Reliability Assurance for COTS Capacitors

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Presented by Alexander Teverovsky at the NEPP Electronics Technology Workshop (ETW), Greenbelt, MD, June 13-16, 2022.

Abstract

Burn-in (BI) and life testing (LT) are the most important reliability related elements of quality assurance for components used in space systems. This presentation discusses the need of transition from the existing approach to BI, LT, and destructive physical analysis (DPA) of COTS capacitors that is based on military specifications to an alternative approach that is based on Physics of Failure and HALT.

List of Acronyms

AF	acceleration factor	**NR**	not required
BI	burn in	**NT**	new technology
COTS	commercial off the shelf	**PoF**	physics of failure
CPTC	chip polymer tantalum capacitor	**PTC**	polymer tantalum capacitor
DLA	Defense Logistics Agency	**S&Q**	screening and qualification
DPA	destructive physical analysis	**TBD**	to be determined
FR	failure rate	**TDDB**	time dependent dielectric breakdown
HALT	highly accelerated life testing	**TTF**	time to failure
IM	infant mortality	**VR**	voltage rating
LT	life test	**WGT**	Weibull grading test
MTC	MnO2 tantalum capacitor	**WO**	wear-out

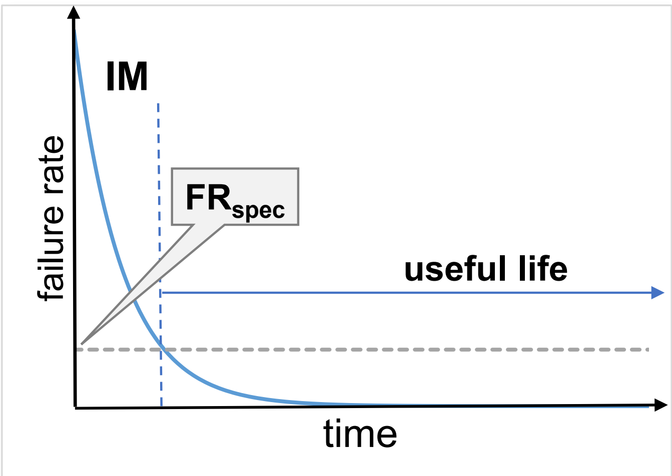
Outline

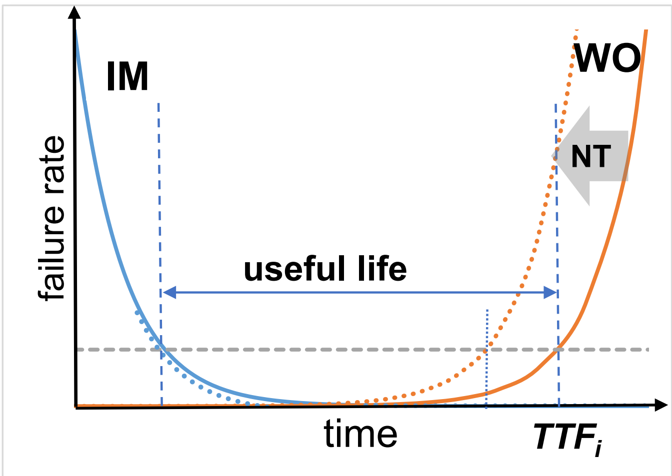
Guidelines for COTS are easy to explain but difficult to understand

- Introduction
- Explanations and attempts to understand major elements of quality assurance system for COTS capacitors:
  - Life test
  - Burn-in
  - Destructive physical analysis
  - Derating
- Conclusion

Introduction

- The level of reliability is characterized by FR.
- A trend with NT: reduction of IM and increase of WO failures.





- ✓ New technologies require new approaches for reliability assessment.
- ✓ Times to WO failures can be analyzed using PoF methodology.

Explanations/Guidelines

- The guidelines set simple rules for a given project level
- Different organizations have similar guidelines that follow MIL specifications

