National Aeronautics and Space Administration

Reversed Tantalum Capacitor Problem.

A Failure to Fail,

a Case Study.

Safety and Mission Assurance

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December, 2018

SAFETY and MISSION ASSURANCE DIRECTORATE Code 300

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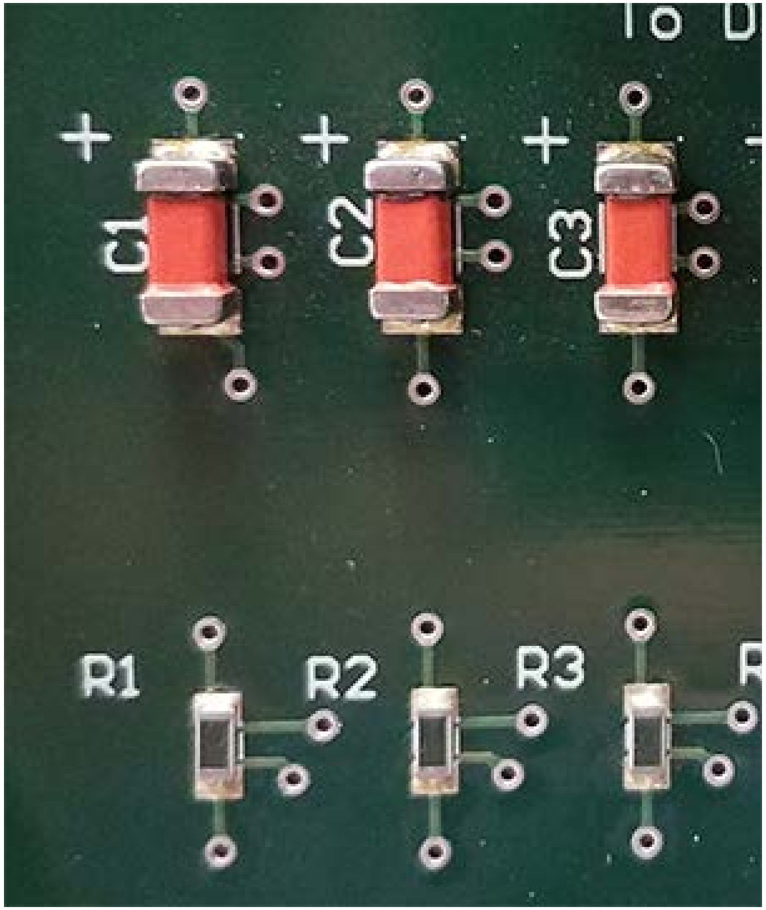
Outline

- Every Electrical Engineer Should Know
- It happens
- Ground testing failures but not on orbit
- Fishing for answers
- Testing taking place
- Experience summary
- Summary



Every Electrical Engineer Should Know

Every Electrical Engineer is taught on day one,

Do not reverse bias Polarized Tantalum Capacitors.

Every Electrical Technician is taught on day one,

Do not reverse bias Polarized Tantalum Capacitors;
they **explode!**

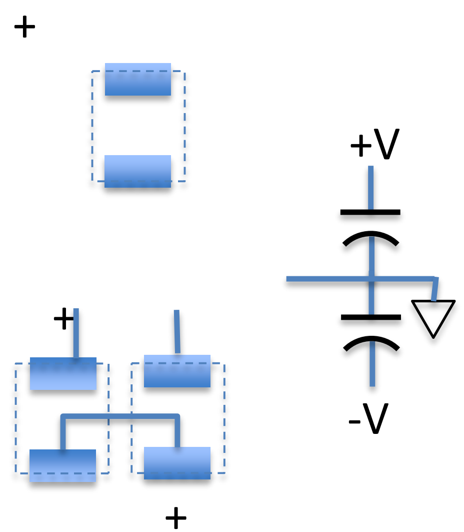
Rule of Thumb for Electrical Engineers

Ta capacitors become leaky when reverse biased. Generally they can tolerate 1.5 Volts in the reversed direction. The parts in question are **25 Volt capacitors**.

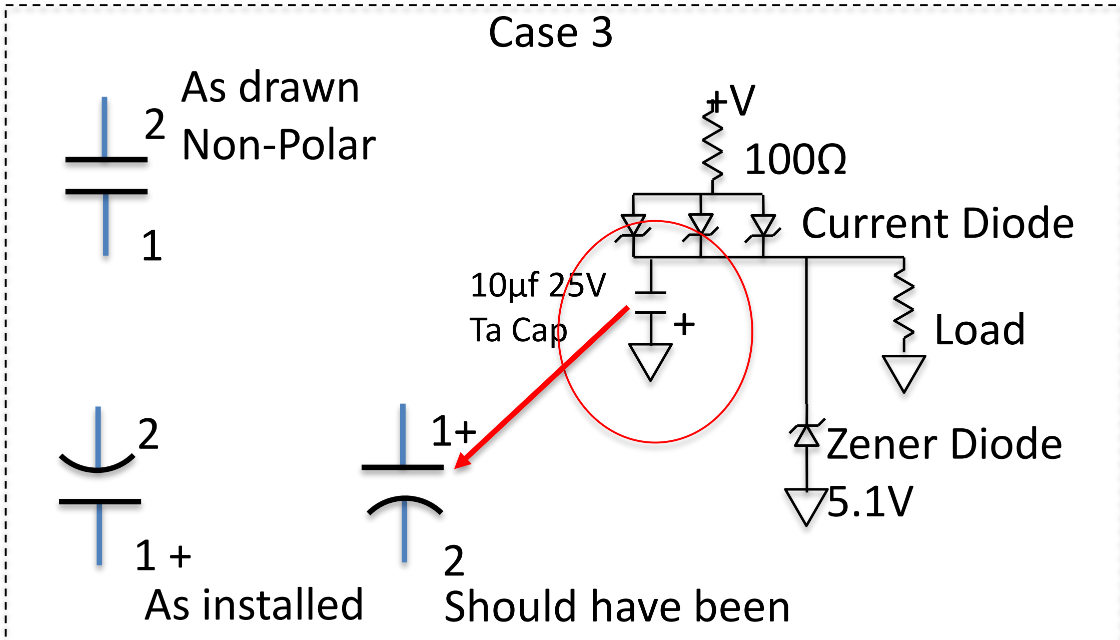
Notice that no environmental conditions are given other than voltage in the broad warnings.

