A Technical Evaluation of Surface Mount Base Metal Capacitors (BME) X7R for the European Space Agency - European Space Components Coordination (ESCC) Contract No. 22484/09/NL/CP

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ABSTRACT

This will detail this new space product showing history of this product and results/data from the evaluation study. Base metal electrode technology has been used in the automotive industry for many years. The basis for automotive qualification i.e. AECQ200 specification and Advancements in ceramic technology including particle size reduction, led to a higher volt per micron in dielectric strength with the Base metal electrode system. Also improvements in the equipment required to successfully cast, print and stack very thin ceramic layers has enabled the production of higher capacitance components. ESA asked AVX to take part in a study using BME technology as the basis for the evaluation study. The ensuing programme including extensive testing of the components and interpretation of results took approximately two and half years to complete. The results of the test programme showed that the AVX high CV BME product was suitable for space applications and this product is now available as EPPL level 2. This will result in the space industry having available much more volume efficient ceramic capacitors. Smaller, lighter components can now be used to replace larger capacitors of a similar voltage/capacitance combination. The EPPL qualification range is based on one particular X7R formulation that was in common use 3 to 4 years ago. Since then the automotive product has moved onto another ceramic formulation which has given further improvements. It is envisaged that when AVX carry out the QPL qualification of this product range this new formulation will be utilised thereby delivering further efficiency improvements. As ESCC embrace this technology they will be able to take advantage of its future development towards ever increasing CV.

INTRODUCTION

This paper describes the technical evaluation of BME X7R Multi Layered Ceramic Capacitors (MLCC) using a perovskite material, Barium Titanate. These products have been manufactured for over twenty years by the MLCC industry and have gradually replaced most of the Precious Metal Electrode (PME) capacitor systems in all applications, with the exception of space products where there are restrictions placed on the use of BME capacitor products.

BME systems normally use nickel electrodes instead of the PME combinations (Palladium/Silver) as the electrode structure. This is accompanied by a change to the termination material set from a Silver/Palladium or Silver termination to a Copper termination material. BME capacitors consist mainly of non-reducing dielectric materials, barium titanate, doped with a range of intermediate ionic sized rare earth ions. The ionic rare earth ions are used primarily to improve the reliability performance of the dielectric material [1,2,3].

Ceramic capacitors with BME systems are now used in almost all areas of electronics such as Automotive, Medical, Industrial, Telecommunications and many commercial applications. Even in the Space Industry there are some occasions where the only available product utilises a BME material set and therefore is selected for use but tested to the usual stringent requirements for space.

The present qualified BME ceramic capacitor product range available from AVX Limited (AVX) contains Surface Mount, Leaded Products and Stacked Assembly type products, which are supplied throughout Europe and the rest of the World.

EUROPEAN SPACE PRODUCT EVALUATION PROJECT

In 2008 a program for evaluating BME capacitors was initiated between the European Space Agency (ESA) and AVX. This program involved a planning phase to establish which ceramic capacitor product ranges to be evaluated for Surface Mount Devices (SMD) and what type of testing programs should be used. The testing was carried out in AVX's laboratories with the use of sub-contractors for the soldering processes to mount the MLCCs on to the printed circuit boards (PCB). ESA designed the format for the reliability testing with a significant focus on "overstressing" the components using higher temperatures and voltages to establish the performance of the product range at elevated conditions.

The initial product range of interest was established using a component case size from 0603 (EIA values) up to a maximum size of 1812. The smaller 0402 BME products were available but were not selected for the evaluation back in 2008, although since then their actual usage has increased significantly across many electronic applications and are in demand significantly throughout the USA Space and Aerospace industries

The voltage range selected for evaluation was from 25 V - 100 V, the more common higher reliability voltage range. The 25-100 V capacitor product range is positioned well inside the current BME range, (4V – 3 KV) and has a long history of reliability data. The product portfolio map illustrated in Fig.1 indicates the various selected range of components used today including that of the range used for the ESA evaluation work.

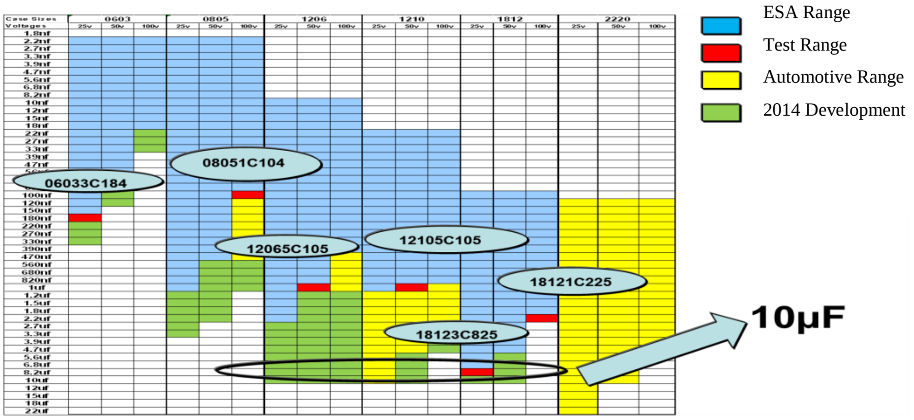


Fig. 1. ESA Evaluation Study Range

PRODUCT DESIGN FOR SPACE APPLICATION

MLCC product design is based upon four key component areas of a capacitor: dielectric layer thickness, side/end margin dimensions, capacitor cover layer thickness and capacitance value as illustrated in Fig. 2 [4].

