COTS Ceramic Chip Capacitors:

An Evaluation of the Parts and Assurance Methodologies

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Mike Sampson - NASA Goddard Space Flight Center

Participating Organizations

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

NAVSEA

NASA

JPL

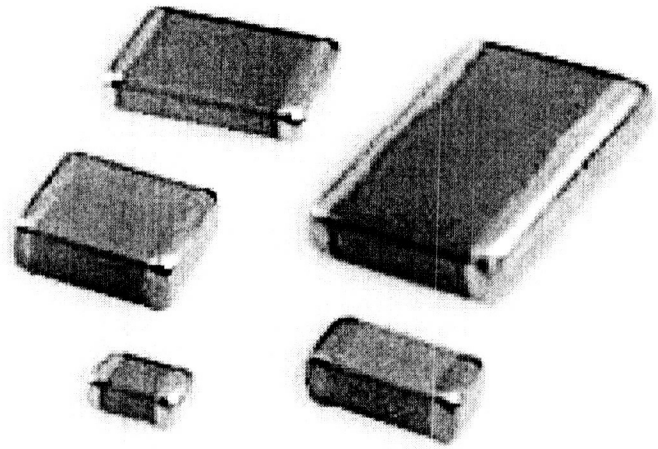
THE AEROSPACE CORPORATION

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

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

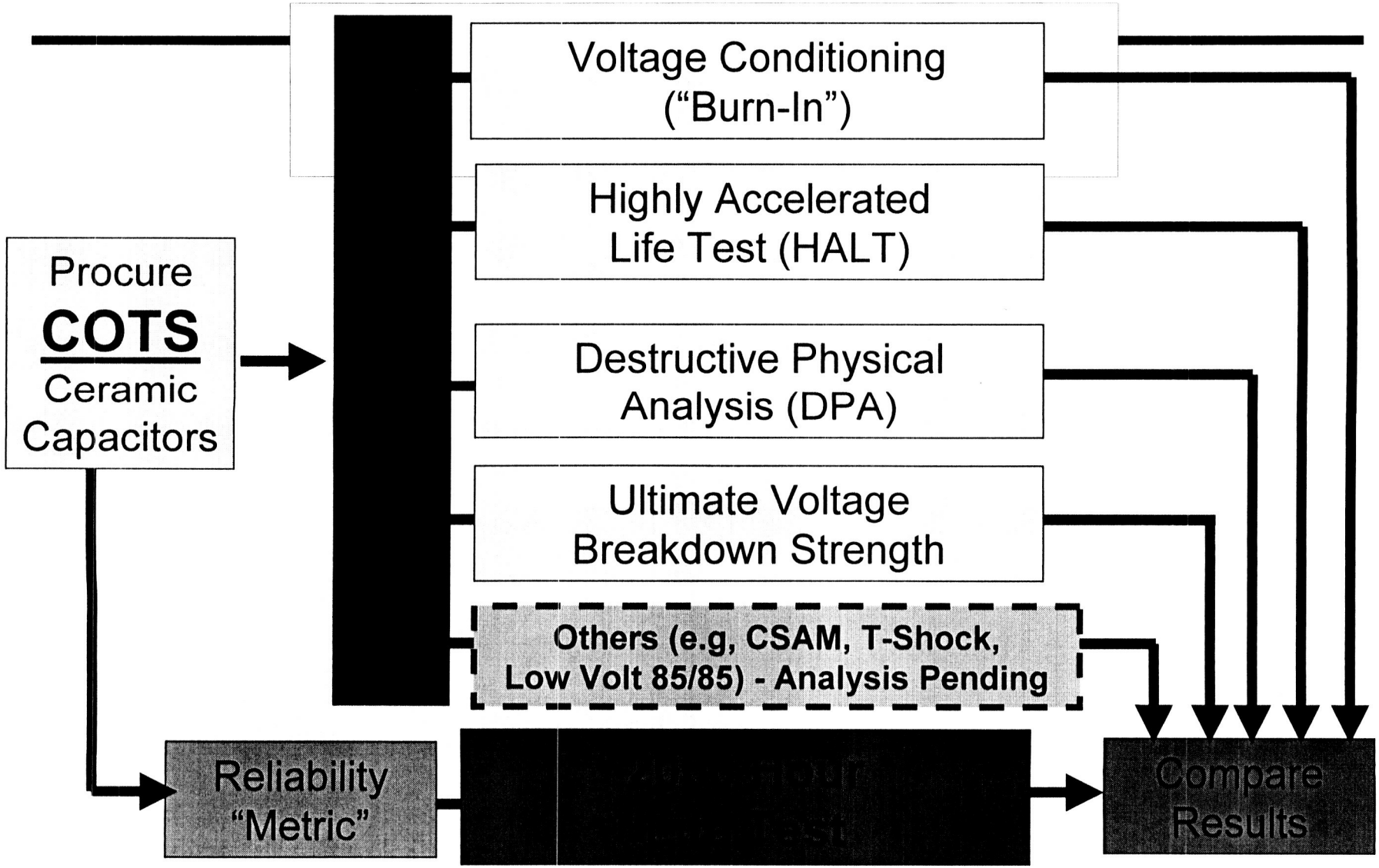
The "Bottom Line"