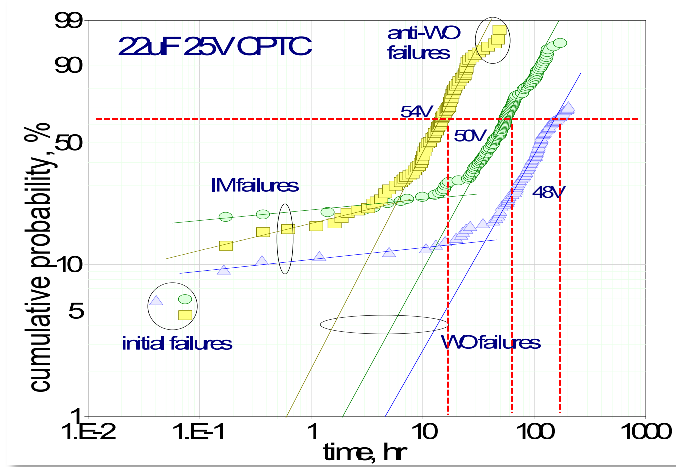
Test cond.	Ceramic	Wet Ta	Chip Ta	Poly
MIL, BI (or VC) T/V/t	**M123:** 125C/2VR/ 168hr	**M39006:** 85C/VR/ 48hr	**M55365 (WGT):** 85C/(1.1-1.52)VR/ 40hr	**M3700:** 85C/VR/ 40hr
MIL, Life Test (gr.B) T/V/t/N(F)	125C/2VR/ 1000hr/25(0)	85C/VR/ 10000hr/10(0)	WGT: 85C/(≤1.52)VR/ 40hr/300 (no limit)	85C/VR/ 2000hr/24(1)
BI, INST-002 L1 L2 L3	125C/2VR/ 168hr 96hr 48hr	85C/VR/ 160hr 96hr 48hr	85C/(1.1-1.5)VR /40hr 0.001%/1000hr 0.01% - 0.1%/1000hr 0.01% - 0.1%/1000hr	TBD
LT, INST-002 L1 L2 L3	125C/2VR 2000hr/ 45(0) 1000hr/ 45(1) NR	85C/VR AC 2000hr/ 45(0) 1000hr/ 45(1) NR	85C/VR DC 2000hr/ 45(0) 1000hr/ 45(1) NR	TBD
Derating	110C/0.6VR	70-110C/0.6-0.4VR	70-110C/0.5-0.3VR	0.8VR?

Problems with Life Testing

- <u>Purpose</u>: compliance to the rule or assessments of FR?
- What reliability do we need?
  - T-grade FR = 0.001%/1000hr = 1E-8 1/hr. → The probability that one of 10 caps fails during 20y, P(20y) = 1.7%
  - For COTS, FR = 0.1%/1000hr → P(20y) = 83%
- What results of the existing tests tell us?
  - VR, 85C, 1000hr, 45(1) for L2 → λ = 8.7%/1000hr
  - VR, 85C, 2000hr, 45(0) for L1 → λ = 2.5%/1000hr.
  - VR, 85C, 2000hr, 102(1) for M55365 → λ = 1.9%/1000hr.
- Why long-term reliable operation is still possible?
  - Calculations based on LT results are valid for random failures, actual failures are due to IM or WO
  - Derating → AFs are needed for more accurate predictions

HALT as an Alternative to Life Testing

- Both types, PTC and MTC, have WO failures. → How to model and assess useful life?



- Modified thermochemical TDDB model:

$$TTF = t_0 \times exp[B \times (u_{BR} - u)]$$

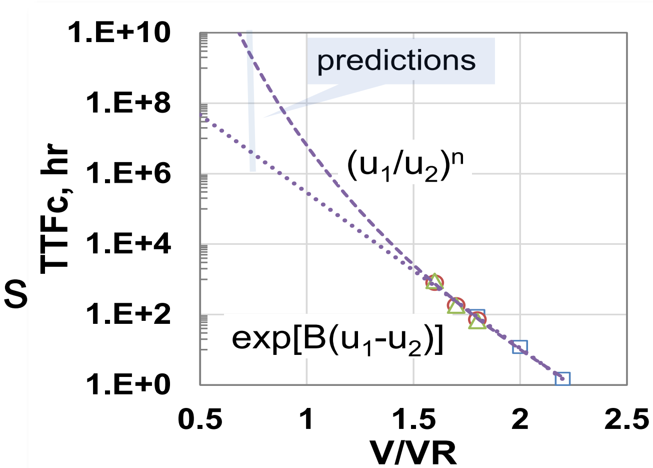
$$B = {}^{\Delta H}/_{kTu_{BR}} \qquad u = {}^{V}/_{V_{BR}}$$

$$AF_V = \exp[B \times (u_2 - u_1)]$$

- Useful life is limited by TTF_i (P=0.1%):

