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New Passives for Space: Hermetic Al Electrolytic Capacitors

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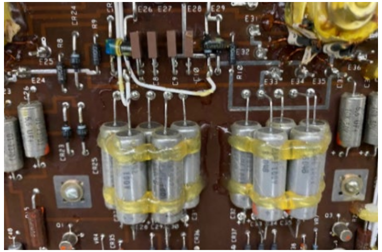
Outline

- Motivation and Objectives
- Background
- Application Requirements
- Test Plan
- Preliminary Results
- Summary

Motivation and Objective

- The next generation of power systems for NASA require high value capacitors with high voltage (>100V) capability.
- Current solutions utilize multiple tantalum (Ta) electrolytic capacitors in parallel and series to address these needs.
- Aluminum (Al) electrolytic capacitors have the capability to meet the capacitance, voltage and equivalent series resistance requirements of future power systems and the recent availability of fully hermetic solutions makes this a viable solution.

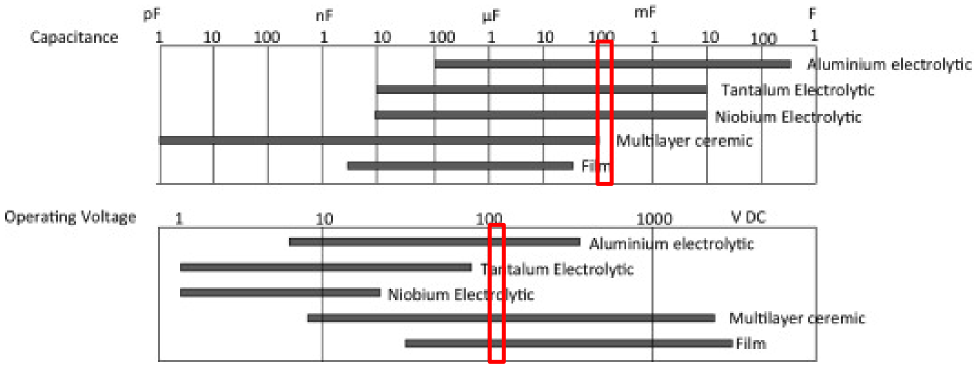


Ta Capacitor Stack for Heritage Space Power System

- The objective of this proposed work is to determine any degradation processes in hermetic Al electrolytic capacitors that might limit space applications.

Background

Capacitor Comparison



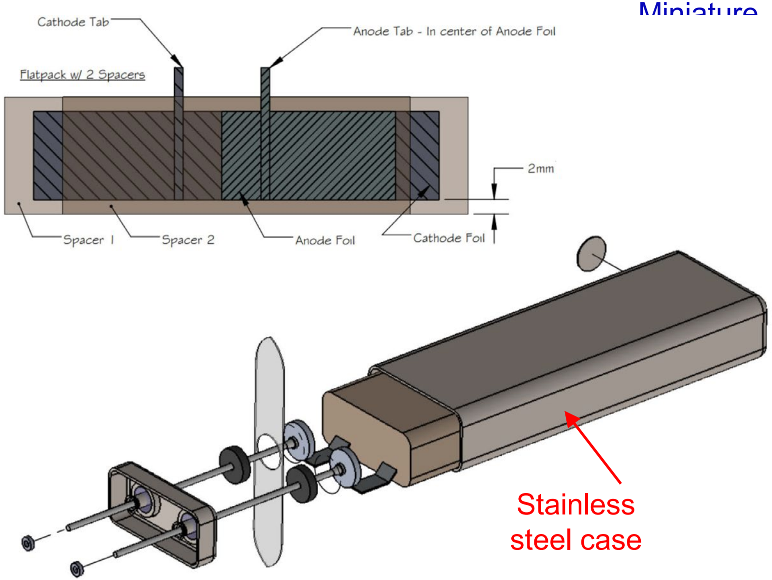
Ranges of capacitance and operating voltage of various capacitors.[1]

