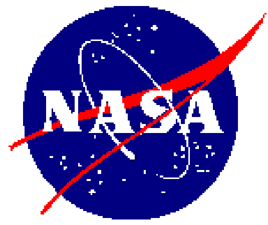
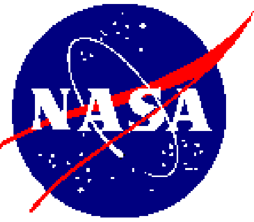


COTS Ceramic Chip Capacitors:

An Evaluation of the Parts and Assurance Methodologies

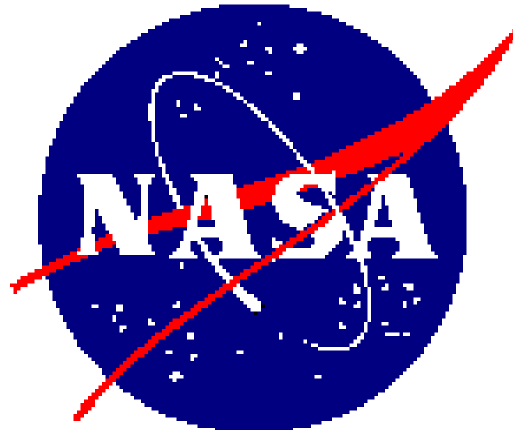
Capacitor and Resistor Technology Symposium
March/April 2004
San Antonio, TX

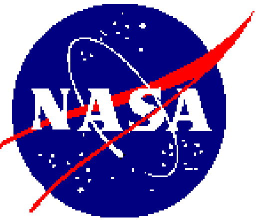
Jay Brusse – QSS Group, Inc. @ NASA Goddard



Participating Organizations

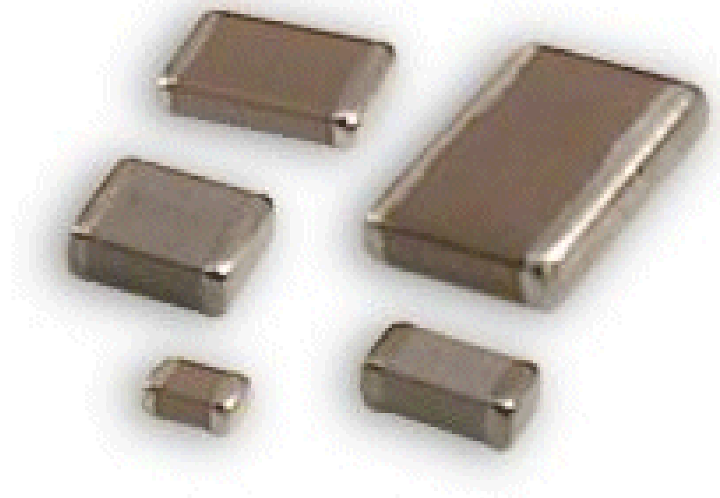
This Evaluation Was Performed as a Collaborative Effort Amongst the Organizations Listed Below:

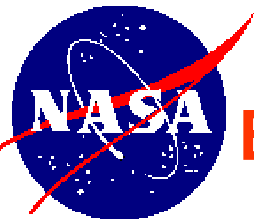




Outline

- Why Consider COTS Ceramic Chip Caps for NASA Spaceflight Applications?
- Objectives
- Experimental Approach
- Experimental Results
- Conclusions & Recommendations



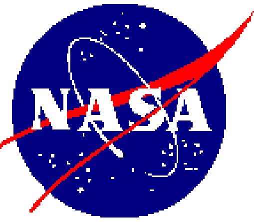


Benefits of COTS vs. MIL Established Reliability

Multilayer Ceramic Chip Capacitors

Attributes	COTS	MIL (ref: M55681)
Capacitance Per Volume	High	Low
Smallest Chip Sizes	0402, 0201 (Common) 01005 (Coming Soon!?)	0805 (Smallest Available)
Lowest Voltage Ratings	6.3 Volts	50 Volts
# of Sources	Numerous	Very Few
Delivery-Time	Days to Weeks	Weeks to Months
Procurement Costs	Pennies/Part	Dollars/Part

