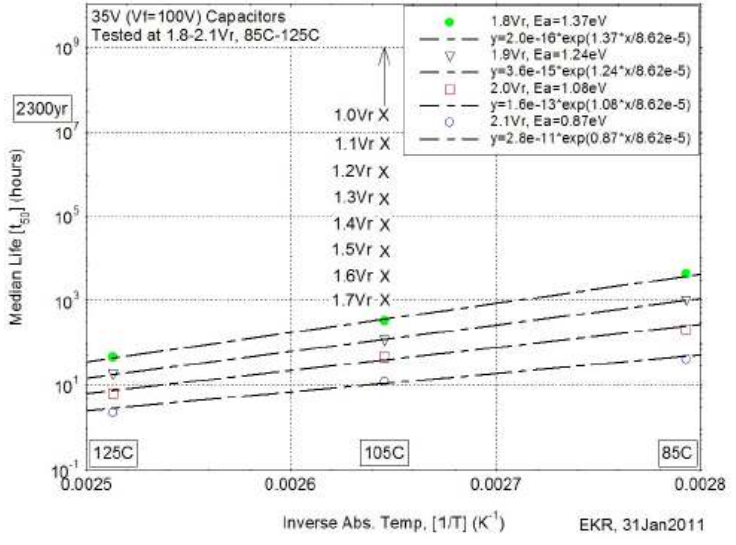
Characterization of 35 V Capacitors

- Charac
- Voltag
  maxim
- Tempe
  maximum rated voltage

Nonlinearity of data points for 85°C is evidence that another failure mechanism is at work



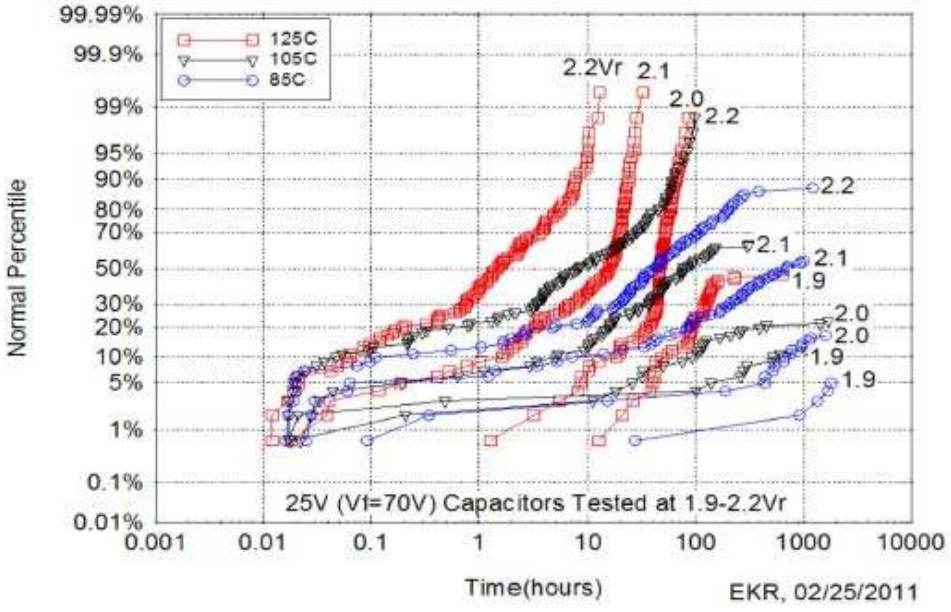
Median Life vs. Test Voltage



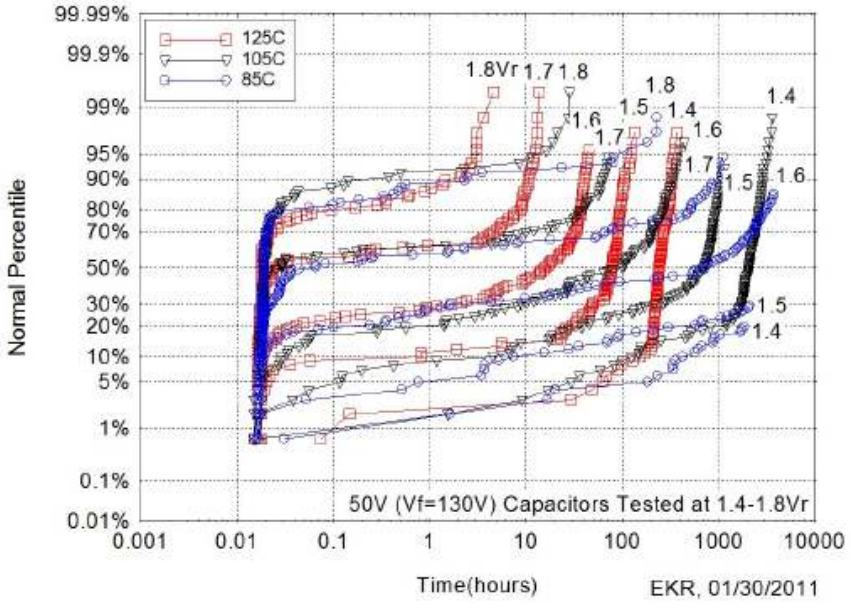
Median Life vs. Inverse Absolute Temperature