But we still encounter reverse Ta Caps. Why?

1. Assemblers put them on backwards.
2. Assembly drawings are confusing or contradictory.
3. Schematics start with a different kind of capacitor and are later changed by only changing the part number.



Confusing Assembly Instructions



Note. Some conventions allow for 2 parallel plates with polarized caps if marked.

Opening of the ELC Investigation

ELC 1 & 2	Launched on Nov.	16	2009
ELC 4	Launched on Feb.	24	2011
ELC 3	Launched on May	16	2011

First sign of problem on June 23 2011 in Ground Support (test) Equipment

(PR ELC-WOA-002058-002)

ELC #	Hours
1	14016 (flight)
2	14016 (flight)
3	2856 (flight)
4	912 (flight)
GSE	**~ 300 to 400 (ground)**

Opening of the ELC Investigation

A second GSE failure occurs and the reverse polarity problem is discovered. Testing starts to see what should be done on March 28 2013.

ELC #	Hours in Flight before second problem
1	29472 (flight)
2	29472 (flight)
4	18312 (flight)
3	16368 (flight)
Testing	1680 (ground) with 336 at “high temperatures (~25C)”

Note. Ground Testing is 0.1X actual minimum flight time.

Independent testing was performed

- Numerous tests performed at a variety of temperatures in ambient pressure.
- Long duration test performed at room temperature in vacuum
- Conclusion:
  - The capacitors can run at -5 Volts if the temperature of the capacitors remains at or below 25C.
  - A new add-on box would be required on payloads to bypass the ”problematic” circuit.

Note. There is no telemetry giving insight into the actual leakage current.

Impact to Instruments on ELC.

1. An add-on box was expensive and had to connect to both the affected circuits and match the instrument's footprint.

2. Temperatures on existing payloads without the added box had to be controlled to keep the circuit cold. This kept some instruments running at less than 35% duty cycle.

Questions Remained for ELC.

1. Did ELC get lucky with the capacitors that were installed? Were they all better than what should be expected?
2. Why did the capacitors on the ground seem to fail so quickly at 25C?

Test Run

In the end a total of 6 different test sets were run and all on shoestring budgets.

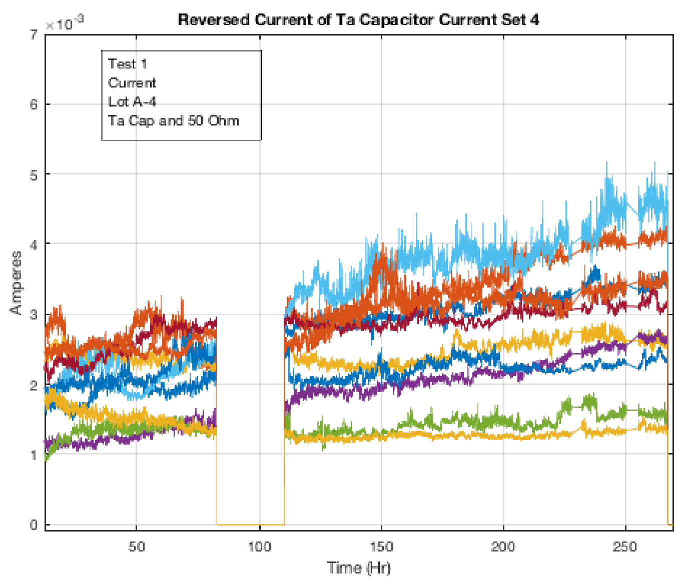
At the outset of each test it was not clear where the next test would go, or if there would even be a next test.

Test 1. Did ELC get lucky on which capacitors were used?
Test 2. What role did voltage play?
Test 3A. Was there something about the complete circuit that played a role in the circuits lasting?
Test 3B. Is it temperature, or is it humidity?
Test 4. How did vacuum operation affect performance?
Test 5. With low moisture (humidity) how does temperature fit in?
Test 6. How does time in vacuum at the beginning of the test (prior to power-up) affect the results?

Did ELC Get Lucky?

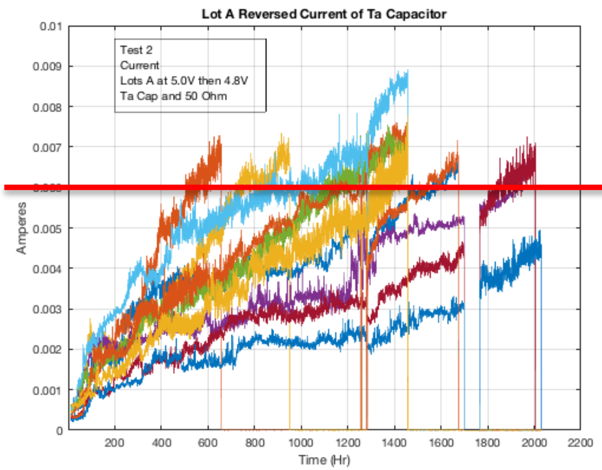
Rumor had it that even within a single lot of capacitors there could be strong and weak capacitors that would divide out. Had we hit a good set of capacitors?

