Raytheon

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

Space and Airborne Systems

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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

Moisture sensitivity level –
IPC/JEDEC J-STD-020E

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- 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 Rating	Ambient Exposure- Mandatory Bake Prior to Reflow
MSL 6	Mandatory
MSL 5A	24 hours
MSL 5	48 hours
MSL 4	72 hours
MSL 3	168 hours
MSL 2A	4 weeks
MSL 2	1 Year
MSL 1	Unlimited

- ✓ 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***

Defines moisture barrier, handling, storage & bake out requirements

Enhanced COTS- Standard & Low ESR

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- 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

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- 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

Reference- [1] Advanced Test Methods for Up-screened Tantalum Capacitors, B. Brunette, AVX

COTS NOT suited for High Reliability Designs

Military Vs. COTS-
Construction, Sintering Process

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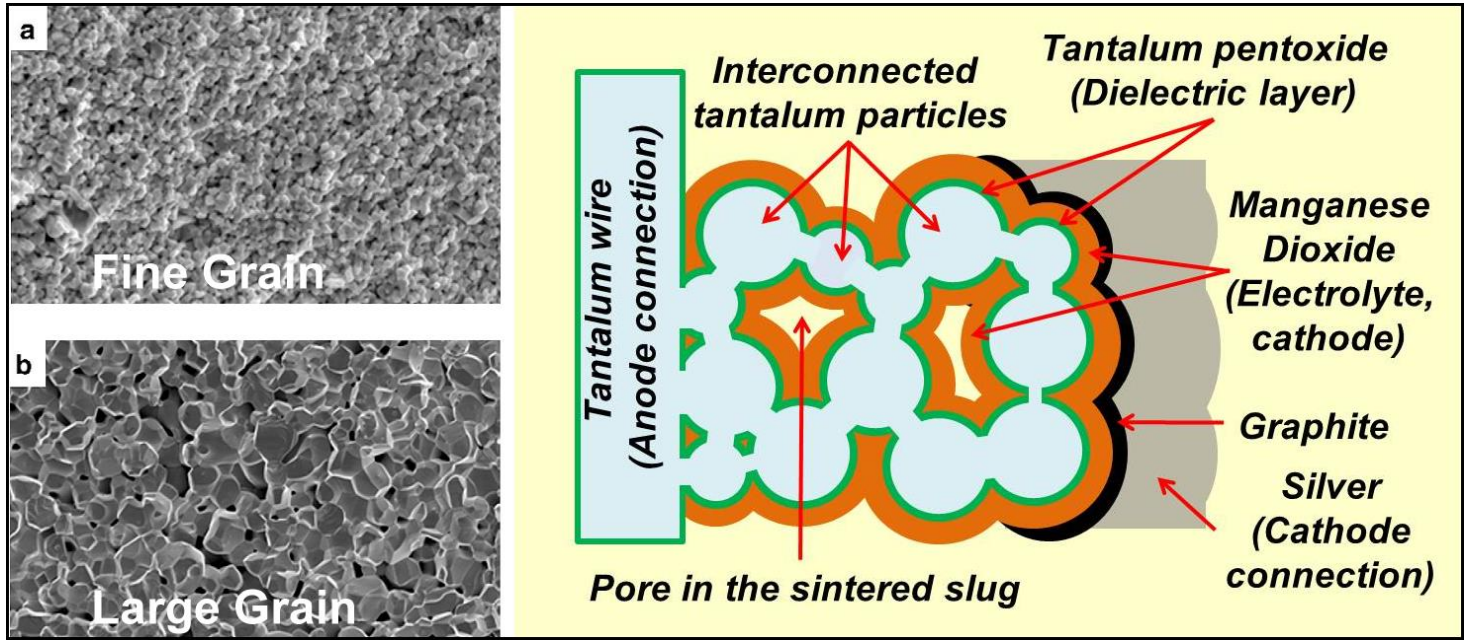
Grain Size, Effects:

- 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



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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***

Failure History at Raytheon

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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
  (4) Major Failure Investigations in 2009, 2010 & 2013
- ✓ 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