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



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**

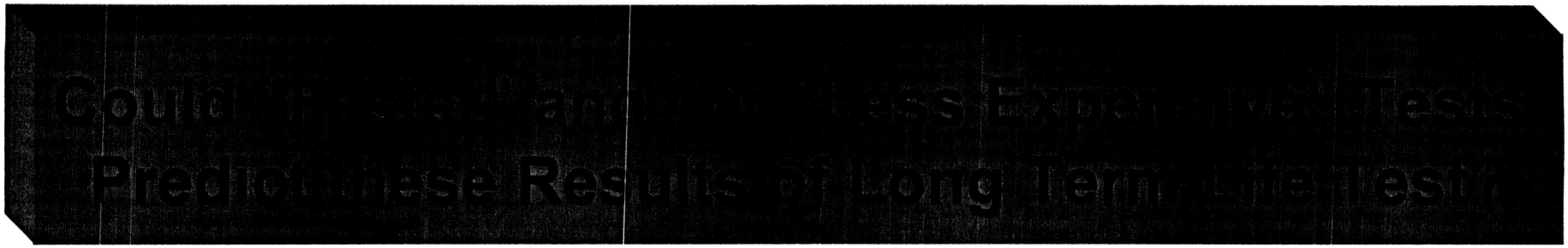
Life Test - Results

	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		
	C	8	0.0390	6.3	0402	Pass	Pass	Pass	*Pass*
		9	0.0047	50	0402	Parametric			
		10	1.0000	10	0805		Parametric	Parametric	
		11	0.1200	50	0805				
	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				
		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



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

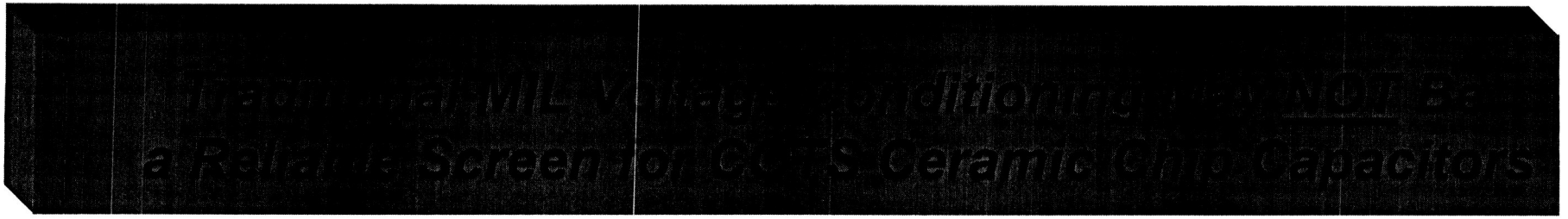
Voltage Conditioning vs. Life Test - Results

	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		Pass	Pass		
	C	8	0.0390	6.3	0402	Pass	Pass	Pass	Pass	*Pass*
		9	0.0047	50	0402	Parametric	Parametric			
		10	1.0000	10	0805			Parametric	Parametric	
		11	0.1200	50	0805	Pass				
	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				
		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

