Raytheon
Customer Success Is Our Mission

Polymer Tantalum Capacitors Vacuum Effects – Part 1

Michael J Cozzolino
Dr. Mark Richardson
Raytheon Space and Airborne Systems
El Segundo, Ca 90230
(310) 616-0980
Michael_cozzolino@raytheon.com

Outline

- Introduction
- The physics behind leakage current in polymer tantalum capacitors
- What we know regarding the lack of moisture on polymer tantalum capacitor electrical characteristics
- Concerns for Space applications
- Planned testing
- Summary

Introduction

- Polymer tantalum SMT capacitors exhibit performance and reliability advantages that make them desirable for use in high reliability space applications. Two user concerns exist that have been impeding this application:

1. Polymer based tantalum capacitors exhibit unique behaviors that are not well characterized and may limit usage in applications that need to function under vacuum.

2. Calculation of worst case end of life (EOL) deltas results in numbers more extreme then other capacitors and drives design to higher capacitance parts that are 'binned' to tight tolerances.

Raytheon

Tantalum Capacitor Physics

- Many capacitors are usually modeled as two conductors separated by a dielectric and are non-polar devices.
- Tantalum SMT capacitors consist of a metal anode, a Ta_2O_5, dielectric and a cathode consisting of a semiconducting layer. These interfaces create a MIS semiconductor junction.
  - Tantalum capacitors are polar devices.
- A capacitor’s leakage current is controlled by the dielectric and the dielectric’s interface with the polymer cathode material.
  - Different polymer processes exhibit different electrical characteristics.

Tantalum Capacitor Physics

- Capacitors with lower voltage ratings often use a cathode material that is polymerized in-situ. These materials typically have high leakage currents that are driven by a Pool – Frenkel mechanism.
  - The activation energy for the P-F effect has been published as 0.15 ev. (“INVESTIGATING PRE-BREAKDOWN CURRENTS IN POLYMER TANTALUM CAPACITORS”, Githin Francis Alapatt, Clemson University Masters Thesis, 2010)

- Capacitors with higher (above 16 to 20 volts) voltage ratings use either a pre-polymerized material or a combination of in-situ and pre-polymerized materials. The leakage current in these tend to be lower and are driven by a combination of Poole – Frenkel and Schottky effect’s.
  - The activation energy for the P-F effect has been published as 0.75 ev for this process (see above reference).

Moisture

- Tantalum SMT capacitors are environmentally sealed devices and are sensitive to moisture to various degrees.
  - Some moisture is required for a tantalum capacitor to function normally. A lack of moisture can affect the charging mechanism in polymer based capacitors.
    - Multiple authors have reported anomalous electrical behavior for polymer capacitors that have been “dried out”. Normal performance is restored if the capacitor in left in a normal ambient environment for some time.
    - Capacitors utilized in vacuum applications that would not have an opportunity to re-normalize.

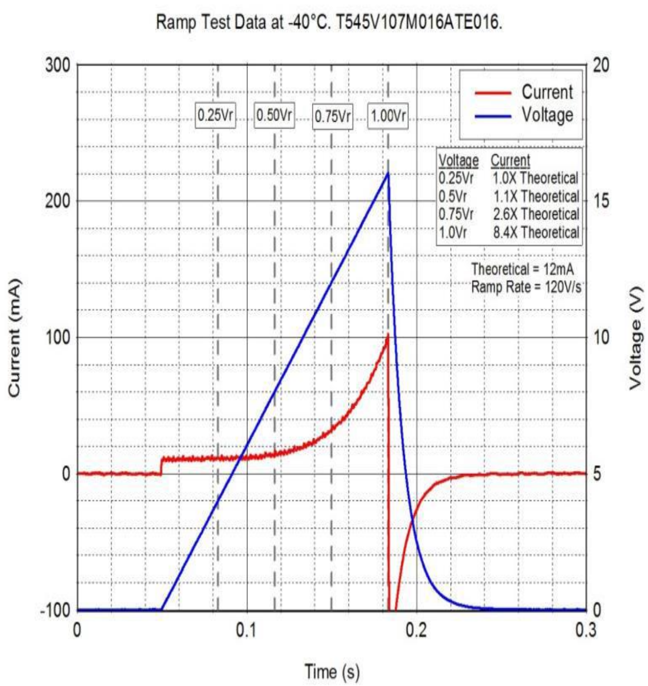
Anomalous Charging Characteristic (ACC)