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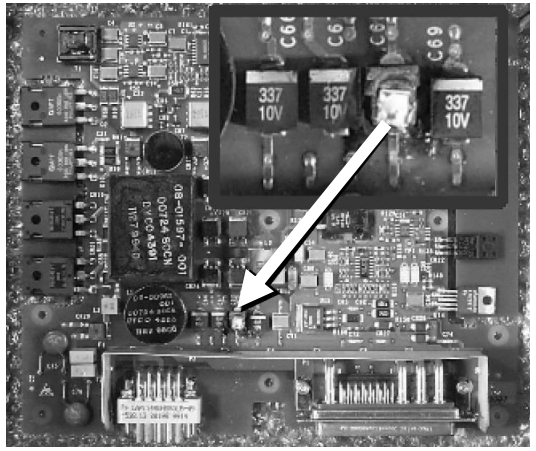
19 Supplier 1 Cap. shorts on, 15 & 28V Bus **10V** 330µf & **25V** 68µf

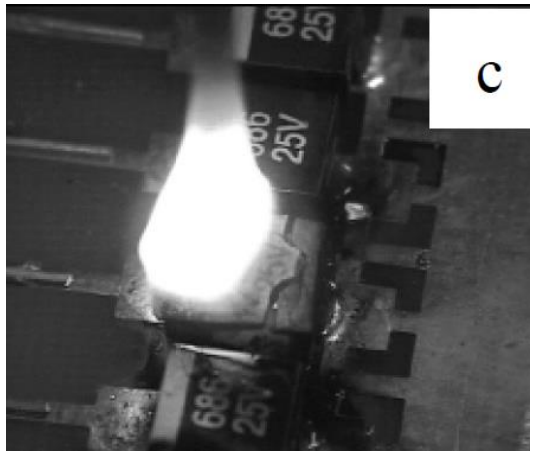
>> Components failing during ICT & Power on **>> 2.9% Failure Rate effecting 80+ CCAs**

Major Failure investigation launched

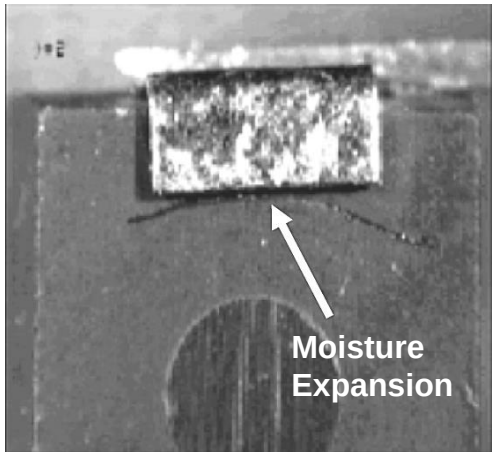
- **Circuit analysis revealed DERATING issue** (addressed)**, did not explain process failures**
- **Military, Enhanced COTS & up-screen methods compared, differences noted**
  Differences in powder & process, not communicated
- **Supplier 1 FA indicated parts acquired as MSL1, absorbed moisture with 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***