Parameter	Tantalum[2]	Aluminum[3]
Applicable Standard/DLA Drawing	MIL-PRF-39006/25F (currently used for this application)	DLA#05019 (closest available-different seal) Data below is from the manufacturer
Capacitance Range (µF)	6.8-2200	120-8000
Voltage Range (Vdc)	85-4 @125℃	250-30 @125℃
ESR max at 25℃ (Ω)	1.03-11.71 120Hz	0.043-1.200 120Hz 0.041-0.96 10kHz
Size (inch)	L: (0.453-1.062) / D: (0.188-0.375)	1.50 x1.00 x 0.50
Dielectric	Ta_2O_5	Al_2O_3
Construction	Hermetic (glass to Ta), Ta case	Hermetic glass to metal, stainless steel case

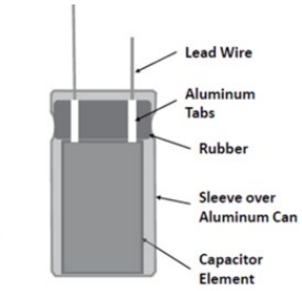
Background

Construction

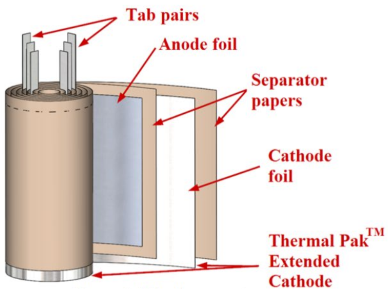
- Hermetic Al Electrolytic Capacitors
    - Glass to metal seal
    - Stainless steel case
    - Wound construction
    - Anodized Al foil anode
    - Self-healing



Hermetic Al capacitor overall construction schematic [5]



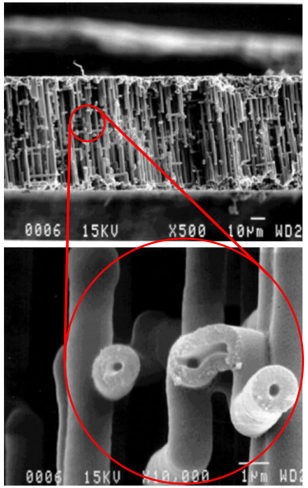
Miniature Radial-leaded construction. [4]



Winding construction. [4]

100um thick anodized Al anode foil w/ Al removed

Hollow Al_2O_3 tubes filled with electrolyte for sealed capacitor

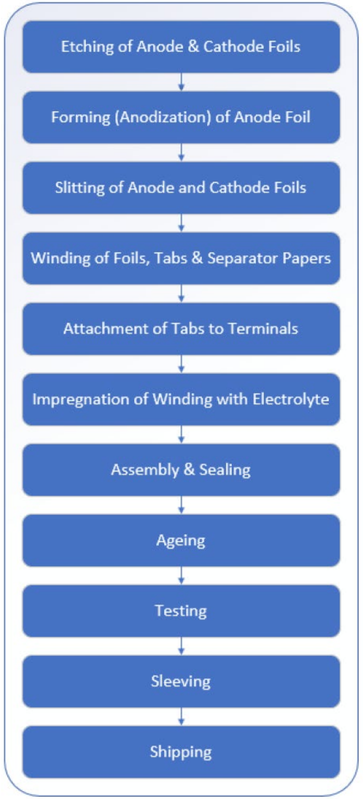


SEM images of anode foil dielectric on 400VDC rated Al electrolytic capacitor (surrounding Al removed). [4]

Background

Process and Test

- Available hermetic Al electrolytic capacitors are not built towards a military standard.
- The process used to build these capacitors and typical tests performed are shown.



Hermetic Al Capacitor Manufacturing Process. [4]

Hermetic Al Capacitor Typical Tests [6]