$$TTF_i = TTF_c(u_{op}, T_{op}) \times [-\ln(0.999)]^{1/\beta}$$

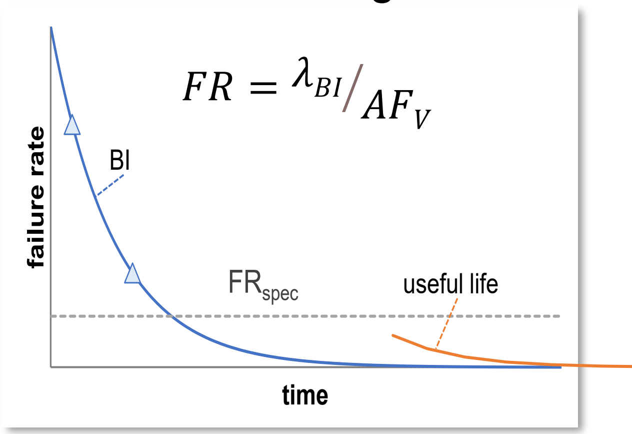
- Problems with MIL-PRF-3700:
  - Implementation of HALT
  - Power model gives too optimistic predictions
  - FR is calculated using AF_V determined for WO failures



Problems with Burn-In

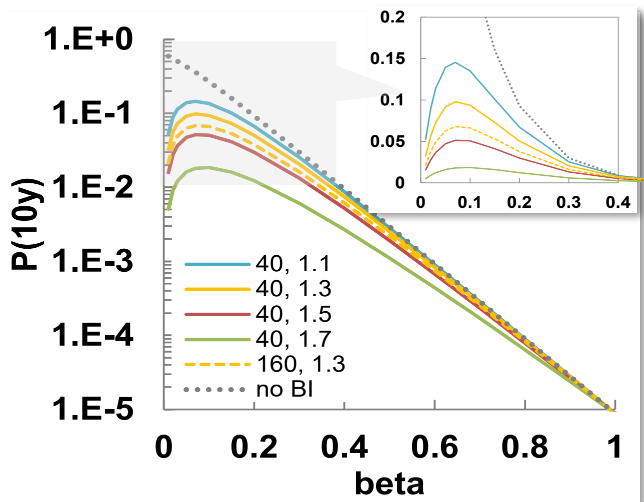
- Purpose: remove parts with defects that might cause IM failures
- WGT is a great idea for BI, but it does not work for new technology COTS
- Experience with COTS+: 3 out of 8 lots had BI failures → BI is needed

Weibull Grading Test



Conditional probability of failures during a 10-year mission, B = 15, AF= exp (B(u-1))

$$F(t) = \frac{F(t + AF \times t_{BI}) - F(AF \times t_{BI})}{1 - F(AF \times t_{BI})}$$

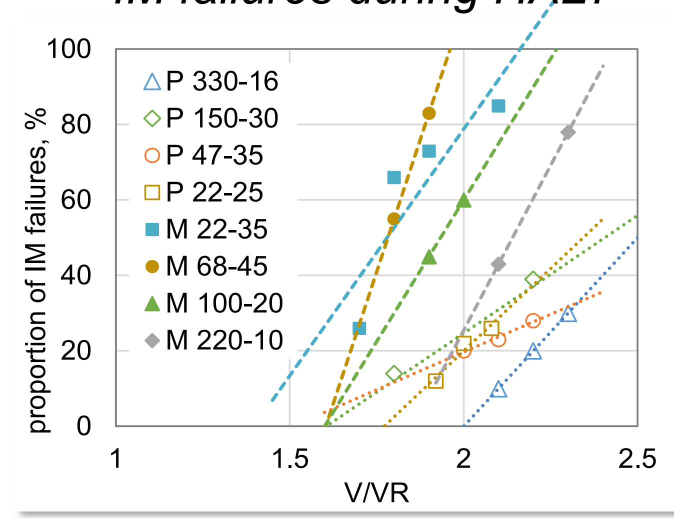


- Calculations show that the efficiency of BI increases at higher stress voltages

Problems with Burn-In, Cont'd

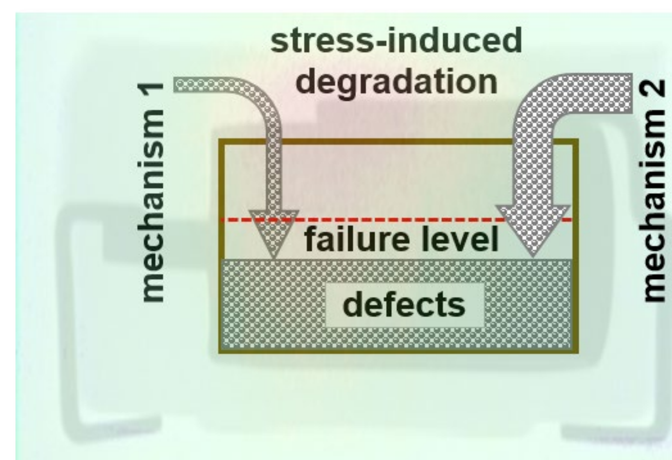
- HALT results for Ta capacitors show that the proportion of IM failures increases with the level of stress

