1.2 COTS & Enhanced COTS Tantalum Capacitor Failures Confirm Systemic Moisture Sensitivity Issues

Space and Airborne Systems

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SESSION 1: Hermetic Vs Non-Hermetic Packaging, *Is Our Fate Sealed?* 09:10-09:35
Outline

1. MSL Ratings- Handling & Storage Requirements
2. Enhanced COTS & COTS low ESR Capacitors
   Military Vs. COTS- Intended use & Construction Differences
3. History- Raytheon Programs Effected
   Failures- Moisture Absorption in Tantalum Capacitors
4. Past & Present Failure Analyses- Raytheon
   Supplier & NEPP analysis of Process Lot Related Defects
5. Conclusions
6. Recommended Actions, Preventive Measures
Packaging / Handling requirements for semiconductors
- Majority of electronics are plastic encapsulated which IS moisture permeable
- MSL relates to moisture absorption rate & provides exposure time periods at ambient room conditions before bake out is required

### Ambient = 30°C, 85% RH (Level 1) → 30°C, 60% RH (Level 2 & ABOVE)

- MSL 1 No protective packaging / handling requirements
- Moisture exposure cumulative, **UNLESS** temperature increases & RH drops

CCA reflow without bake results in:
- Expansion of trapped moisture
- Momentary extreme Internal pressure, causing non-visible component damage
- Popcorn effect: Cracking / bulging visible on the component surface
- MSL 2 or greater: Moisture barrier ESD bags with desiccant & Indicator **required**

<table>
<thead>
<tr>
<th>MSL Rating</th>
<th>Ambient Exposure- Mandatory Bake Prior to Reflow</th>
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<tbody>
<tr>
<td>MSL 6</td>
<td>Mandatory</td>
</tr>
<tr>
<td>MSL 5A</td>
<td>24 hours</td>
</tr>
<tr>
<td>MSL 5</td>
<td>48 hours</td>
</tr>
<tr>
<td>MSL 4</td>
<td>72 hours</td>
</tr>
<tr>
<td>MSL 3</td>
<td>168 hours</td>
</tr>
<tr>
<td>MSL 2A</td>
<td>4 weeks</td>
</tr>
<tr>
<td>MSL 2</td>
<td>1 Year</td>
</tr>
<tr>
<td>MSL 1</td>
<td>Unlimited</td>
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</table>

**Defines moisture barrier, handling, storage & bake out requirements**
Enhanced COTS - Standard & Low ESR

**Standard** - Black resin molding, qualified to MIL-PRF-55365/4
- Electrically Interchangeable with CWR06 conformal type
- Molded body construction, compliant Terminations
- **Optional:** Weibull Grading, Surge Current, Group A custom test limits
- Shipped in barrier packaging, some case sizes still MSL 1!
- Handling, MSL & bake out information updated on website

Target Markets → Avionics, Military, Space

**Low ESR** - Yellow resin molding, “NOT High-Rel!” like MIL series
- Commercial grade, Low pwr. DC/DC converters
- Thermal / electrical stress testing - Removes weak parts
- MSL 3 Moisture barrier packaging on request only, “Option V”
- NO Handling, Storage or bake out information on website

Target Markets → Automotive, Commercial - NO optional tests

Optional or NO Testing & Screening **NOT Equal to MIL Grade**
Military Vs. COTS - Intended use & Construction Differences

### Potential Applications
- COTS targeted for commercial / industrial sectors, NOT intended for critical applications
- Mass produced, NOT intended for designs that require an established reliability
  
  Example: Critical mission application Sub-assy X with 45,000 hours
  MTBF up time availability > 99.99%. Goals set by program or customer
- Step stress screening methods used to remove weaker parts from population

### Construction Differences

**Commercial Grade** - Powder grain smaller than military
- Results in reduced sintered bond strength between particles
- Difficulty in counter electrode deposition, effects dielectric thickness due to smaller pore structures
- Derating at ≤ 50% is **critical** due to thinner electrode / dielectric layers

**Military Grade** - Larger grain powder forms thicker dielectric
- Provides greater surge current & electric field handling


COTS NOT suited for High Reliability Designs
Grain Size, Effects:
- Bond area & Strength
- Pore Size
- Cathode & dielectric thickness
- Voltage Standoff
- Derating
- Structural integrity effects vulnerability to CTE stresses during reflow & pressure from RAPID moisture egress

Sintering Process
1. Tantalum powder grain pressed under high pressure into a pellet
2. Contact points between grains initiated, initial bond
3. Pellet heated under vacuum to ~2,000°C, Contact point bond areas expanded
4. Process contaminants pulled out / pyrolyzed, Defects eliminated or Migrated