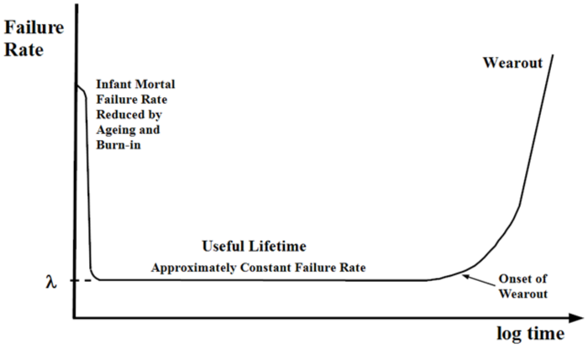
TYPICAL TESTS	MIL-STD/Method	TEST CONDITIONS
Dc Life test	MIL-STD-202/108	Catalog lists DC Life & Endurance Life; Application Guide lists expected base life hours
Derated ripple life	EIA IS-749, MIL-PRF-39018	Catalogs list multipliers for VDC, Frequency & Ripple
Stability	MIL-PRF-39018	Catalog lists Z ratio; Application Guide lists suggested performance
Moisture resistance	MIL-STD-202/106	MIL-PRF-39018 provides guidelines
Vent	MIL-PRF-39018	Details included in MIL-PRF-39018
Vibration	MIL-STD-202/201-204-214	Catalog, Application Guide, MIL-PRF-39018 provides general guidelines
Shock	MIL-STD-202/213	MIL-PRF-39018 Provides general guidelines
Res to solder heat	MIL-STD-202/210	Application Guide provides general guidelines
Terminal Strength	MIL-STD-202/211	Catalog & Application Guide provides general guidelines
DWV	MIL-STD-202/301	Application Guide Provides general guidelines
Altitude simulation	MIL-STD-202/105	Application Guide provides limits
Reverse voltage	MIL-PRF-39018	MIL-PRF-39018 Provides general guidelines
Ripple Life test	EIA IS-749, MIL-PRF-39018	Catalog lists DC Life & Endurance Life; Application guide lists expected base life hours
Derated DC life	MIL-STD-202/108	DC Lifetime & voltage temperature multipliers per CDE literature
Shelf Life	MIL-STD-1131B	Catalog lists Shelf Life, Application Guide also provides general guidelines
Surge	MIL-PRF-39018*	Catalog lists Surge , Application Guide lists suggested performance
Marking	MIL-STD-202/215	Application Guides suggests basic perminency, MIL-STD-202 for procedure
Solderability	MIL-STD-202/208	Details included in MIL-STD-202
Thermal shock	MIL-STD-202/107*	Catalog lists temperature extremes, Application Guide suggests operation between extremes
Temp Cycle & Immersion	MIL-STD-202/104*	MIL-STD-202 provides additional details
Insulation Resistance	MIL-STD-202/302	Application Guide provides basic limits, MIL-STD-202 for procedure
Salt Atmosphere	MIL-STD-202/101	Details included in MIL-STD-202

100% Hermeticity performed MIL-STD-883G
Fine Helium Leak Test, Method A1, Table II, ≥ 1 - < 10 cc.
Gross Leak Test, Condition C1.

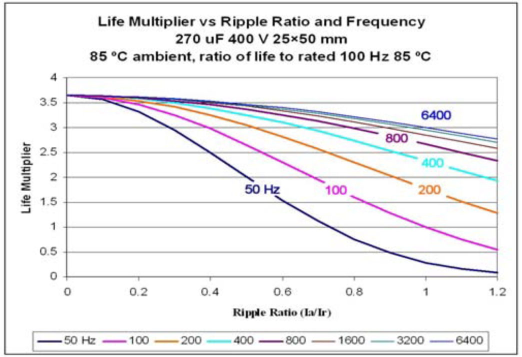
Background

Reliability and Lifetime

- Most common failure mode is wear-out, where resistance gradually increases to an eventual open circuit.
- Infant mortality failure prior to wear-out is reduced through aging and screening processes performed on each capacitor prior to shipment.
- An estimation of the constant failure rate (λ) prior to onset of wear-out for this series of capacitors is provided online at http://www.cde.com/technical-support/life-temperature-calculators
- The model used for this calculator is shown below.[4-5]
- λ [1/hr] = 0.0004 × N × (V_A/1[V]) × (V_A/V_R)² × (Cs/1[F])1/2 × 2(Tc-Tm)/10[°C] / Lb
  - N is the number of capacitors in the array
  - VA is the applied DC voltage
  - VR is the rated DC voltage
  - Cs is the capacitance of each capacitor
  - Tc is the core temperature
  - Tm is the maximum rated core temperature
  - Lb is the base lifetime