Ceramic Layer Dielectric Thickness

BME capacitor products are presently utilising fired dielectric thicknesses of anywhere from <=2 µm for low voltage (4V) X5R devices to 80µm for the higher Voltage (2kV) X7R devices. So the 25 V - 100 V X7R product would have a dielectric thickness in the region of 5µm to 18µm depending on actual voltage rating. This may differ from supplier to supplier but these are typical design parameters for the AVX product range.

For all of the space products designed for this evaluation the AVX design team decided to use a very conservative approach and build in additional dielectric layer thickness beyond the present Automotive designs. As an example the present 50V automotive grade would use a dielectric layer of around 4.5 - 5µm and for an equivalent space part a figure of 11µm was chosen as the minimum for ceramic layer thickness.

Capacitor End and Side Margins

The capacitor margins are used to protect the inner electrode structure from the outside environment and the end terminations with an opposing polarity and are usually made as small as feasible for manufacturing, so as to maximise the area of the electrode plate and hence the capacitance value. This means that the minimum designed side and end green margins for a commercial part are around 75µm, whereas for an automotive part this would be 100µm.

For the space product designs this was set at 170µm for 25V rated product for both side and end margins to ensure an extra design safety feature.

Dielectric Cover layers Top and Bottom

The cover layers that are set on the top and bottom of the internal electrode stack are designed normally at a minimum of approximately 75µm for a commercial part and 100µm for an automotive part. For the space product designs the 25V has minimum cover layer thickness of 112µm the 50V parts have 160µm and the 100V parts are minimum 160µm.

Capacitance Value.

The capacitance value for each MLCC case size is determined by the following equation (1):

$$C = \varepsilon \frac{(N-1)A}{t} \qquad (1)$$

Here, C is capacitance, ε is the dielectric permittivity of the MLCC materials, N is the number of electrodes layers, A is overlap area of the internal electrodes and t is the thickness of each of the dielectric layer.
The design team use this formulae to calculate the actual number of electrodes needed for the required capacitance value.

Fig. 2. Shows the key component areas of a capacitor: cover layers, margins and dielectric thickness.

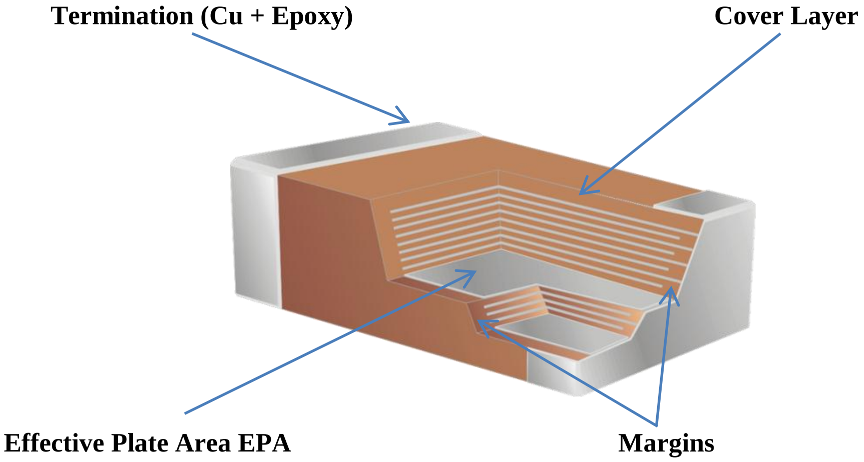


Fig. 2. Capacitor Design.

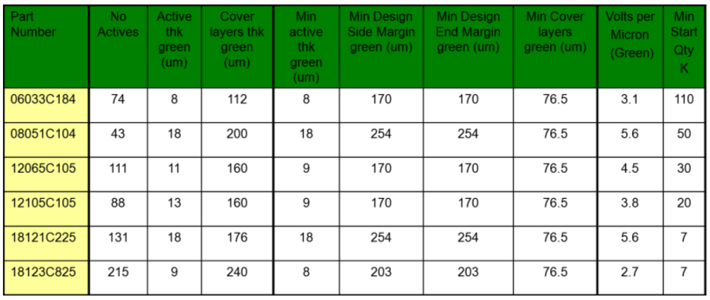
PRODUCT SELECTION AND DESIGN DETAILS

Six capacitor values were selected by the ESA for evaluation and these covered the following criteria:

> The five case sizes: 0603, 0805, 1206, 1210, 1812
> The three voltages: 25, 50 and 100V
> The maximum capacitance value 8.2µF
> The product with the maximum voltage stress placed on it i.e., the 1812 100V 2.2 µF has a voltage stress of 5.6 V/µm

The details of this test summary are in Table 1 below. This gives the detailed design attributes of each part with the number of active layers, the dielectric thickness (green), the minimum cover layers and the side /end margin minimums for each of the six selected parts for testing. The v/µm value is a theoretical calculation based on designs and voltage rating. The capacitance, IR and DF values were measured on a pre-calibrated HP4278A and HP4339B meters. Thermal cycling testing was completed on ESPEC Thermal Cycling chamber.