* "Reliability of High-Voltage Tantalum Polymer Capacitors," CARTS USA 2011

Failure Distribution of 25 V and 50 V Capacitors



Lognormal Plot of Failures vs. Time-To-Failures, 25 V Tested at 85°C, 105°C and 125°C



Lognormal Plot of Failures vs. Time-To-Failures, 50 V Tested at 85°C, 105°C and 125°C

- Acceleration models were not generated

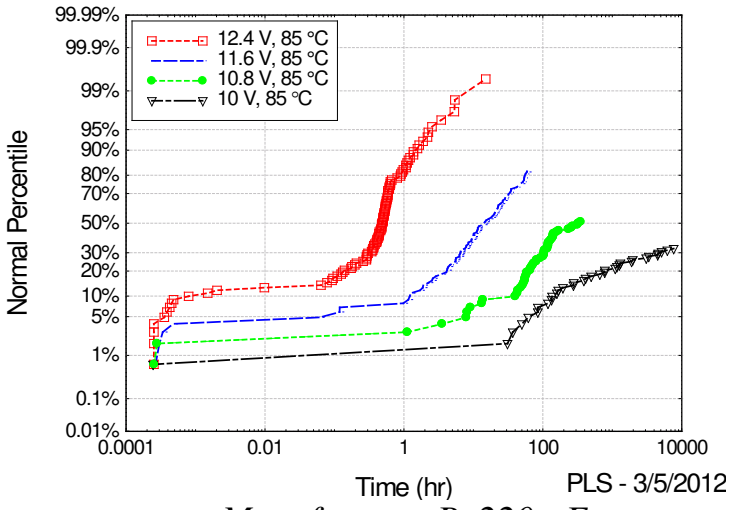
* "Reliability of High-Voltage Tantalum Polymer Capacitors," CARTS USA 2011

JPL Characterization of 4 V Capacitors (B)

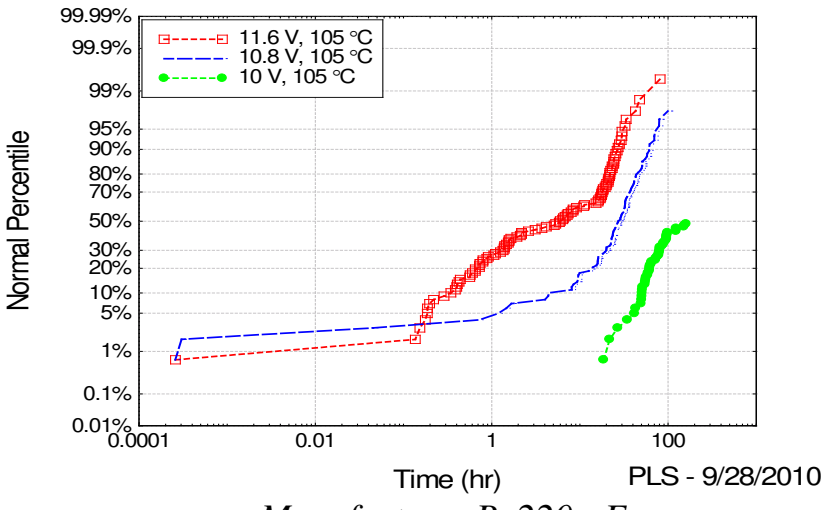
- Test matrix and resulting t_{50} times:

Manufacturer B: 220 µF, 4 V						
85 C			105 C		125 C	
V_{Test} (V)	t_{50} (hr)		V_{Test} (V)	t_{50} (hr)	V_{Test} (V)	t_{50} (hr)
10	2,000		10	110	8.8	50
10.8	300		10.8	26	9.2	28
11.6	13		11.6	10	9.6	19
12.4	0.4		-	-	-	-

