DfR Solutions

reliability designed, reliability delivered

A New Method for Testing Electrolytic Capacitors to Compare Life Expectancy

2013 IMAPS Device Packaging Conference

March 11-13, 2014

Stephani Gulbrandsen[1], Ken Cartmill[2], Joelle Arnold[1], Nicholas Kirsch[1], Greg Caswell[1]

[1] DfR Solutions, LLC – Beltsville, MD USA
301-474-0607
[2]LED Roadway Lighting – Halifax, NS Canada
877-533-5755

Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out
- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
  - Traditional vs. Accelerated
- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D
- Conclusions

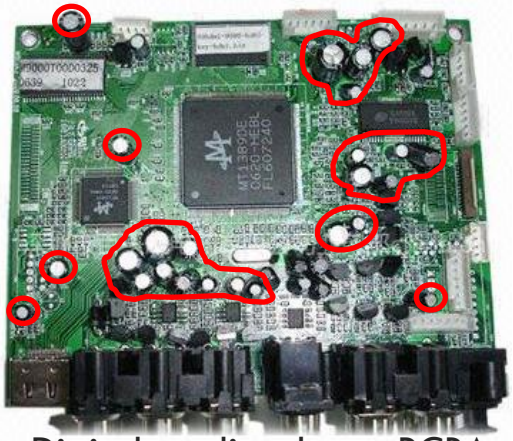
Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out
- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
  - Traditional vs. Accelerated
- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D
- Conclusions

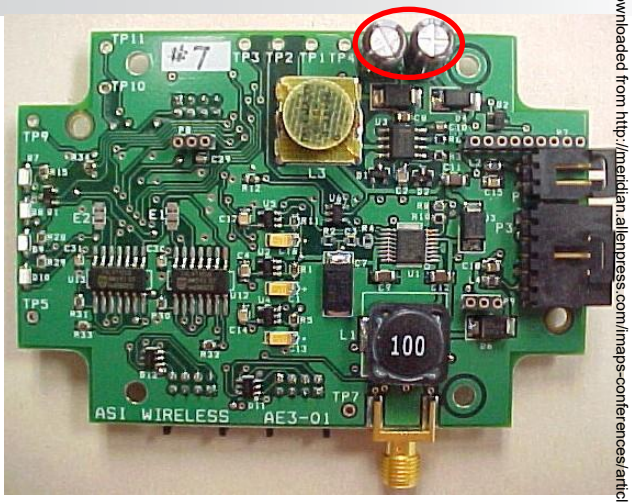
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Aluminum Electrolytic Capacitors – Introduction

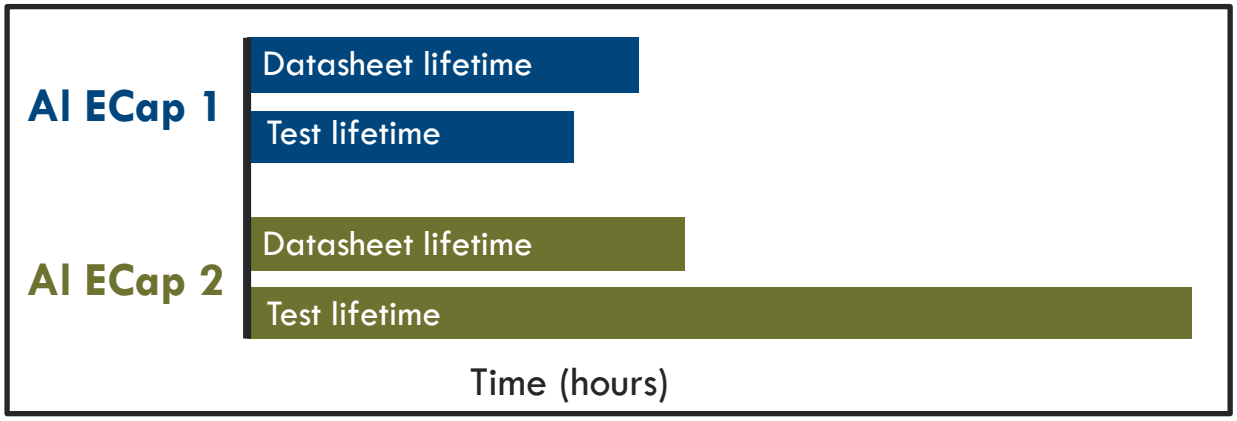
Industrial customer communication interface PCBA from Monico Inc.



Digital media player PCBA from Shenzhen Sinetech Electronic Co Ltd.



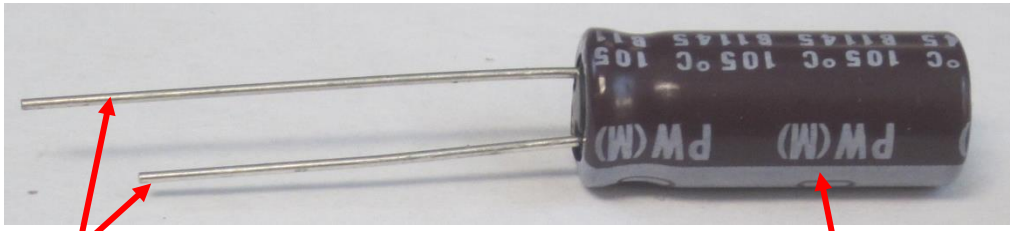
Automotive asset tracking PCBA from Theta Engineering Inc.



Traditional life testing of Al ECaps indicates test lifetime can be slightly less than or 2-3x greater than datasheet lifetime.

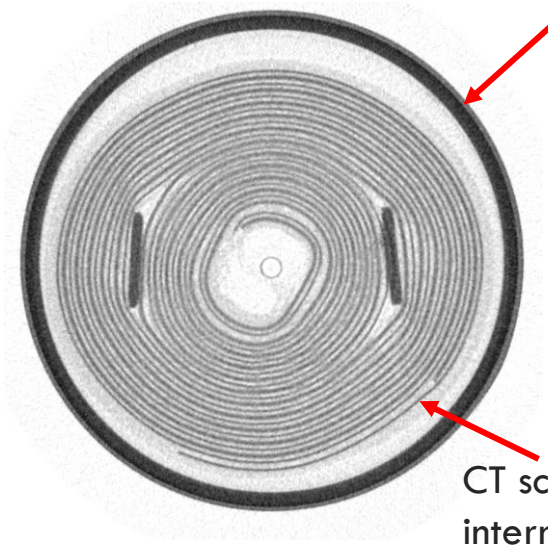
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Aluminum Electrolytic Capacitors – Construction

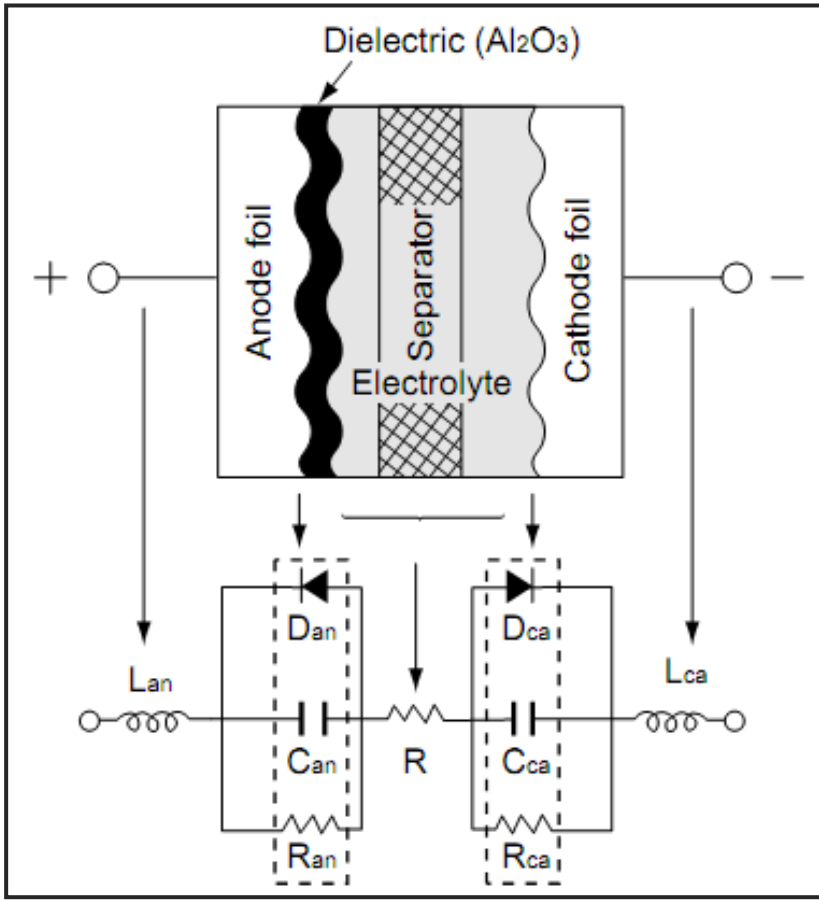


Different lead lengths distinguish the anode (long) and the cathode (short) leads.