Table 1. Test Vehicle Summary

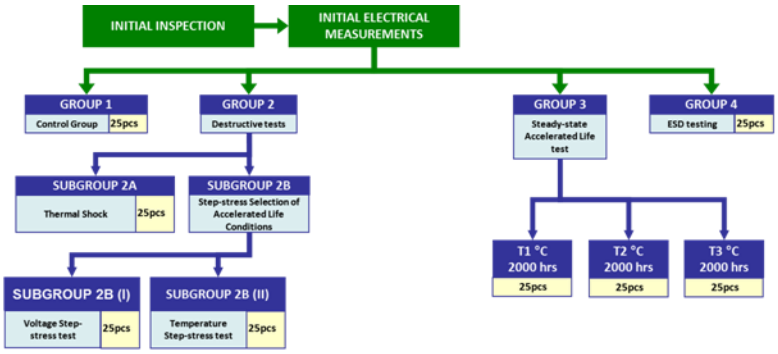


Part Number	No Actives	Active thk green (um)	Cover layers thk green (um)	Min active thk green (um)	Min Design Side Margin green (um)	Min Design End Margin green (um)	Min Cover layers green (um)	Volts per Micron (Green)	Min Start Qty K
06033C184	74	8	112	8	170	170	76.5	3.1	110
08051C104	43	18	200	18	254	254	76.5	5.6	50
12065C105	111	11	160	9	170	170	76.5	4.5	30
12105C105	88	13	160	9	170	170	76.5	3.8	20
18121C225	131	18	176	18	254	254	76.5	5.6	7
18123C825	215	9	240	8	203	203	76.5	2.7	7

- **8 um chosen for min dielectric thickness to meet TC X7R requirement**
- **Number of active layers ranged from 43 to 215**

ESA TEST EVALUATION PROGRAM

The program as set out by ESA had 4 phases to it. This is shown Fig. 3.



- **VOLTAGE STEP STRESS TEST = VSS : TEMPERATURE STRESS TEST = TSS**
- **For Sub Group 2B and Group 3 , Tests were halted as soon as 50%+ fails were realised**
- **Analysis was performed on all components that were stressed to electrical failure.**
- **Life Test Conditions (ie Group 3) were decided by ESA based on VSS & TSS results(ie Sub Group 2B)**

Fig. 3. Test Programme

Group 1

Completed initial electrical, visual and dimensional analysis on 25 pcs from the six part numbers by selecting random samples from production lots.

Group 2

The second phase had two subgroups:

Subgroup 2A

Thermal Shock test on 25pcs from each lot.

Subgroup 2B

This Sub group was split into a voltage and temperature stress test whereby the samples are deliberately over stressed in an increasing step sequence until 50% of the samples have failed.

(1) The capacitor samples were initially tested at 125°C for 168 hours then with the voltage set at increasing multiples of rated voltage; example 4 x rated voltage first step → 5 x rated voltage second step→ 6 x rated etc.

(2)The capacitor samples were initially tested at rated voltage for 168 hours with the temperature set at increasing levels from 100°C →125°C→150°C etc up to 225°C.

Group 3

Group 3 test regime whereby the samples will be tested at significantly elevated voltages and temperatures combinations for up to a maximum 2000hrs until 50% of the parts have failed. These test conditions will be well above any normal parameters and are designed to take the product to failure.

Group 4

Group 4 was an ESD test on a sample from each of the six part numbers.

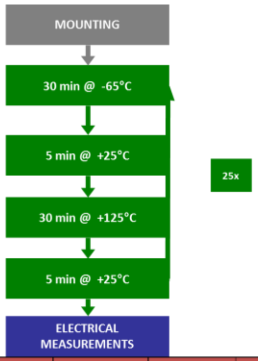
RESULTS FOR GROUP 1, 2

Group 1 Results

All of the samples for each of the part numbers were inside specification.

Group 2 Results

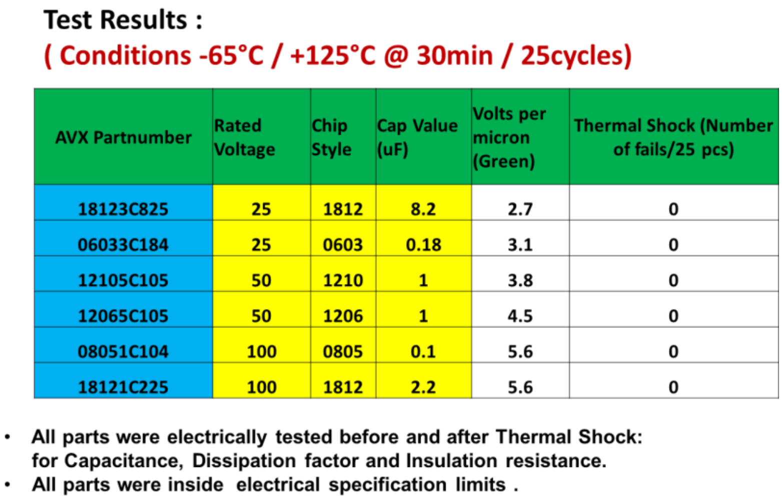
The thermal shock results from Subgroup 2A were of surface mounted MLCCs which had been reflow soldered and then subjected to temperature shock from -65°C to 125°C through 25 cycles, details are below in Fig. 4. This is a standard test which all products would be expected to pass and no defects were found in any of the samples tested, see Table 2 for results.



