SAND2019-6076PE

KEMET TELECOM AND FACE TO FACE VISIT

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Proposed Agenda for Face to Face Meeting

- **Sandia National Laboratories/Honeywell FM&T Overview and Program Overview – Christine Mitchell**
- **Review of SNL Test Methodologies and Test Results**
- **KEMET knowledge and experience in accelerated testing and failure mechanisms**
- **KEMET tracing of manufacturing differences for part numbers that show variation in performance across lot numbers**
  - SNL is looking for an understanding of process controls and associated tracking as it relates to lot numbers to guide our path forward for parts we have already purchased
- **Discussion of KEMET's Hi-Rel XR7 and MIL-PRF-32535 processing**
  - What are the manufacturing differences that allow for MIL-PRF-32535 quality parts?
  - How homogeneous are lot numbers and how are various processing steps traced? If SNL tests a sample of a given lot number how confident can we be that we are testing a representative sample? What should our confidence level be for Hi-Rel vs MIL-PRF-32535
- **Discussion on KEMET custom screening options and shorter term consultation for SNL performed screening of KEMET Hi-Rel XR7 capacitors**
  - KEMET capabilities for screening parts we already have purchased

Sandia Part Family Description

- **Sandia Labs has defined a part family consisting of High-Rel COTS parts**

Kemet PN	Sandia PN	Size	Cap (uF)	Vr (V)
C0603T104K5RCLTM	445306-239	0603	0.1	50
C0805T334K5RCLTM	445306-383	0805	0.33	50
C0805T684K5RCLTM	445306-395	0805	0.68	50
C0805T824K3RCLTM	445306-401	0805	0.82	25
C0805T105K3RCLTM	445306-404	0805	1	25
C1206T105K5RCLTM	445306-476	1206	1	50
C1206T225K5RCLTM	445306-488	1206	2.2	50
C1206T335K3RCLTM	445306-497	1206	3.3	25
C1206T475K3RCLTM	445306-503	1206	4.7	25
C1206T106K4RCLTM	445306-518	1206	10	16
C1210T105K1RCLTM	445306-542	1210	1	100
C1210T475K5RCLTM	445306-566	1210	4.7	50
C1210T106K3RCLTM	445306-581	1210	10	25
C1210T226K8RCLTM	445306-587	1210	22	10
C2220T106K5RCLTM	445306-656	2220	10	50
C2220T226K3RCLTM	445306-665	2220	22	25

Testing done by Kemet before delivery

- **Per MIL-PRF-55681,PDA 8%, DPA PER EIA-469, Humidity per MIL-STD-202 method 103, condition A.**
  - Voltage conditioning: 125 C, 100 hrs, 2 x Vr
  - DWV is 5 seconds at 2.5 x Vr at ambient.
  - IR then measured only at ambient

NO.	TEST	CONDITION(S)	QUANTITY TEST	QUANTITY REJ	QUANTITY ACC	DATE
COTS Level C						
1.0	Voltage Conditioning	MIL-PRF-55681	20,825	0	20,825	09/05/16
2.0	Dielectric Withstanding Voltage	MIL-PRF-55681	20,825	4	20,821	09/09/16
	Insulation Resistance +25°C	500 Megohms Min.				
	Capacitance	+ 10% - 10%	20,821	13	20,808	09/09/16
	Dissipation Factor	3.5 %				
3.0	Visual Mechanical Inspection	MIL-PRF-55681	2,903	267	2,636	11/10/16
4.0	PDA Electricals	8 % Max	20,825	17 / 0.08%	20,808	09/09/16
LEVEL C TEST SUMMARY						
1.0	DESTRUCTIVE PHYSICAL ANALYSIS	RS-469 SAMPLE 5 0/1	32	0	32	09/13/16
2.0	LOW VOLTAGE HUMIDITY	MIL-PRF-55681 SAMPLE SIZE 12 0/1	12	0	12	10/05/16