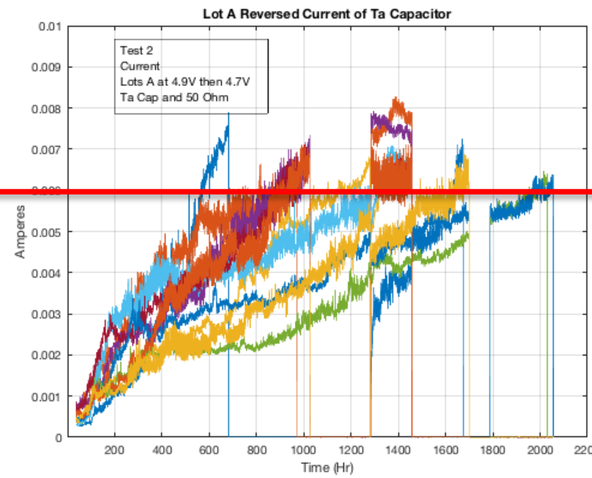
Test 1 involved a large number of capacitors (40) from the ELC lot that were placed on a PCB with a resistor to look at the current. Data were taken every 30 seconds, and the voltage was set to what was expected on ELC (5 Volts).



<u>**No ELC did not get lucky.**</u> Caps at 25C are getting leaky after 250 Hr. Was 5 Volts too high (i.e., are we not properly representing the circuit behavior)?

What role did voltage play?
Test 2

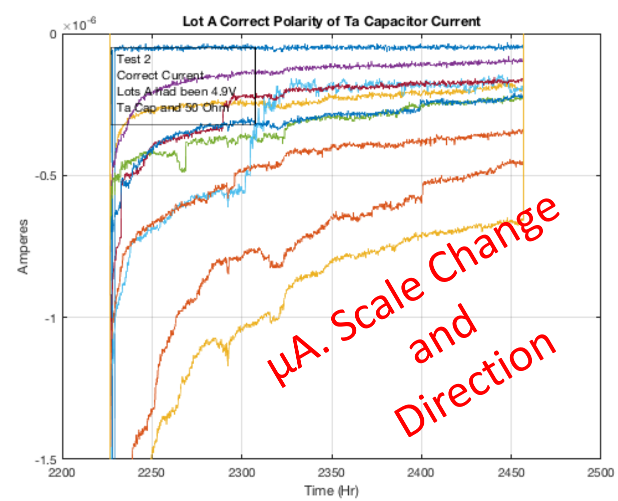




6mA

Starting to notice that the current is progressing unevenly

The parts appear fine if we return to forward bias!



2000 Hours later

From 5.0 V down to 4.6 V the current keeps rising very quickly. This does not explain what we are seeing in orbit, and the parts are at 25C.

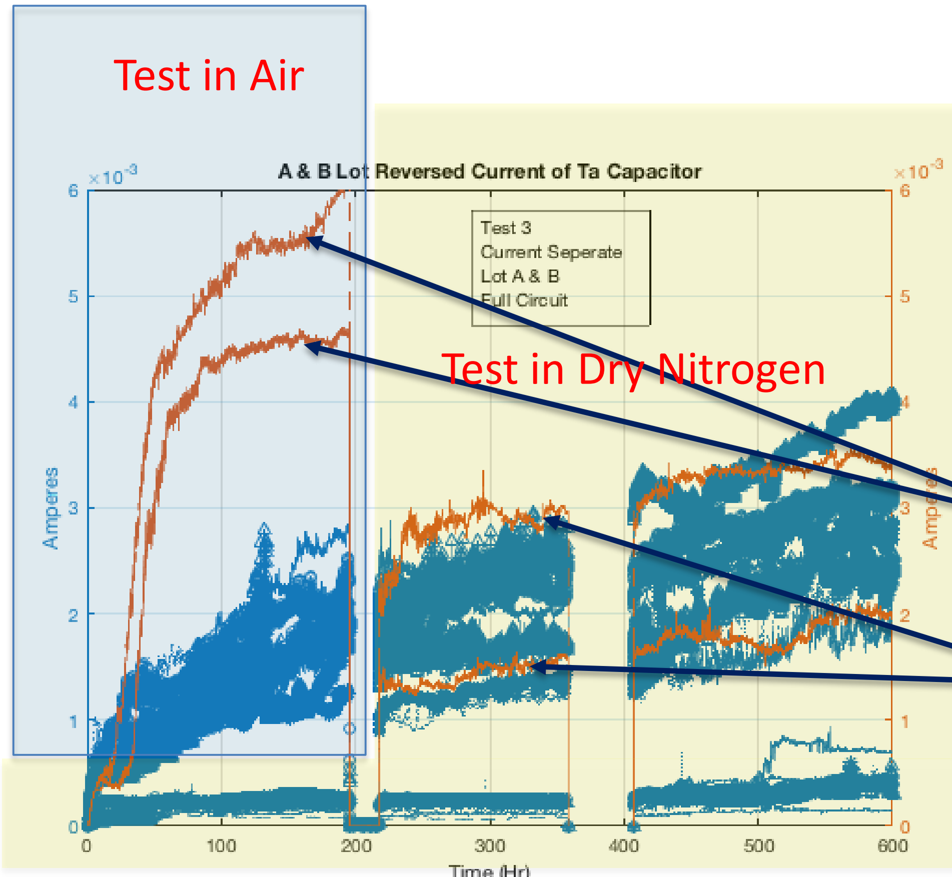
400 hours to "failure", not years.