	Condition	Limits	Procedure	Equipment
MOUNTING	IEC 60384-1	-	IEC 60384-1	Reflow oven
THERMAL SHOCK	-65 / +125; 25 cycles	-	ESCC 2263000	Cyclic temp. chamber ESPEC
EXTERNAL VISUAL	-	ESCC 20400	ESCC 20400	Microscope
CAPACITANCE	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
DF	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
INSULATION RESISTANCE	1*RV	UHR/QAC/ 35-94	UHR/QAC/ 50-28	HP 4339B, IR scanner

Fig. 4. Thermal Shock

Table 2. Thermal Shock Results



Test Results :

(Conditions -65°C / +125°C @ 30min / 25cycles)

AVX Partnumber	Rated Voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Thermal Shock (Number of fails/25 pcs)
18123C825	25	1812	8.2	2.7	0
06033C184	25	0603	0.18	3.1	0
12105C105	50	1210	1	3.8	0
12065C105	50	1206	1	4.5	0
08051C104	100	0805	0.1	5.6	0
18121C225	100	1812	2.2	5.6	0

- All parts were electrically tested before and after Thermal Shock: for Capacitance, Dissipation factor and Insulation resistance.
- All parts were inside electrical specification limits .

Subgroup 2B

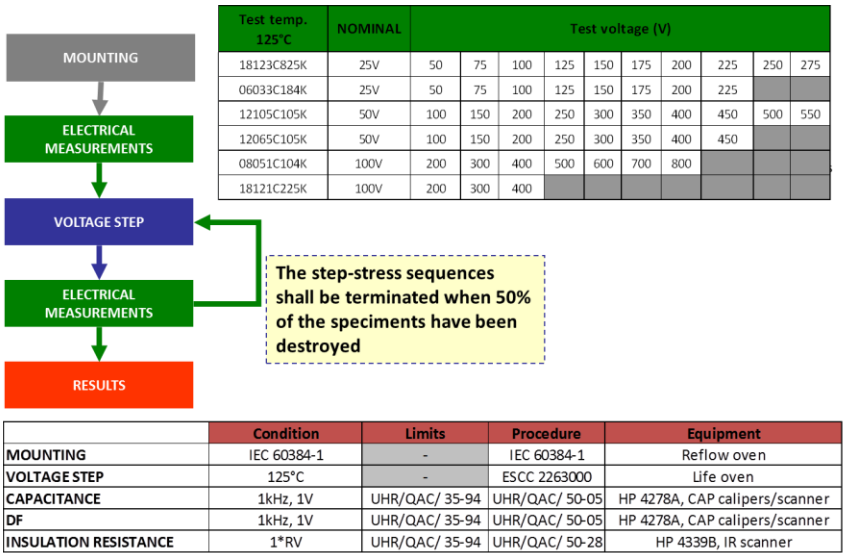
Subgroup 2B is split into 2B (1) and 2B (2).

Subgroup 2B (1)

This subgroup of parts were tested with increasing voltage stress until 50% of the parts had failed, the failure mode being defined by a short circuit (<= 1MOhm Resistance).

Note any failed part was subsequently analysed and categorised. The test cycle is shown below in Fig. 5 with the reference specifications and equipment.

During each step of the test the sample experienced 125°C for 168 hours in the life chamber with the voltage factor set to multiples of the rated voltage. The exact voltage settings are shown in Table 3.



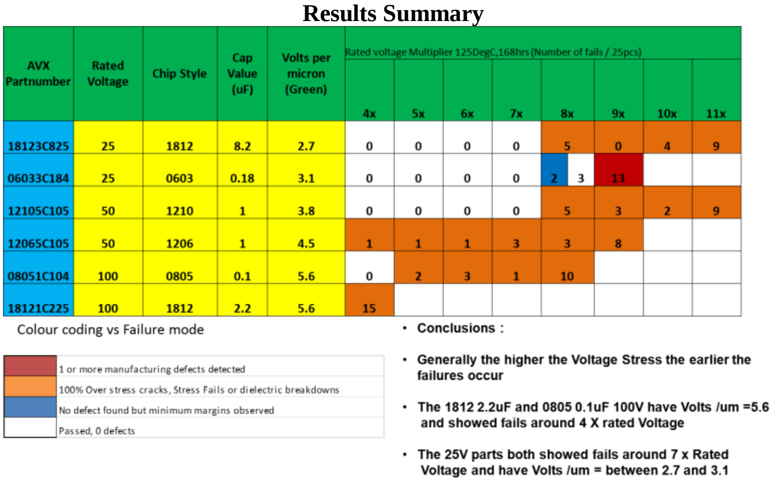
Test temp. 125°C	NOMINAL	Test voltage (V)									
18123C825K	25V	50	75	100	125	150	175	200	225	250	275
06033C184K	25V	50	75	100	125	150	175	200	225		
12105C105K	50V	100	150	200	250	300	350	400	450	500	550
12065C105K	50V	100	150	200	250	300	350	400	450		
08051C104K	100V	200	300	400	500	600	700	800			
18121C225K	100V	200	300	400							