Image Credit: Elcap Own work, CC0
https://commons.wikimedia.org/w/index.php?curid=33793513
Failure History at Raytheon

At Least 5 Programs **EFFECTED:** Post assembly or reflow

- IDS CCA’s, (2) RMS Missile Programs [up-screened, Enhanced COTS]
  Mid/Late 90’s **35V** Supplier 1 & **16V** Supplier 2
  Multiple lot related power on, ICT & FCT failures

- SAS DC/DC Converter CCA, (1) RMS Missile Program [up-screened, Enhanced COTS]
  Late 90’s, **10V & 25V** Supplier 1, post assy. reflow
  19 ICT & Power on failures

- IDS CCA’s built for (1) RMS Missile Program, [Enhanced COTS]
  2009-10, **35V** Supplier 1, 3 CCA’s: **25** ICT & **3** FCT Failures
  2013-14, **50V** Supplier 1, 3 CCA’s: **36** Failures between ICT & FCT

- SAS Power Supply CCA, Comm. Radio [COTS ONLY]
  2016, **20V** Supplier 1, Post assembly power on & ESS failures
  FA 2016-257 & previous 2013 / 2014 lot related failures

**Multiple Failures, effecting Enhanced COTS & COTS Caps!**
SAS DC/DC Converter CCA-
Up-screened Enhanced COTS

19 Supplier 1 Cap. shorts on, 15 & 28V Bus 10V 330μf & 25V 68μf

>> Components failing during ICT & Power on 10V Line Failures 25V Bus Failures

>> 2.9% Failure Rate effecting 80+ CCAs

Major Failure investigation launched

— Circuit analysis revealed DERATING issue (addressed), did not explain process failures
— Military, Enhanced COTS & up-screen methods compared, differences noted
  Differences in powder & process, not communicated
— Supplier 1 FA indicated parts acquired as MSL1, absorbed moisture with storage & recommended bake out
  Moisture expansion during reflow formally indicted as culprit
— Case & tantalum slug damage consistent with moisture expansion damage
— CAN be ordered as COTS MSL1 or MIL MSL3 (Moisture Barrier / Desiccant / Indicator) option

4/12/17
IDS CCA Built for RMS-Enhanced COTS, NO Up-screening

Supplier 1 Enhanced COTS Failures, post reflow

- 3 CCA P/N's failing during shorts/open, ICT & functional test
- 2009 / 2013 (2) Major Investigations 66+ failures, 35V & 50V Caps

FA Lab & Supplier 1 Findings

- FA Lab results (Physical, Electrical, X-Ray, IR Thermography & DPA)
  Consistent with moisture damage: Slug edge fail site & Body fractures
- Supplier 1 findings concurred with 35V failures disagreed on 50V findings “undetermined” root cause
- Supplier agreed / recommended material in stores & WIP requires bake out prior to reflow. Provided guidance on bake out for Loose & Reeled Material
- Raytheon to ONLY order MSL 3 Enhanced COTS Newer Option Provided
Raytheon & ASL CCA Supplier issue

- **Raytheon QA**: Parts that failed in 2009 & in 2013 were produced early 2008 in stores acquired from AVNET.
- In 2008 NO barrier packaging & NOT recommended or provided with COTS / Enhanced COTS products.
- No recommendations for Storage / Handling of low volume reeled components over LONG build intervals.
- Months, possibly years of material received from AD’s. Example- Replacement Supplier 1 20V 68μf, Date Code 1998!

Supplier 1 FA Customer Findings (IDS CCA)

<table>
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<tr>
<th>CR# 10-XXX</th>
<th>Qty. Returned</th>
<th>Date Returned</th>
<th>Customer P/N</th>
<th>Advised Failure Mode</th>
<th>Date Code</th>
<th>Short Circuit</th>
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<td>3/2/2010</td>
<td></td>
<td></td>
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**Root Cause / Corrective Action** - Analysis of the returned product and the location and appearance of the localized dielectric disruptions are consistent with product affected by moisture absorption prior to reflow mounting. Affected product may be baked out prior to use. Product on reels can be baked out for 16-24 hours at 50°C +/-5°C.

<table>
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<tr>
<th>CR# 14-YYY</th>
<th>Qty. Returned</th>
<th>Date Returned</th>
<th>Customer P/N</th>
<th>Advised Failure Mode</th>
<th>Date Code</th>
<th>Short Circuit</th>
</tr>
</thead>
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<tr>
<td></td>
<td>6</td>
<td>3/13/2014</td>
<td></td>
<td></td>
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**Root Cause / Corrective Action** - Attributable to design or manufacture of capacitors could not be determined. Presence of tooling marks on bottom of unit #5 raised concern. Affected product may be baked out prior to use. Product on reels can be baked out for 16-24 hours at 50°C +/-5°C.

