COTS Ceramic Chip Capacitors:
An Evaluation of the Parts and Assurance Methodologies

Commercialization of Military and Space Electronics Symposium
February 2004
Los Angeles, CA

Mike Sampson - NASA Goddard Space Flight Center
This Evaluation Was Performed as a Collaborative Effort
Amongst the Organizations Listed Below:
Outline

- Why Consider COTS Ceramic Chip Caps for NASA Spaceflight Applications?
- Objectives
- Experimental Approach
- Experimental Results
- Conclusions & Recommendations
### Benefits of COTS vs. MIL Established Reliability Multilayer Ceramic Chip Capacitors

<table>
<thead>
<tr>
<th>Attributes</th>
<th>COTS</th>
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<td>Capacitance Per Volume</td>
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<td>Smallest Chip Sizes</td>
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<td>Lowest Voltage Ratings</td>
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<td>Procurement Costs</td>
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**NOTE:** May **Increase Substantially** if End-User Requires Upgrade Via MIL-Type Screening / Qualification

February 2004  
COTS Ceramic Chip Capacitors Evaluation
## "Challenges" with COTS vs. MIL "ER" Multilayer Ceramic Chip Capacitors

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<td>Reliability</td>
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<td>Published Failure Rate / Established Reliability (ER) as low as 0.001% / 1000 hrs</td>
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The "Bottom Line"

February 2004 COTS Ceramic Chip Capacitors Evaluation
Objectives

- **Facts:**
  - COTS Capacitors Offer Advantages & Challenges to Designers
  - Applying MIL Screening and Qualification Methods (e.g., MIL-PRF-55681) to COTS Capacitors Can Drive “Cost of Ownership” to Levels Higher than Buying MIL Parts**

- **Objective of Evaluation:**
  - Identify (If Possible) Effective, Low Cost Methods of Assessing COTS Ceramic Capacitors for Hi-Rel MIL / Aero Applications
  - Ideally Methods Should Provide Equivalent Confidence in Reliability of COTS Parts as Similar MIL “ER” Parts

**Source:** “Cost/Benefit of Using COTS EEE Parts in Space” M. Sampson-NASA Goddard, CMSE 2002
Experimental Approach

Voltage Conditioning ("Burn-In")
Highly Accelerated Life Test (HALT)
Destructive Physical Analysis (DPA)
Ultimate Voltage Breakdown Strength
Others (e.g., CSAM, T-Shock, Low Volt 85/85) - Analysis Pending

Reliability "Metric"

Procure COTS Ceramic Capacitors

Compare Results

February 2004
COTS Ceramic Chip Capacitors Evaluation
**Ceramic Chip Capacitors Selected for Evaluation**

**Suppliers:** 4 Different Suppliers
- 2 Supply COTS Only
- 2 Supply COTS + MIL 55681

**Dielectric:** Class II - Stable
- X7R (COTS)
- BX (MIL)

**Ratings:** “Most” Cap for Rating
- Sizes: 2 (0402 and 0805)
- Voltages: Low (6.3V) to Med (50V)
- Cap: Max. Available for Size
- Temp: -55°C to 125°C

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“Control” Lots for Comparison (MIL-PRF-55681 CDR31)
2000 Hour Life Test - Reliability "Metric" for Our Evaluation

- **Test Conditions:** Standard M55681 Test Conditions
  - Sample Size 90 pcs/lot **
  - Temperature 125°C
  - Test Voltage $2 \times V_R$
  - Duration 2000 Hours

- **Acceptance Criteria**
  - Delta Cap ± 10%
  - DF per MIL Spec or Vendor Limit
  - IR > 30% of Initial MIL Spec Limit

** 162 pcs/lot Subjected to 100 Hr Voltage Conditioning Prior to Life Test. 90 VC Survivors Selected for the Life Test
## Life Test - Results

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**4 / 5 Lots with “Shorts” During Life Test Also Had “Parametric” Rejects**

February 2004

COTS Ceramic Chip Capacitors Evaluation
Life Test - Summary

- **MIL “ER” Lots - No Rejects** (as expected)

- **COTS Lots - 8 out of 15 Lots Unsatisfactory !!!**
  - 5 out of 15 Lots Suffer **SHORT** Circuit Failures
    - Shorts at 500 hrs, 1000 hrs and 2000 hrs Observed in Multiple Lots
  - 3 Additional Lots With “Parametric” Failures Through Life Test
    - Mostly Degradation of Insulation Resistance
  - At Least 1 Lot from Each COTS Supplier Showed Poor Life Test Performance

Could these Earlier and Non “Less Expensive” Tests Predict These Results of Long Term Life Tests?

