Humidity Steady State Low Voltage Testing of MLCCs (Based on NESC Technical Assessment Report)

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Purpose of NESC* Task

Review of the low voltage reduced Insulation Resistance (IR) failure phenomenon in MLCCs and NASA approaches to contend with this risk.

1. Analyze published materials on root cause mechanisms.
2. Investigate suitability of current test methods to assess MLCC lots for susceptibility.
3. Review current NASA parts selection and application guidelines in consideration of benefits vs. disadvantages.

*NESC = NASA Engineering and Safety Center

Team List

Name	Discipline	Organization/Location
Core Team		
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Joseph Dougherty	Consultant	Pennsylvania State University
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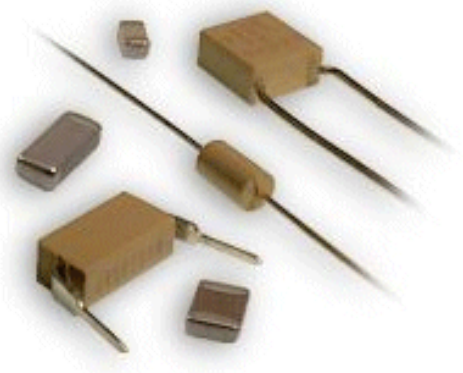
Christina Williams	Technical Writer	LaRC, ATK

MLCC Usage

- Multilayer ceramic capacitors (MLCCs) are among the most commonly used electronic components in electronic systems.
- MLCC components are used on every electrical assembly with quantities usually in the thousands.
- Majority of the parts are used in low-voltage (compared to rated voltage, VR) applications**. =>**
  Importance of low-voltage failure (LVF) phenomena for reliability assurance.



History of MLCC Problems in Low Voltage Applications

1978: -Brennan (Sperry) first to document MLCC LVFs.

1981: -NASA-MSFC issues GIDEP describing LVFs.

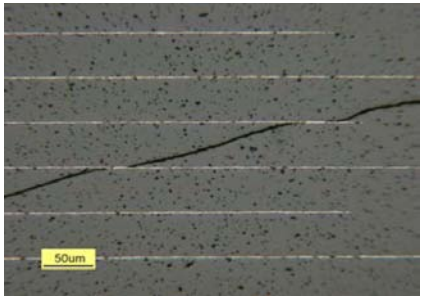
1980s: -MLCC LVF experiences are at their peak.
-NASA contracts Hughes to study MLCC LVF.
-Bulk of industry research is conducted.
-NASA risk reduction strategies are developed.
-MIL-C-123A space-level MLCCs features LVF avoidance.

1980s-90s: -Sporadic MLCC LVFs reported.

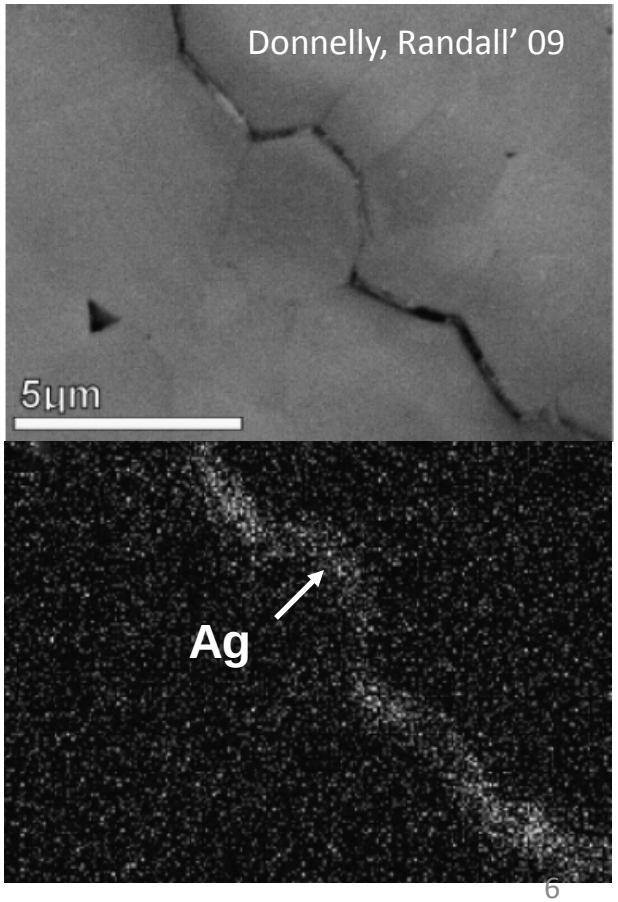
2000s: -Continued need for MLCC LVF guidelines questioned.