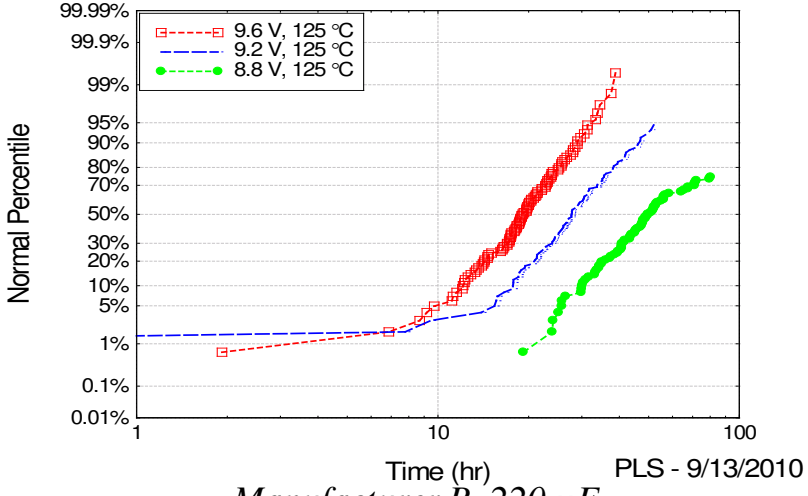
Failure Distributions for Manufacturer B



Manufacturer B, 220 µF, 4 V tested at 85°C



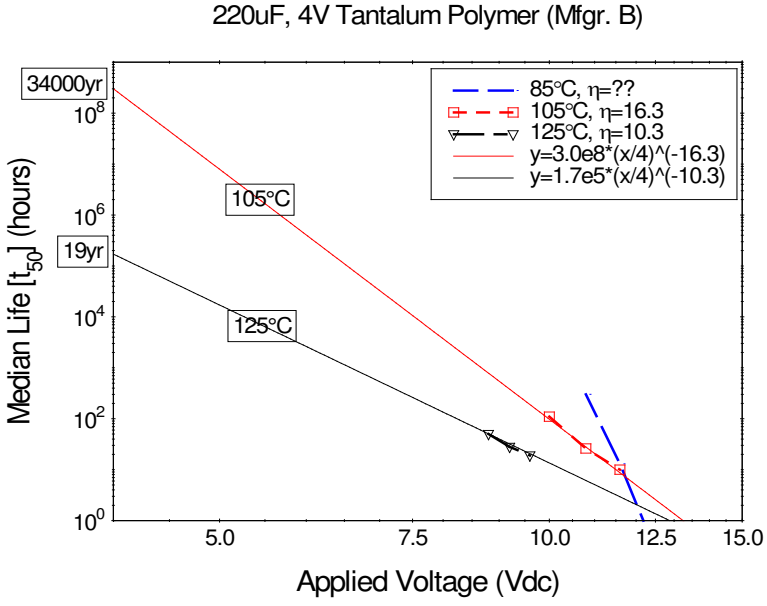
Manufacturer B, 220 µF, 4 V tested at 105°C



Manufacturer B, 220 µF, 4 V tested at 125°C

Acceleration Models of 4 V Capacitors (B)