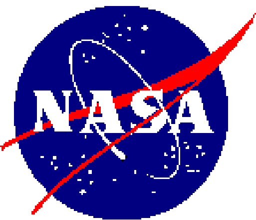
NOTE: May **Increase Substantially** If End-User Requires Upgrade Via MIL-Type Screening / Qualification



"Challenges" with COTS vs. MIL "ER" Multilayer Ceramic Chip Capacitors

Attributes	COTS	MIL (ref: M55681)
Vendor Design Rules	Variable --> Aggressive	Stable --> Conservative
Qualification Basis	Non-Standardized / Varies by Vendor & Product	Standardized / User-Involvement
Process Change	Without Notice	Requires Re-Qualification / Notification
Reliability	???	Published Failure Rate / Established Reliability (ER) as low as 0.001% / 1000 hrs

The "Bottom Line"

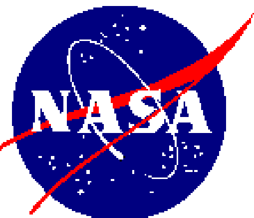


Objectives

- **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



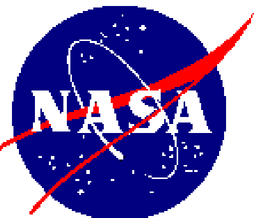
Experimental Approach

Procure **COTS** Ceramic Capacitors → Reliability "Indicator" Tests:

- 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

→ Compare Results

Procure **COTS** Ceramic Capacitors → Reliability "Metric" — **2000 Hour Life Test** → Compare Results

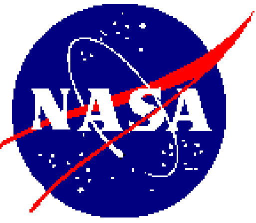


Ceramic Chip Capacitors Selected for Evaluation

- **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)

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	Dielectric Type
COTS	A	1	0.0039	50	0402	X7R
		2	0.1000	50	0805	
		3	0.0220	16	0402	
		4	0.4700	16	0805	
	B	5	0.0056	16	0402	
		6	0.0039	50	0402	
		7	0.1000	50	0805	
	C	8	0.0390	6.3	0402	
		9	0.0047	50	0402	
		10	1.0000	10	0805	
		11	0.1200	50	0805	
	D	12	0.0100	6.3	0402	
		13	0.0015	50	0402	
		14	1.0000	6.3	0805	
		15	0.1000	50	0805	
MIL	E	16	0.0180	50	0805	BX
	F	17	0.0180	50	0805	



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 x V_R**
  - Duration 2000 Hours

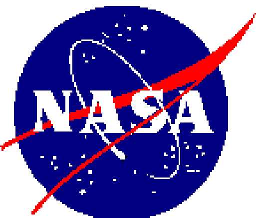
- **Acceptance Criteria**
  - Delta Cap ± 10%
  - DF per MIL Spec or Vendor Limit
  - IR > 30% of Initial MIL Spec Limit

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

Life Test - Results

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	500 Hrs Life Test	1000 Hrs Life Test	2000 Hrs Life Test	*Life Test Disposition*
COTS	A	1	0.0039	50	0402	Parametric	Parametric	Parametric	*Borderline*
		2	0.1000	50	0805	Pass	Pass	Pass	*Pass*
		3	0.0220	16	0402	Pass	Parametric	Parametric	*Borderline*
		4	0.4700	16	0805	Pass	Pass	Pass	*Pass*
	B	5	0.0056	16	0402	Pass	Pass	Pass	*Pass*
		6	0.0039	50	0402	Pass	Pass	Parametric	*Borderline*
		7	0.1000	50	0805	Pass	Pass	1 Short	*Fail*
	C	8	0.0390	6.3	0402	Pass	Pass	Pass	*Pass*
		9	0.0047	50	0402	Parametric	1 Short	12 Shorts	*Fail*
		10	1.0000	10	0805	1 Short	Parametric	Parametric	*Fail*
		11	0.1200	50	0805	1 Short	1 Short	1 Short	*Fail*
	D	12	0.0100	6.3	0402	Pass	Pass	Pass	*Pass*
		13	0.0015	50	0402	Pass	Pass	Pass	*Pass*
		14	1.0000	6.3	0805	1 Short	2 Shorts	1 Short	*Fail*
		15	0.1000	50	0805	Pass	Pass	Pass	*Pass*
MIL	E	16	0.0180	50	0805	Pass	Pass	Pass	*Pass*
	F	17	0.0180	50	0805	Pass	Pass	Pass	*Pass*