- Historically, LVFs were attributed to lots with large proportion of manufacturing defects.
- Currently, LVFs are more likely to be caused by cracking due to soldering and handling.

Description of LVF Phenomena for MLCCs



- LVF are phenomena which produce insulation resistance (IR) degradation below the device limits at voltage bias well below MLCC ratings.
  - Typical IR limits are in GΩ range.
  - LVF can be from ~0.1k Ω to > 1MΩ.
- IR recovery may occur through application of voltage higher than that resulting in the original failure.
- Two main categories of LVF:
  - Low impedance circuit failures.
    - Tend to be catastrophic, PWB damage possible.
  - High impedance circuit failures.
    - Can be intermittent or persistent.
    - May not cause circuit failure unless sensitive to IR degradation.



NASA Guidelines to Reduce Risk of MLCC LVF

Basic approaches involve combination of the following:

- Procure MIL-PRF-123 parts and **use as-is**;

Otherwise NASA Guidance Suggests:

- Restrict MLCC Selections
  - 100 V ratings or higher
  - Minimum dielectric thickness (0.8 mil for VR=50V)
- Destructive Physical Analysis (DPA) to specialty standard EIA-469
- Humidity, Steady-State, Low Voltage (HSSLV) Lot Acceptance Test (aka “Low Volt 85/85”)

Drives selection to larger parts; more prone to handling damage

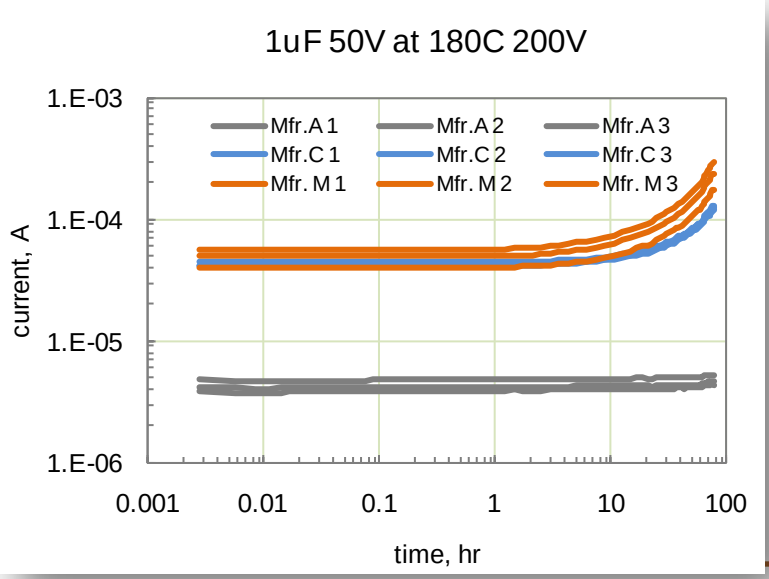
NESC Team Approach

1. Conduct literature review.
2. Survey the industry for recent LVF experiences.
3. Review past and current NASA and industry guidelines for LVF risk reduction.
4. Review current and historical results from screening and lot acceptance testing.
   - *Discussion of HSSLV is emphasized since this has been one key element of NASA's MLCC LVF risk reduction strategy since the 1980s.*
5. Consider future NASA evaluation of alternative test methods.