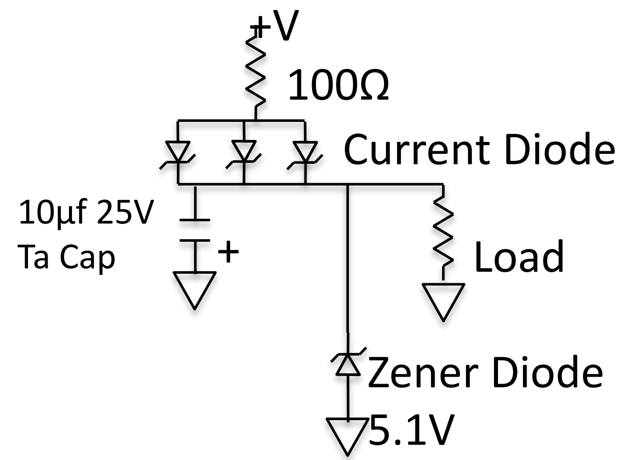
What are we missing?

1. Did we need the complete circuit to tame the leakage?
2. Is the **temperature** really the driving factor? If so, why does 25C take us to failure on the ground but not on-orbit?
3. Is moisture an important factor?

Was it the complete circuit?

Still at 25C

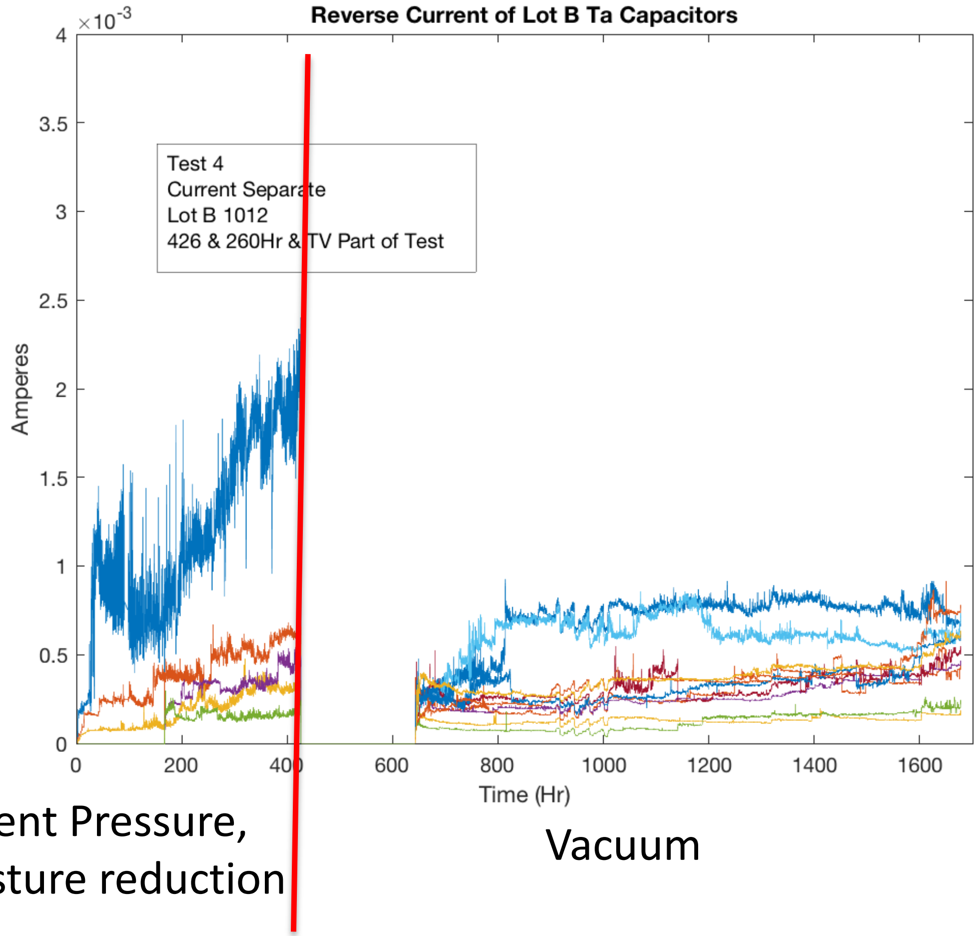




Even parts that were failing in atmosphere recover in Dry N.

No it's the **HUMIDITY!**

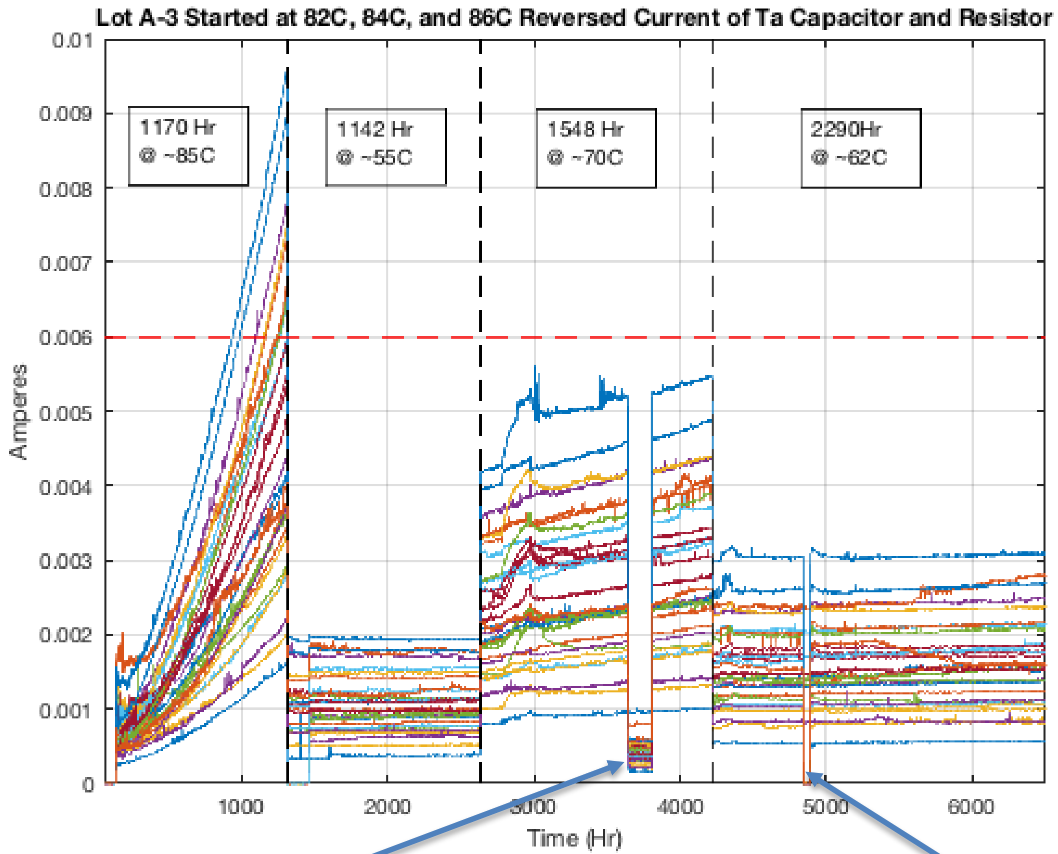
Test 4. How did vacuum affect performance?