The body consists of an Al can encased with a plastic sleeve.



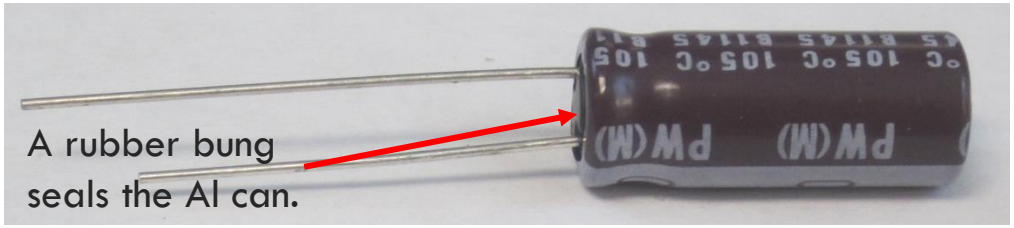
CT scan showing the internal windings.

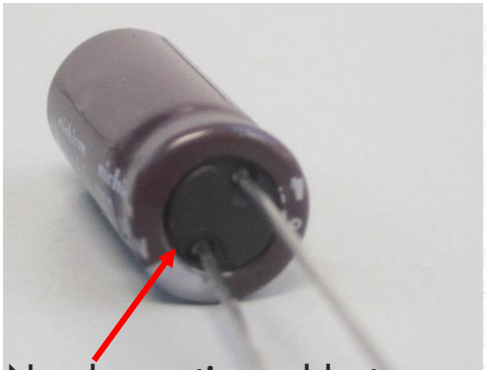


Internal construction of an Al ECap with equivalent circuit from Nippon Chemi-Con.

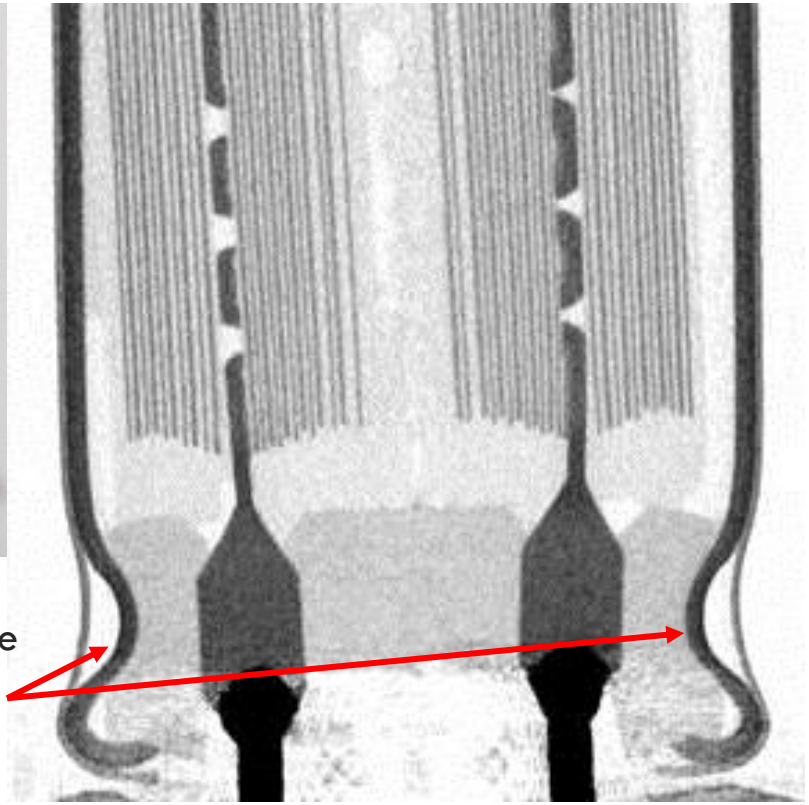
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Aluminum Electrolytic Capacitors – Construction

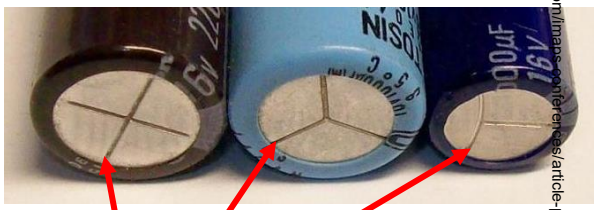




Non-hermetic seal between bung and can allows for evaporation of electrolyte during operation.



CT scan showing the crimped seal between the can and the bung.



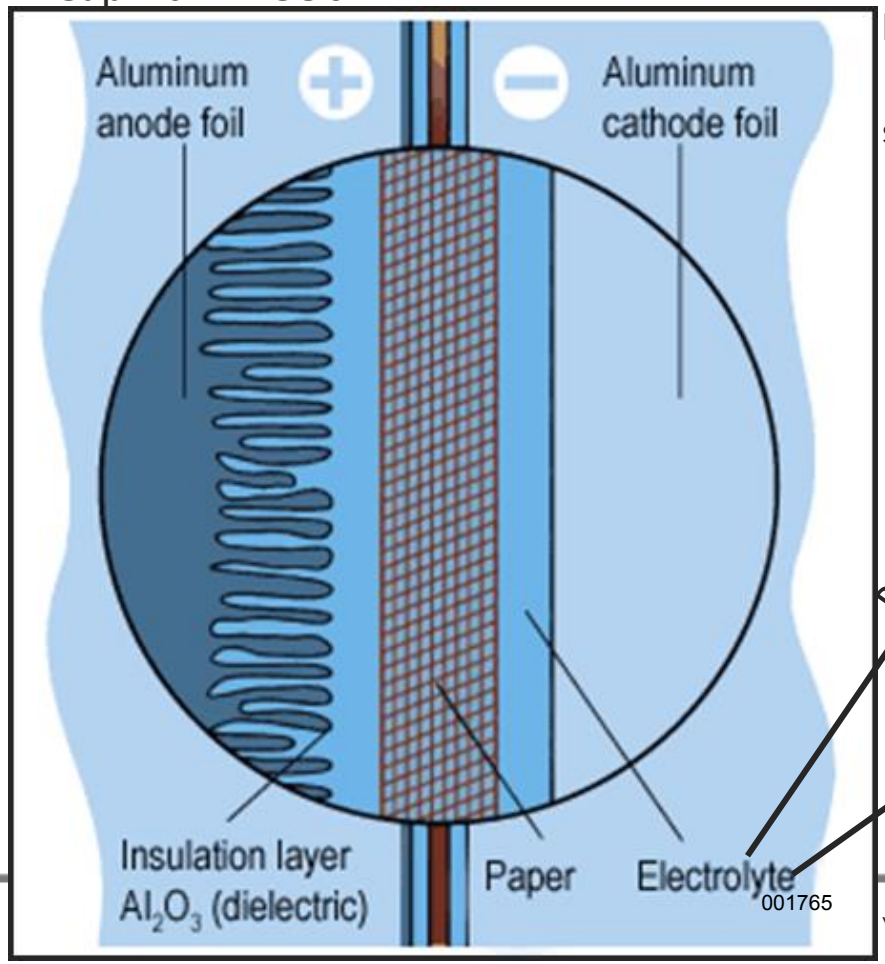
Smaller capacitors have etched vents at can top. These are designed so that in the event of a failure, leaking electrolyte is directed away from the PCB.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Aluminum Electrolytic Capacitors – Failure Criteria

Capacitance Change	Within +/- 20% of initial value
Dissipation Factor	Not more than 200% of the specified value
Leakage Current	Initial specific value or less

Detailed internal construction of an Al ECap from EPCOS.