Mechanisms of IR Degradation

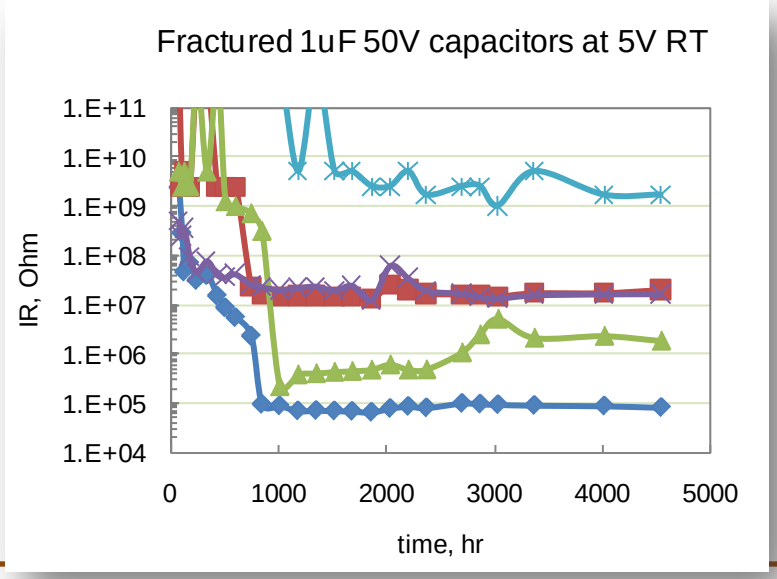
Charge instability in the dielectric (migration of oxygen vacancies).

- Graceful increase in DCL.
- Activated by T and V.
- Can be revealed during HALT.
- Can be mitigated by derating.



Formation of conductive path via mechanical defects .

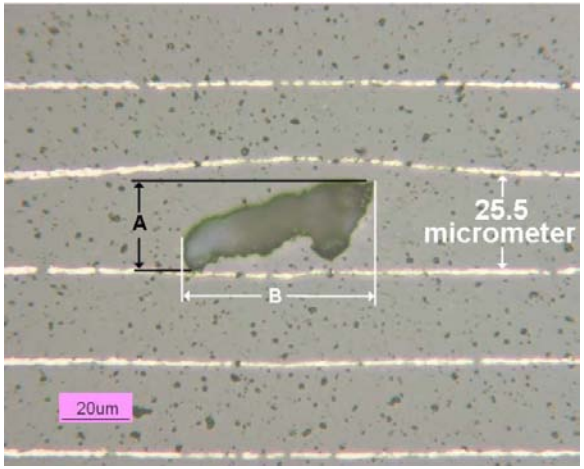
- Erratic behavior.
- Activated by moisture.
- Effect of T and V is not clear.
- No effective screens to reveal.
- Derating does not help.