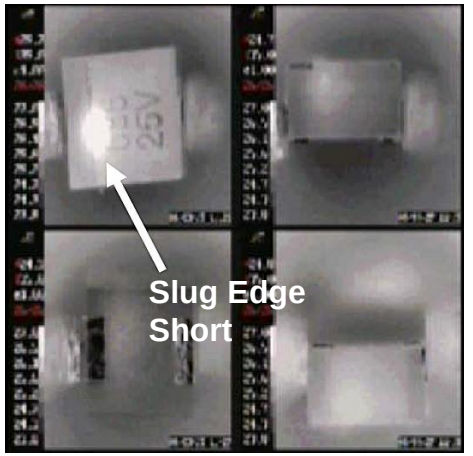
10V Line Failures



25V Bus Failures



CTE effect



IR Thermography

IDS CCA Built for RMS-
Enhanced COTS, NO Up-screening

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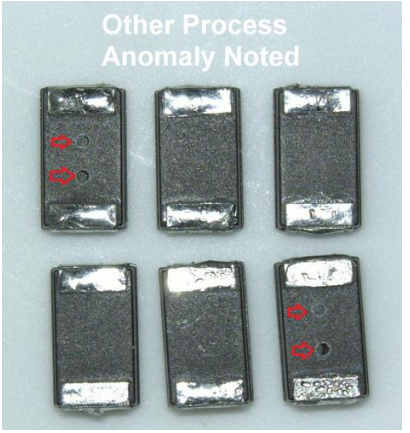
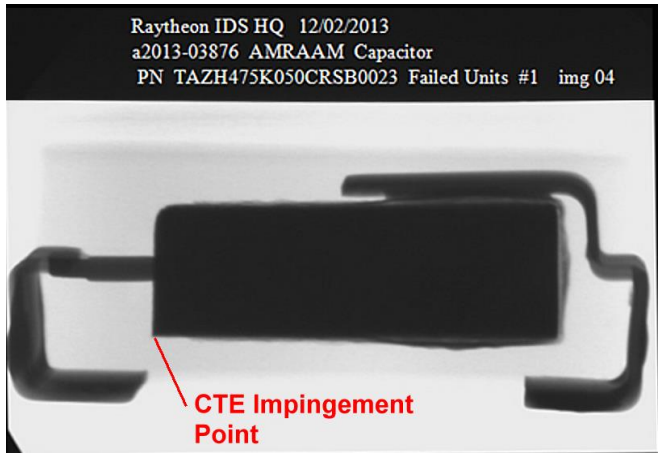


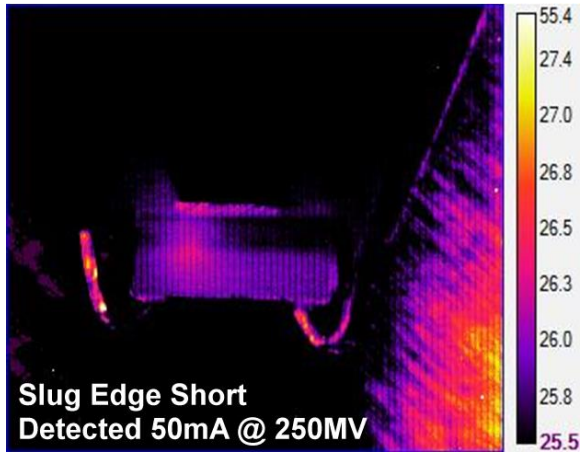
Supplier 1 Enhanced COTS Failures, post reflow

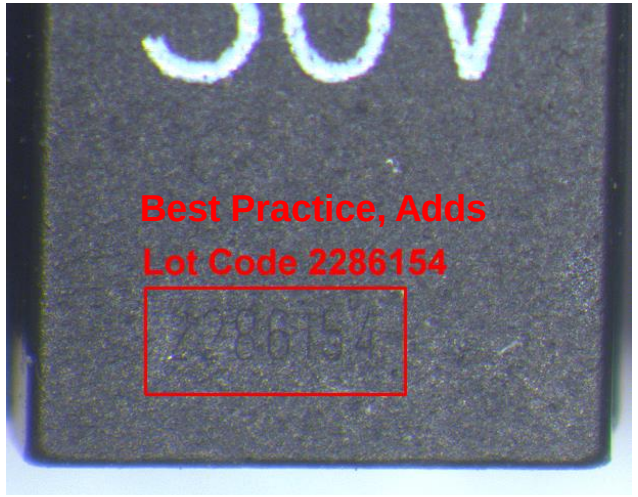
- 3 CCA P/N's failing during shorts/open, ICT & functional test
- 2009 / 2013 (2) Major Investigations **66+** failures, **35V** & **50V** Caps

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**







Storage & Handing-
COTS, Enhanced COTS Issues & Supplier 1 FA RC/CA

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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)

CR# 10-XXX:

Qty. Returned:	8	Customer P/N:	
Date Returned:	3/2/2010	Advised Failure Mode:	Short Circuit
		Date Code:	0845

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

CR# 14-YYY:

Qty. Returned:	6	Customer P/N:	
Date Returned:	3/13/2014	Advised Failure Mode:	Short Circuit
		Date Code:	

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!