- The anomalous charging characteristics refers to a phenomenon where there is a higher amount of current flowing into a capacitor while charging than predicted by theory.

$$I_{ideal} = C \frac{dV}{dt}$$

  - The impact is greater at lower temperatures.
  - The impact is greater near the rated voltage

The chart on the right (Kemet) illustrates the response of certain "dried" polymer tantalum capacitors in response to a voltage ramp



Anomalous Charging Characteristic (ACC)

- This electrical behavior has been termed anomalous charging.
  - It has been published that this phenomenon is caused by "charged polymer chains in the conducting polymer cathode at its interface with the oxide dielectric. These dipoles will reorient when an electric field is applied, and this reorientation determines the potential barrier at the oxide-polymer interface". (Anomalous Currents in Low Voltage Polymer Tantalum Capacitors**,** Y. Freeman, et al; *ECS Journal of Solid State Science and Technology,* 2 (11) Nl97-N204 (2013)) Moisture appears to effect the response time for this reorientation. The height of the interfacial barrier affects the ease of leakage current flow.

- The details of this effect as a function of voltage slew rate, temperature and specific part family is not well understood; especially by the user community.

Tantalum Capacitor Physics

- It might be expected, based upon activation energy, that pre-polymerized polymer tantalum capacitors offer the superior choice in all applications.

- Empirical operation indicates that is not the case. Pre-polymerized and hybrid combinations of in-situ and pre-polymerized polymer cathodes, exhibit a stronger reaction to the lack of moisture than do in-situ polymerized tantalum capacitors.

Design Concerns for Space Applications

Testing (in vacuum) has been initiated to address the following concerns:

- Polymer tantalum capacitors have an anomalous charging characteristic at low moisture levels that is not sufficiently characterized yet
  - Charging may require 8x more current than ideal: $C\,dv/dt + leakage$
  - Can appear after 10min, 125C bake out and solder reflow; can last 1 week.
- End-of-life tolerance (initial+temp stability+aging) creates challenges (up to -70%) for use in hi-rel circuit

Raytheon

Questions to be answered

- Does the ACC effect dissipate with repetitive cycling?
  - What is the time scale? Is the effect in vacuum the same as published in air?
- Is ACC is reduced by the use of less de-rating?
  - Is the effect the same in vacuum?
- What EOL (End of Life) limits does design need to impose to successfully use polymer tantalum capacitors in vacuum?
  - Can ESR be reliably ‘binned’ to ensure end of life performance?
  - Are the end of life factors truly additive?
  - Should different factors be used for different specific capacitance/voltage/case size selections?