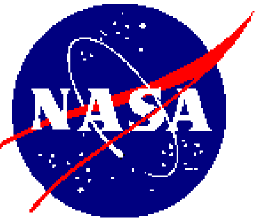
** 4 / 5 Lots with "Shorts" During Life Test Also Had "Parametric" Rejects



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 "Faster" and / or "Less Expensive" Tests Predict these Results of Long Term Life Test?

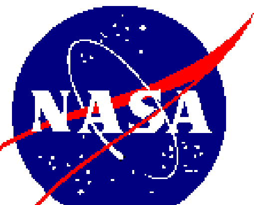


Voltage Conditioning - Description

- **Test Conditions:** **Standard MIL-PRF- 55681 Test Conditions**
  - Sample Size: 162 pcs/lot
  - Temperature **125°C**
  - Test Voltage **2 x 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)

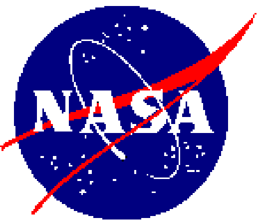
** NOTE: Parts that "Passed" Voltage Conditioning were Used In the Life Test Group



Voltage Conditioning vs. Life Test - Results

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	100 Hrs Volt Condition	500 Hrs Life Test	1000 Hrs Life Test	2000 Hrs Life Test	*Life Test Disposition*
COTS	A	1	0.0039	50	0402	Parametric	Parametric	Parametric	Parametric	*Borderline*
		2	0.1000	50	0805	Pass	Pass	Pass	Pass	*Pass*
		3	0.0220	16	0402	Pass	Pass	Parametric	Parametric	*Borderline*
		4	0.4700	16	0805	Pass	Pass	Pass	Pass	*Pass*
	B	5	0.0056	16	0402	Pass	Pass	Pass	Pass	*Pass*
		6	0.0039	50	0402	Pass	Pass	Pass	Parametric	*Borderline*
		7	0.1000	50	0805	1 Short	Pass	Pass	1 Short	*Fail*
	C	8	0.0390	6.3	0402	Pass	Pass	Pass	Pass	*Pass*
		9	0.0047	50	0402	Parametric	Parametric	1 Short	12 Shorts	*Fail*
		10	1.0000	10	0805	2 Shorts	1 Short	Parametric	Parametric	*Fail*
		11	0.1200	50	0805	Pass	1 Short	1 Short	1 Short	*Fail*
	D	12	0.0100	6.3	0402	Pass	Pass	Pass	Pass	*Pass*
		13	0.0015	50	0402	Pass	Pass	Pass	Pass	*Pass*
		14	1.0000	6.3	0805	Parametric	1 Short	2 Shorts	1 Short	*Fail*
		15	0.1000	50	0805	Pass	Pass	Pass	Pass	*Pass*
MIL	E	16	0.0180	50	0805	Pass	Pass	Pass	Pass	*Pass*
	F	17	0.0180	50	0805	Pass	Pass	Pass	Pass	*Pass*

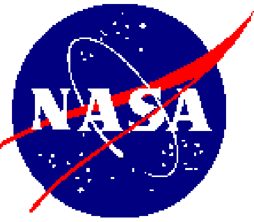
***** 4 / 5 Lots with "Shorts" During Life Test Also Have "Parametric" Rejects***



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

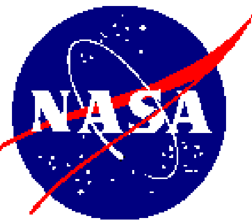


Highly Accelerated Life Test (HALT) - Description

Highly Accelerated "Destructive Test" For Eval ONLY

- **Test Conditions:**
  - Sample Size 30 pcs / lot
  - Temperature *140°C*
  - Test Voltage *6 x V_R* for V_R < 50 Volts
    8 x 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