IM failures during HALT



- Risks of using high voltages during BI:
  - Consumption of useful life
  - Creating failures that might never happen during applications

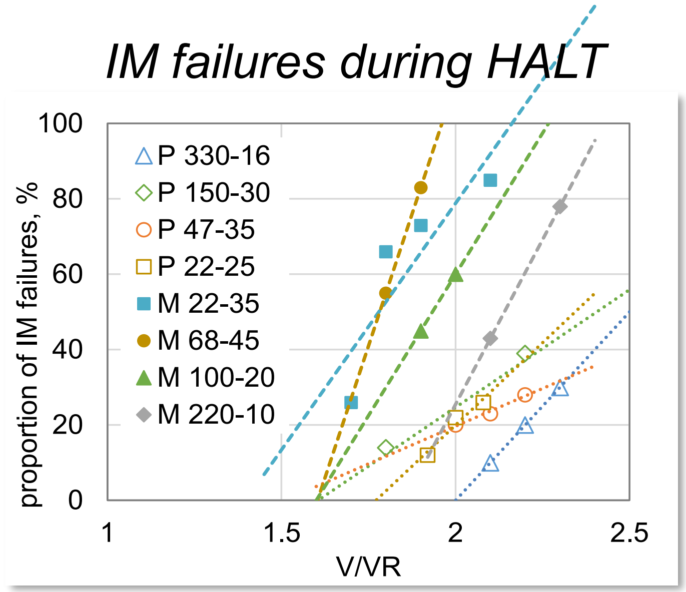
Risk of high-voltage BI



Problems with Burn-In, Cont'd

❑ HALT results for Ta capacitors show that the proportion of IM failures increases with the level of stress

IM failures during HALT



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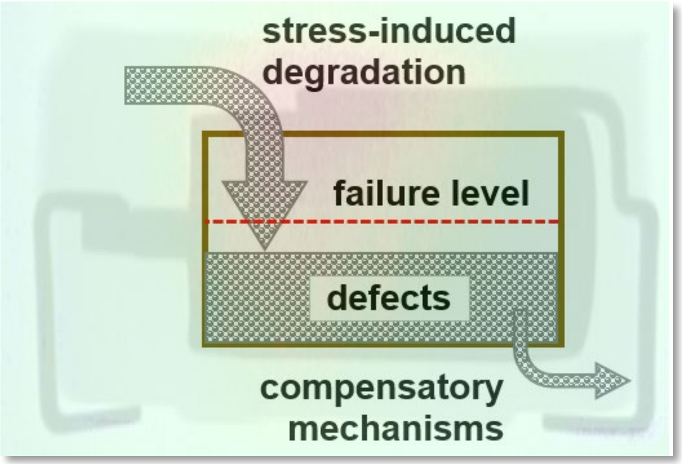
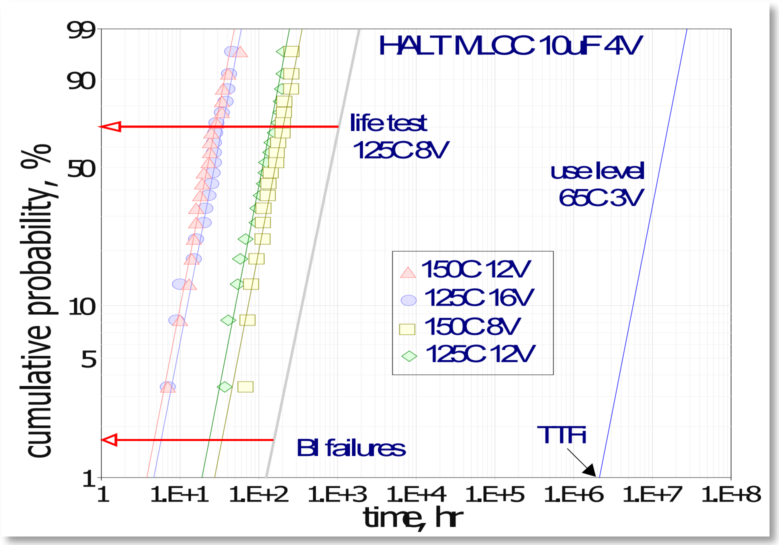
Risk of high-voltage BI