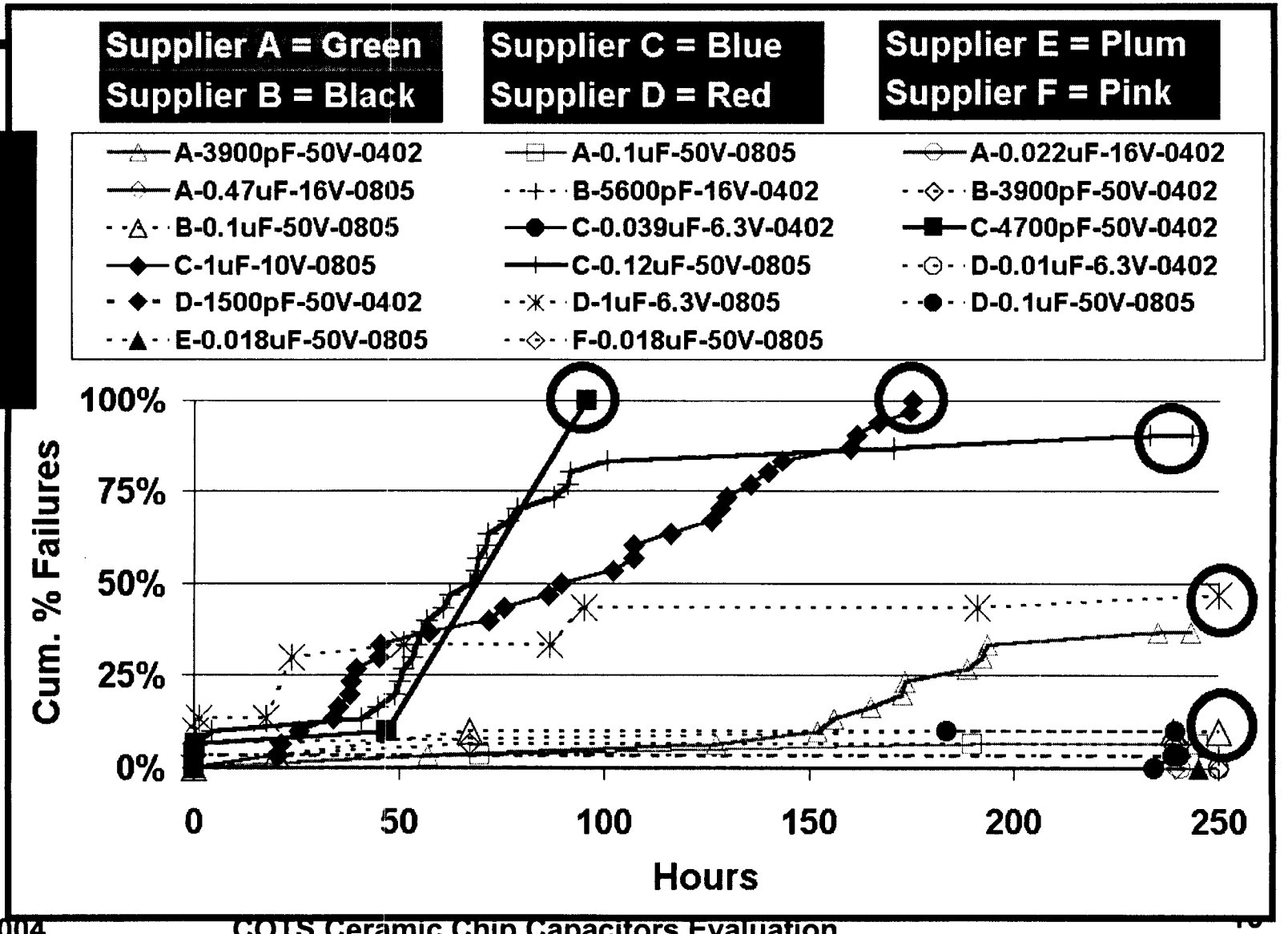


Highly Accelerated Life Test (HALT) - Description

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



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	
	C	8	0.0390	6.3	0402	Good	*Pass*
		9	0.0047	50	0402		
		10	1.0000	10	0805		
		11	0.1200	50	0805		
	D	12	0.0100	6.3	0402	Good	*Pass*
		13	0.0015	50	0402	Good	*Pass*
		14	1.0000	6.3	0805		
		15	0.1000	50	0805	Good	*Pass*
MIL	E	16	0.0180	50	0805	Good	*Pass*
	F	17	0.0180	50	0805	Good	*Pass*