○ = Lots With Shorts During Std Life Test

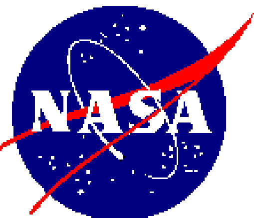
A-3900pF-50V-0402
A-0.1uF-50V-0805
A-0.022uF-16V-0402
A-0.47uF-16V-0805
B-5600pF-16V-0402
B-3900pF-50V-0402
B-0.1uF-50V-0805
C-0.039uF-6.3V-0402
C-4700pF-50V-0402
C-1uF-10V-0805
C-0.12uF-50V-0805
D-0.01uF-6.3V-0402
D-1500pF-50V-0402
D-1uF-6.3V-0805
D-0.1uF-50V-0805
E-0.018uF-50V-0805
F-0.018uF-50V-0805

Cum. % Failures

100%
75%
50%
25%
0%

0
50
100
150
200
250

Hours

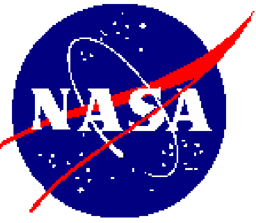


HALT vs. Life Test - Results

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	HALT	*Life Test Disposition*
COTS	A	1	0.0039	50	0402	Moderate	*Borderline*
		2	0.1000	50	0805	Good	*Pass*
		3	0.0220	16	0402	Good	*Borderline*
		4	0.4700	16	0805	Good	*Pass*
	B	5	0.0056	16	0402	Good	*Pass*
		6	0.0039	50	0402	Good	*Borderline*
		7	0.1000	50	0805	Good	*Fail*
	C	8	0.0390	6.3	0402	Good	*Pass*
		9	0.0047	50	0402	Poor	*Fail*
		10	1.0000	10	0805	Poor	*Fail*
		11	0.1200	50	0805	Poor	*Fail*
	D	12	0.0100	6.3	0402	Good	*Pass*
		13	0.0015	50	0402	Good	*Pass*
		14	1.0000	6.3	0805	Poor	*Fail*
		15	0.1000	50	0805	Good	*Pass*
MIL	E	16	0.0180	50	0805	Good	*Pass*
	F	17	0.0180	50	0805	Good	*Pass*

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

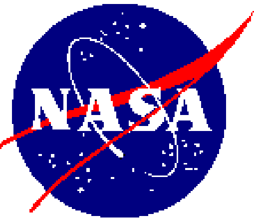
HALT Shows "Merit" as Lot Acceptance Test
- Low Cost (except NRE)
- Short Duration
- Small Sample Size



Highly Accelerated Life Test (HALT) - Recommendations

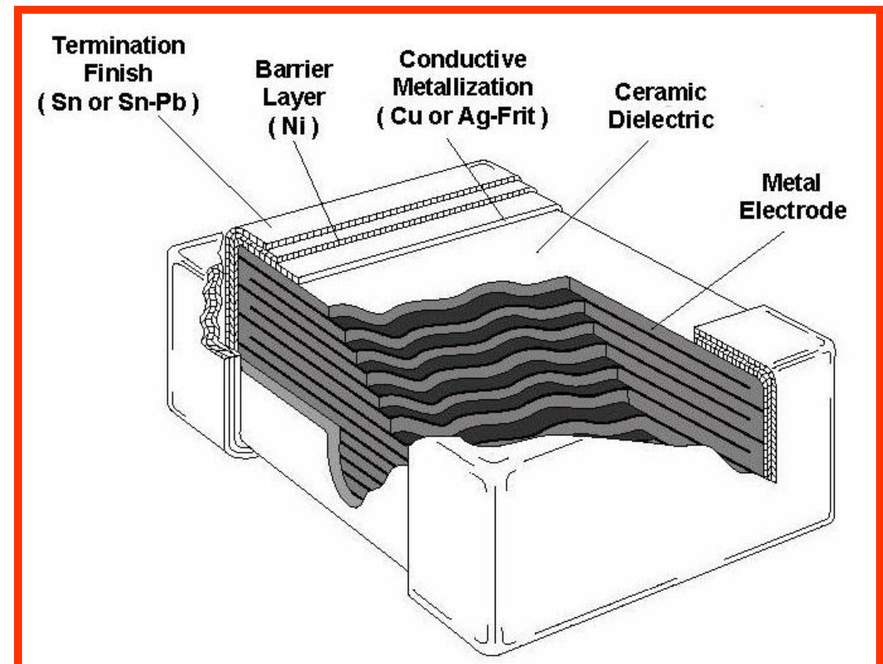
- **Use HALT as a "Pre-Qualification" Discriminator of "Good" vs. "Poor" Quality Lots**
  - Provides Relatively Quick / Inexpensive Way to Weed Out "Poor Lots" BEFORE Conducting More Time Consuming and Expensive Screen / Qual Test Protocols