Ambient Pressure,
no moisture reduction

Vacuum

Test 5. With low moisture (humidity) how does temperature fit in?



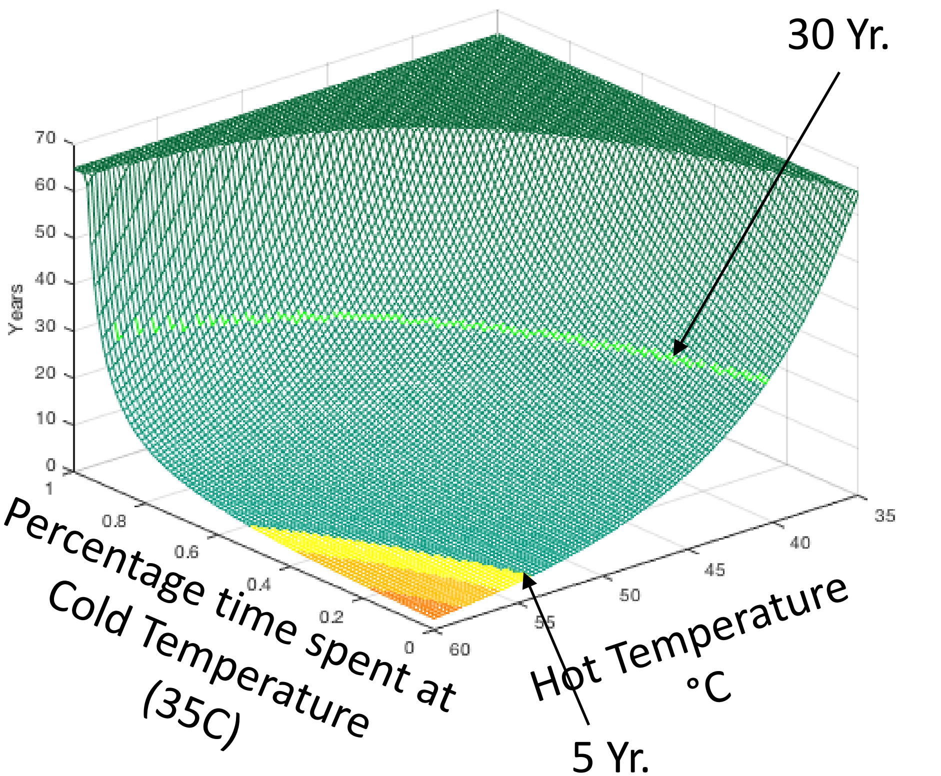
Loss of thermal control

Loss of power

Test 5. How long can we stay at higher temperatures?

How Long 35C to 60C?

(Arrhenius Equation)



Temperature °C (Percentage Time Cold; values in Years)

	60°C	55°C	50°C	45°C	40°C	35°C
0%	2.5	3.1	4.1	6.2	12.4	64.7
10%	3.4	4.2	5.6	8.4	16.9	64.7
20%	4.6	5.7	7.6	11.5	22.9	64.7
30%	6.3	7.8	10.5	15.7	31.4	64.7
40%	8.6	10.8	14.4	21.6	43.1	64.7
50%	11.9	14.9	19.9	29.8	59.6	64.7
60%	16.5	20.7	27.6	41.3	64.7	64.7
70%	23.1	28.8	38.5	57.7	64.7	64.7
80%	32.4	40.5	53.9	64.7	64.7	64.7
90%	45.6	57.1	64.7	64.7	64.7	64.7
100%	64.7	64.7	64.7	64.7	64.7	64.7

