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
Participating Organizations

This Evaluation Was Performed as a Collaborative Effort Amongst the Organizations Listed Below:

NASA

NAVSEA

JPL

THE AEROSPACE CORPORATION

QSS

QSS Group, Inc.
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>
<th>MIL (ref: M55681)</th>
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<td>Capacitance Per Volume</td>
<td>High</td>
<td>Low</td>
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<td>Smallest Chip Sizes</td>
<td>0402, 0201 (Common) 01005 (Coming Soon!?)</td>
<td>0805 (Smallest Available)</td>
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<tr>
<td>Lowest Voltage Ratings</td>
<td>6.3 Volts</td>
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<td># of Sources</td>
<td>Numerous</td>
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<td>Delivery-Time</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**

<table>
<thead>
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<th>Attributes</th>
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<th>MIL (ref: M55681)</th>
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<td>Vendor Design Rules</td>
<td>Variable --&gt; Aggressive</td>
<td>Stable --&gt; Conservative</td>
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<td>Qualification Basis</td>
<td>Non-Standardized / Varies by Vendor &amp; Product</td>
<td>Standardized / User-Involvement</td>
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<td>Process Change</td>
<td>Without Notice</td>
<td>Requires Re-Qualification / Notification</td>
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<td>Reliability</td>
<td>???</td>
<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**

February 2004 COTS Ceramic Chip Capacitors Evaluation
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

Comparison Results

Produce COTS Ceramic Capacitors

Reliability "Metric"
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

"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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<th>Mfr</th>
<th>Lot #</th>
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**4 / 5 Lots with “Shorts” During Life Test Also Had “Parametric” Rejects**

February 2004

COTS Ceramic Chip Capacitors Evaluation
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 results and/or "less expensive" Tests Predict these Results of Long Term Life Tests?
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 $\pm 10\%$
  - 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
# Voltage Conditioning vs. Life Test - Results

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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
Highly Accelerated Life Test (HALT) - Description

- **Test Conditions:**
  - Sample Size: 30 pcs / lot
  - Temperature: 140°C
  - Test Voltage: \[6 \times V_R\] for \(V_R < 50\) Volts, \[8 \times V_R\] for \(V_R = 50\) 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
Supplier B = Black
Supplier C = Blue
Supplier D = Red
Supplier E = Plum
Supplier F = Pink

- △ 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

- □ 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

- ◇ A-0.022uF-16V-0402
- ◇ B-3900pF-50V-0402
- ▲ C-4700pF-50V-0402
- ● D-0.01uF-6.3V-0402
- ◇ D-0.1uF-50V-0805

Cum. % Failures

0% 25% 50% 75% 100%

0 50 100 150 200 250

Hours

February 2004

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

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<th>Mfr</th>
<th>Lot #</th>
<th>Cap (μF)</th>
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- **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 50 V Design

Very Uniform Dielectric

Uniform Frit

Good Termination

February 2004

COTS Ceramic Chip Capacitors Evaluation
<table>
<thead>
<tr>
<th>Mfr</th>
<th>Lot #</th>
<th>Cap (uF)</th>
<th>Rated Voltage (V)</th>
<th>Size</th>
<th># of Electrodes</th>
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February 2004 ** Analysis of DPA Results is STILL IN PROGRESS **
DPA - Summary

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:**
  - 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

Rated Voltage (Volts)

Dielectric Breakdown Strength (Volts/mil)
## Dielectric Voltage Breakdown Strength vs. Life Test

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<th>Mfr</th>
<th>Lot #</th>
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- No "Correlation" Between VBS vs. Life Test
- VBS Not Recommended as a Reliability Indicator

February 2004 COTS Ceramic Chip Capacitors Evaluation
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

- DPA
  - NO
    - DO NOT USE
  - YES
    - HALT
      - NO
        - DO NOT USE
      - YES
        - Pass?

Step 2: Screen / Qualify Lot

- Screen (100%)
- Qual (Sample)
  - Voltage Conditioning
  - Life Test

- NO
  - Pass?
    - NO
      - DO NOT USE
    - YES
      - USE Screened Parts

MIL Caps?
- NO
  - USE "As-Is" M55681 or M123 types
- YES
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

Mike Sampson
NASA Goddard Space Flight Center
301-286-3335
Michael.J.Sampson@nasa.gov

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Jay Brusse
QSS Group, Inc.

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The Aerospace Corporation

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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