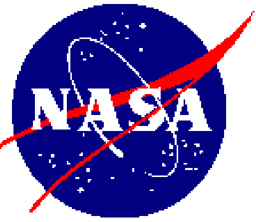
- **HALT Methodology Needs More Evaluation to Establish Quantitative Pass/Fail Criteria**
  - Appropriate Test Conditions (Voltage, Temperature, Duration)
  - Acceleration Factors
  - Activation Energies



Destructive Physical Analysis (DPA)

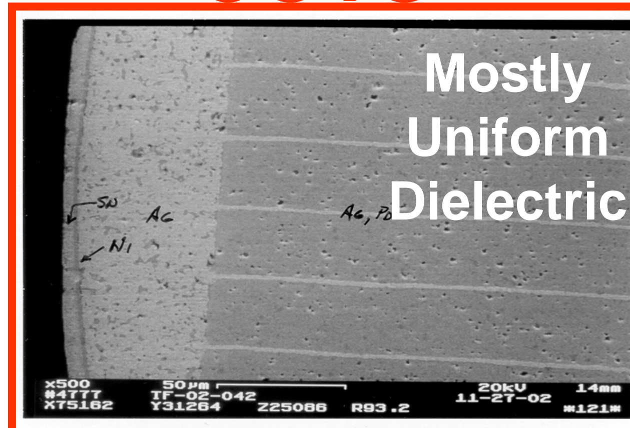
- **Test Condition:** 5 pcs / Lot
  - Standard Cross Section
  - Optical Microscopy + SEM
- **Criteria:**
  - Identify Construction Attributes
    - Electrode Design
      - Base Metal Electrode (BME) vs. Precious Metal Electrode (PME)
    - Dielectric Thickness
    - Termination Integrity
  - **Inspect for Defects**
    - Cracks
    - Delaminations
    - Voids
    - Dielectric Porosity
    - Inclusions/Impurities