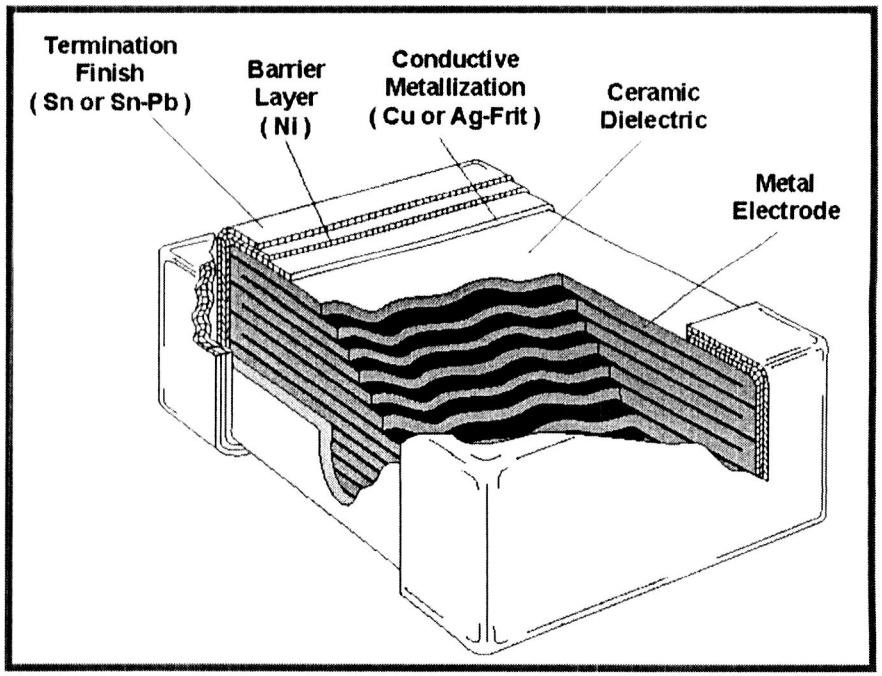
- **Strong Relationship Between HALT & Life Test Performance**
  - Not 100% Correlation
  - 1 / 10 "Good" had 1 Short at 2000 Hr Life
- **HALT Shows "Merit" as Lot Acceptance Test**
  - Low Cost (except NRE)
  - Short Duration
  - Small Sample Size

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

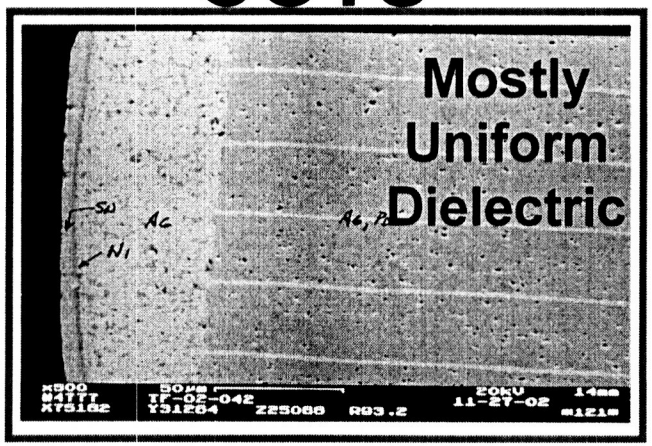
Destructive Physical Analysis (DPA)

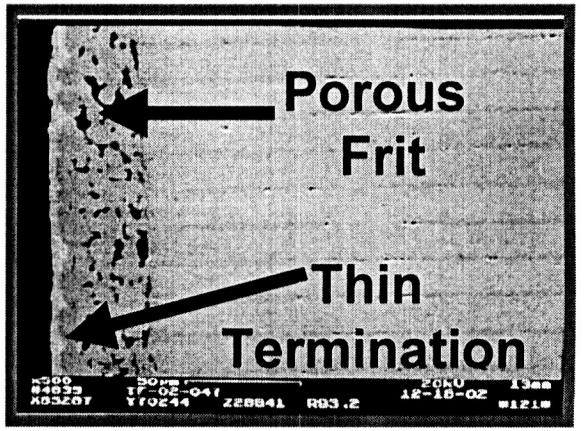
- **Test Condition:** 5 pcs / Lot
  - Standard Cross Section
  - Optical Microscopy + SEM
- **Criteria:**
  - Identify Construction Attributes
    - •Electrode D esign
      - Base Metal Electrode (BME) vs. Precious Metal Electrode (PME)
    - •Diel ectric Thickness
    - •T ermination Integrity
  - **Inspect for Defects**
    - •Cracks
    - •Delam inations
    - •Voids
    - •Diel ectric Porosity
    - •Inclusio ns/Impurities