Type	Lb (h)	Tm
Screw-Terminal Styles		
DCMC	5000	95
500C	7500	98
520C	12000	103
550C	15000	108
101C	8000	108
Flatpack Styles		
MLSG	5000	125
MLSH	5000	125



Power System Application

- Lifetime: 10+ years.
- Capacitance range of interest: 100 to 200 μF
- Temperature during applications: -40 to 70C (qualification)
- Stable ESR over temperature
- DC voltage: 100 to 200V
- Ripple Current:
    - No significant ripple currents expected
    - Ripple current rating equivalent or better than MIL-PRF 390006/25 (CLR81) capacitor desired
- Surge current: 5A maximum in 1ms
- Dormant conditions: No damage at -55C (gradually heated to -40C or above for operation)
- Failure conditions: Greater than 1mA of leakage current is concern and 10mA is failure

Test Plan

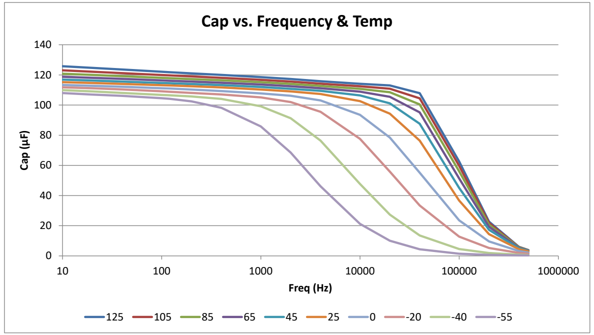
- Component Selection: two capacitor values were selected
    - 120 μF 20% 250V
    - 210 μF 20% 150V (9 received, 30 on order)

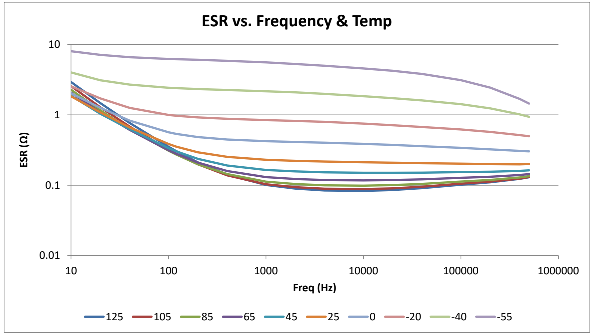
- Hermeticity
- Performance as a function of frequency and temperature
- Aging
- Thermal Vacuum
- Thermal Cycling

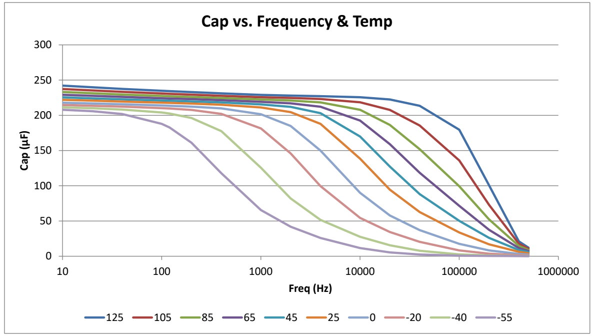
Test Plan

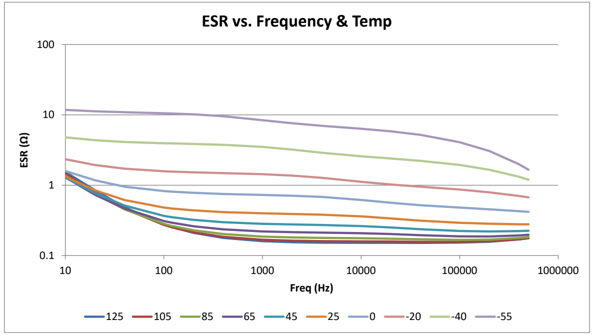
Performance

- Performance Curves for the two selected capacitor types were provided by the manufacturer.[5]