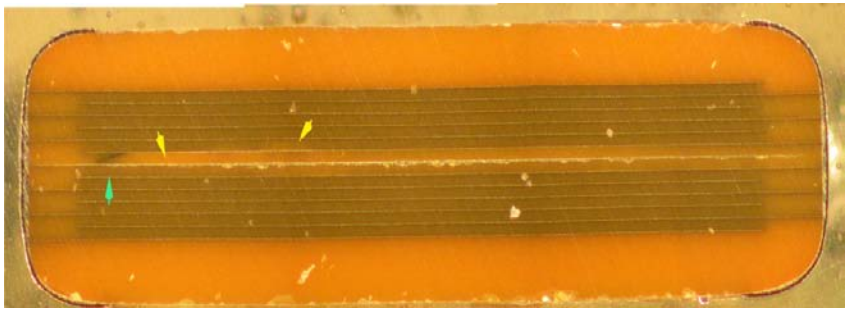
Mechanical Defects in MLCCs

Manufacturing defects

CDR 0.1uF 50V DPA failure

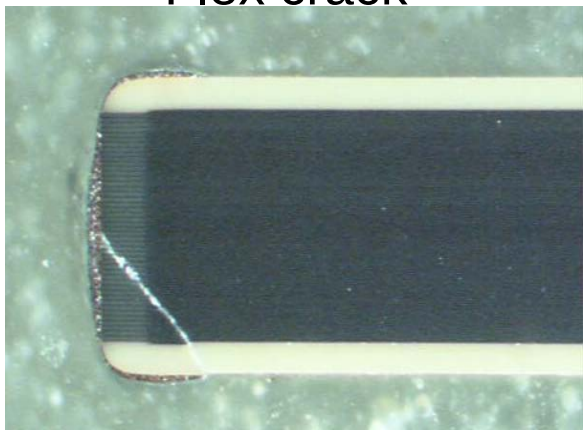


CDR 0.1 uF 100V failed due to delamination at R~1.5 kohm during board-level testing