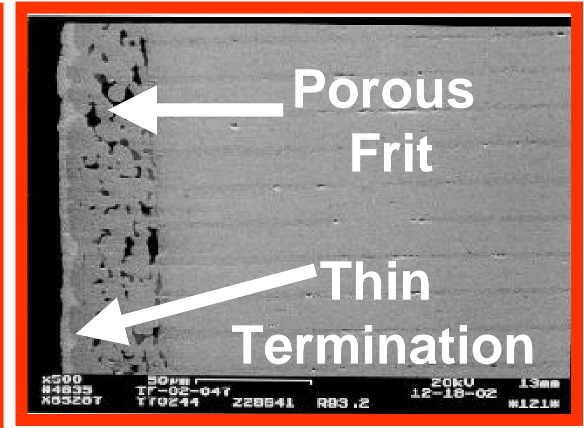




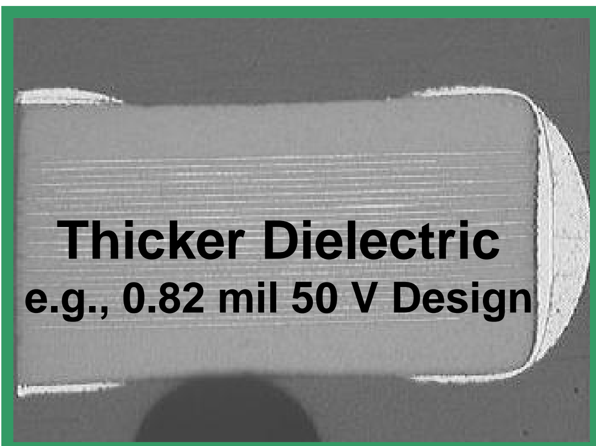
DPA - Representative Images

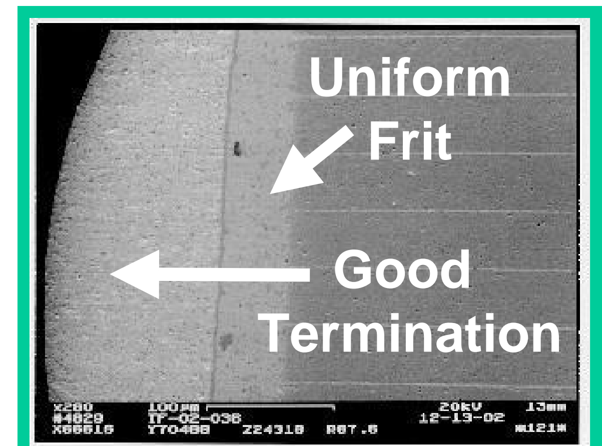
COTS

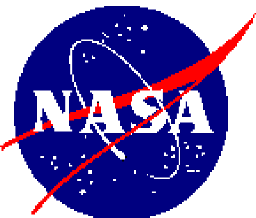




MIL





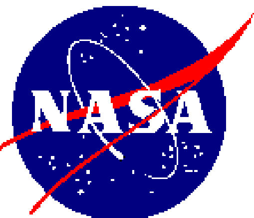


DPA Failure

Delaminations Found In
Lot C-9 (4700pF/50V – 0402)

This Lot ALSO was the WORST in Terms of:

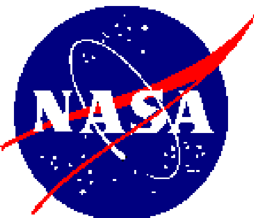
- Life Test Performance (13 Shorts)
- HALT Performance



DPA / Capacitor Design Attributes vs. Life Test-Results**

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	# of Electrodes	Electrode Type	Dielectric Thickness (mils)	Design CV (uF x V)	Design V/mil	Life Test Disposition
COTS	A	1	0.0039	50	0402	16	BME	0.54	0.20	93.0	Borderline
		2	0.1000	50	0805	39	BME	0.46	5.00	108.4	Pass
		3	0.0220	16	0402	39	BME	0.28	0.35	57.4	Borderline
		4	0.4700	16	0805	96	BME	0.36	7.52	44.7	Pass
	B	5	0.0056	16	0402	26	PME	0.56	0.09	28.6	Pass
		6	0.0039	50	0402	23	PME	0.65	0.20	77.5	Borderline
		7	0.1000	50	0805	55	PME	0.63	5.00	79.1	Fail
	C	8	0.0390	6.3	0402	40	BME	0.24	0.25	25.7	Pass
		9	0.0047	50	0402	15	BME	0.53	0.24	94.5	Fail
		10	1.0000	10	0805	120	BME	0.25	10.00	40.4	Fail
		11	0.1200	50	0805	45	BME	0.69	6.00	72.4	Fail
	D	12	0.0100	6.3	0402	29	BME	0.33	0.06	18.9	Pass
		13	0.0015	50	0402	14	BME	0.64	0.08	78.3	Pass
		14	1.0000	6.3	0805	128	PME	0.30	6.30	20.9	Fail
		15	0.1000	50	0805	39	PME	0.44	5.00	114.2	Pass
MIL	E	16	0.0180	50	0805	24	PME	0.82	0.90	60.9	Pass
	F	17	0.0180	50	0805	24	PME	1.01	0.90	49.7	Pass