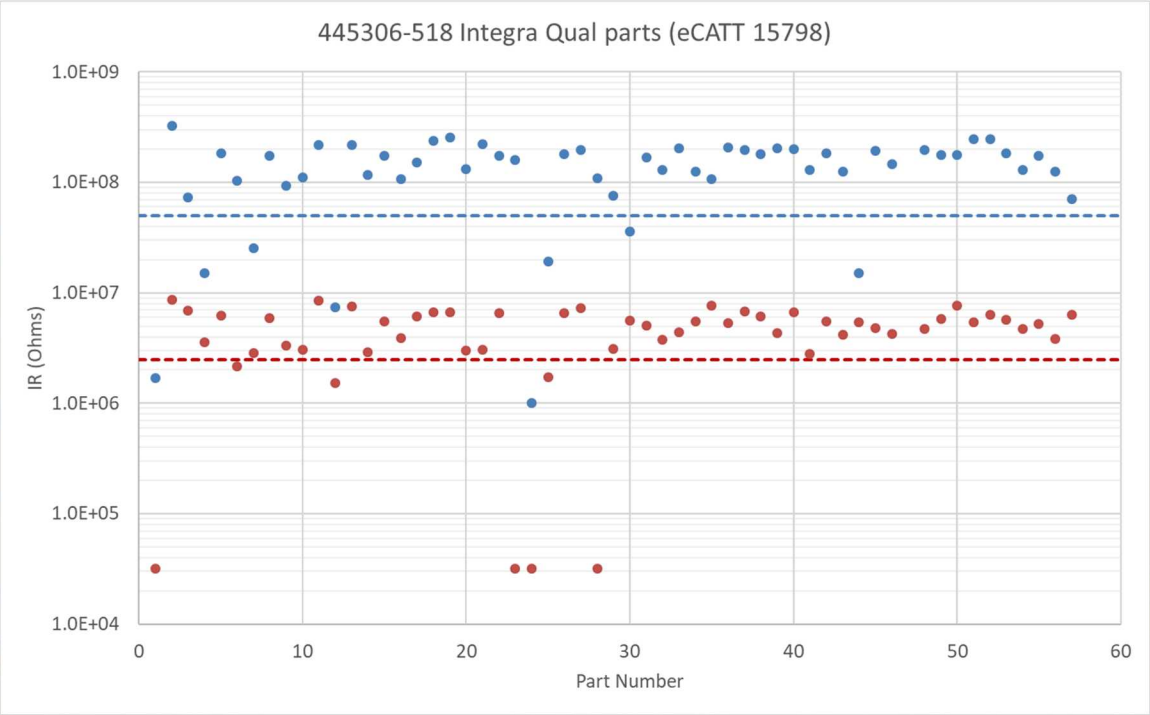
Qualification Testing

- **NSC performs qualification testing on family of parts before accepting for production use.**
  - Initially to be performed on a 61 piece sample of the -518 suffix (C1206T106K4RCLTM)
  - Based on MIL-STD-202, MIL-PRF-123, and MIL-PRF-32535

Test		Criteria
Electrical Tests	Capacitance	+/- 10%
	Dissipation Factor	<5%, Vr<=10V <3.5%, Vr=16V, 25V <2.5%, V4>=50V
	Dielectric Withstanding Voltage	2.5 x Vr @ ambient, 5 sec.
	Insulation Resistance	Tested at Vr, ambient
	Insulation Resistance @ 125 C	Tested at Vr, 125 C
Thermal Shock		5 cycles, -55 C to 125 C
Voltage conditioning		168 hrs, 125 C, 2 x Vr
Electrical Tests		