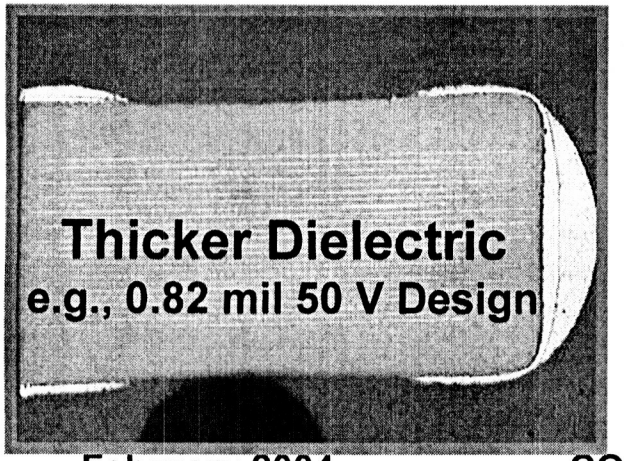
DPA - Representative Images

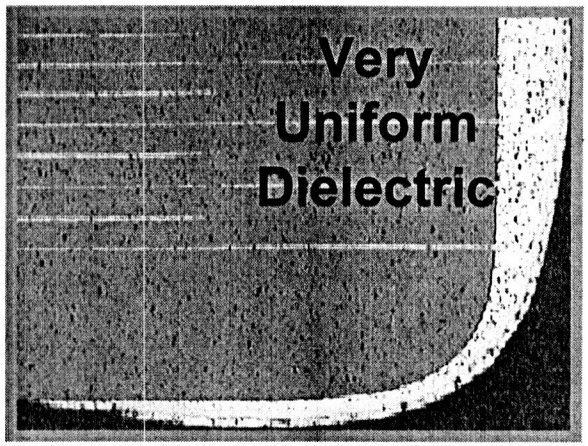
COTS

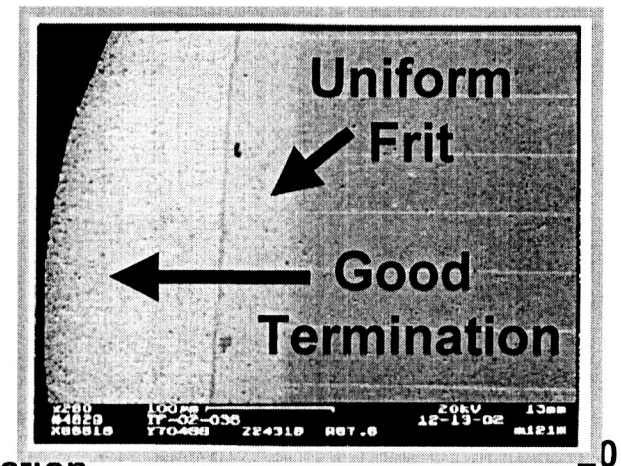




MIL







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	
	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	
		10	1.0000	10	0805	120	BME	0.25	10.00	40.4	
		11	0.1200	50	0805	45	BME	0.69	6.00	72.4	
	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	
		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 <u>STILL IN PROGRESS</u>*