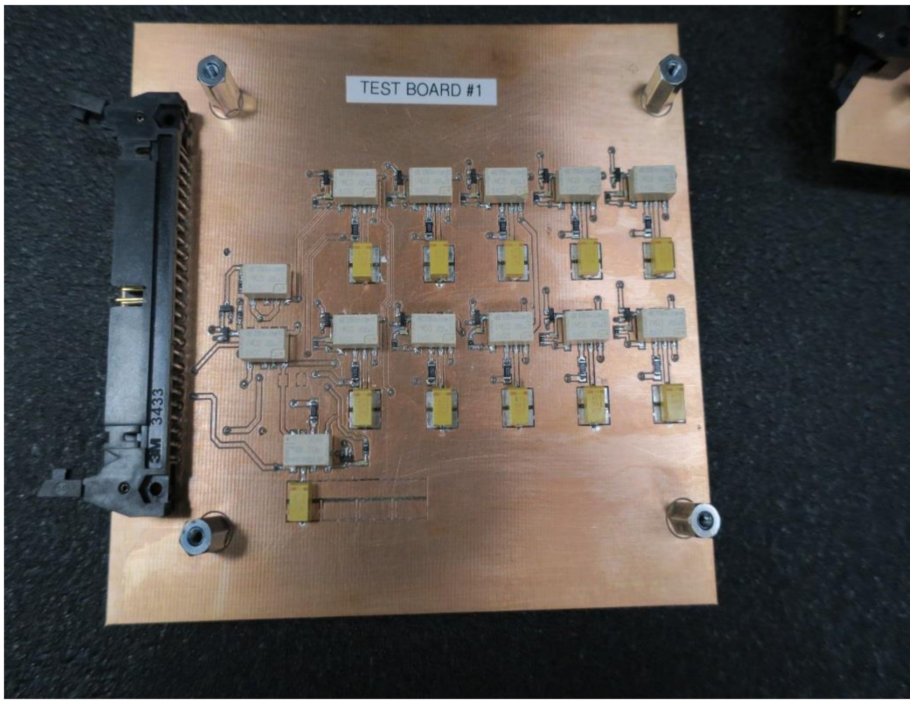
Planned Test Sequences

Test Name	Comment
"Vacc": ACC Onset Voltage	Primary Purpose of Testing. Define 'onset' Vacc (see graph on next slide)
Vacc vs. Temp	Does Vacc vary significantly with temperature
Vacc charge magnitude	Raw data collected during test of ACC Onset Voltage by charging caps to 80-90%, data usage TBD
ACC initialization	Determine sequence to ensure full ACC behavior occurs at each temperature, etc.
Cap Temperature Coefficient	Main interest: temperature coefficient in vacuum
Cap Aging	Main interest: aging in vacuum (capacitance & ESR)
ESR Aging & initial shift with vacuum	Main interests: aging in vacuum, is there shift when polymer dries out.
ESR Temperature Coefficient	Main interest: ESR at temperature extremes, esp. hot (ripple current rating)

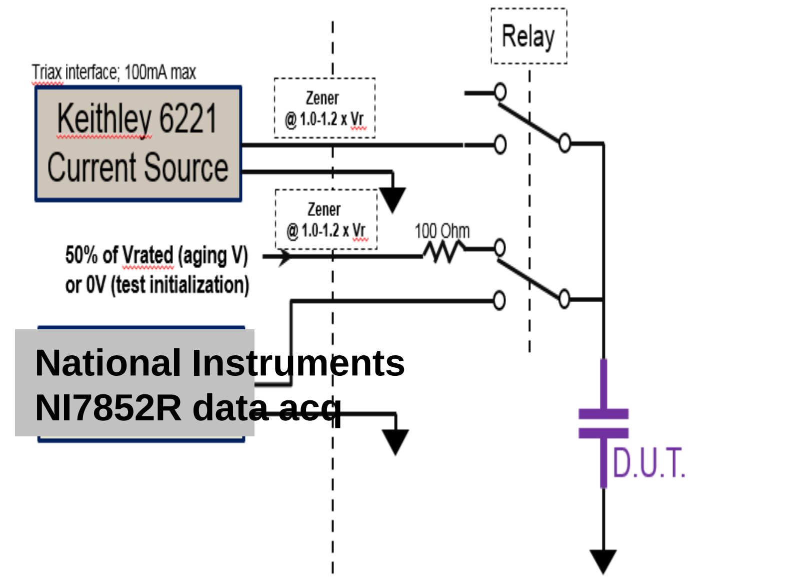
Testing

- Test preparation has been on-going. Test boards have been fabricated and test software is being generated.
- 10 capacitors in each of multiple voltage ratings and case sizes to be evaluated:
  - Both single and multi-anode
  - Voltage range from 4 to 63 volts
  - Case sizes – B, D and X
- Four planned initial phases:
  - Phase I Software Prep & 1st board tryout; bench-top (no vacuum, room temperature)
  - Phase II Populate & initial test of all boards (no vacuum, room temperature)
  - Phase III Setup at vacuum chamber, configure power supplies, measure all capacitors (room pressure & temperature)
  - Phase IV Apply Vacuum & Verify ACC initialization sequence