Failure criteria defined in manufacturer datasheets. Dissipation factor is proportional to equivalent series resistance (ESR), so >200% increase in ESR is classified as failed.

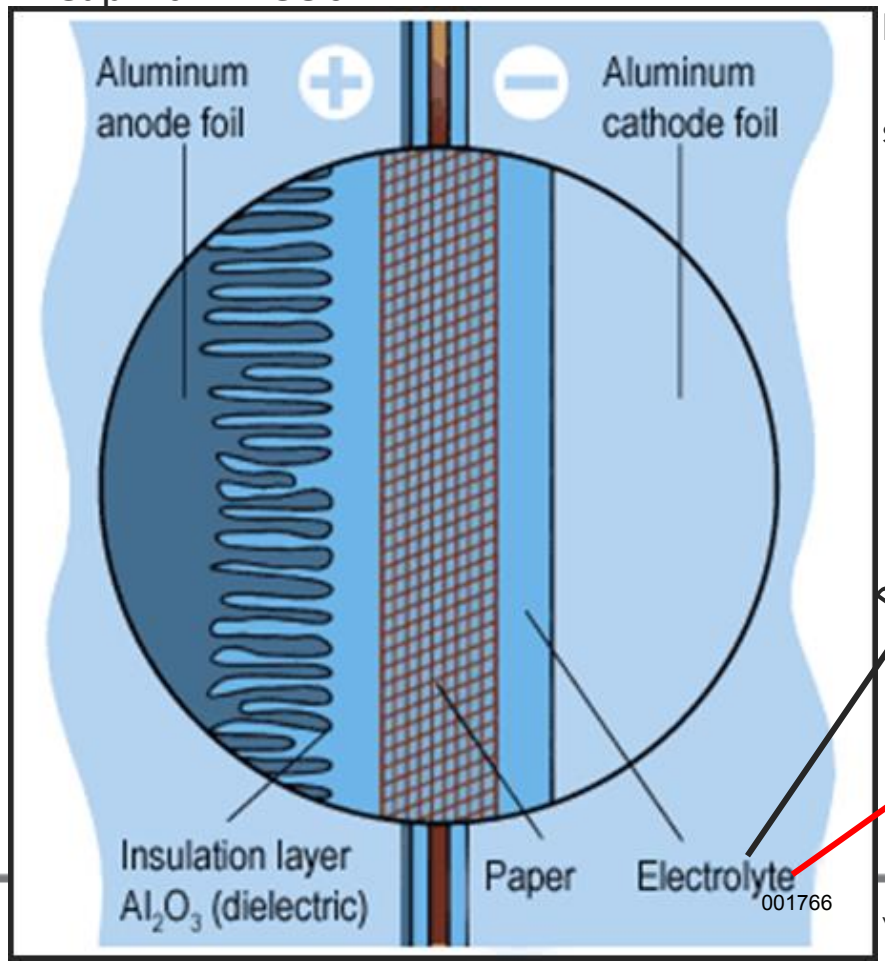
Bad chemistry → Increase in leakage current

Evaporation → Increase in dissipation factor (ESR); Decrease in capacitance

Aluminum Electrolytic Capacitors – Failure Criteria

Capacitance Change	Within +/- 20% of initial value
Dissipation Factor	Not more than 200% of the specified value
Leakage Current	Initial specific value or less

Detailed internal construction of an Al ECap from EPCOS.

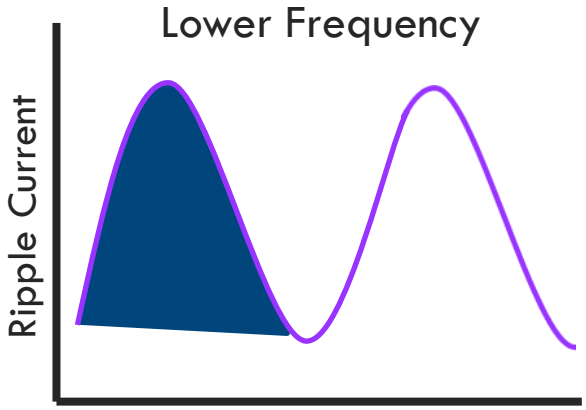


Failure criteria defined in manufacturer datasheets. Dissipation factor is proportional to equivalent series resistance (ESR), so >200% increase in ESR is classified as failed.

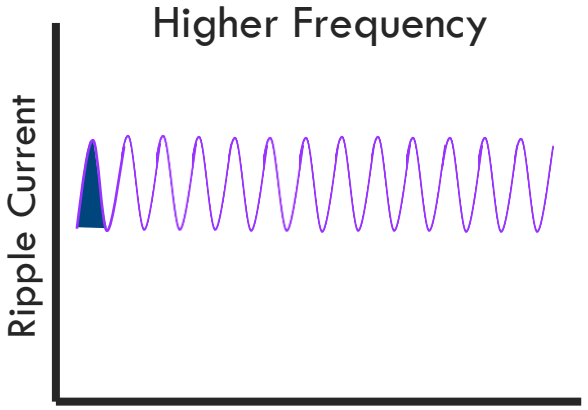
Bad chemistry → Increase in leakage current

Evaporation → Increase in dissipation factor (ESR); Decrease in capacitance

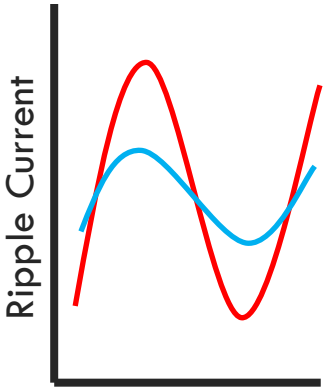
Aluminum Electrolytic Capacitors – Ripple Current

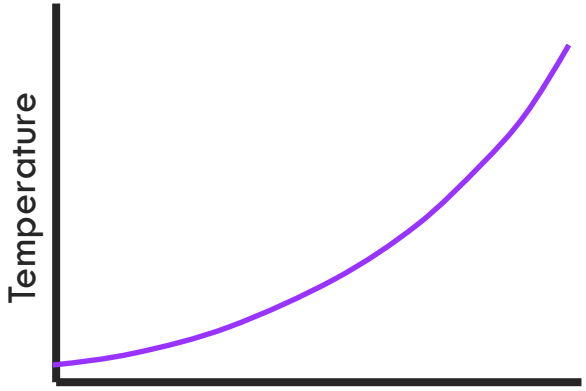


Lower frequencies allow the capacitor to fully charge and discharge.



Higher frequencies do not allow the capacitor to fully charge and discharge.



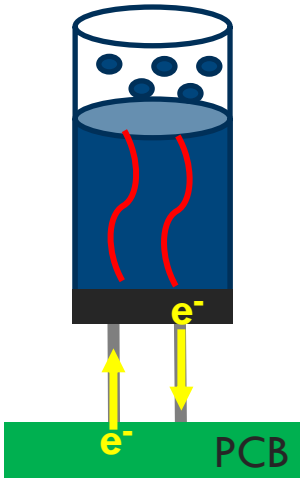


Larger amplitude and larger applied ripple currents induce greater internal temperature rise.

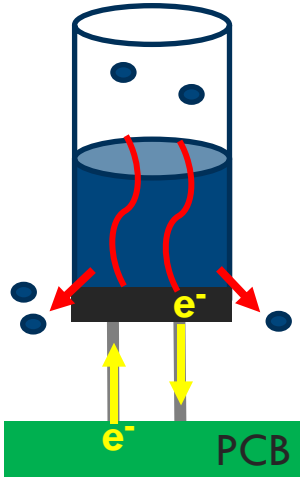
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Aluminum Electrolytic Capacitors – Wear-Out

Apply ripple and bias



Heating of the capacitor from applied ripple current causes evaporation of the electrolyte.