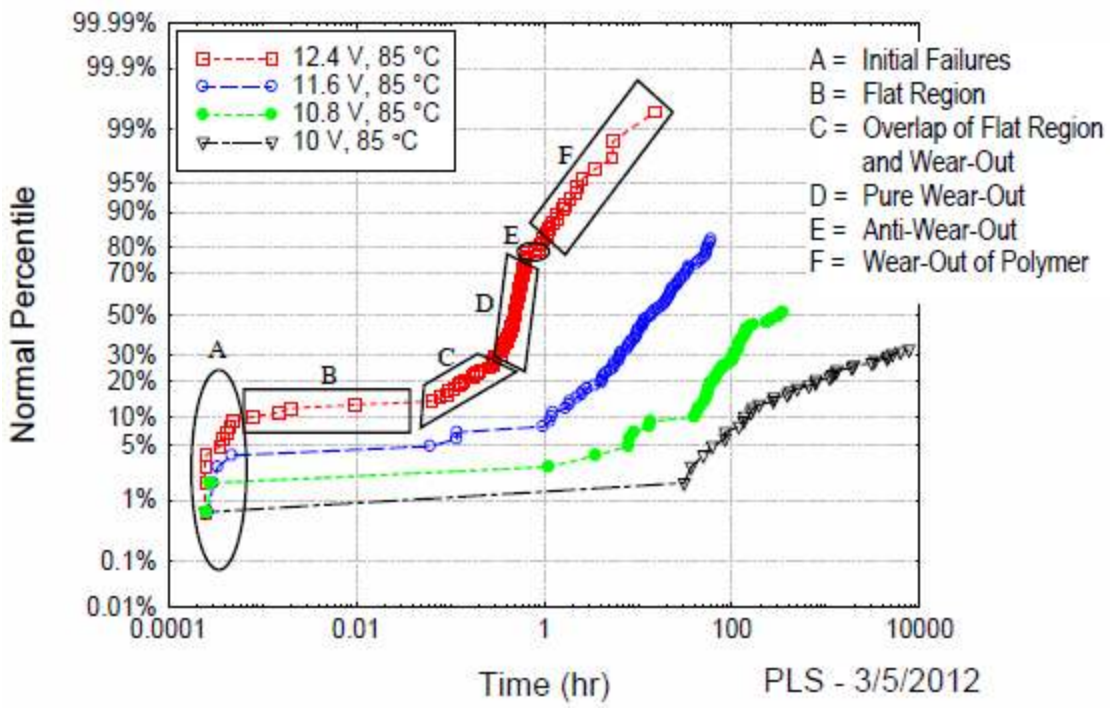
- Voltage acceleration data are questionable for 105°C
- Voltage acceleration data do not support meaningful extrapolation for 85°C
- Test voltages were too high, most likely too close to oxide formation voltage
- Evidence of limits to accelerated testing



Median Life vs. Test Voltage

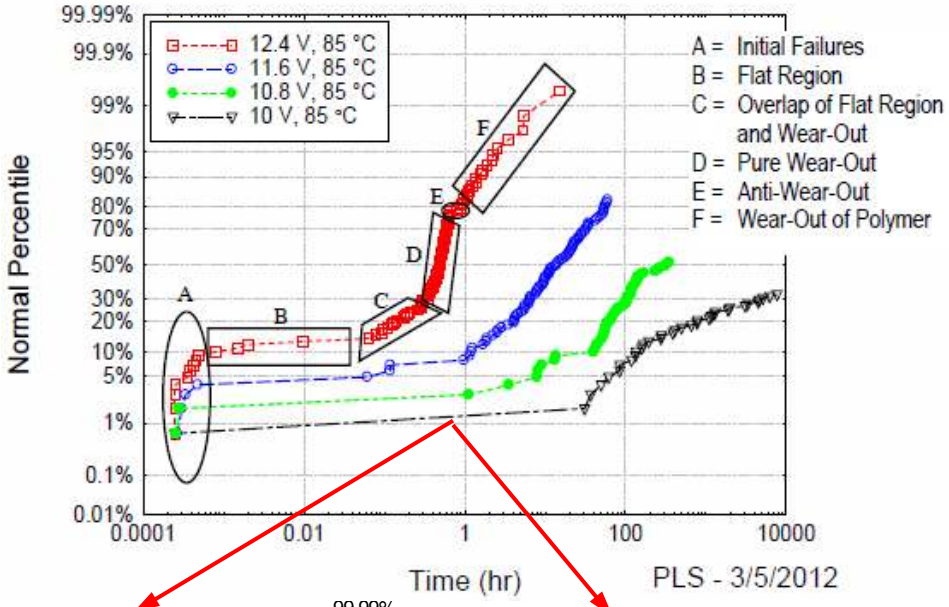
Unexpected Behavior in 4 V Capacitors (B)