Raytheon FA- “Tool Marks” are Injection mold blemishes not removed in process.
SAS Radio Power Supply- COTS, No Mil OR up-screen Testing!

COTS Failures post solder reflow (External CCA Supplier)
- CCA’s failing, ½ on power up, ½ ESS functional test; REQUIRED R&R of ~122 Caps.
- 170 CCA assemblies effected, 7 Caps. per board, potential Failure rate @ CCA test = 4.3% & @ ESS = 6%

FA Lab Findings, FA & MA Recommendations
- FA Lab results (Physical, Electrical, X-Ray & DPA) Consistent with moisture damage, slug edge fail site location & component body fractures
- Remediation- Power cycle built CCA’s min. for 10x to remove weak parts, 5 cycles failure free
- Remediation- Raytheon & CCA supplier to bake out ALL material in WIP & stores / handle product as MSL 3
- Due to functional criticality, Commercial grade cap. To be disqualified & replaced with Enhanced COTS Equivalent & Handled as MSL 3 ONLY
- Supplier 1 SHOULD add the same MSL “best practice” tech. note to webpage

CTE “Popcorning”

Dielectric Breakdown
Process Contributing Factors- Elevated power on failure rates

1. Reactivation of post DI wash Phosphoric acid remnant desiccates
2. Reactivation of disruption forming voltage heal sites
   Non-conductive (High R) → Conductive (Low R); localized current leads to dielectric breakdown
3. Process Factors that Contribute to batch related failures!

Conclusions / Recommendations-
Review of Failure Analyses, Best Practice Preventive Measures

1. COTS / Enhanced COTS Tantalum Capacitors-
   - Failures- Across multiple programs & business units for 20 years
   - Significant Cost- Associated with failures, production down time, rework & allocation of resources to investigate & implement corrective actions
   - MSL3 Mil Grade Specified Caps- Would have reduced possibly eliminated COST & IMPACT!

2. MSL 1 & 3 Rated Tantalum Capacitors-
   - EQUALLY vulnerable to moisture sorption over time!
   - Enhanced COTS & MIL grade- NOW ship in moisture protective packaging
   - COTS- Can be ordered with optional MSL 3 moisture barrier packaging, SPECIFY & Handle as MSL 3

3. COTS Tantalum Capacitors-
   - NOT appropriate- For Space / Military applications
   - Differences in- Construction, Processing, Testing & Storage / Handling
4. **COTS Tantalum Capacitors** (Continued)-
   - **Supplier 1 States**- Not for circuits which have **Established Reliability Requirements**
   - **Phase out**- COTS commercial products on existing & legacy designs

5. **ALL Resin Encapsulated Tantalum Capacitors**-
   - **Enhanced COTS or Mil Grade**- MUST be ordered with Moisture Barrier Packaging
   - **MUST Be Handled as MSL3**- Use, Storage, Re-Storage including bake out

6. **Additional Handling Requirements**-
   - **Add Requirements to**- Specifications & Drawings
   - **Incorporate**- In Program & Supplier TDP & MDP Packages
   - **Communicate**- to **ALL** ASL suppliers & Sub-tiers!

**NOT ALL Capacitors are built or tested the SAME way!**
Cases & studies on the effects of moisture on Plastic Encapsulated Tantalum Capacitors


[2] Effect of Moisture on Characteristics of Surface Mount Solid Tantalum Capacitors
CARTS 04, A. Teverovsky NASA GODDARD {NGSFC}, Greenbelt, MD https://nepp.nasa.gov/

[3] New Wear-out Failure Mechanism Discovered In Surface Mount Solid Tantalum Capacitors
CARTS 03, R. Dobson, Raytheon- Space and Airborne Systems, Largo FL


[5] A rapid technique for moisture diffusion characterization of molding compounds in PEMs
A. Teverovsky NASA GODDARD {NGSFC}, Greenbelt, MD https://nepp.nasa.gov/

[6] Characteristic times of moisture diffusion and bake-out conditions for plastic encapsulated parts
A. Teverovsky NASA GODDARD {NGSFC}, Greenbelt, MD https://nepp.nasa.gov/

[7] A new view on failure phenomena in solid tantalum capacitors
CARTS 96, P. Fagerholt pp. 162-166, 1996
Acronyms, Definitions