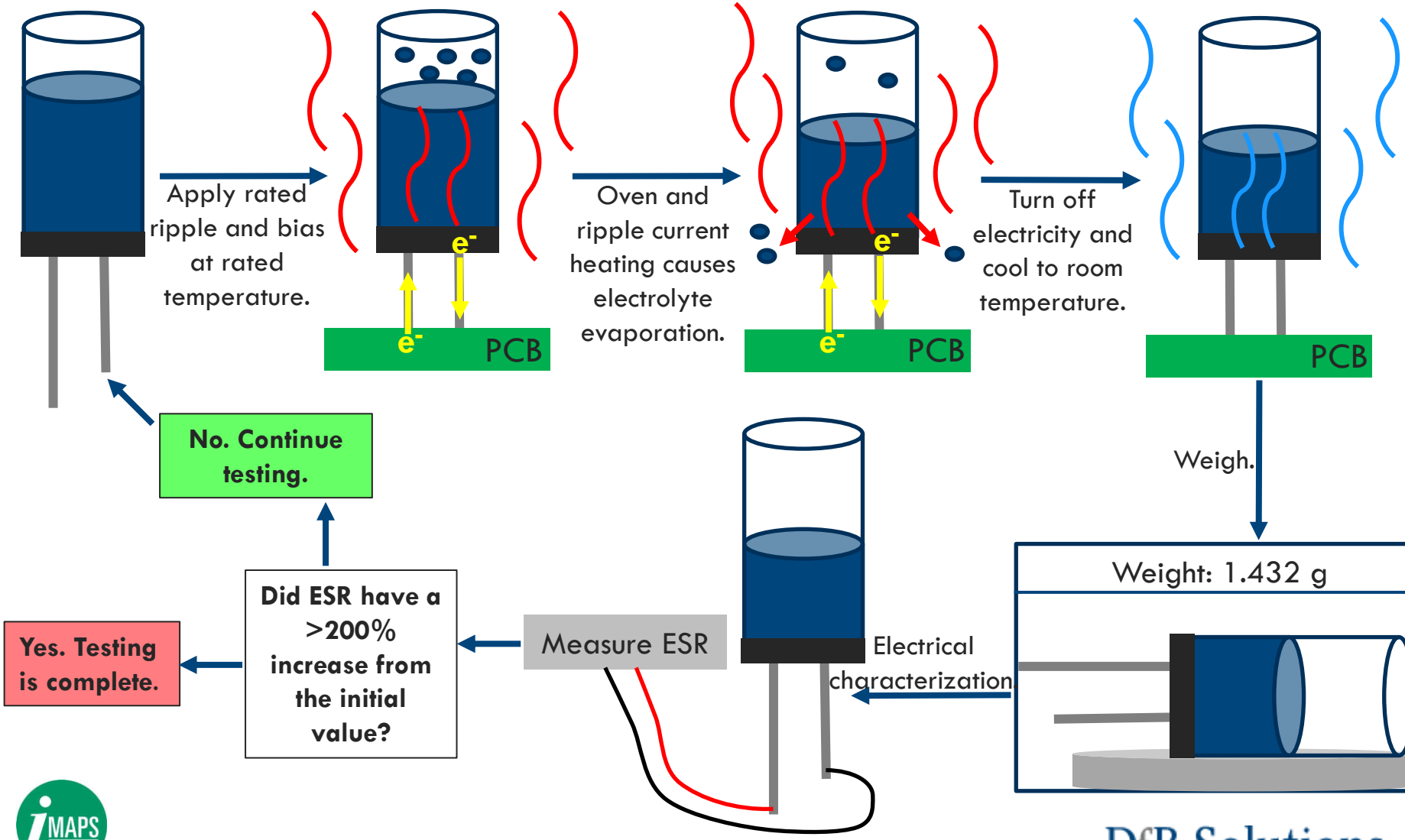
Internal pressure increase from electrolyte evaporation facilitates electrolyte egress between the rubber bung and Al case.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

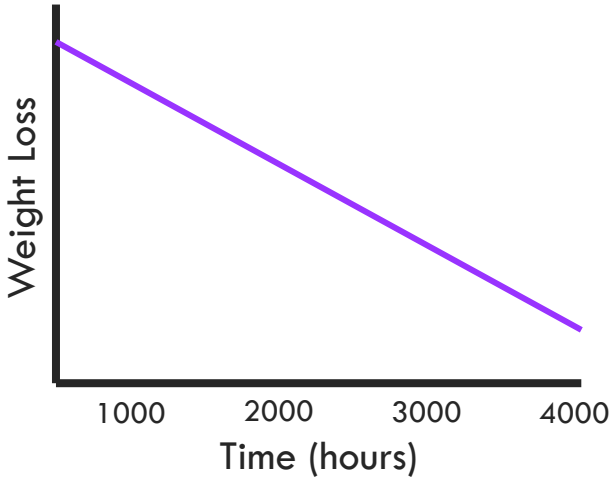
Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out
- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
  - Traditional vs. Accelerated
- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D
- Conclusions

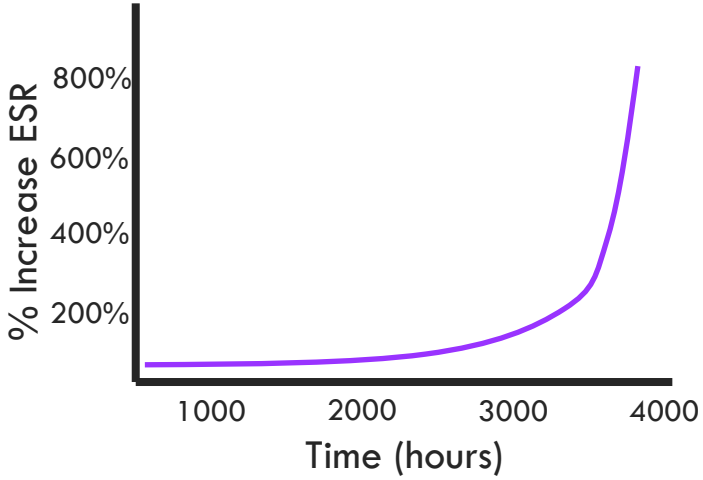
Life Test – Traditional (& Accelerated: Rate of Weight Loss)



Life Test – Trends in Traditional Data



Linear throughout entire test lifetime of an Al ECap population.