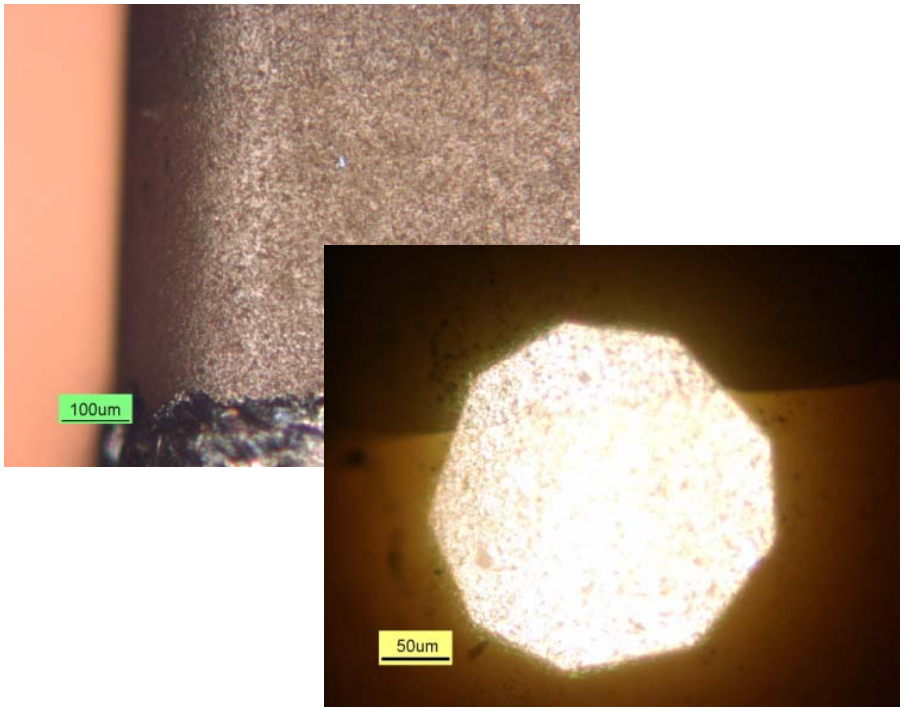
Assembly defects

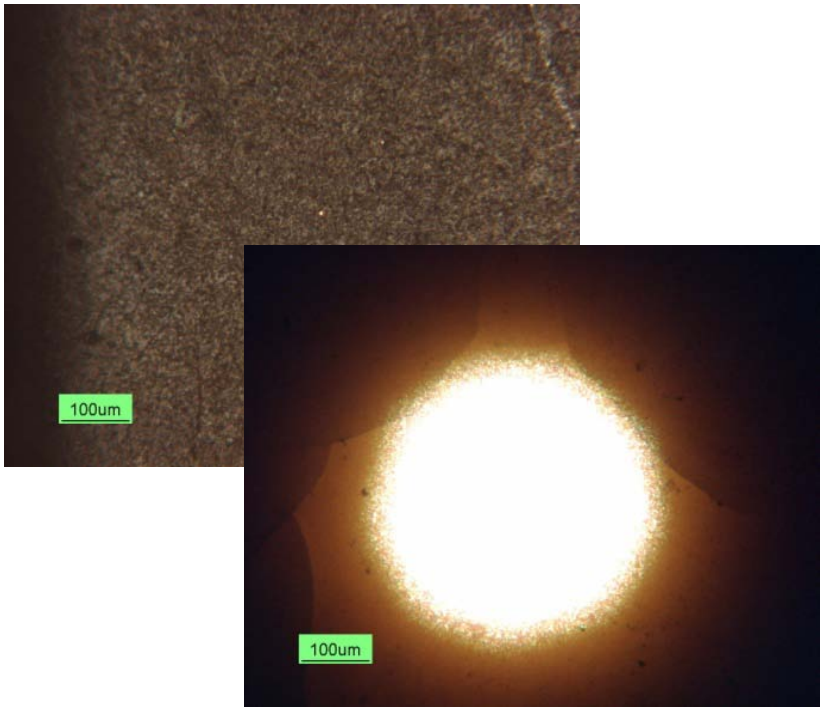
Flex crack



Thermal crack

Mechanical Defects in MLCCs, Cont.





- Cracks are difficult to observe even using a high power microscope. Some failures might be not identified properly.
- Vicinal illumination is an effective method for revealing cracks.

S. Hull/NASA, "Nondestructive Detection of Cracks in Ceramics Using Vicinal Illumination", ASM International, Nov. 1999, ISBN 0-87170-646-6

Revealing Mechanical Defects in MLCCs

Origin	Defect	Screen /Qual	Comment
Manufacturing	•Void •Delamination •Crack	•Electrical: DWV, IR •Acoustic Microscopy •DPA •**HSSLV**	Effectiveness of these tests needs to be evaluated.
Soldering-related thermal shock	•Delamination •Crack	•Thermal shock •Resistance to Soldering Heat	Effectiveness of these tests is currently being evaluated by NEPP.
Board handling (flex cracking)	•Delamination •Crack	•Flex crack testing	Mfr. standards; AEC-Q200-005; A need for NASA?

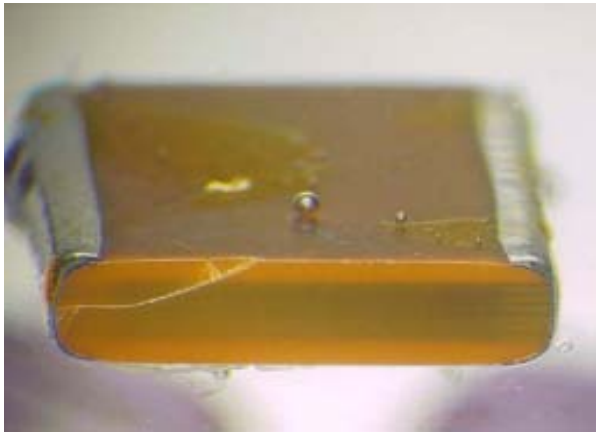
NESC task was focused on the effectiveness of the Humidity Steady State Low Voltage Testing

Is Soldering-Induced Cracking Parts or Workmanship Issue?

They are both:

- Assuring that capacitors are robust enough and can withstand normal level stresses associated with soldering and handling is a part issue.

  This is a manufacturer responsibility and should be achieved by adequate screening and qualification procedures.



- Assuring that soldering and handling conditions are in compliance with the existing guidelines and requirements is a workmanship issue.

  This is a user responsibility and should be achieved by developing adequate assembly guidelines and process control.