**AT&L:** Acquisition, Technology & Logistics; DoD undersecretary (OSD)

**AD:** Authorized Distributor

**AOI / AXI:** Automated Optical / X-Ray Inspection, Process improvement

**ASL / PSL:** Approved or Preferred Supplier List

**BU:** Business Unit

**CAT:** Counterfeit Avoidance Team (Enterprise wide)

**CB:** Certification Body

**CCAT:** Counterfeit Component Avoidance Training

**COTS:** Commercial Off The Shelf (components, products)

**CPB:** Customs Protection & Borders

**CPI/Ci:** Critical Program Information / Counterintelligence

**CTN:** Components Technology Network (Enterprise wide)

**DFARS:** Defense Federal Acquisition Regulation Supplement

**DHS:** Department of Homeland Security

**DI:** De-Ionized (Water)

**DLA:** Defense Logistics Agency

**DMS:** Diminishing Manufacturing Supply (source)

**DoD:** Department of Defense (U.S.)

**DoJ:** Department of Justice (U.S.)

**EHS:** Environmental Health & Safety

**EOL:** End Of Life (System Refurbishment / Upgrades)

**ERAI:** Electronic Resellers Association Incorporated

**ESS:** Environmental Stress Screening

**ETMA:** Engineering Technology & Mission Assurance

**FA:** Failure Analysis

**FCT:** Functional Test

**FD:** Franchised Distributor

**GAO:** Government Accountability Office (U.S.)

**GIDEP:** Government-Industry Data Exchange Program

**IC:** Integrated Circuit

**ICT:** In-Circuit Test

**ID:** Independent Distributor

**IDEA:** Independent Distributors of Electronics Association

**ITAR:** International Traffic in Arms Regulations

**Legacy:** Previous generation system (Military / Aerospace)

**LF:** Lead Free

**LTB:** Last Time Buy

**MA:** Mission Assurance, Internal Raytheon Function

**MDA:** Missile Defense Agency

**MIL Spec:** Military Specifications

**MIL-STD:** Military Standard (specifications)

**MSL:** Moisture Sensitivity Level (defined in J-STD-020E)

**NC:** Non-Conformance, Electronic Components, Hardware, Material or Process

**NASA:** National Aeronautics and Space Administration (U.S.)

**NDAA:** National Defense Authorization Act, Implemented Annually

**NEPP:** NASA Electronics Parts and Packaging program

**NFD:** Non-Franchised Distributor

**NHA:** Next Higher Assembly

**OCM:** Original Component Manufacturer

**OEM:** Original Equipment Manufacturer (Systems)

**OSD:** Office of the Secretary of Defense (U.S.)

**PCN:** Product Change Notice

**PLCP:** Product Life Cycle Process

**POC:** Point Of Contact

**PPP:** Program Protection Plan

**Prime:** System Design Lead / Provider

**QC:** Quality Control

**QPL:** Quality Parts List

**RH:** Relative Humidity

**R&R:** Remove & Replace (Operations Action)

**RTN:** Raytheon

**SAE:** Society of Automotive & Aerospace Engineering

**SEM-edx:** Scanning Electron Microscopy-energy dispersive x-ray spectroscopy

**SASC:** Senate Armed Services Committee

**SIA:** Semiconductor Industry Association

**SME:** Subject Matter Expert

**SMT:** Surface Mount Technology

**Supplier:** Sub-system component provider, Sub-Contractor

**SAE:** Society of Automotive & Aerospace Engineering

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Abstract

SMD plastic encapsulated tantalum capacitors have been utilized for more than 2 decades in Raytheon circuit designs across programs and business units (IDS, RMS & SAS). During that time, Failure Analysis labs. at various sites have dealt with populations of very early life component level failures, most often following assembly and CCA level power up. Analysis at the component supplier and in the lab. have revealed that plastic encapsulated Tantalum caps which require long term storage, prior to use become susceptible to moisture ingress and result in CTE related stress failures following assembly solder reflow.

Batch related failures have also been observed at Raytheon sub-tier suppliers (CCA assembly, DC-DC Converters). We will review historical data then go over details of a recent failure analysis on a SAS program. OCM’s involved with the failure investigations are now realizing that standard MSL 1 ratings for both their COTs and Mil-Tested Tantalum product lines are inadequate for companies which have very large / long build cycles. Changes have been implemented on some product lines but NOT all.

Topics Covered-
1. Review Industry Standard MSL ratings and how these impact the storage, handling and bake out requirements prior to assembly
2. History of failures & programs effected. Past findings and recommendations
3. Review a recent CCA level failure where moisture and lack of moisture control were contributors, highlighting industry lack of awareness of these issues
4. Provide best practices and Corporate level recommendations on how these device types should be handled and stored