Initial Indication of Failure

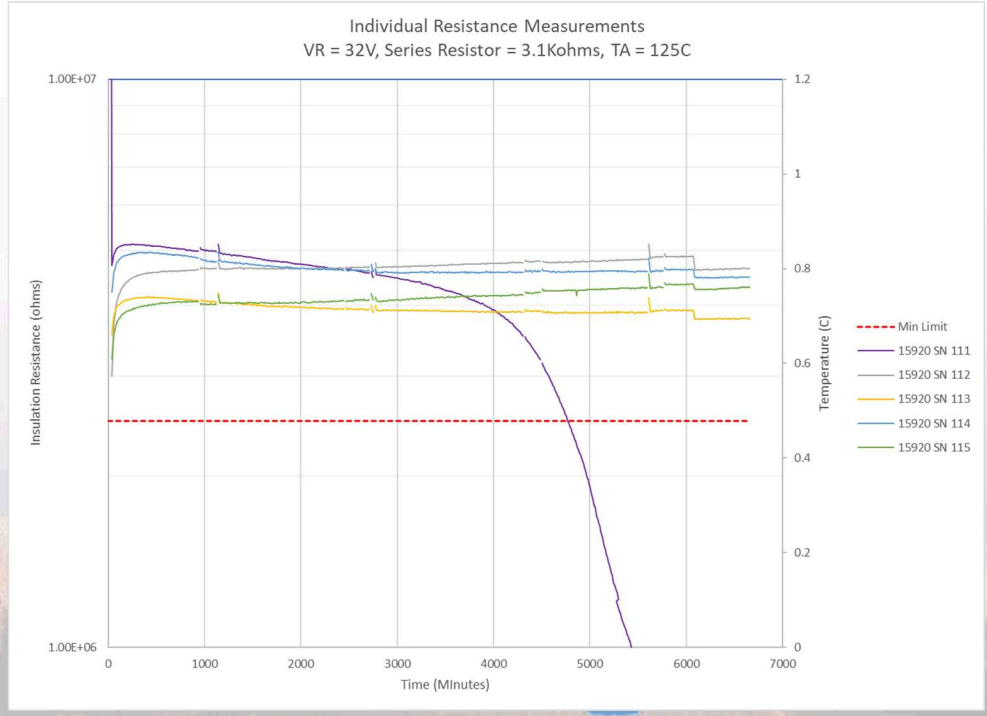
- **Parts failed IR after voltage conditioning**
  - 61 parts tested to VC, with 10 parts held as controls.
  - 8/61 failed IR at 25C (4 of these passed @125C)
  - 7/61 failed at 125 C (3 of these passed @ambient)
  - Limit of 50 Mohm ambient and 2.5 Mohm at 125 C (based on 1/10 ambient limit, then reduced to 50% after voltage conditioning)
  - One part failed catastrophic as a short.



Failure Discussion

- **Sandia recognizes that this is an up-screen of a part not sold to this level of reliability. Parts meet KEMET's datasheet requirements as received.**
- **We also recognize that the 2Vr test is beyond rated use. Experience and literature would indicate that this is a valid acceleration mechanism to evaluate reliability.**
- **Initial failures have caused us to dive deeper into the reliability of this family of parts to determine if it can be used in our application**
  - Considering lot sampling or additional 100% screening
- **We have learned about:**
  - Absorption current effects after initial capacitor charging
  - Degradation mechanisms that lead to failure, to include oxygen vacancy migration and the significance of grain size and grain boundaries
  - We have also detected high failure rates associated with individual lot numbers, not specific to part design

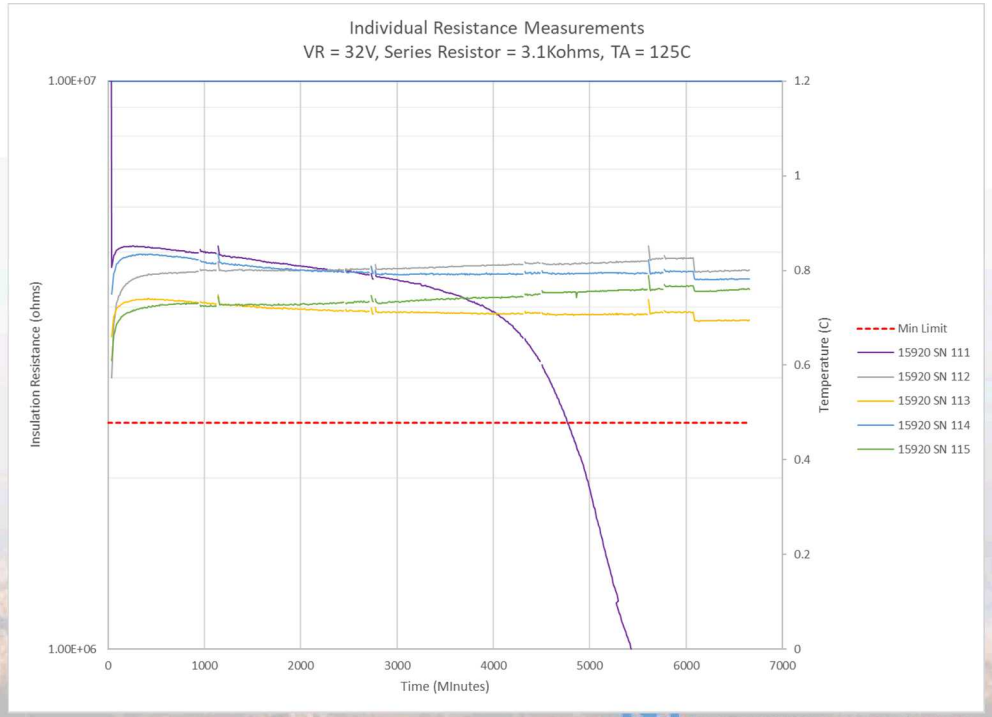
$$\frac{t_1}{t_2} = \left(\frac{V_2}{V_1}\right)^n \exp\left[\frac{E_a}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$