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COTS Failures post solder reflow (External CCA Supplier)

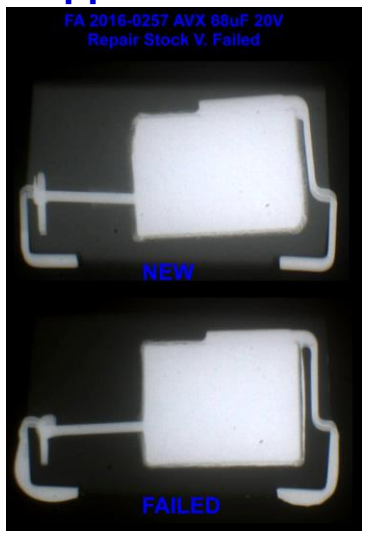
- **CCA's failing, ½ on power up, ½ ESS functional test ; REQUIRED R&R of ~122 Caps.**
- **170 CCA assemblies effected, 7 Caps. per board, potential Failure rate @ CCA test = 4.3% & @ ESS = 6%**

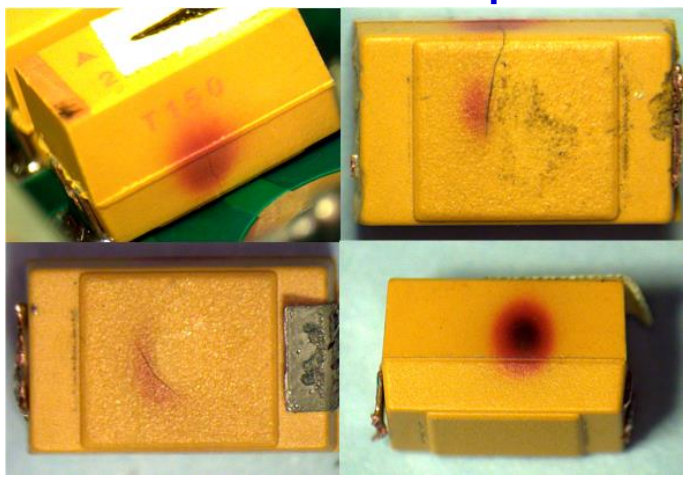
FA Lab Findings, FA & MA Recommendations

- **FA Lab results** (Physical, Electrical, X-Ray & DPA) **Consistent with moisture damage, slug edge fail site location & component body fractures**

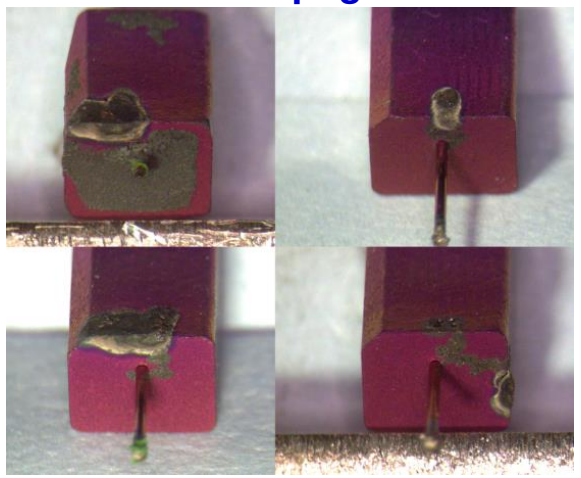
  Remediation- Power cycle built CCA's min. for 10x to remove weak parts, 5 cycles failure free

  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**

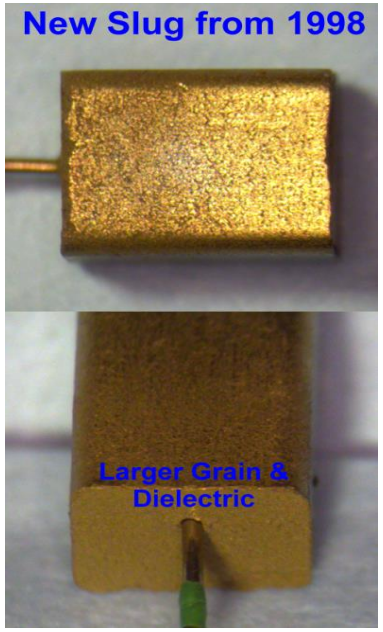




CTE "Popcorning"