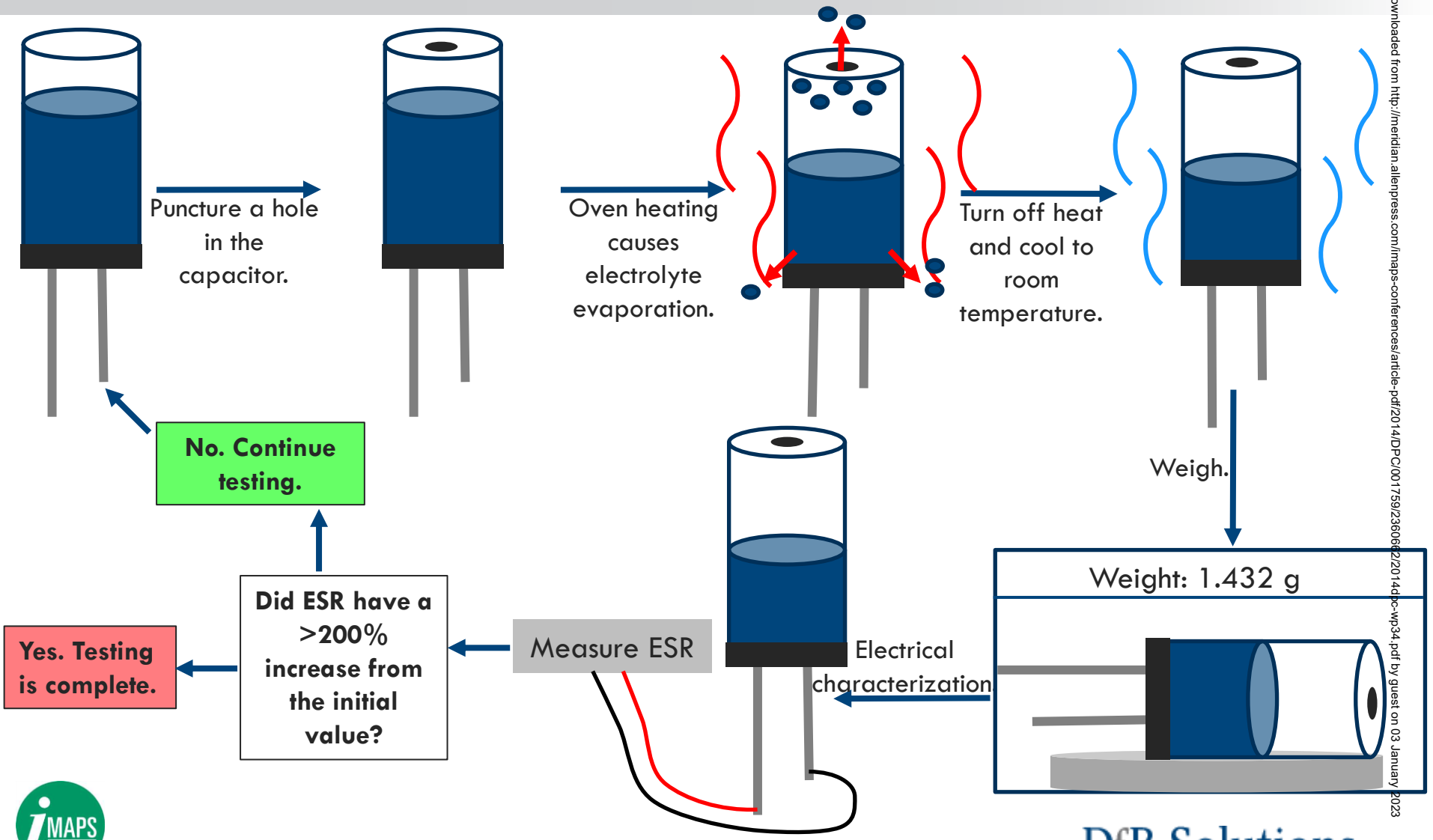


Exponential behavior that is relatively constant until approach time to failure.

Variable	Impact on Rate of Weight Loss
↑ Ambient temperature	↑
↑ Applied ripple current	↑
↑ Heat dissipation	↓
↑ Crimp between bung and can	↑

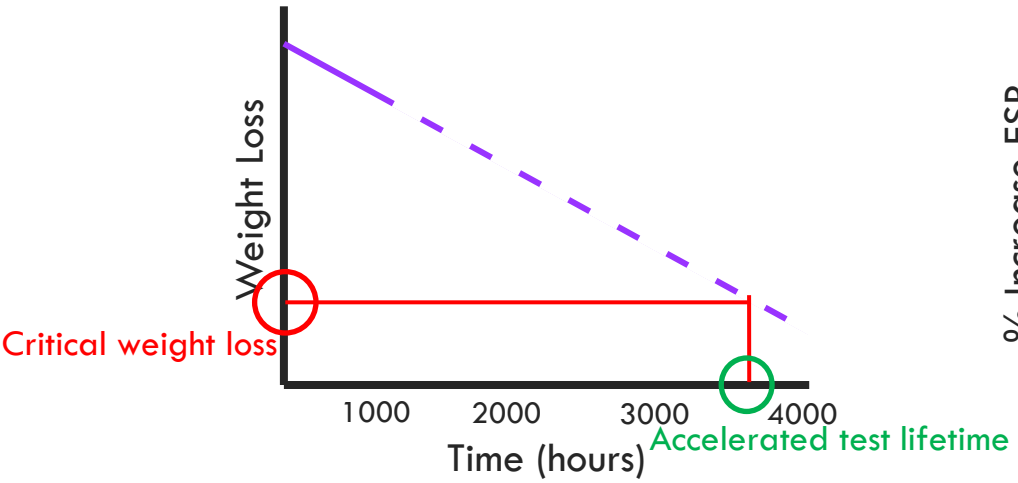
Variable	Impact on Critical Weight Loss
↑ Electrolyte stability	↑
↑ Initial ESR measurement	↓

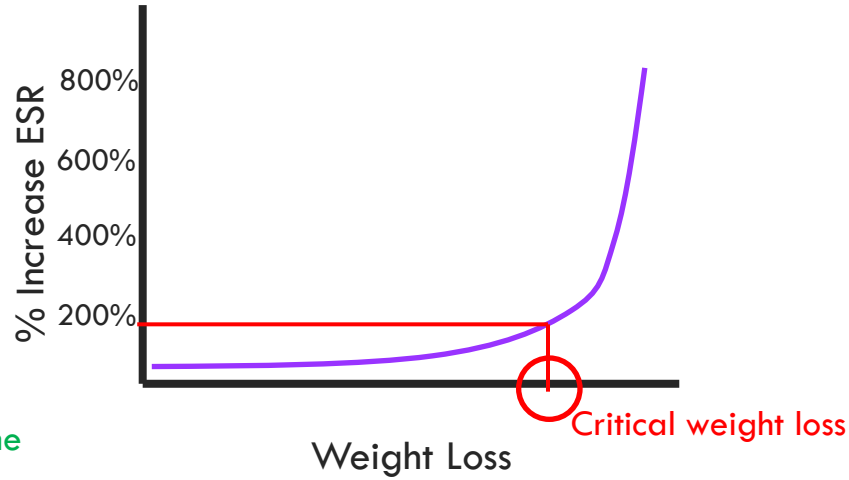
Life Test– Accelerated: Critical Weight Loss



9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Life Test– Accelerated Calculations

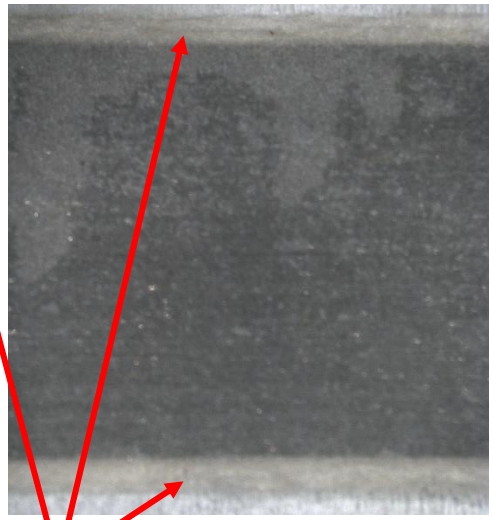




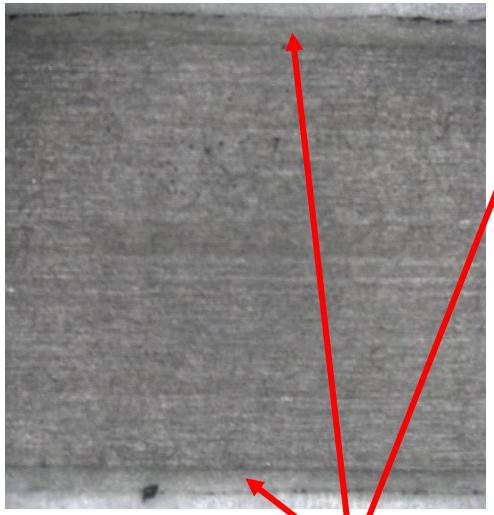
1. Critical weight loss at 200% increase in ESR is calculated using the ESR-Weight Loss curve
2. Rate of weight loss is extrapolated to the critical weight loss and the corresponding time is recorded as the accelerated test lifetime

Life Test – Accelerated Wear-Out Failure Mode

Accelerated test



Dried out, off white paper indicative of electrolyte evaporation.