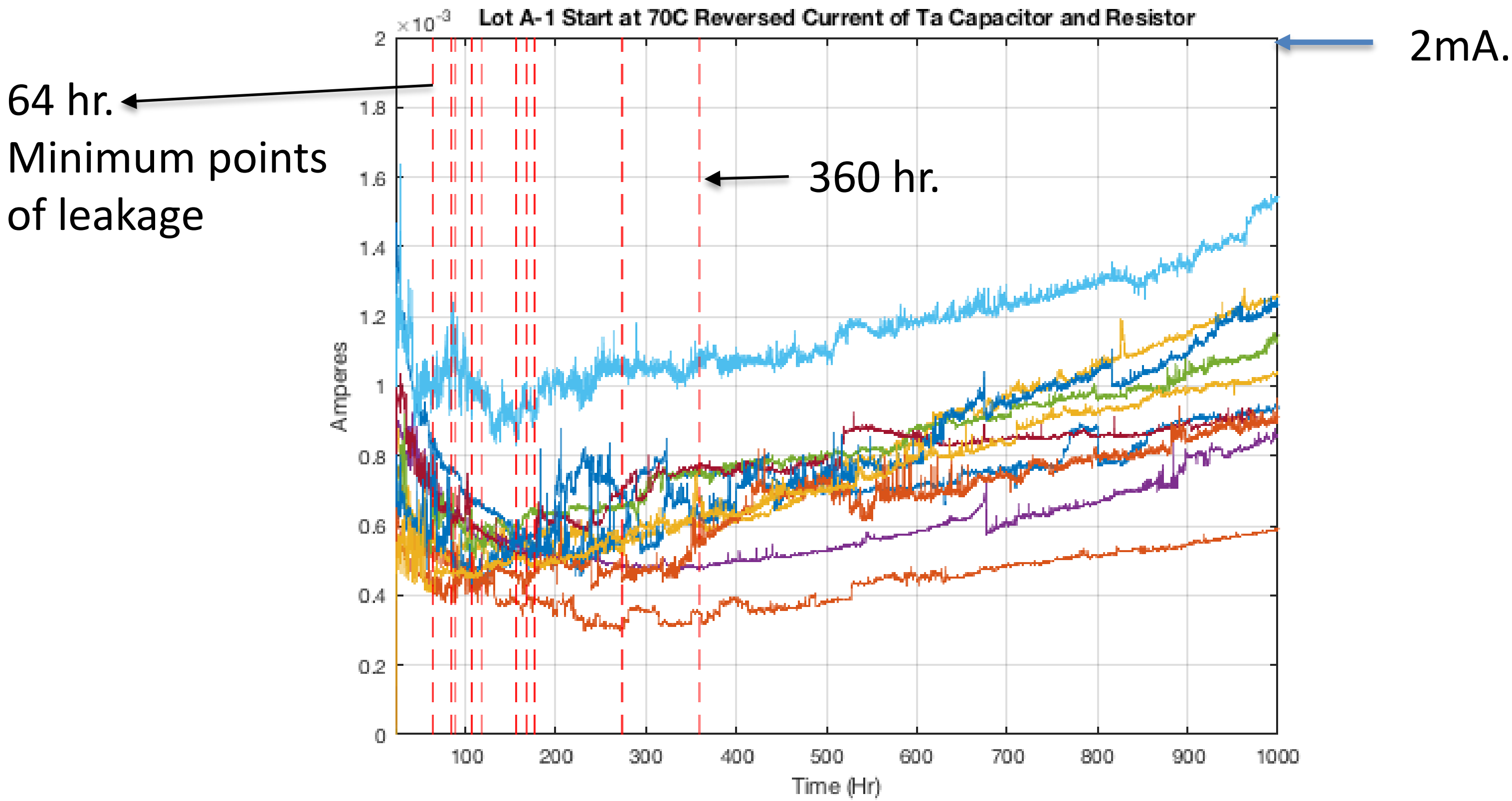
Test 6. How does time in vacuum at the beginning of the test affect the results?

ELC had a minimum of 48 hours between launch and installation / power-up. Did this affect how the capacitors behaved?

Parts were placed in a vacuum for 24 hr. before they were turned on.
(Test as you fly.)

Parts were exposed to 70C.

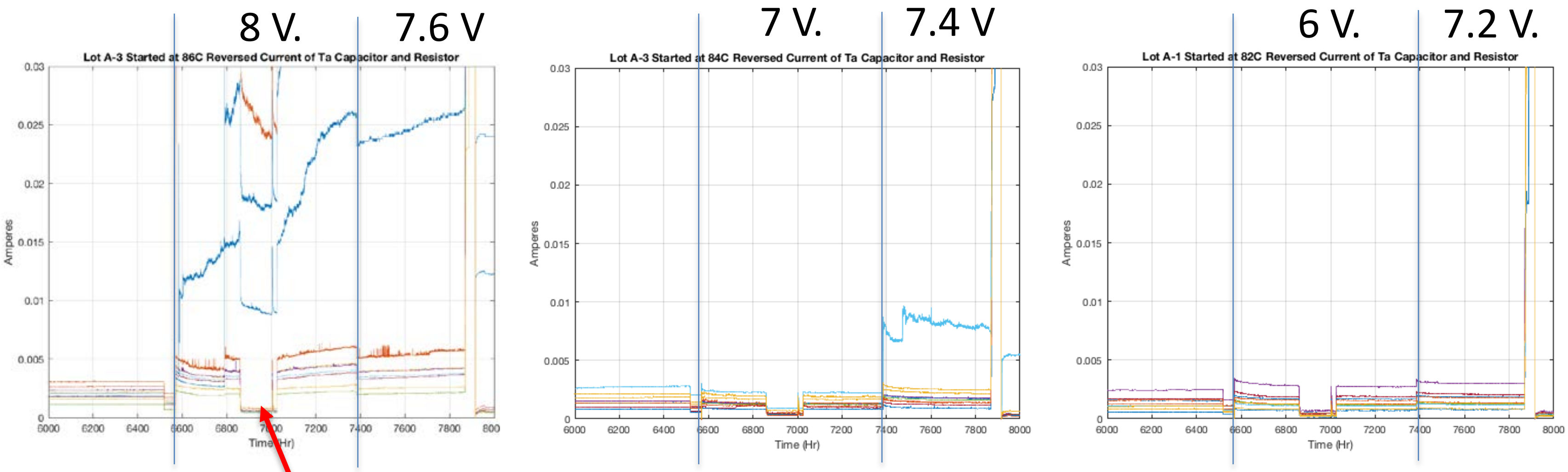
Test 6. How does time in vacuum at the beginning of the test affect the results?