The step-stress sequences shall be terminated when 50% of the speciments have been destroyed

	Condition	Limits	Procedure	Equipment
MOUNTING	IEC 60384-1	-	IEC 60384-1	Reflow oven
VOLTAGE STEP	125°C	-	ESCC 2263000	Life oven
CAPACITANCE	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
DF	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
INSULATION RESISTANCE	1*RV	UHR/QAC/ 35-94	UHR/QAC/ 50-28	HP 4339B, IR scanner

Fig. 5. Voltage Step Stress (VSS)

Table 3. Voltage Step Stress (VSS)



Results Summary

AVX Partnumber	Rated Voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Rated voltage Multiplier 125DegC,168hrs (Number of fails / 25pcs)							
					4x	5x	6x	7x	8x	9x	10x	11x
18123C825	25	1812	8.2	2.7	0	0	0	0	5	0	4	9
06033C184	25	0603	0.18	3.1	0	0	0	0	2 3	13		
12105C105	50	1210	1	3.8	0	0	0	0	5	3	2	9
12065C105	50	1206	1	4.5	1	1	1	3	3	8		
08051C104	100	0805	0.1	5.6	0	2	3	1	10			
18121C225	100	1812	2.2	5.6	15							

Colour coding vs Failure mode

🟥	1 or more manufacturing defects detected
🟧	100% Over stress cracks, Stress Fails or dielectric breakdowns
🟦	No defect found but minimum margins observed
⬜	Passed, 0 defects

- **Conclusions :**
- **Generally the higher the Voltage Stress the earlier the failures occur**
- **The 1812 2.2uF and 0805 0.1uF 100V have Volts /um =5.6 and showed fails around 4 X rated Voltage**
- **The 25V parts both showed fails around 7 x Rated Voltage and have Volts /um = between 2.7 and 3.1**

SUBGROUP 2B (1) - DISCUSSION

The results for the 2 x 25V rated parts, 18123C825 & 06033C104, show that these two parts started to show some fails around the 8 x rated voltage. The product with the higher V/µm stressed levels, 1812 8.2µF, shows more fails overall as the voltage was increased. When it reached 9 x rated voltage this product had reached the 50% failure rate. This follows the theory of higher V/µm stressing results in earlier/more failures [5].

The results for the 1210 50V 1µF (2 x 50V) rated part did not have any failures until 8 x rated voltage (400V) whereas the 1206 1µF had initial fails at 4 x rated (200V) and by 9 x rated it was over the 50% failure rate. The difference in voltage stress between the two components was 0.7 V/µm, with the 1210 case size component seeing the lowest stress as it had a thicker dielectric layer thickness of 13 µm versus 11 µm for the 1206 size, so this follows the trend as above. Both these parts performed well since there is large voltage acceleration factor being applied, but the 1210 50V 1µF has a greater performance compared with a similar cap value in a smaller case size.

The results for the 100V MLCC showed that the 1812 2.2µF capacitor showed failures at 4 x rated voltage whereas the 0805 0.1µm did not exhibit failures until 5 x rated voltage. Both the 100 V capacitors experienced the same v/µm stress levels but at the same time the total electrode area was significantly different between the two case sizes. The 1812 had

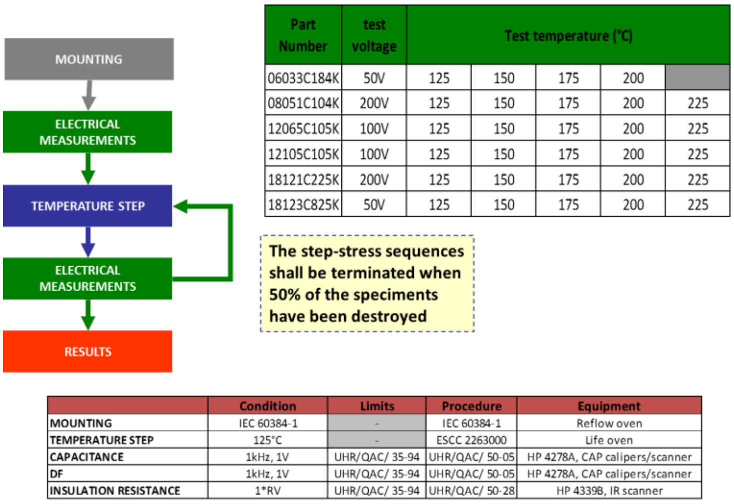
132 electrodes with a large electrode area whereas the 0805 size had only 44 electrodes with smaller electrode area so that the possible opportunity for failure is less with the smaller case size.