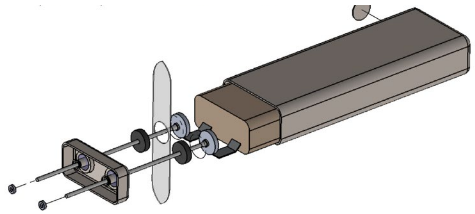




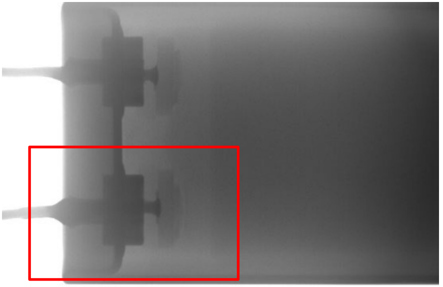


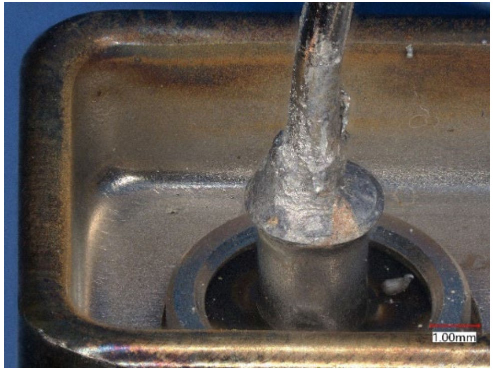
Preliminary Results

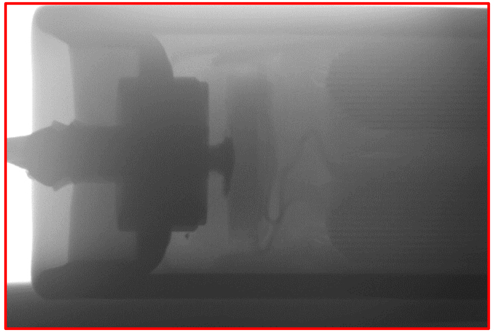
Inspection



- Visual and X-ray inspection was performed on the samples received.
- Construction analysis is underway.







Preliminary Results

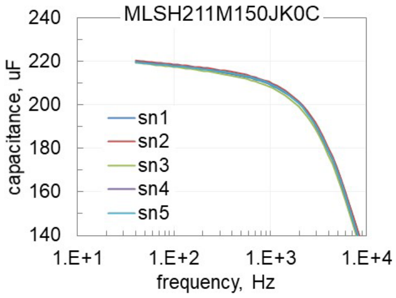
Hermeticity

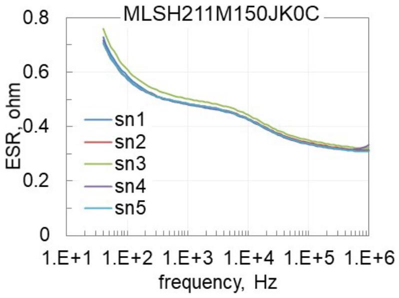
- Upon receipt (JPL), parts were hermeticity testing according to manufacturer conditions (MIL-STD-883G Fine Helium Leak Test, Method A1, Table II, ≥ 1 - < 10 cc and Gross Leak Test, Condition C1). It is worth noting that manufacturer hermeticity testing is performed prior to final labeling.
- Following incoming inspection at GSFC, labels were removed and parts were cleaned.
- Hermeticity testing was repeated using a High Sensitivity Helium Leak Detection System (HSHLD) per MIL-STD-750, Method 1071, test condition H3: (Combined He/O2 dry/gross leak, and He fine leak) at a bombing pressure of 75 psia for 6 hours and dwell time 1 hour.
- Hermeticity testing was repeated following 1 week at 125℃.