Even at 70C the parts improved for up to 360 hours before starting to start leaking again.

So what did it take to cause the capacitors to fail?

1. At 55C the first set of capacitors were exposed to 10 V. and current went above the power sources current limit at turn on, and the parts got hot.
2. At 55C Three voltages, 6, 7, and 8 Volts.
3. At 55C Three new voltages 7.2, 7.4, and, 7.8 Volts.
4. Then to finish them off 85C at voltage.



Drop to 25C to see if they would repair themselves

Total Hours As of Memorial Day 2018

ELC #	Hours in Flight
1	74784
2	74784
4	56400*
3	61680

*Out of caution ELC #4' capacitors were replaced in Aug. 2017. All were functioning at the time of replacement.

Some of our test capacitors saw about 10000 hours.

Conclusions

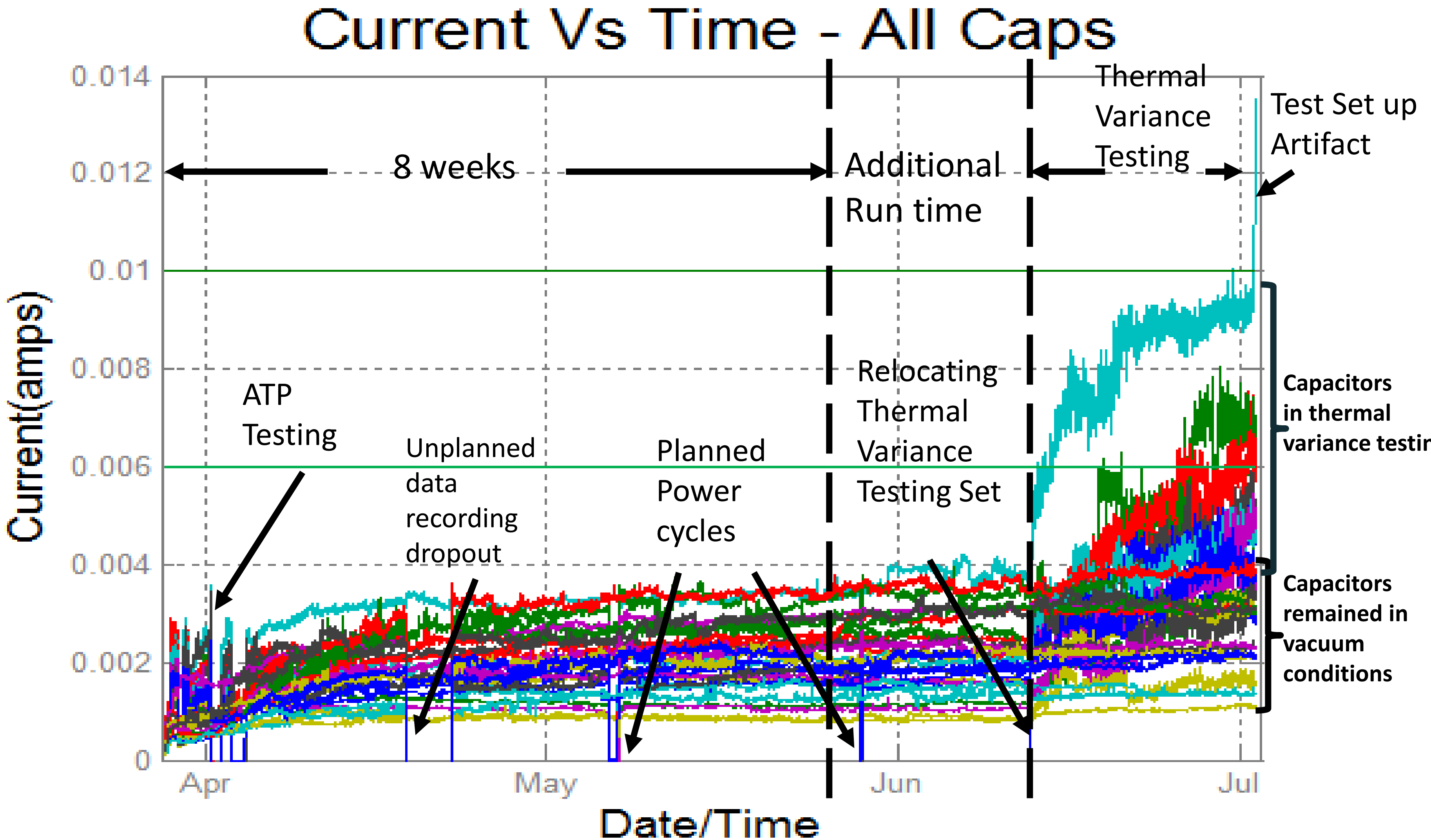
1. If water is fully removed the tantalum capacitor survived in vacuum for much longer periods of time, and at higher temperatures than were expected.
2. Capacitors would recover to lower currents when temperatures were lowered.
3. When dry, the capacitors could be used at temperatures at least as high as 55C without affecting the life of the capacitors.
4. Mission life could well be limited to something other than the capacitors' lives.
5. The capacitors would return to nominal leakage currents if the polarity were returned to forward bias except after stressing the caps with higher reverse voltages.
6. For ELC the overall risk to NASA of changing capacitors or imposing restrictions was higher than flying as is.

Back Up Slides.