February 2004 COTS Ceramic Chip Capacitors Evaluation
Voltage Conditioning - Description

- **Test Conditions:** Standard MIL-PRF- 55681 Test Conditions
  - Sample Size: 162 pcs/lot
  - Temperature: 125°C
  - Test Voltage: $2 \times V_R$
  - Duration: 100 Hours

- **Acceptance Criteria**
  - Cap Tolerance and Delta ± 10%
  - DF per MIL Spec or Vendor Limits
  - IR per MIL Spec Limits (May Differ from Vendor Data Sheet)

**NOTE:** Parts that “Passed” Voltage Conditioning were Used In the Life Test Group

February 2004  COTS Ceramic Chip Capacitors Evaluation
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**4 / 5 Lots with “Shorts” During Life Test Also Have “Parametric” Rejects**

February 2004  
COTS Ceramic Chip Capacitors Evaluation
Voltage Conditioning - Summary

- **MIL "ER" Lots** - **No Rejects** During Voltage Conditioning (as expected)

- **COTS Lots** - 5 / 15 Lots Have A "Few" Rejects
  - 2 / 15 Lots Have **Shorts** During Voltage Conditioning but 5 / 15 have Shorts During Life Test
  - 4 / 15 Lots Have a "Few" Parametric Rejects (e.g., IR, Cap, DF)

- **DISTURBING Revelation:**
  - 100 Hr Voltage Conditioning @ 2 x Vrated Failed to Eliminate Subsequent Life Test Failures

Traditional MIL Voltage Conditioning may NOT Be a Reliable Screen for COTS Ceramic Chip Capacitors
Highly Accelerated Life Test (HALT) - Description

- **Test Conditions:**
  - Sample Size: 30 pcs / lot
  - Temperature: 140°C
  - Test Voltage: 6 \times V_R \quad \text{for } V_R < 50 \text{ Volts}
  \quad 8 \times V_R \quad \text{for } V_R = 50 \text{ Volts}
  - Duration: 240 Hours MAX.
  - Record: "Catastrophic" Failures vs. Time to Fail

- **Criteria:**
  - Comparative Analysis of "Catastrophic" Failures in Time
Highly Accelerated Life Test (HALT) - Results

- Supplier A = Green
  - A-3900pF-50V-0402
  - A-0.47uF-16V-0805
  - B-0.1uF-50V-0805
  - C-1uF-10V-0805
  - D-1500pF-50V-0402
  - E-0.018uF-50V-0805

- Supplier B = Black
- Supplier C = Blue
  - A-0.1uF-50V-0805
  - B-5600pF-16V-0402
  - C-0.039uF-6.3V-0402
  - C-0.12uF-50V-0805
  - D-1uF-6.3V-0805
  - F-0.018uF-50V-0805

- Supplier D = Red

- Supplier E = Plum
  - A-0.022uF-16V-0402
  - B-3900pF-50V-0402
  - C-4700pF-50V-0402

- Supplier F = Pink
  - D-0.01uF-6.3V-0402
  - D-0.1uF-50V-0805

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COTS Ceramic Chip Capacitors Evaluation
## HALT vs. Life Test - Results

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### Observations:

- **Strong Relationship Between HALT & Life Test Performance**
  - Not 100% Correlation
  - 1/10 “Good” had 1 Short at 2000 Hr Life

- **HALT Shows “Merit” as Lot Acceptance Test**
  - Low Cost (except NRE)
  - Short Duration
  - Small Sample Size

**February 2004**

COTS Ceramic Chip Capacitors Evaluation
Highly Accelerated Life Test (HALT) - Recommendations

- Use HALT as a "Pre-Qualification" Discriminator of "Good" vs. "Poor" Quality Lots
  - Provides Relatively Quick / Inexpensive Way to Weed Out "Poor Lots" BEFORE Conducting More Time Consuming and Expensive Screen / Qual Test Protocols

- HALT Methodology Needs More Evaluation to Establish Quantitative Pass/Fail Criteria
  - Appropriate Test Conditions (Voltage, Temperature, Duration)
  - Acceleration Factors
  - Activation Energies
Destructive Physical Analysis (DPA)

- **Test Condition**: 5 pcs / Lot
  - Standard Cross Section
  - Optical Microscopy + SEM

- **Criteria**:
  - Identify Construction Attributes
    - Electrode Design
      - Base Metal Electrode (BME) vs. Precious Metal Electrode (PME)
    - Dielectric Thickness
    - Termination Integrity
  - Inspect for Defects
    - Cracks
    - Delaminations
    - Voids
    - Dielectric Porosity
    - Inclusions/Impurities
DPA - Representative Images

COTS

Thinner Dielectric
- e.g., 0.46 mil 50V Design

Mostly Uniform Dielectric

Porous Frit

Thin Termination

MIL

Thicker Dielectric
- e.g., 0.82 mil 50V Design

Very Uniform Dielectric

Uniform Frit

Good Termination

February 2004

COTS Ceramic Chip Capacitors Evaluation
### DPA / Capacitor Design Attributes vs. Life Test Results**