Degradation Mechanism Failure Summary

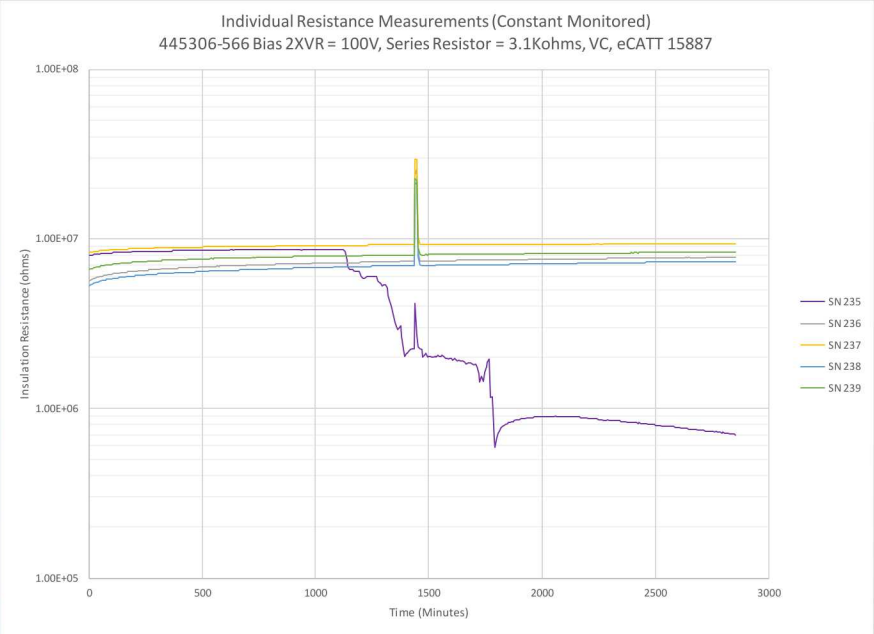
- First observed failures appear to be degradation due to known degradation mechanisms as published in literature.
- For -518 suffix, 801 capacitors tested, 12 total failures.
- Based on an assumed acceleration factor, these may still prove acceptable for our limited use conditions.

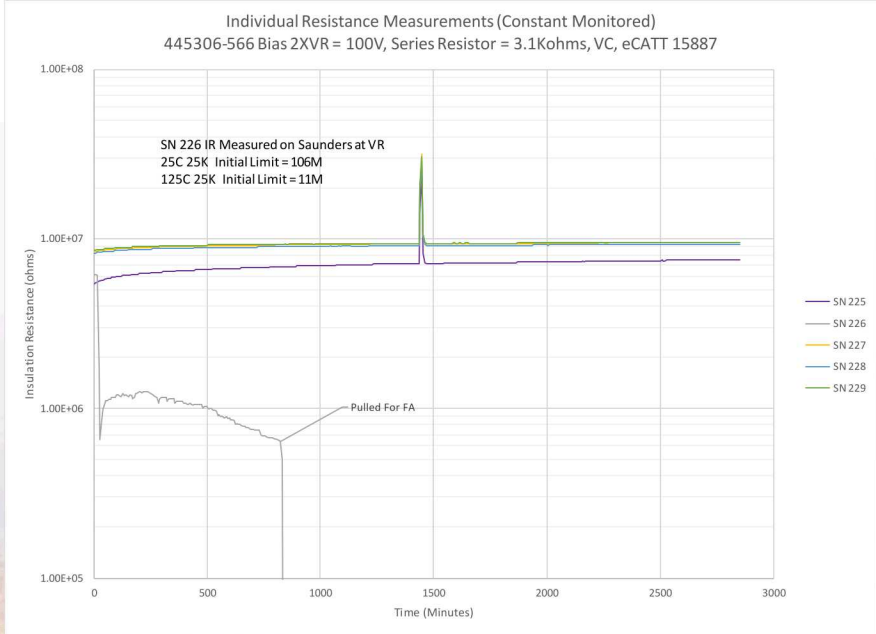
Suffix	Count	Hours	Failures
-518 (1206 pkg, 10 uF, 16 V)	187	168	7 (not monitored, time unknown)
	61	236	1 at 199 hrs.
	33	500	1 at 79 hrs.
	40	534	1 at 351 hrs.
	120	93	1 at 6.5 hrs. 1 at 8 hrs.
	360	48	Zero failures
-587 (1210 pkg, 22 uF, 10 V)	60	168	2 low IR failures
-581 (1210 pkg, 10 uF, 25 V)	61	168	1 low IR failure
-665 (2220 pkg, 22 uF, 25 V)	61	168	1 shorted part