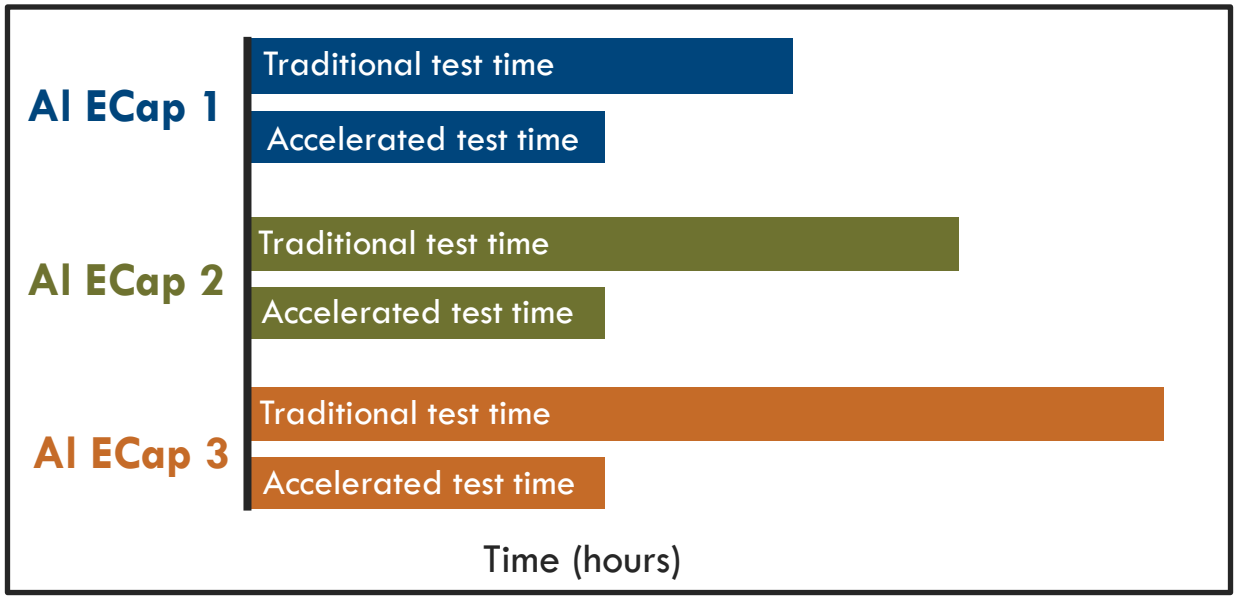


Grey paper indicative of electrolyte saturation.

As-received

DfR Solutions

Life Test – Traditional vs. Accelerated



Applied Test Conditions*		
	Traditional (T)	Accelerated (A)
Ripple Current (I)	$I_T = I_R$	$0 < I_A \leq I_R$
Bias Voltage (V)	$V_T = V_R$	$0 < V_A \leq V_R$
Temperature (T)	$T_T = T_R$	$T_A = T_R$

* Datasheet rating (R). All ripple applied at 120 Hz.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out
- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
  - Traditional vs. Accelerated
- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D
- Conclusions

Accelerated Life Test – Conditions

- The accelerated test approached was used to compare the behavior of the following two pairs of Al ECaps.

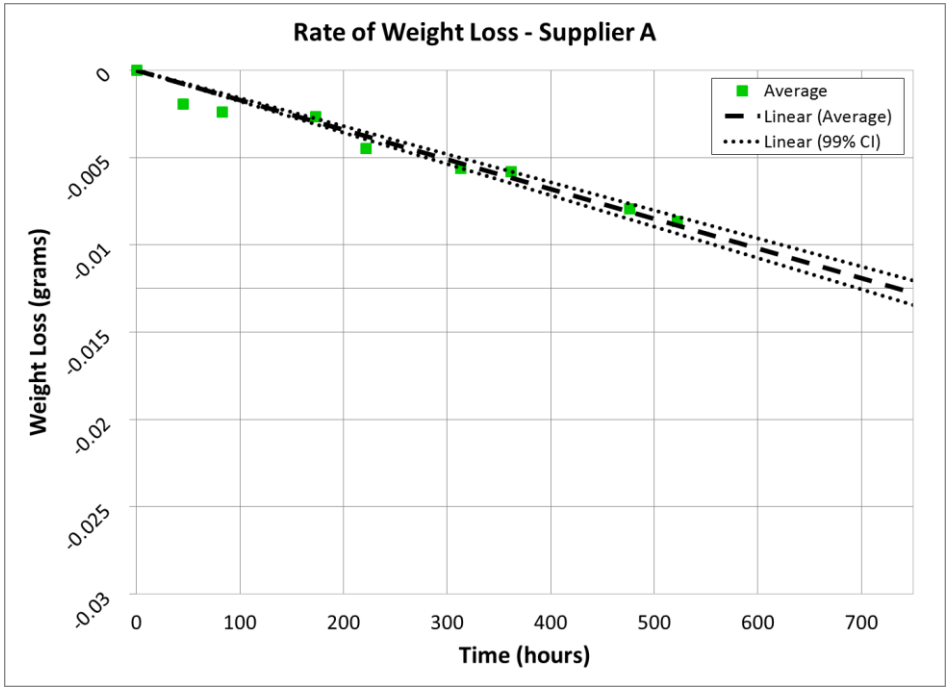
Supplier	Capacitance (μF)	Size (mm)	Rated Lifetime (hrs)	Voltage (V)	Test Voltage (V)	Rated Ripple Current (mA RMS)	Test Ripple Current* (mA RMS)
A	68	18 x 31.5	10,000	450	225	1575	300
B	68	18 x 40	>15,000	450	225	1517	300
C	2.2	10 x 20	10,175	450	225	43	20
D	2.2	10 x 20	5,000	450	225	29	15

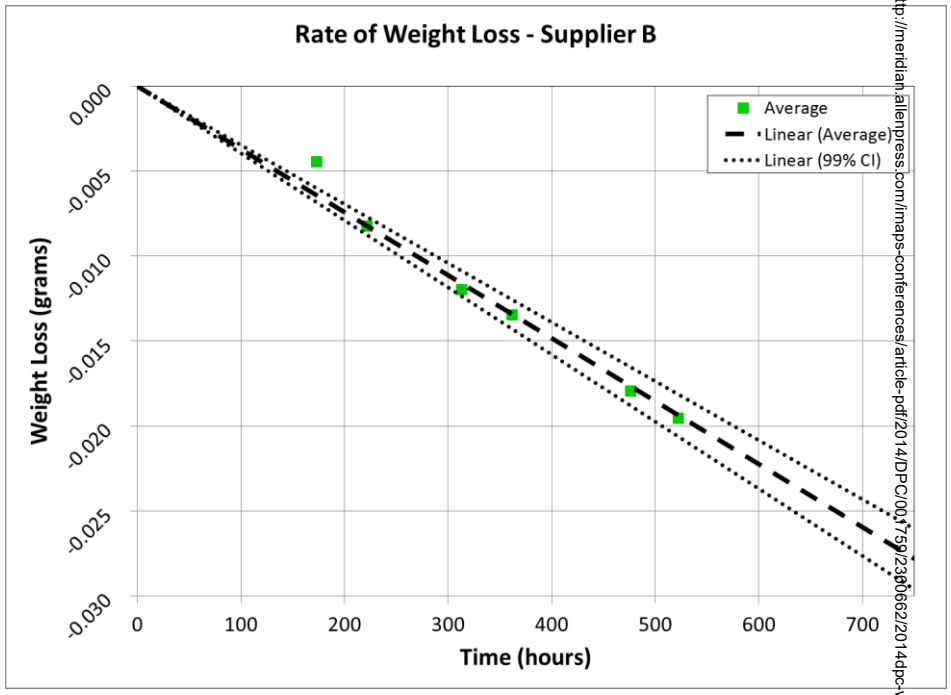
* Ripple applied at 120 Hz.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Accelerated Life Test – Suppliers A & B Rate of Weight Loss