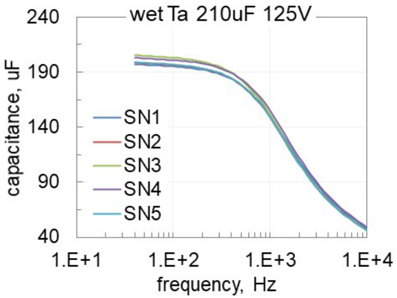
Sample	JPL, atm_cc/s He	GSFC, atm_cc/s He	GSFC, after 1wk 125C, atm_cc/s He
SN1	7.2E-8	8.1E-10	8.1E-10
SN2	1.6E-8	1.2E-9	4.6E-10
SN3	1.1E-8	7.6E-10	6.5E-10
SN4	1.1E-8	4.6E-10	4.8E-10
SN5	8.4E-9	6.4E-10	3.7E-10

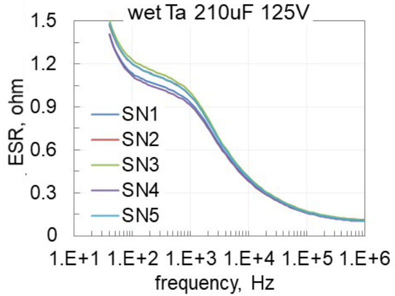
Preliminary Results

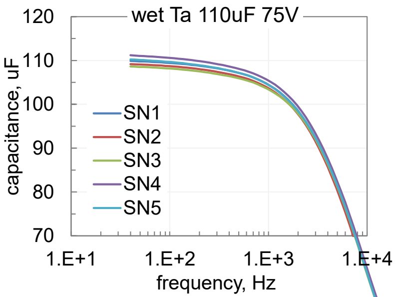
Comparison Capacitance and ESR

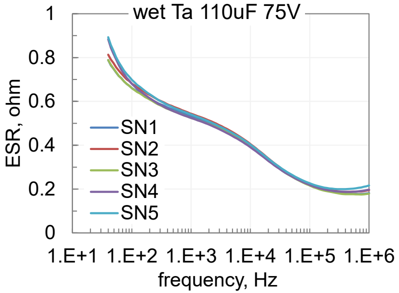










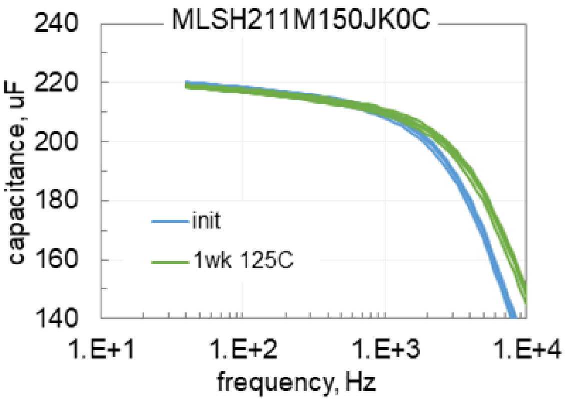


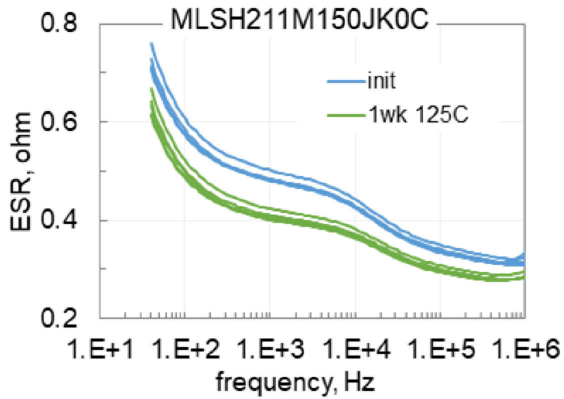
- Capacitance and ESR were measured for the 210μF hermetic Al capacitors.
- Results are shown along with those obtained for similar hermetic Ta capacitors.

Preliminary Results

Performance and Ageing

- Parts were subjected to 1 week unpowered ageing at 125℃.
- Capacitance and ESR were measured before and after exposure.
- Relatively small changes were seen after ageing.





Summary

- An overview of hermetic Al capacitor technology indicates that it may be a viable alternative for future space power systems.
- Initial results are promising.
- Work continues with a more comprehensive study of two different capacitor values and a larger sample set.

Acknowledgements

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- Special thanks to CDE Cornell Dubilier, JPL Analysis and Test Laboratory, and GSFC Parts Analysis Laboratory.

References

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3. Specification Sheet for Type MLSH 125 °C Hermetic SlimpackTM, Aluminum Electrolytic Capacitor, CDM Cornell Dubilier.
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