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

Porous Frit/ Thin Termination

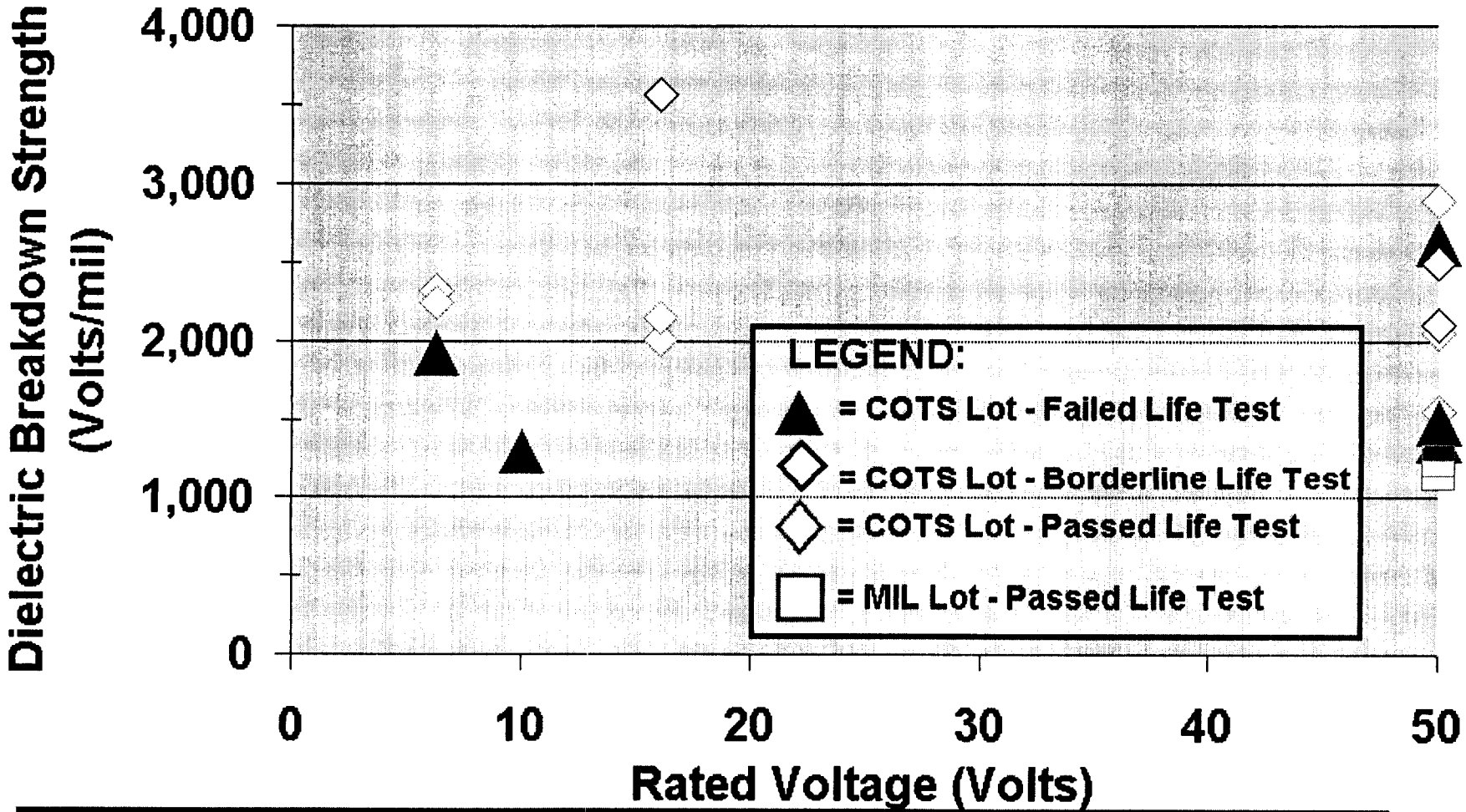
- **Continue to Use DPA as a "First Cut" to Eliminate "Poor" Lots from Further Consideration**
  - Can Save Time and $$$
  - However, "Passing" DPA Does Not Necessarily Predict Reliable Long-Term Performance

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



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	
	C	8	0.0390	6.3	0402	2240	*Pass*
		9	0.0047	50	0402	2624	
		10	1.0000	10	0805	1293	
		11	0.1200	50	0805	1378	
	D	12	0.0100	6.3	0402	2316	*Pass*
		13	0.0015	50	0402	1554	*Pass*
		14	1.0000	6.3	0805	1924	
		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 <u>Not Recommended</u> as a Reliability Indicator

Conclusions - Parts

For the Ceramic Chip Capacitors Evaluated:

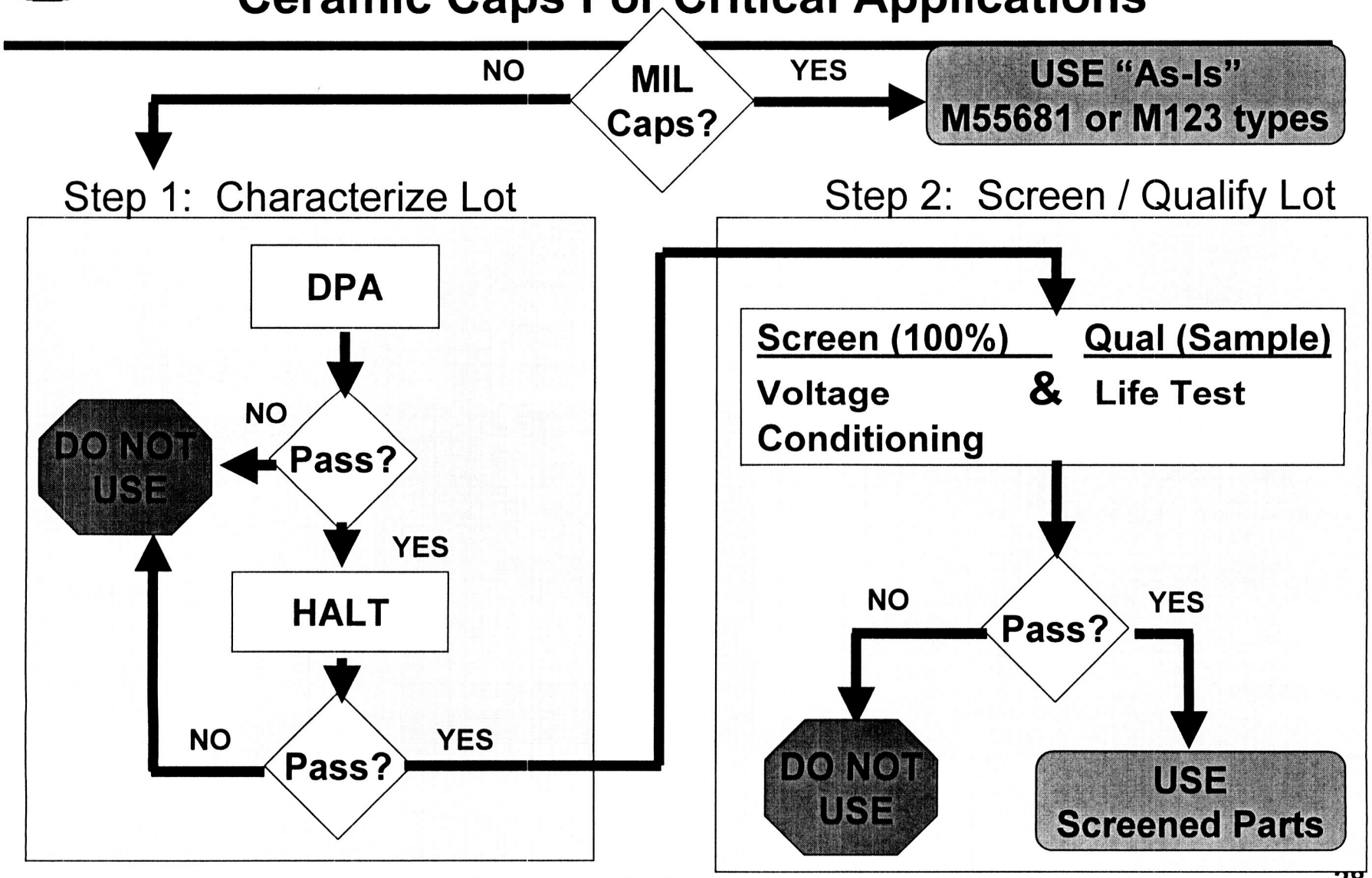
- **MIL "ER" Lots - Performance is "Excellent"**
  - No Reliability Problems Found During Evaluation
  - Procure and "Use As-Is" Recommendation Supported
- **COTS Lots - Performance is "Variable"**
  - Several Lots Perform **Excellently!!!**
  - But Some Lots Perform **Poorly!!!**
  - Procure and "Use 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



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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http://nepp.nasa.gov/nepag

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