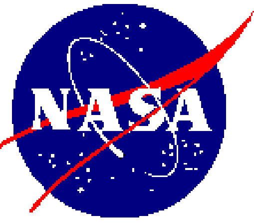
*** Analysis of DPA Results is STILL IN PROGRESS*



DPA - Summary

DPA Analysis is STILL IN PROGRESS. Preliminary Review Suggests:

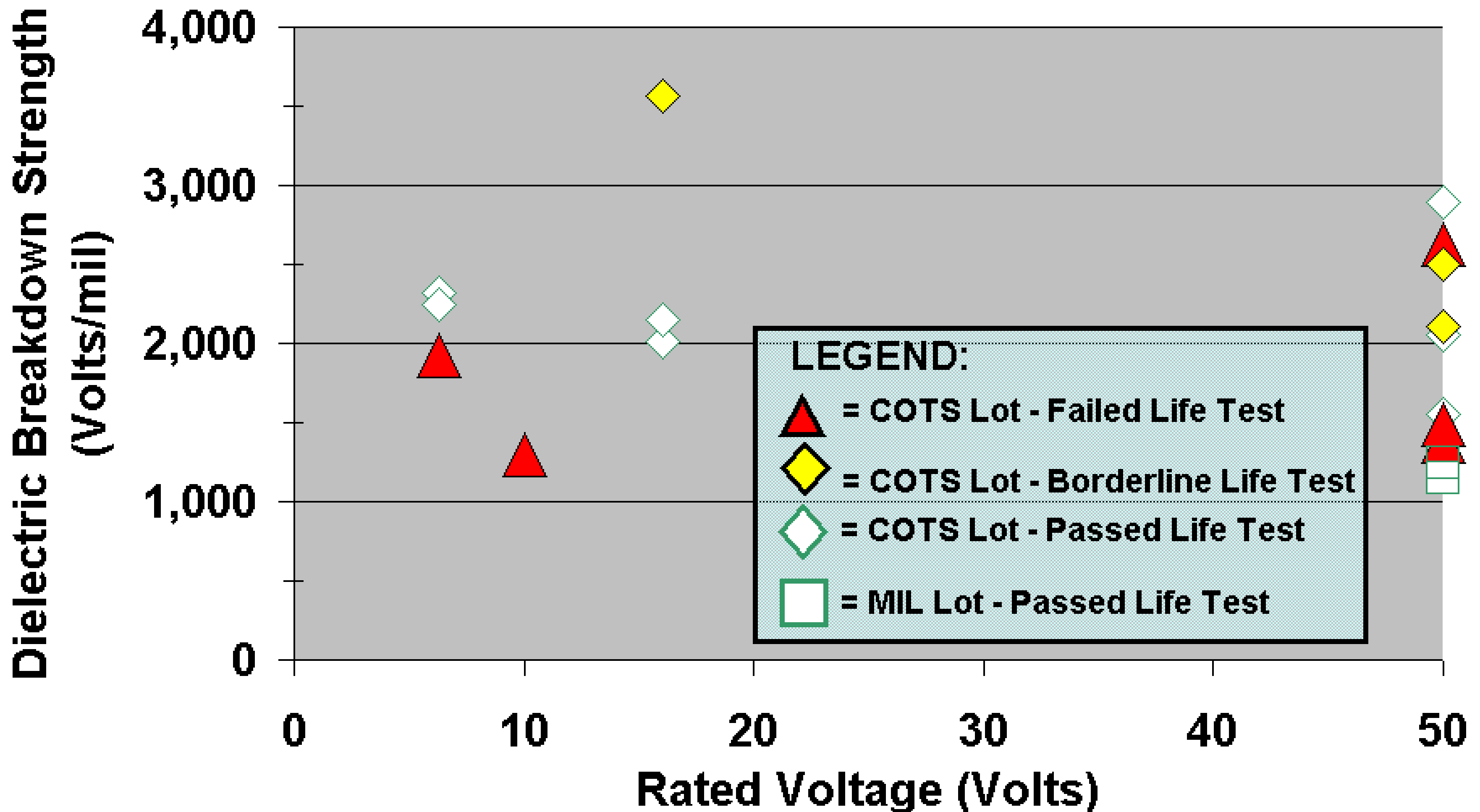
- **COTS BME / PME (Electrode Design) vs. Life Test**
  - No Obvious Trend -- 5 / 10 BME Fail Life; 3 / 5 PME Fail Life
- **Design "CV" (Cap x Volt Rating) vs. Life Test**
  - More Analysis Needed Before We Understand if this is a Useful "Indicator" of Long Term Performance
  - Results (for 0402 chip 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