450 V, 68 µF



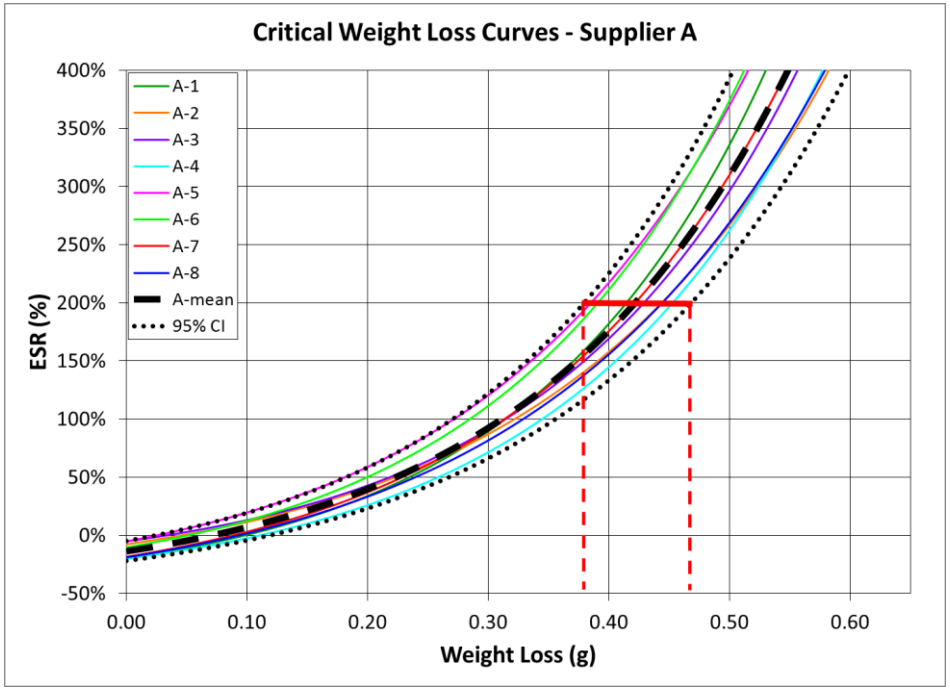


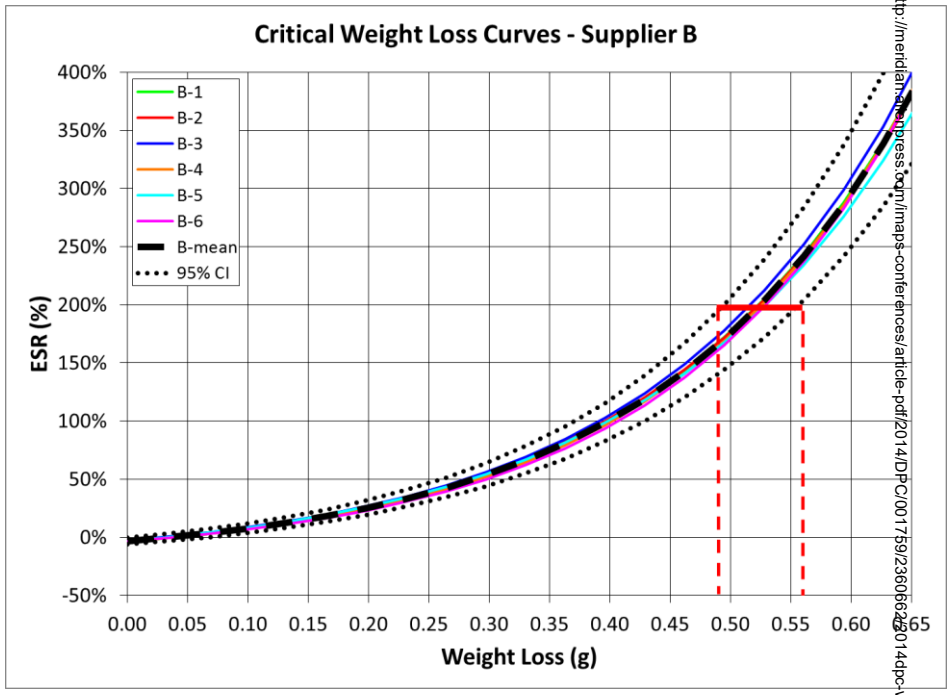
- Supplier $A_{\text{Rate of Weight Loss}} \approx \frac{1}{2}$ Supplier $B_{\text{Rate of Weight Loss}}$
  - Supplier A capacitors have a better seal between the can and bung

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Accelerated Life Test – Suppliers A & B Critical Weight Loss

450 V, 68 µF





- Supplier $A_{\text{Critical Weight Loss}} \approx$ Supplier $B_{\text{Critical Weight Loss}}$
  - Chemical stability of Supplier A and Supplier B electrolyte is comparable

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

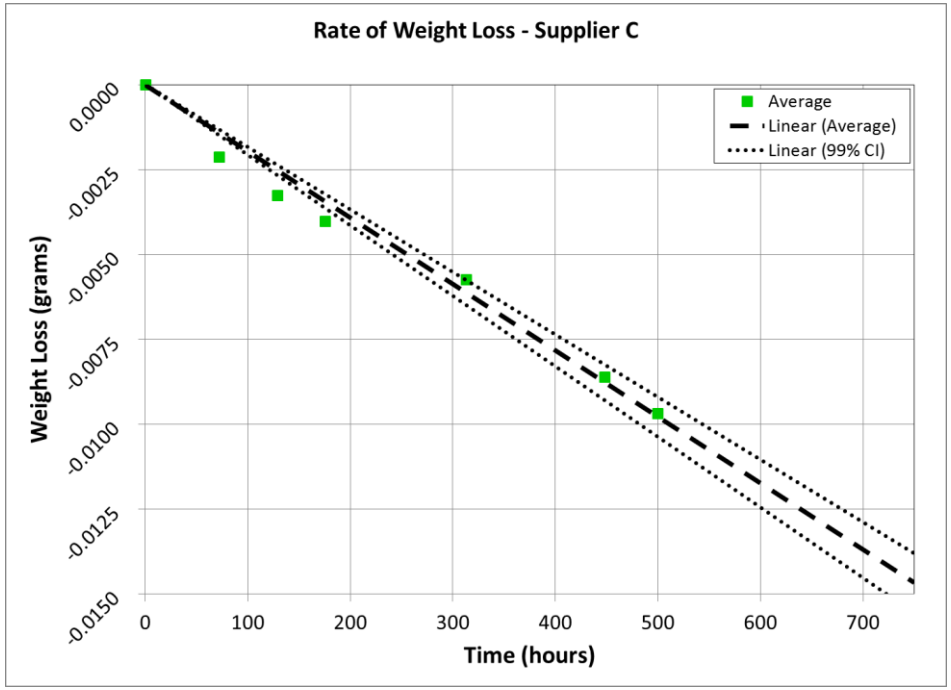
Accelerated Life Test – Suppliers A & B Comparison

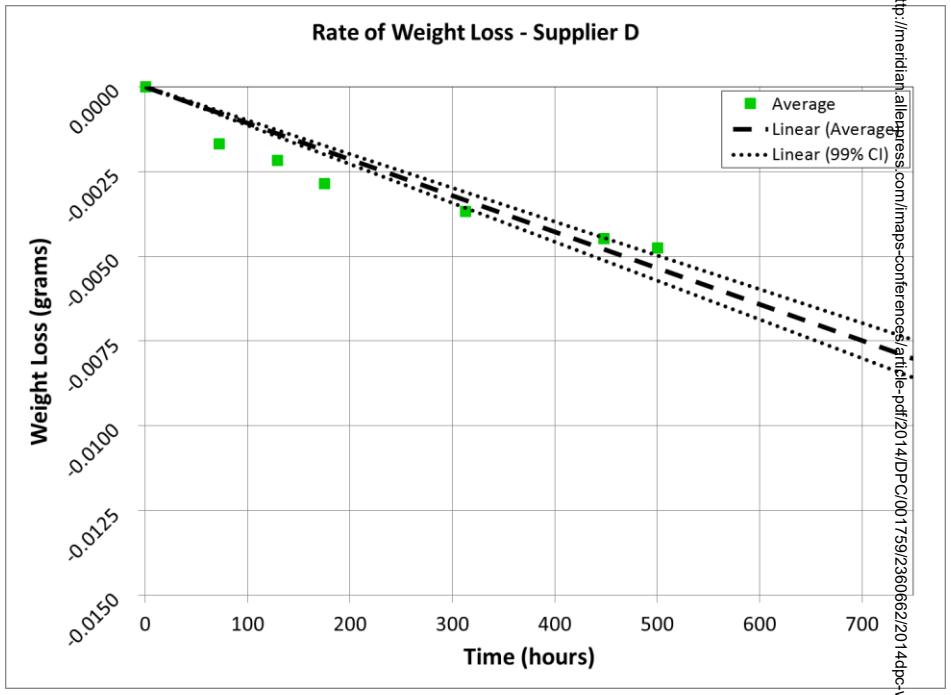
Supplier	Minimum Accelerated Lifetime (hours)	Maximum Accelerated Lifetime (hours)	Datasheet Lifetime (hours)
A	21,130	29,140	10,000
B	12,540	16,030	>15,000

- Accelerated life test results indicate that the Supplier A Al ECap is more reliable than Supplier B
  - This is opposite of what the datasheet lifetimes suggest