445306-566 Lot Number Specific Failures

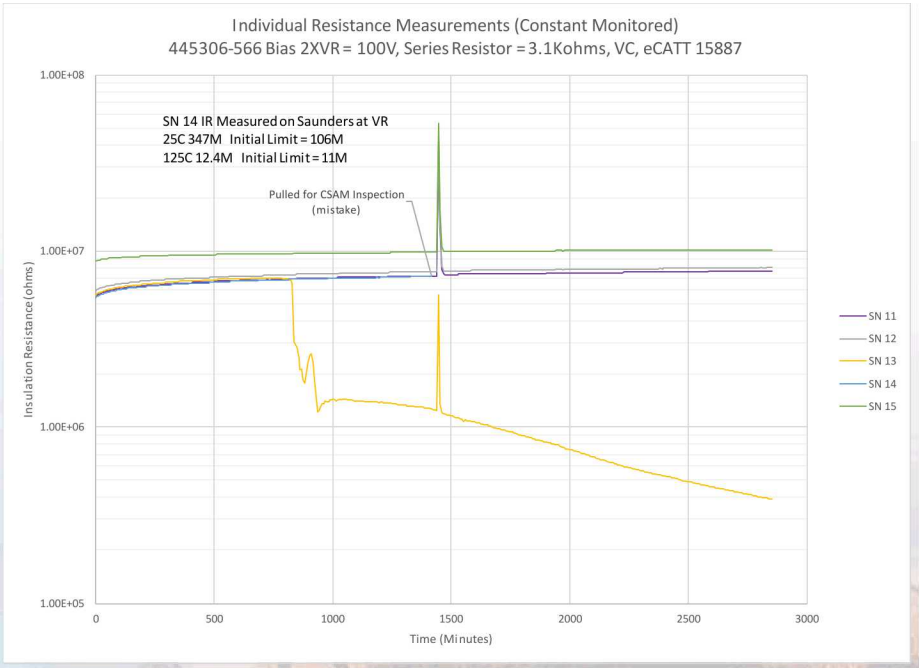
- **Testing performed on C1210T475K5RCLTM (445306-566) lot number 161248093**
  - As-received units exposed to thermal shock test, 5 cycles from -55 C to 125 C, alternating between two forced-air thermal chambers, unpowered
  - After thermal shock, 120 capacitors put on voltage conditioning test at 2 Vr (100 V), 125 C, for 48 hours
  - Observed 17 failures out of 120 parts tested (14%)
- **Data shows measured IR, monitored continuously during the 48 hour voltage conditioning test.**
  - Failed parts have sudden drops in measured IR
  - Note: spike in IR at 1450 minutes is due to temp. change as chamber door was opened for another experiment.