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**Analysis of DPA Results is STILL IN PROGRESS**

February 2004  

**NASA EEE Parts Program**
DPA Analysis is STILL IN PROGRESS. Preliminary Review Suggests:

- **COTS BME / PME (Electrode Design) vs. Life Test**
  - No Obvious Trend -- 5 / 10 BME Fail Life; 3 / 5 PME Fail Life

- **Design “CV” (Cap x Volt Rating) vs. Life Test**
  - More Analysis Needed Before We Understand if this is a Useful “Indicator” of Long Term Performance
  - Results (for 0402 chip sizes in particular) Suggest Some Higher CV Designs are Less Reliable

- **Design “Volts / mil” vs. Life Test**
  - No Trend

- **Continue to Use DPA as a “First Cut” to Eliminate “Poor” Lots from Further Consideration**
  - Can Save Time and $$$
  - However, “Passing” DPA Does Not Necessarily Predict Reliable Long-Term Performance
Dielectric Voltage Breakdown Strength

- **Test Conditions:** Non-Std Lot Characterization
  - Sample Size: 20 pcs / lot
  - Voltage Ramp Rate: 10 V/sec Approx.
  - Test to "Destruction"

- **Criteria:**
  - Read & Record Ultimate Voltage Breakdown Strength
  - Comparative Analysis of Results
Dielectric Voltage Breakdown Strength vs. Rated Voltage

LEGEND:

▲ = COTS Lot - Failed Life Test
◇ = COTS Lot - Borderline Life Test
◇ = COTS Lot - Passed Life Test
□ = MIL Lot - Passed Life Test
## Dielectric Voltage Breakdown Strength vs. Life Test

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- No "Correlation" Between VBS vs. Life Test
- VBS Not Recommended as a Reliability Indicator
Conclusions - Parts

For the Ceramic Chip Capacitors Evaluated:

- **MIL “ER” Lots - Performance is “Excellent”**
  - No Reliability Problems Found During Evaluation
  - Procure and “Use As-Is” Recommendation Supported

- **COTS Lots - Performance is “Variable”**
  - Several Lots Perform **Excellently!!!**
  - But Some Lots Perform **Poorly!!!**
  - Procure and “Use As-Is” Recommendation **NOT** Supported By This Evaluation

*For COTS a Balance Among*
Conclusions - Assurance Methodologies

- **Voltage Conditioning**
  - Concern: Std Voltage Conditioning Not Sufficient Screen for COTS
  - May Be "Value-Added" When Used in Conjunction with 2000 Hour Life Test

- **HALT** Offers a "Good" (NOT Perfect) Predictor of Long Term Reliability
  - Potentially High "Cost / Time-Savings" When Used for "Pre-Qual"
  - We Need to Learn More About HALT

- **Destructive Physical Analysis** Can Offer Insight into Quality of Lot
  - "Value-Added" When Used for "Pre-Qual" Lot Assessment
  - More Analysis of "COTS Design Attributes" Needed

- **Dielectric Voltage Breakdown Strength** Shows No Correlation to
  Long Term Reliability
  - Low "Value-Added"
"Preliminary" Recommendations - Ceramic Caps For Critical Applications

Step 1: Characterize Lot

DO NOT USE

DPA

NO

Pass?

YES

HALT

NO

YES

Pass?

NO

YES

USE "As-Is" M55681 or M123 types

Step 2: Screen / Qualify Lot

Screen (100%) Qual (Sample)

Voltage Conditioning & Life Test

Pass?

NO

YES

DO NOT USE

USE Screened Parts

February 2004

COTS Ceramic Chip Capacitors Evaluation
What’s Next?

- Refine Analysis of Data Presented Herein
  - Analyze BME vs. PME for “Subtle” Reliability Indications that May Have Escaped this Initial “Coarse” Analysis

- Analyze Data from “Other” Tests Conducted as Part of this Eval
  - Low Voltage 85/85
  - Thermal Shock
  - CSAM
  - etc.

- Evaluate Other “Conditions” for Voltage Conditioning
  - Higher vs. Lower Volts
  - Shorter vs. Longer Duration

- Further “Exploration” of HALT as a Lot Assessment Tool
Contact Information

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http://nepp.nasa.gov/nepag

February 2004  
COTS Ceramic Chip Capacitors Evaluation
Limitations of Experiment

- **Con:** Could have included COTS of same cap/volt/size as MIL “ER” parts tested for a “1-to-1” comparison of COTS design rules vs. MIL design rules

- **Counter:** Selection of COTS instead of MIL for Hi-Rel is most often to take advantage of higher volumetric efficiency. Therefore… Picking MOST cap in the package made sense