SUBGROUP 2B (2)

This group of parts were tested with increasing temperature stress until 50% of the parts failed, the failure mode being defined by a short circuit (<= 1MOhm Resistance).

Note the failure on any part was subsequently analysed and categorised. The test cycle is shown below in Fig. 6 with the reference specifications and equipment.

During each step of the test, the sample will see rated voltage applied for 168hrs in the life chamber with the temperature setting increasing from 100^{o}C to 225^{o}C, values are shown in Table 4.



Part Number	test voltage	Test temperature (°C)				
06033C184K	50V	125	150	175	200	
08051C104K	200V	125	150	175	200	225
12065C105K	100V	125	150	175	200	225
12105C105K	100V	125	150	175	200	225
18121C225K	200V	125	150	175	200	225
18123C825K	50V	125	150	175	200	225

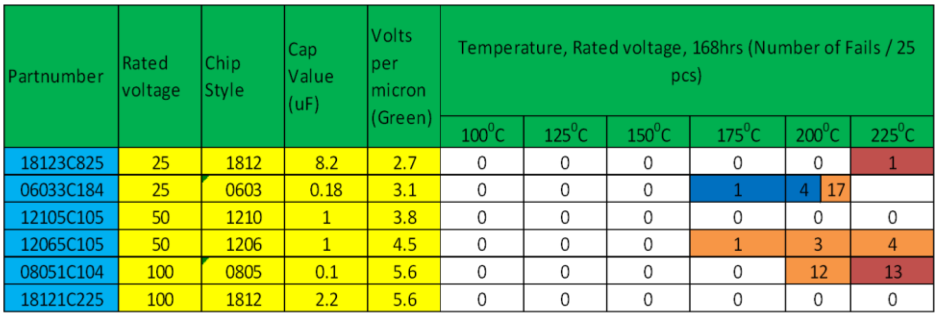
The step-stress sequences shall be terminated when 50% of the speciments have been destroyed

	Condition	Limits	Procedure	Equipment
MOUNTING	IEC 60384-1	-	IEC 60384-1	Reflow oven
TEMPERATURE STEP	125°C	-	ESCC 2263000	Life oven
CAPACITANCE	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
DF	1kHz, 1V	UHR/QAC/ 35-94	UHR/QAC/ 50-05	HP 4278A, CAP calipers/scanner
INSULATION RESISTANCE	1*RV	UHR/QAC/ 35-94	UHR/QAC/ 50-28	HP 4339B, IR scanner

Fig. 6. Temperature Step Stress (TSS)

Table 4. Temperature Step Stress (TSS)

Results Summary



Partnumber	Rated voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Temperature, Rated voltage, 168hrs (Number of Fails / 25 pcs)					
					100^{0}C	125^{0}C	150^{0}C	175^{0}C	200^{0}C	225^{0}C
18123C825	25	1812	8.2	2.7	0	0	0	0	0	🟥 1
06033C184	25	0603	0.18	3.1	0	0	0	🟦 1	🟦 4 🟧 17	
12105C105	50	1210	1	3.8	0	0	0	0	0	0
12065C105	50	1206	1	4.5	0	0	0	🟧 1	🟧 3	🟧 4
08051C104	100	0805	0.1	5.6	0	0	0	0	🟧 12	🟥 13
18121C225	100	1812	2.2	5.6	0	0	0	0	0	0

Colour coding vs Failure mode

🟥	1 or more manufacturing defects detected
🟧	100% Over stress cracks, Stress Fails or dielectric breakdowns
🟦	No defect found but minimum margins observed
⬜	Passed, 0 defects

- **Conclusions:**
- **All parts pass at Temperatures up to 150Deg C.**
- **Generally within each rated voltage higher Temperature Stress leads to earlier failures.**
- **The >=1210 Sizes showed the best performance at the Highest Temperatures.**

SUBGROUP 2B (2) – DISCUSSION

The results for the 2 x 25V rated parts showed that the 1812 8.2µF part was very reliable even up to 225°C temperature with only one defect at the 225°C test. The 0603 chip showed >50% fails at the 200°C testing point and again this part had a higher V/µm stress. The results follow the accepted behaviour of accelerated life testing were the higher voltages and temperatures result in greater acceleration factors. The higher temperatures results in an increased the mobility of the conductive mobile species contained within the barium titanate structure leading to an increased failure level.

The results for the 2 x 50V rated parts showed a similar trend as above in that the thicker dielectric MLCC (12105C105) parts showed a lower level of failures when the test temperature was increased above 175°C compared to the thinner dielectric MLCC (12065C105).