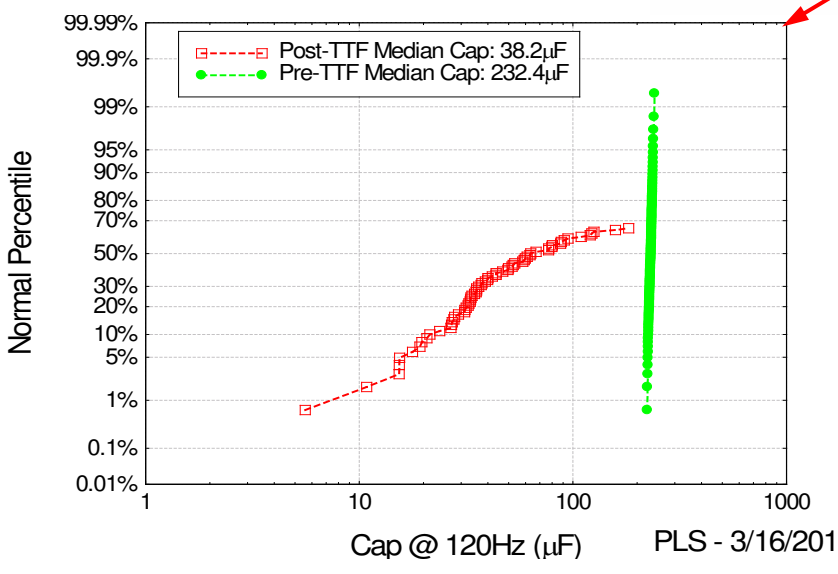
- Two new regions identified:
  - Overlap of Flat Region and Wear-Out
  - Wear-Out of Polymer

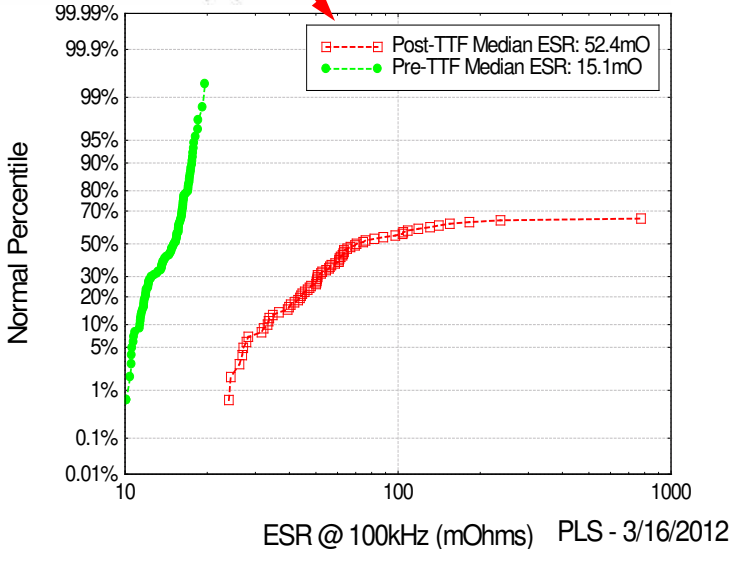


Anti-Wear-Out in 4 V Capacitors (B)

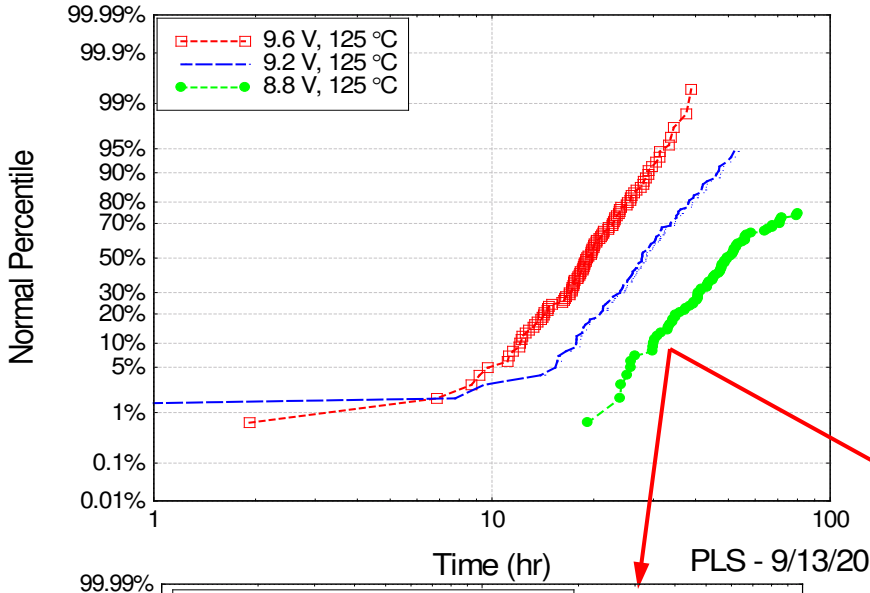
- Capacitance and ESR of remaining 4 V capacitors from Manufacturer B tested at 85°C and 10 V