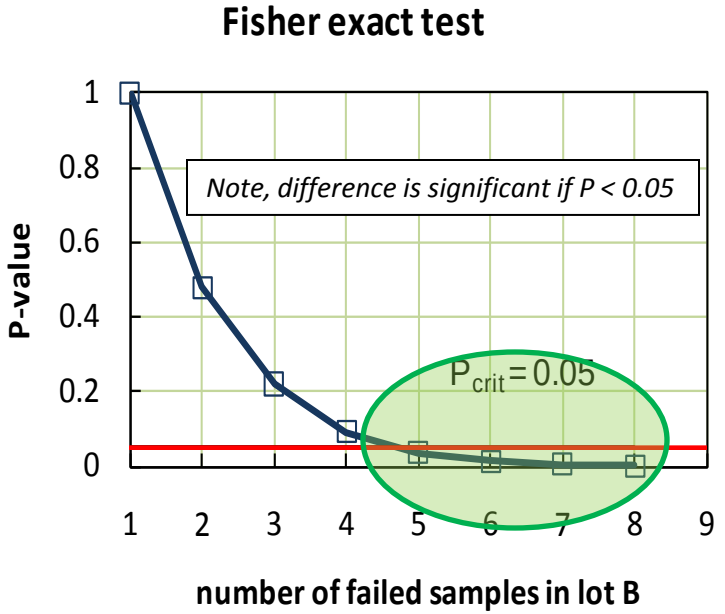
HSSLV Test Conditions per MIL-PRF-123

Test Conditions	Acceptance Criteria
Preconditioning: 40°C for 24 hours **Test Voltage:** 1.3 ± 0.25 VDC applied through a 100kΩ **Temperature:** 85°C **Relative Humidity:** 85% **Test Duration:** 240 hours **Post Exposure:** Dry at 25°C for 3.5 hrs **Mounting:** Leads may be attached to chip capacitors for mounting and loading purposes. Mechanical loading is acceptable.	**Sample Size:** 12 pcs per lot **Failure criteria:** IR < specified limit* *measured at 1.3V thru 100kΩ ***Accept lot on zero failures;*** ***Reject lot on 1 or more failures.***

- Voltage range from 1.05V to 1.55V seems too large.
- Can monitoring of DCL at higher voltages be more effective?
- Is sample size adequate?

Statistical Significance of HSSLV

- Consider two HSSLV test results:
  - Lot A 0 / 12 failures
  - Lot B *m* / 12 failures
- Fisher exact test determines if Lot A and B are statistically different.
  - Difference in test results is significant if the calculated P-value is less than 0.05
- Fisher exact test shows that Lot A (0 failures) and Lot B (1 failure) are not statistically different.
- A "failed" lot can be considered different from the "passed" lot if m > 5.



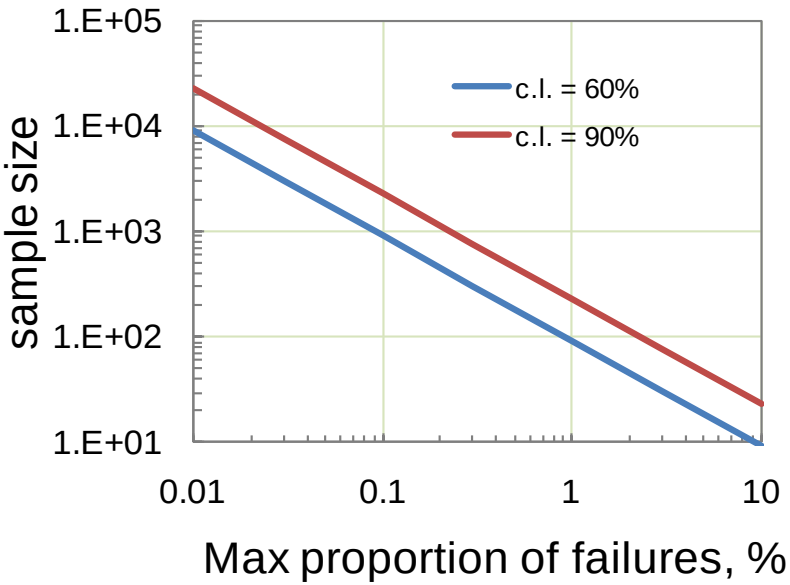
P-values for comparison of test results for lot A having 0 failures out of 12 samples and lot B having from 1 to 8 failures out of 12 samples.

What sample size is necessary to assure low probability of defects in a lot?