Old Slide from First Test

Summary of Actions-Capacitor Characterization Test Results

- **Capacitor Characterization Data – All 30 Capacitors**



Old Slide from First Test

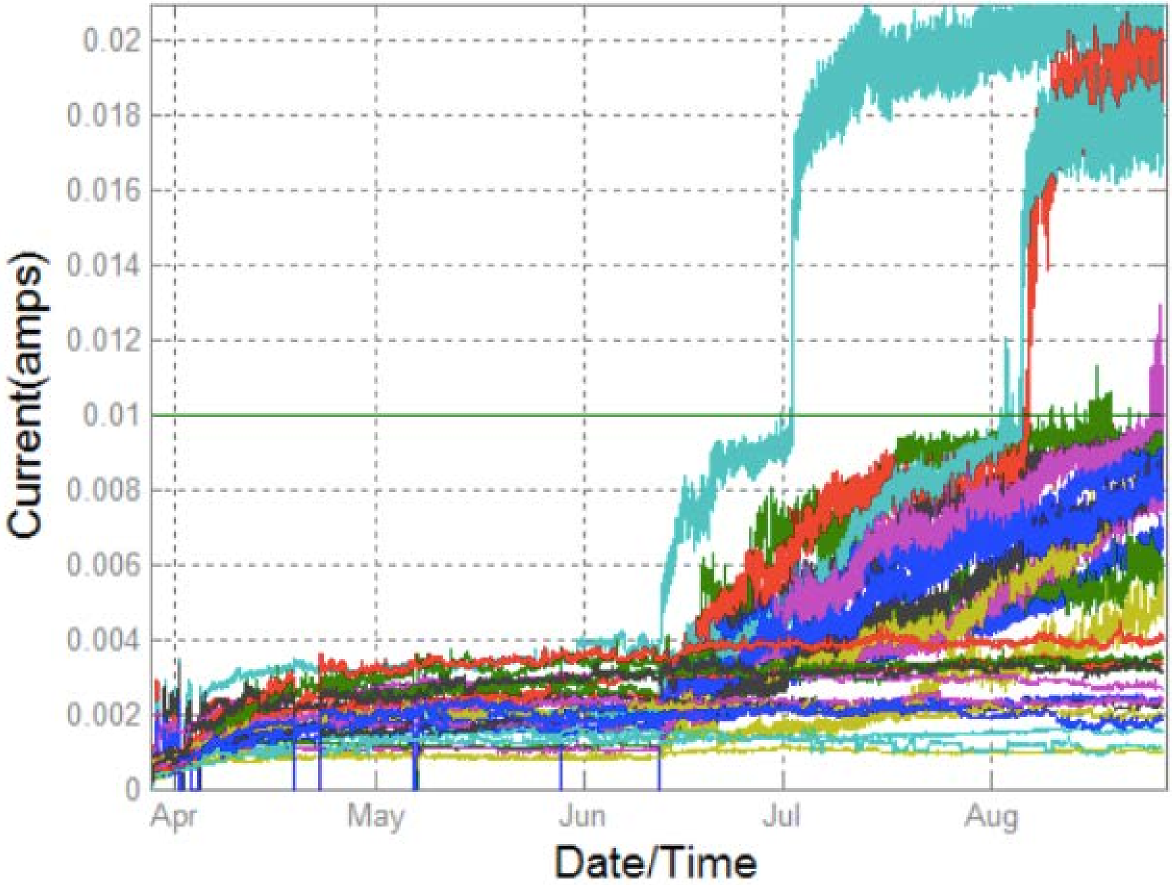
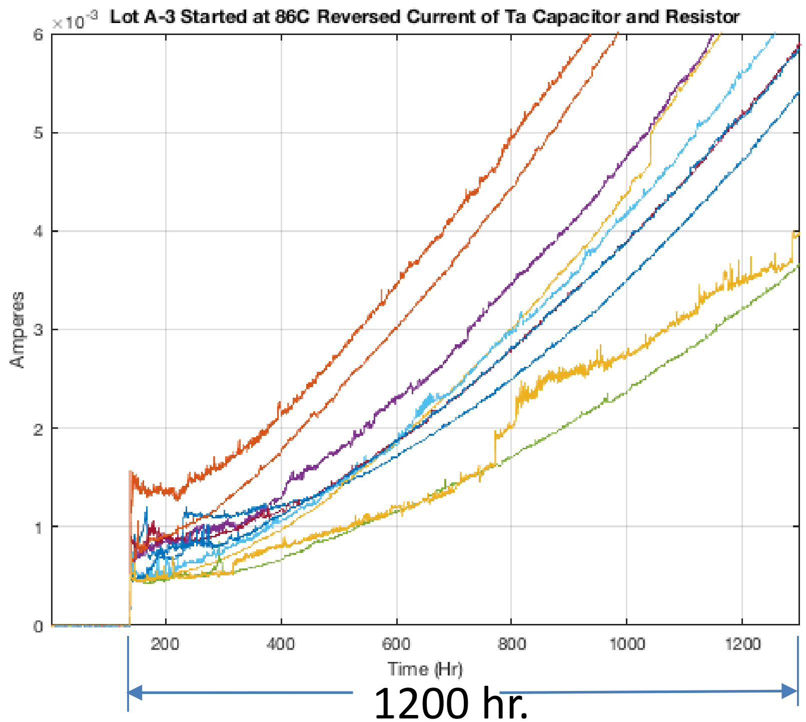


Figure 1. Leakage currents of all capacitors tested in vacuum until mid-June. Those that start to rise after mid-June were taken from the chamber and cycled between 25 deg C and 35 deg C in ambient pressure. The 0.006 Amp level was determined to represent the onset of circuit problems in the ELC avionics.

Assuming that the Activation Energy is from a Single Source (Arrhenius Equation)



@86°C $k = Ae^{-E/(RT)}$

$= 8e\text{-}14^{(13369/(273+86))}$

$K_{86C} \approx 1193$ hr.