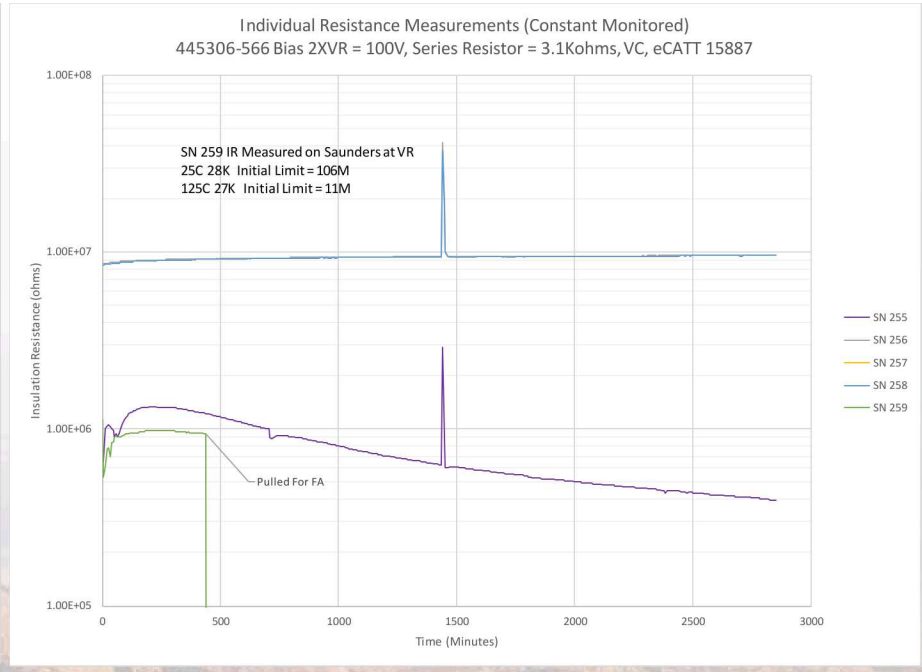




445306-566 Test Failures

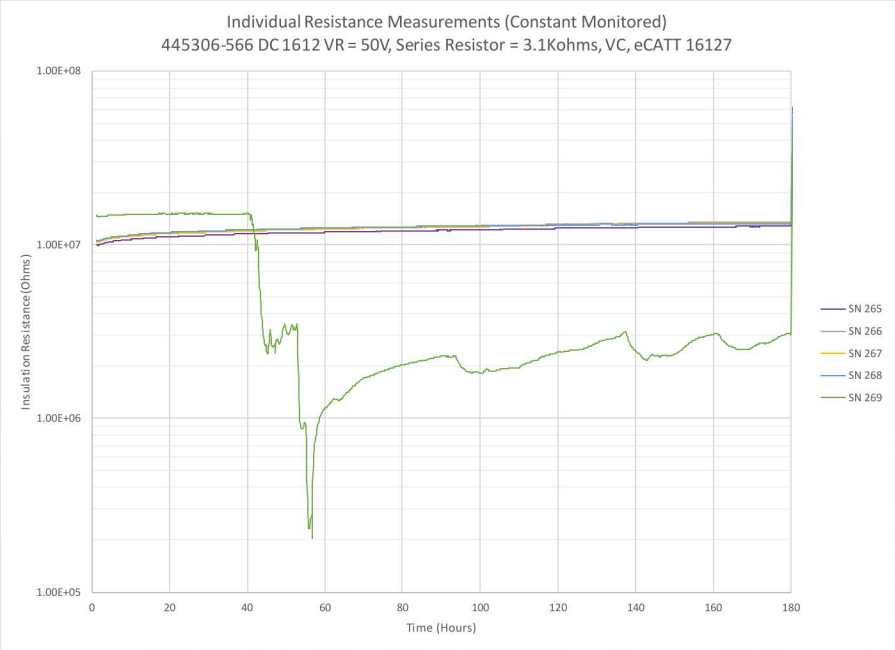
- **Additional data shown to illustrate failure mode**
  - Initial drop in IR occurred within first few minutes of testing on several parts.
  - Also observed to occur throughout the 48 hour test, as late as 30 hours.
  - In some cases the initial IR drop was followed by slow degradation.
  - In some cases initial drop was followed by failure to a hard short.