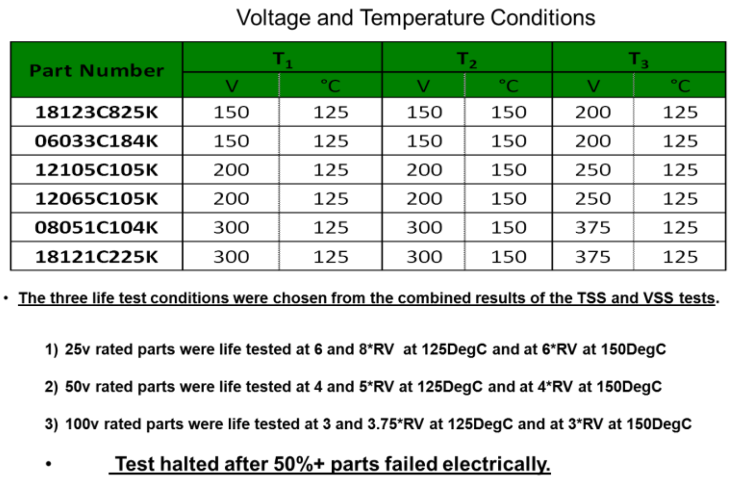
The results for the 100V part showed that the 1812 2.2µF had no fails even at the maximum temperature 225°C.

GROUP 3 TESTING

The ESA test matrix was devised to evaluate six AVX MLCCs and test them to 2000 hrs at higher than standard reliability test conditions. The six MLCCs were selected by the ESA criteria as mentioned earlier in the report. The samples were surface mount soldered and placed into the life test chambers at the defined conditions. Measurements were taken for Capacitance (C), Dissipation Factor (DF) and Insulation Resistance (IR) at specified intervals in the 2000 hour maximum test cycle. The data was logged in a database and used to prepare parametric data graphs for which some examples are shown later in this paper, page 13. The IR is the primary parameter to indicate a failure.

The data collected for the Group 2B voltage and temperature overstress testing was used to design the conditions used in Group 3 testing. Test group 3 had three subsets T1, T2 and T3 with each one using a different fixed temperature and voltage combination to overstress the components up to 2000 hours maximum test time until 50% of the samples had failed. These conditions were selected by ESA and are listed in Table 5 below. The maximum temperature used in this group was 150°C and the maximum voltage was 8 x rated voltage used on the 25V samples.

Table 5. Steady-State Accelerated Life Test



Voltage and Temperature Conditions

Part Number	T_1		T_2		T_3	
	V	°C	V	°C	V	°C
18123C825K	150	125	150	150	200	125
06033C184K	150	125	150	150	200	125
12105C105K	200	125	200	150	250	125
12065C105K	200	125	200	150	250	125
08051C104K	300	125	300	150	375	125
18121C225K	300	125	300	150	375	125

- **The three life test conditions were chosen from the combined results of the TSS and VSS tests.**

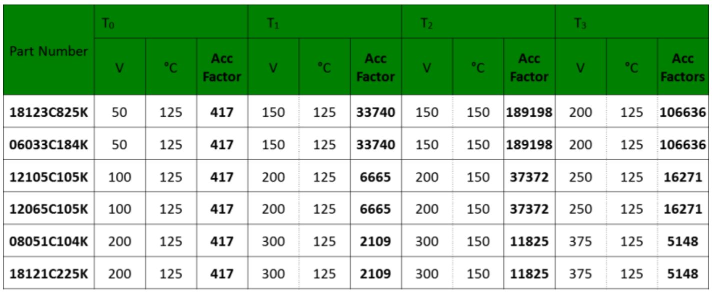
1) **25v rated parts were life tested at 6 and 8*RV at 125DegC and at 6*RV at 150DegC**
2) **50v rated parts were life tested at 4 and 5*RV at 125DegC and at 4*RV at 150DegC**
3) **100v rated parts were life tested at 3 and 3.75*RV at 125DegC and at 3*RV at 150DegC**

- **Test halted after 50%+ parts failed electrically.**

ACCELERATION FACTORS

The temperature and voltage acceleration conditions used during the steady state accelerated life test gave a substantial increase to the accelerator factors as calculated by the model devised by Prokopowicz and Vaskas [6,7]. These had been calculated for each of the six MLCC parts at each of the set test conditions and are listed below in Table 6. These values compare the relative acceleration between T1 versus T2 versus T3 compared to the normal acceleration used for life testing which is the T0 series (2 x rated voltage and 125°C).

Table 6. Acceleration Factors*



Part Number	T_0			T_1			T_2			T_3		
	V	°C	Acc Factor	V	°C	Acc Factor	V	°C	Acc Factor	V	°C	Acc Factors
18123C825K	50	125	**417**	150	125	**33740**	150	150	**189198**	200	125	**106636**
06033C184K	50	125	**417**	150	125	**33740**	150	150	**189198**	200	125	**106636**
12105C105K	100	125	**417**	200	125	**6665**	200	150	**37372**	250	125	**16271**
12065C105K	100	125	**417**	200	125	**6665**	200	150	**37372**	250	125	**16271**
08051C104K	200	125	**417**	300	125	**2109**	300	150	**11825**	375	125	**5148**
18121C225K	200	125	**417**	300	125	**2109**	300	150	**11825**	375	125	**5148**