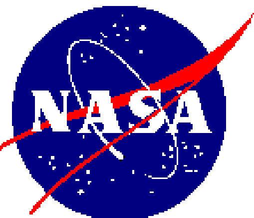
Dielectric Voltage Breakdown Strength

- **Test Conditions:** **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



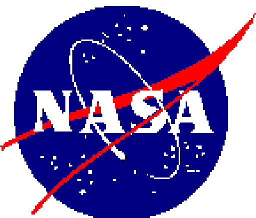
Dielectric Breakdown Strength Does *NOT* Provide A Strong Indication of "Good" vs. "Bad" Lots



Dielectric Voltage Breakdown Strength vs. Life Test

	Mfr	Lot #	Cap (uF)	Rated Voltage (V)	Size	Dielectric Breakdown Strength (V/mil)	*Life Test Disposition*
COTS	A	1	0.0039	50	0402	2497	*Borderline*
		2	0.1000	50	0805	2892	*Pass*
		3	0.0220	16	0402	3567	*Borderline*
		4	0.4700	16	0805	2007	*Pass*
	B	5	0.0056	16	0402	2146	*Pass*
		6	0.0039	50	0402	2104	*Borderline*
		7	0.1000	50	0805	1484	*Fail*
	C	8	0.0390	6.3	0402	2240	*Pass*
		9	0.0047	50	0402	2624	*Fail*
		10	1.0000	10	0805	1293	*Fail*
		11	0.1200	50	0805	1378	*Fail*
	D	12	0.0100	6.3	0402	2316	*Pass*
		13	0.0015	50	0402	1554	*Pass*
		14	1.0000	6.3	0805	1924	*Fail*
		15	0.1000	50	0805	2058	*Pass*
MIL	E	16	0.0180	50	0805	1153	*Pass*
	F	17	0.0180	50	0805	1241	*Pass*

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



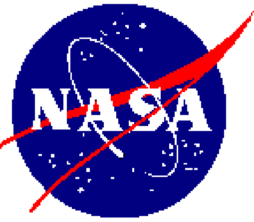
Conclusions - Parts

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

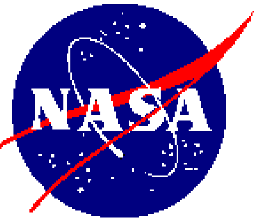
For COTS a Balance Among

Lot Characterization & Screening / Qualification is Recommended for Critical Applications



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
  - Potential "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

MIL Caps?

YES → USE "As-Is" M55681 or M123 types

NO →

Step 1: Characterize Lot

DPA

Pass? NO → DO NOT USE

YES → HALT

Pass? NO → DO NOT USE

YES →

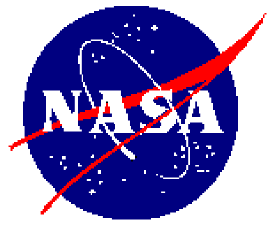
Step 2: Screen / Qualify Lot

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

Pass?

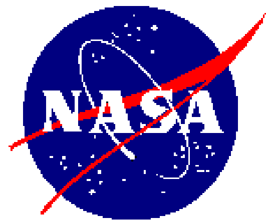
NO → DO NOT USE

YES → USE Screened Parts



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



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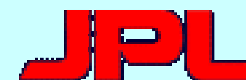

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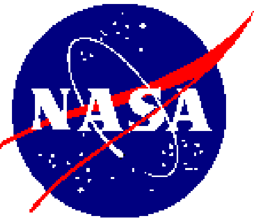

Limitations of Experiment

- **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