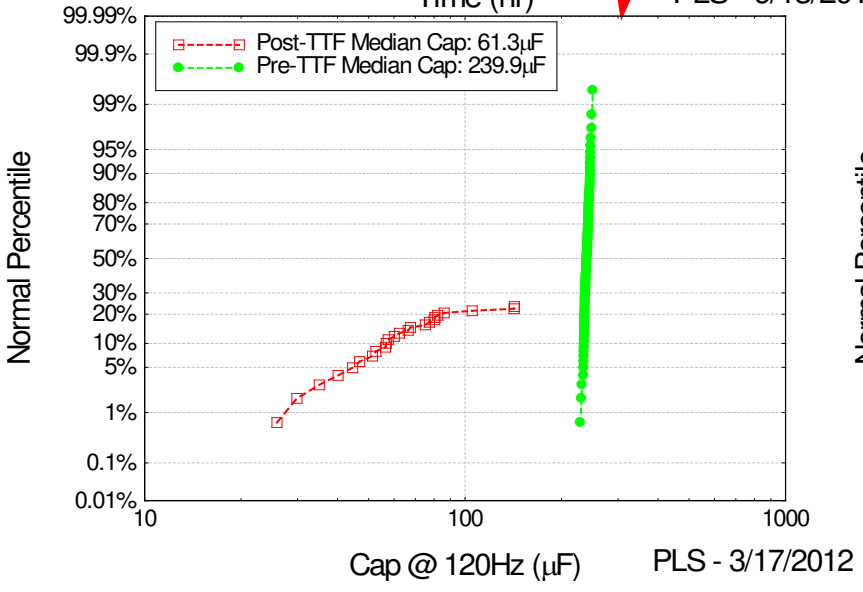


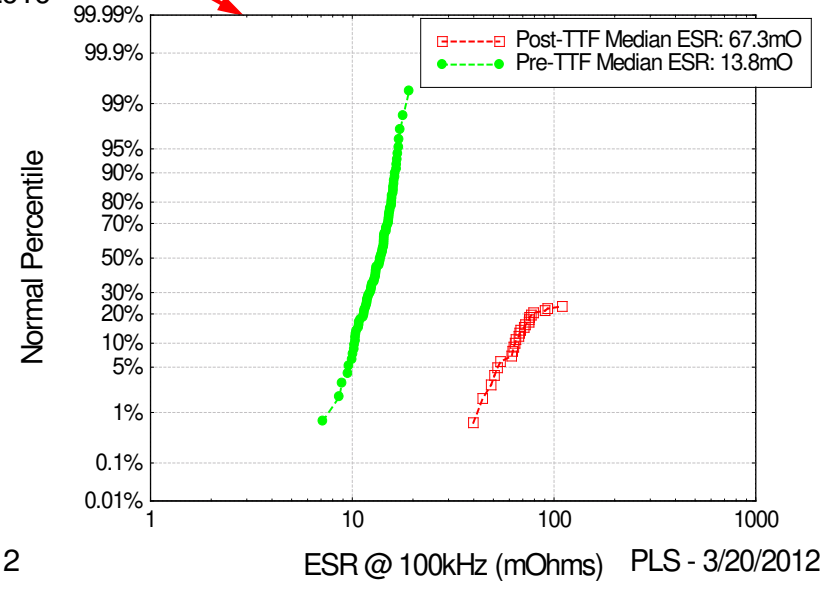


Anti-Wear-Out in 4 V Capacitors (B)



- Capacitance and ESR of remaining 4 V capacitors from Manufacturer B tested at 125°C and 8.8 V





Plans Moving Forward

- Fill the Gap Between 6 V and 25 V Data
  - Test 10 V and 16 V capacitors from both manufacturers
- Extended Less Accelerated Testing
  - Different failure mechanisms become active at the same time skewing the TTF results if the acceleration applied is too harsh
  - Less severe accelerated testing needs to be conducted to produce more reliable and meaningful data
  - This will involve several years of testing since each life test will most likely run a minimum of 3000 hours
- DPA
  - Differences in construction, materials, etc.
- Verify KEMET results of 6 V and 35 V capacitors

Summary and Conclusions

- Overview
- Reviewed data
- Caution must be taken when accelerating test conditions
  - Data not useful to establish an acceleration model
  - Introduction of new failure mechanism skewing results
- Evidence of Anti-Wear-Out
  - De-doping of polymer
  - Decreased capacitance
  - Increased ESR
  - Not dielectric breakdown
  - Needs further investigation
- Further investigation into tantalum polymer capacitor technology
- Promising acceleration model for Manufacturer A
  - Possibility for use in high-reliability space applications with suitable voltage derating