Sample-Based Acceptance Testing

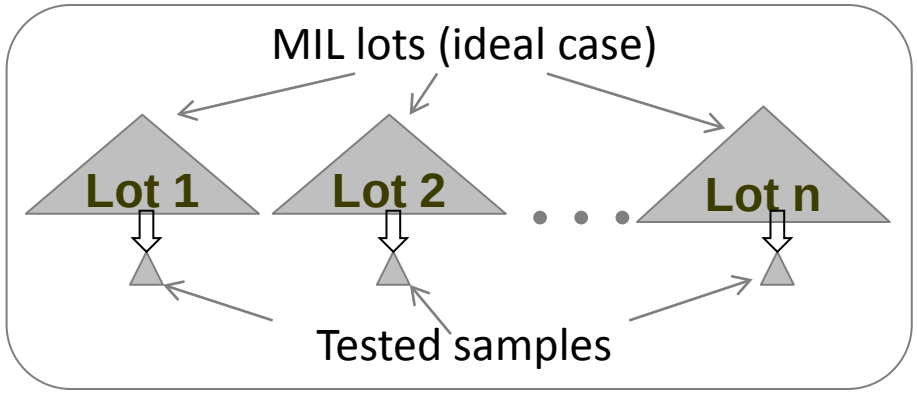
- Purpose of sample-basis screening/lot acceptance testing.
- What is the necessary SS to assure $p_f < 0.1\%$?
- Zero Defect/Failure Sampling: SS that must be tested without failure to prove maximum probability of failure (p_f) at a certain level of confidence (*c.l.):*

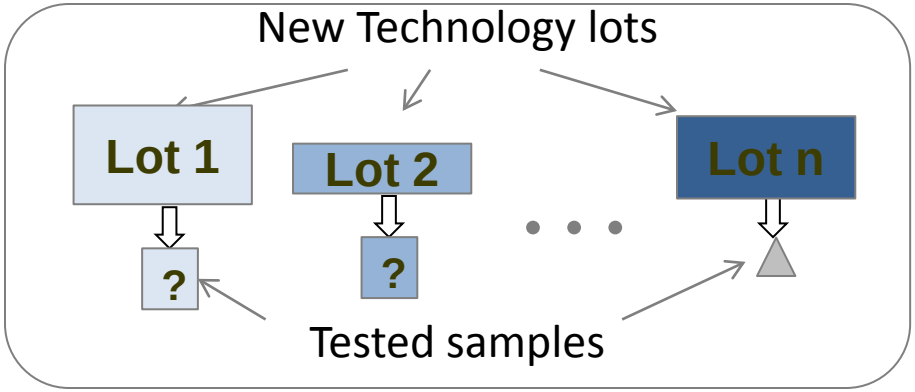
$$n(p_f) = \frac{\ln(1-c.l.)}{\ln(1-p_f)} \approx \frac{-\ln(1-c.l.)}{p_f}$$



If statistics requires 1,000 samples does it make sense to test 10 samples?

MIL vs. New Technology/SCD Parts





Using the same SS may not provide the same level of confidence in quality and reliability

Assumed:

- Consistent quality.
- History of testing.
- SS justified by heritage.
- FR can be calculated based on cumulative data.

Mature Technology: *Sample Size = $n(p_f)$/(number of lots)*

Good news:
a relatively small SS might be sufficient for mature technologies.

Bad news:
new technologies are not mature.

Note: commercial technology can be mature.

Findings (1 of 3)

- No MLCC LVF was identified in NASA flight systems for at least the past 15 years
- For the last 10 years there has been a low incidence rate of field failures of high and established reliability MLCCs due to reduced IR in low voltage circuit applications. Only 7 potentially relevant LVF cases were identified during the time period from 1999 to 2009.
- Most of the literature regarding MLCC LVF is more than 20 years old and this subject seems to have attracted little attention since then.