Accelerated Life Test – Suppliers C & D Rate of Weight Loss

450 V, 2.2 μF



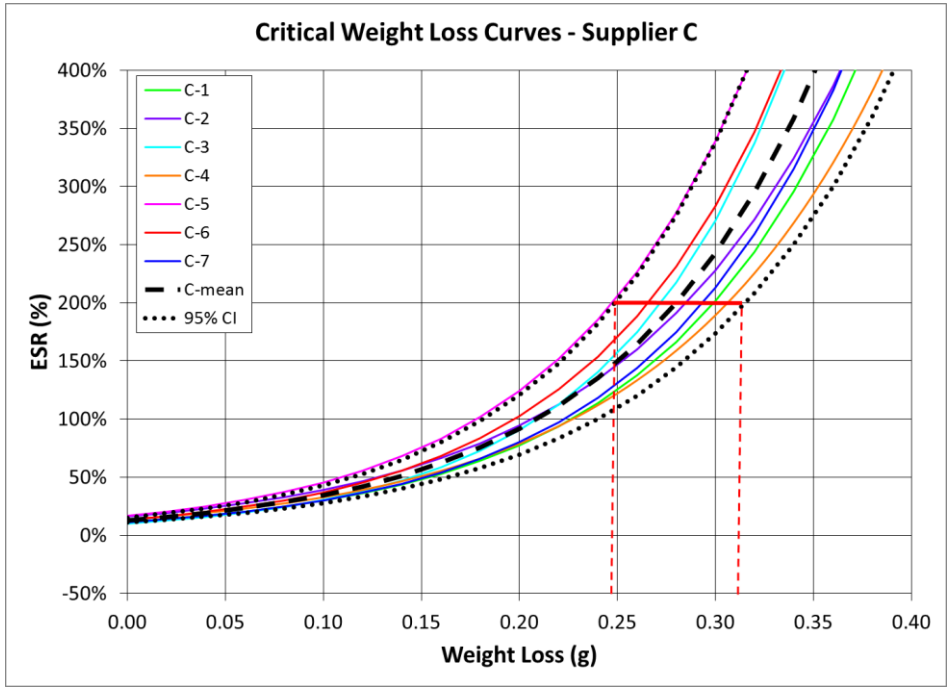


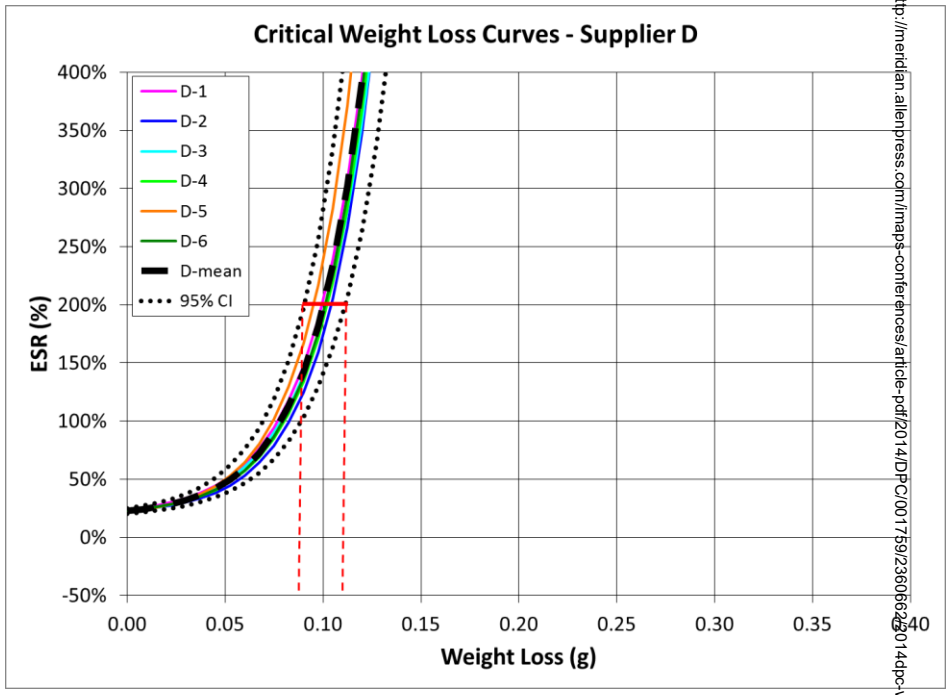
- Supplier $C_{\text{Rate of Weight Loss}} \approx 2$ Supplier $D_{\text{Rate of Weight Loss}}$
  - Supplier C capacitors have a worse seal between the Al can and bung

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Accelerated Life Test – Suppliers C & D Critical Weight Loss

450 V, 2.2 μF





- Supplier $C_{\text{Critical Weight Loss}} \approx 2.5$ Supplier $D_{\text{Critical Weight Loss}}$
  - Supplier C capacitors have a more chemically stable electrolyte

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Accelerated Life Test – Suppliers C & D Comparison

Supplier	Minimum Accelerated Lifetime (hours)	Maximum Accelerated Lifetime (hours)	Datasheet Lifetime (hours)
C	12,010	17,170	10,175
D	7,910	11,160	5,000

- Accelerated life test results indicate that the Supplier C Al ECap is more reliable than Supplier D
  - This supports what the datasheet lifetimes suggest

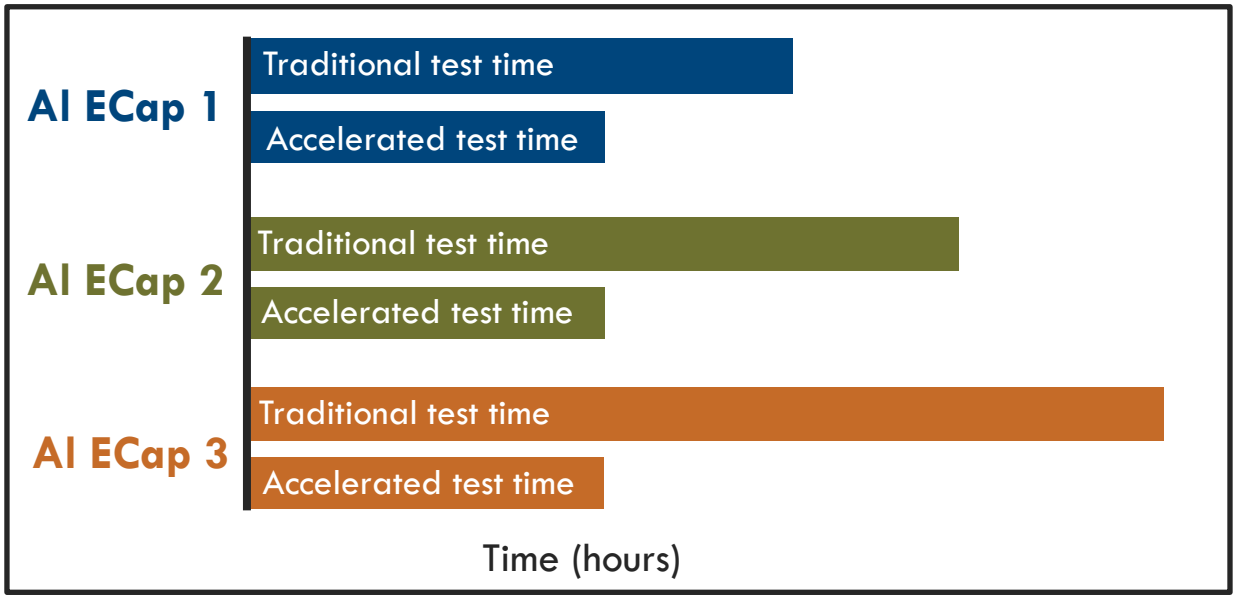
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out
- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
  - Traditional vs. Accelerated
- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D
- Conclusions

Conclusions

- The Al ECap accelerated life test approach is an effective way to compare the reliability of the same capacitors from different manufacturers under applied test conditions
  - Test results indicated that datasheet lifetime values can be inaccurate when compared to the reliability test results



Questions?

Many thanks to Steph, who is the primary author, for letting me present her findings.

Our appreciation as well goes to our collaborators, LED Roadway, for allowing us to publish the findings of this study.