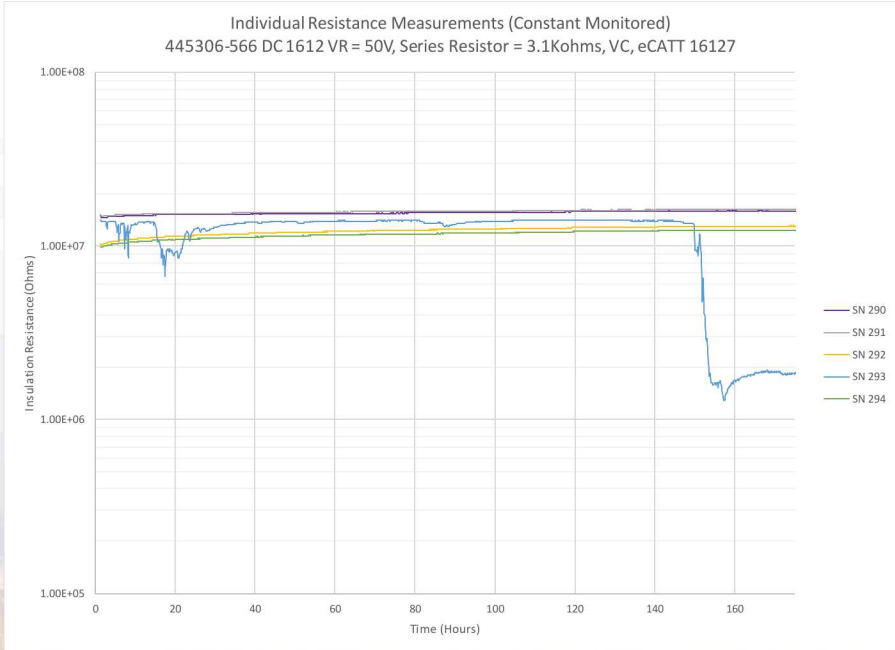




Testing at Rated Voltage

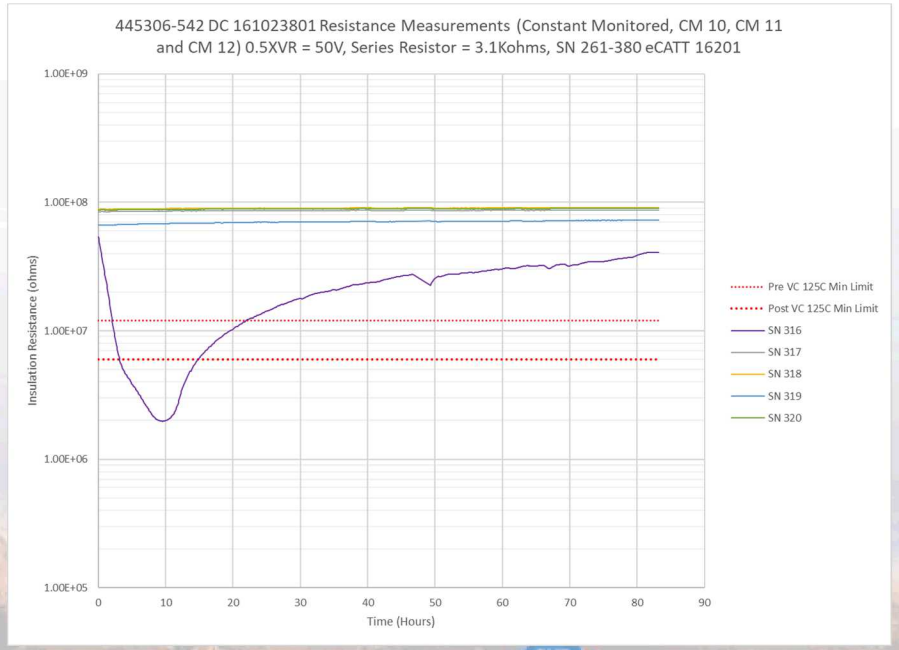
- **Testing performed on C1210T475K5RCLTM (445306-566) lot number 161248093**
  - As-received units exposed to thermal shock test, 5 cycles from -55 C to 125 C, alternating between two forced-air thermal chambers, unpowered
  - After thermal shock, 60 units put on voltage conditioning test at 1 Vr (50 V), 125 C (test is ongoing)
  - Observed 2 failures, at 42 hours and 150 hours.
- **Confirms the failure mechanism at rated voltage**





-542 Testing at 0.5 Vr

- **-542 161023801 20% failure at 2 Vr triggered additional testing at lower voltages to determine if lot number could still be used**
- **Test plan to observe failure rate vs. voltage:**
  - 5 cycles of thermal shock, -55 C to 125 C
  - Measure pre-VC cap/DF, IR at 0.5 Vr, at 25 C and 125 C
  - Voltage conditioning at 0.5 Vr, 125 C, 200 hrs
  - Increase to 1 Vr, 125 C, for 200 additional hrs
  - Increase to 2 Vr, 125 C, for 48 additional hours
  - Measure post-VC cap/DF, IR at 1 Vr, 25 C and 125 C
- **One unit failed to a hard short during pre-test IR measurement at 0.5 Vr, 125 C, within 5 minutes of application of voltage**
- **6/120 parts show early degradation.**
- **This demonstrates that bad lots can fail at realistic use conditions within minutes of use.**



445306-566 Second Lot Number

- **Testing performed on C1210T475K5RCLTM (445306-566) lot number 161700086 or 161748095**
  - Same testing performed, 5 cycles of thermal shock from -55 C to 125 C.
  - After thermal shock, 120 units tested at 2 Vr (100 V), 125 C, for 48 hours
  - Zero failures
- **Indicates that the problem is potentially lot number specific**
  - What differentiates 161700086 and 161748095 from 161248093?