Findings (2 of 3)

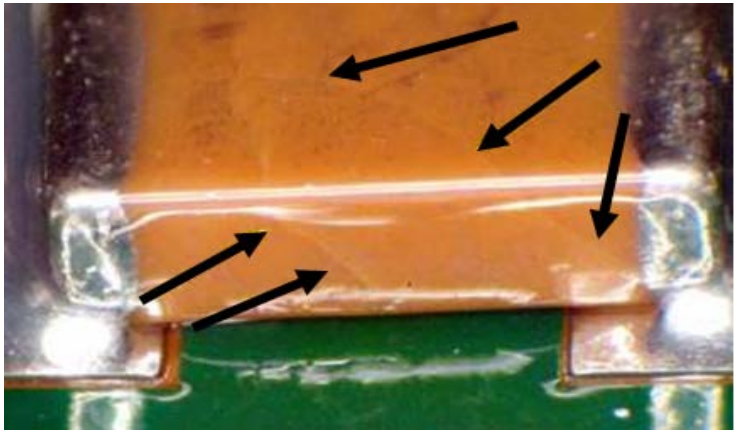
- The literature identifies several degradation mechanisms which could produce LVF in MLCCs. These include metal migration, ionic conduction paths, and semiconductive phases in the dielectric.
- The hybrid manufacturers that responded to the NESC survey were unaware of any MLCC LVF problems in their products and most were unfamiliar with the phenomenon.
- The HSSLV testing on military grade MLCCs has generated zero failures in the last eight years.
- For MIL grade MLCCs the HSSLV test as currently specified is ineffective to reveal lots with less than 6% of flawed MLCCs due to inadequate sample size.

Findings (3 of 3)

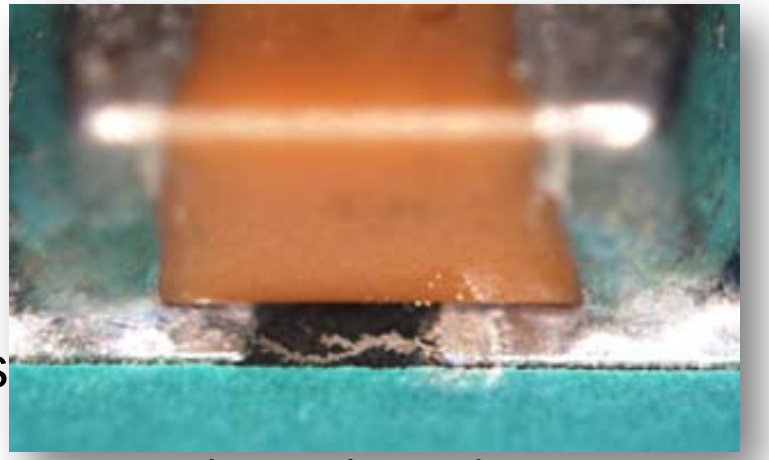
- MLCC manufacturers have reported success and recommend using HSSLV testing (with large sample sizes) as an evaluation tool during development of new MLCC materials, processes and designs.
- No justification was found for continuing NASA's current recommendation to use MLCCs rated at 100 V or greater to mitigate low voltage failure phenomenon.
- Technological advances in manufacturing processes and controls have produced much more uniform dielectric structure, thickness, and low porosity MLCCs.
- Some circuit applications can tolerate MLCCs having reduced insulation resistance which may have obscured instances of failure.

Observations

- Recent failures have been attributed to cracking during installation (especially hand soldering practices and PWB flexure). Larger MLCCs tend to be more prone to thermomechanical damage.



- Flexible termination may reduce the propensity for MLCC flex cracking. However, susceptibility to LVF may be enhanced by end termination structures which could provide a preferred diffusion for moisture.
- Reduced IR failures are sometimes caused by external conductive paths (e.g., metal dendrite formation) resulting from surface contamination.



External Metal Dendrite on PWB beneath the MLCC

Recommendations

- NASA guidelines should be amended to remove requirements to perform HSSLV test as an add-on lot acceptance test for MIL QPL MLCCs.
- Add a NASA guideline to perform a HSSLV test with increased sample size and optimized test conditions on new technology, commercial/industrial grade MLCCs for qualification and lot acceptance.
- NASA guidelines should be amended to remove restrictions on MLCCs rated at less than 100 V when used in low voltage applications.
- During failure analysis of MLCCs NASA parts analysis laboratories should include low-voltage characterization of the failure in order to reduce the likelihood of destroying evidence of the failure site.