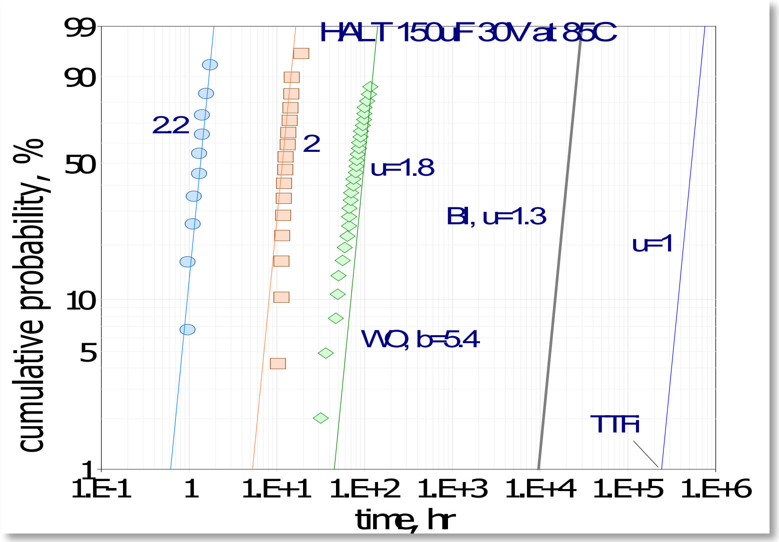


Assessments of TTF_i and Validation of BI using HALT

Modeling of WO failures in ceramic capacitors



Modeling of WO failures in polymer Ta capacitors



- The probability of failure at use conditions is <1% for 228 years
- 1.5% would fail MIL-level BI
- 70% would fail MIL-level LT

- The probability of failure at the rated conditions is <1% for 20 years
- No WO failures would happen during BI at *u* = 1.3 for 40 hours

Problems with Derating

- Purpose: reduce the stress to increase reliability
- According to guidelines, there is no difference in derating for MIL and COTS parts
- What is the reliability gain after derating?
- Can we trade voltage with temperature?
- The less we know about reliability AFs, the more derating is needed
- Manufacturers should assure FRL and provide AFs for their product; derating is a problem for users
- Special cases for derating:
  - Cracking in ceramic capacitors
  - ESR degradation and ACC in PTCs

Problems with DPA

- DPA per MIL-PRF-1580 is a set of procedures/rules for MIL-grade capacitors regarding used materials, workmanship, and acceptable defects
- MIL-PRF-1580 covers 15 types of MIL-grade and 1 type of DLA drawing capacitors
- When carried out by users, the purpose of DPA for MIL parts is verification of compliance. The rules might be not applicable for COTS capacitors
- In some cases, internal DPA requirements set by manufacturers for AEC-Q200 parts are more stringent than MIL
- For COTS, the purpose is to understand construction, materials, and possible reliability issues → DPA should be replaced with Construction Analysis

How Not to Turn Each S&Q into a Research Project?

- Research on reliability issues should be carried out separately or in parallel with the project work
- Specifics of NASA usage of COTS capacitors:
  - Interest in a particular lot
  - Each lot should be evaluated
- HALT does not take much more time than regular life testing
- Improvements of the guidelines should be work in progress
- Development of MIL standards takes 2-3 years, and the result might be far from ideal. → Work with manufacturers on development of NASA-specific SCDs

Future Work

- Metrics for ACC in PTCs
- Effect of moisture on breakdown voltages and reliability of PTCs
- Guidelines for screening qualification and derating of PTCs
- Evaluation of hermetically sealed aluminum electrolytic capacitors (with JPL)
- Evaluation of polymer multilayer (NanoLam) capacitors (with GRC)

Conclusion

- The major benefit of the existing rule-based QA system is simplicity, but it is not sufficient for COTS capacitors
- The existing approach not only impedes the use of hi-rel NT capacitors, but might reduce their useful life
- COTS capacitors might have increased risk of WO failures, so reliability should be characterized not only by FR, but also by the useful life
- Acceptable BI conditions, useful life, and reliability acceleration factors can be determined using HALT
- Derating requirements can be made based on PoF approach
- DPA for COTS should be relaced with construction analysis that suppose to reveal potential weakness in the parts and help in development of S&Q test plans