Test Results as of 4/22/19

Suffix	Lot Number	Testing Result
445306-383	173136356	(15886) n=120 2Vr, one part with bad continuity, otherwise clean.
445306-389	181682572	(16025) n=125 2Vr, no failures
445306-389	181682573	(16025) n=75 2Vr, no failures
445306-395	180564186	(15889) n=37-53, 2Vr, one IR step, within limit, pass (16218) n=120 2Vr, 1 very low IR step at 3 hrs, failure.
445306-395	160547936	(15889) max n=83 2Vr, one IR step, within limit, marginal pass
445306-401	181539428	(16042) n=120 2Vr, one out of family low, failure. Checked on Saunders, confirmed low.
445306-476	163525680	(15890) n=120 2Vr, 1 IR drop, ends in family, marginal pass
445306-488	161256854	(16209) 2 Vr, n=120, 8 IR drop to just below the line. One early hard short (sn103), second hard short at 33 hrs. (16224) 1 Vr, n=120, at 138 hrs no failures or drops. (16223) 1 Vr, n=120, second batch, 138 hrs, 2 part with small drop and noise, not below the line. Second small drop, no failures
445306-488	160923803	(15884) min n=107 2Vr, no failures
445306-503	170903672	(15888) n=120 2Vr, pass 48 hr. (16177) n=120 2Vr, pass 48 hr. (16178) n=120 2Vr, one IR drop below line then recover. Marginal pass
445306-518	161278793	(16202) n=120, 2Vr, contact issue on first 40. Last 80 look good. 40 retested, one starts very low and recovers up. One part rolls off and shorts at 33 hrs. test complete. (16208) n=120, 2Vr, two rapid degradation to short failures, ~7 and ~10 hrs.
445306-518	161234552	(16082) n=300 2Vr, no failures
445306-542	161023801	(15891) n=120 2Vr, 20% failure. Move to lower V testing. (16201) n=120 .5VR. One fail to hard short in pre-IR, sn358 failed limit. 9 dropping during .5VR, all seem to be recovering. (16226) No TS, 2Vr, n=120, at 15 hrs in test. 2 very small squiggle. two early drop then degradation (like -566), one failed to short at 17 hrs, the other at 34 hrs. 2 drop then recover. One drops at ~30 hrs to below line. One that starts at 1e5, 100 times lower than family but flat.
445306-542	184553170	(16225) n=120, 1 Vr, 200 hr. 4 fast drops to the line early in test. 3 that starts low, on the line, stays flat. One starts below line and rises up to in family. SN579 starts hard shorted. SN605 appears open.
445306-542	184628568	(16222) 120 at 1 Vr, one started on line, stayed on line; 5 drop, not below line; bigger drop at 5500 min, well below line; at 159 hrs. SN605 appears open.

Test Results as of 4/22/19

Suffix	Lot Number	Testing Result
445306-566	161248093	(16127) n=60 1Vr, 2 failure (15887) n=120 2Vr, 12% failure. (16188) n=120 2Vr, no thermal shock. One fast drop and degradation. After TS, 3 immediate IR steps, one to short, at 35 hours.
445306-566	161748096	(16167) n=120 2Vr, 1 IR drop failure below line, one IR drop above line.
445306-566	161748095	(16119) n=1-120 2Vr, no failures, split with 161700086
445306-566	161700086	(16119) n=1-120 2Vr, no failures, split with 161748095
445306-581	161144333	(16175) n=40 2Vr, no failures observed. (16174) n=120 2Vr, 48 hr complete. Two failures to short, ~3hr and ~43 hrs. Very limited quantities. No additional controls to be used.
445306-581	160644333	(16172) n=120 2Vr, 5 IR drops, one hard short. This lot number cannot be used without 1 Vr data.
445306-581	160944333	(16175) n=80 2Vr, Two with marginal IR drops above the line

- Lots with high failure rates at 2 Vr also show failures at lower voltages (1 Vr and .5 Vr)
- Lots with high failure rates at 2 Vr also show failures without thermal shock at 2 Vr
- Lots with less severe failure rates at 2 Vr show out of family behavior at 1 Vr

- 11/22 lot numbers tested have failures at 2 Vr
- 4/22 lot numbers tested to date have out of family behavior that is marginal