Dielectric Breakdown



NASA NEPP, Moisture Sorption-
Factors in Lot Variability

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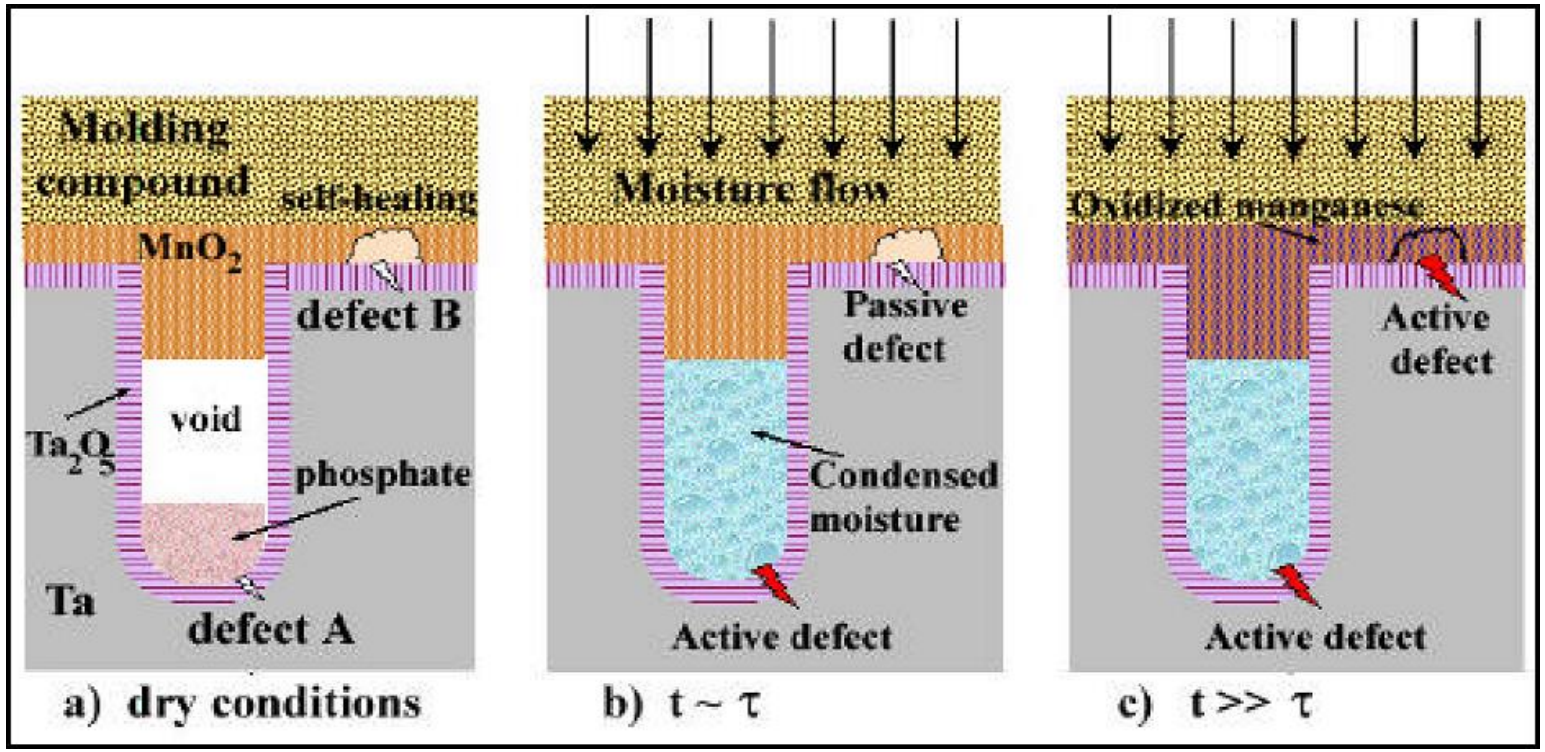
Process Contributing Factors- Elevated power on failure rates

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!



[2] A. Teverovsky, Effect of Moisture on Characteristics of Surface Mount Solid Tantalum Capacitors, 4.2.3

Conclusions / Recommendations-

Review of Failure Analyses, Best Practice Preventive Measures

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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

Conclusions / Recommendations-

Review of Failure Analyses, Best Practice Preventive Measures

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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!

References

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Cases & studies on the effects of moisture on Plastic Encapsulated Tantalum Capacitors

[1] Advanced Test Methods for Up-screened Tantalum Capacitors, COTS+ Discussion
4.30.2015 B. Brunette, AVX Corporation http://www.avx.com/docs/techinfo/COTS-Plus-Paper.pdf

[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

[4] Report on a new failure mechanism for surface mount solid tantalum capacitors
CARTS 98, J. Devaney, Principal High Rel. Labs pp. 183-187, 1998

[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

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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
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

Abstract

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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