Test Circuit/Board



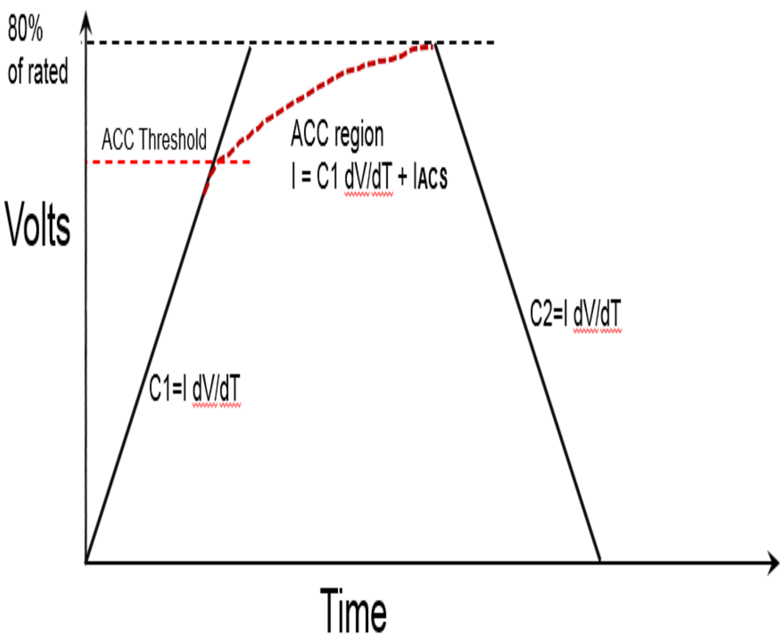
- Apply fixed current to capacitor & measure Vcap with high speed DMM

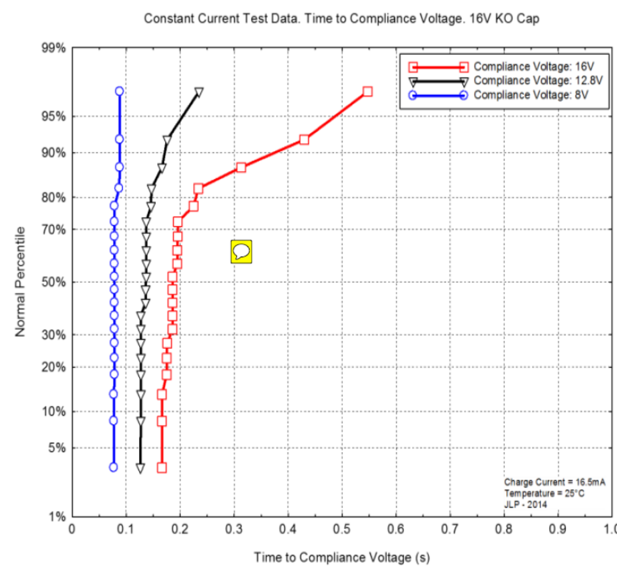


Test Bias

Define Vacc as the voltage at which the apparent capacitance increases 10% when charged by a constant current source.

Kemet De-rating recommendation is 80% of rated voltage





Y. Freeman, "Anomalous Charging Characteristic," Kemet Internal Publication, Mar. 2016.

Summary

- Anomalous performance characteristics have been identified for polymer tantalum capacitors that are either ‘dry’ or are being used in a vacuum environment. Much is unknown about the nature of this phenomenon.

- A test program has been designed to gain insight into this phenomenon and determine if and how polymer tantalum capacitors can be used in Space applications.
  - The test process has been agreed upon and hardware has been fabricated.
  - Test software is in development and upon completion our setup and operation will be verified prior to actual testing.