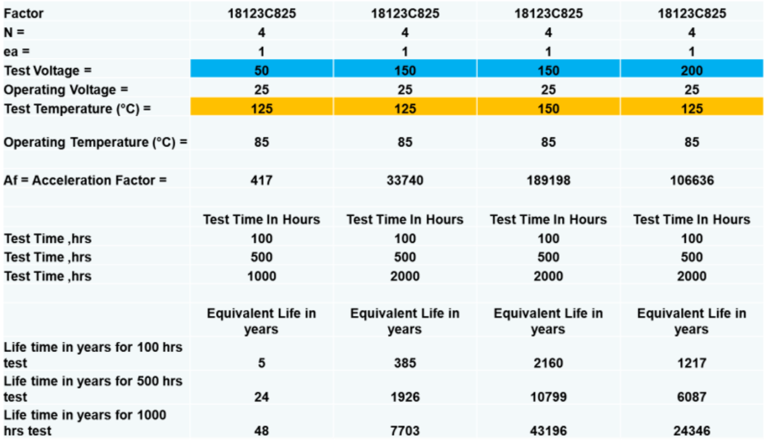
- **The acceleration factors were calculated using the industry standard formula .**
- **T_o refers to standard life testing conditions.**
- **For example the 18123C825K tested at standard life conditions for 168 hours equals approx 8 years field use*.**
  the 18123C825K tested at 150 V 150 C conditions for 168 hours equals approx 3629 years field use*.

*** based on 85 Deg C at rated voltage , Ea = 1 , n = 4.**

Table 7. Shows the equation (2) methodology used to calculate the acceleration factors with the assumptions made for Activation Energy (Ea) and Voltage Stress Exponent (N)

Table 7. Acceleration Factor Calculation – 1812 8.2 u F

$$\frac{t_1}{t_2} = \left(\frac{V_2}{V_1}\right)^n \exp\left(Ea/k\left[\frac{1}{T_1} - \frac{1}{T_2}\right]\right) \qquad \textbf{(2)}$$

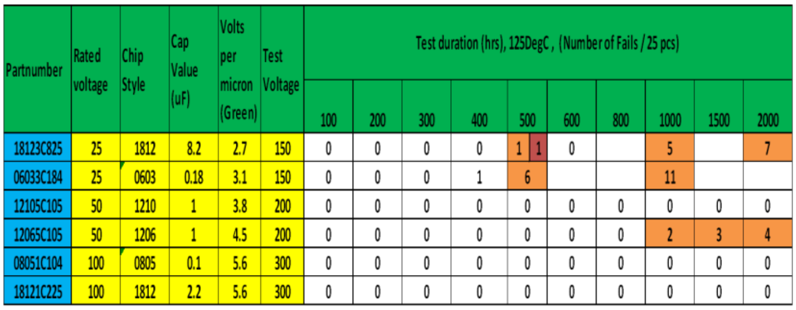


Factor	18123C825	18123C825	18123C825	18123C825
N =	4	4	4	4
ea =	1	1	1	1
Test Voltage =	50	150	150	200
Operating Voltage =	25	25	25	25
Test Temperature (°C) =	125	125	150	125
Operating Temperature (°C) =	85	85	85	85
Af = Acceleration Factor =	417	33740	189198	106636
	Test Time In Hours	Test Time In Hours	Test Time In Hours	Test Time In Hours
Test Time ,hrs	100	100	100	100
Test Time ,hrs	500	500	500	500
Test Time ,hrs	1000	2000	2000	2000
	Equivalent Life in years	Equivalent Life in years	Equivalent Life in years	Equivalent Life in years
Life time in years for 100 hrs test	5	385	2160	1217
Life time in years for 500 hrs test	24	1926	10799	6087
Life time in years for 1000 hrs test	48	7703	43196	24346

RESULTS FROM GROUP 3 TESTING

The following three tables show the results from Tests T1, T2 and T3, (Tables 8, 9 and 10).

Table 8. T_1 – Results Summary



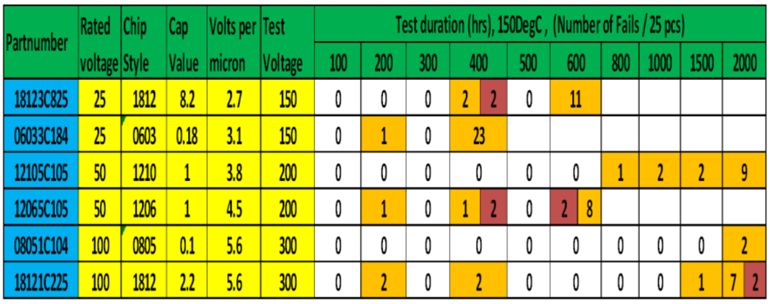
Partnumber	Rated voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Test Voltage	Test duration (hrs), 125DegC , (Number of Fails / 25 pcs)									
						100	200	300	400	500	600	800	1000	1500	2000
18123C825	25	1812	8.2	2.7	150	0	0	0	0	1 1	0		5		7
06033C184	25	0603	0.18	3.1	150	0	0	0	1	6			11		
12105C105	50	1210	1	3.8	200	0	0	0	0	0	0	0	0	0	0
12065C105	50	1206	1	4.5	200	0	0	0	0	0	0	0	2	3	4
08051C104	100	0805	0.1	5.6	300	0	0	0	0	0	0	0	0	0	0
18121C225	100	1812	2.2	5.6	300	0	0	0	0	0	0	0	0	0	0

Colour coding vs Failure mode

🟥	1 or more manufacturing defects detected
🟧	100% Over stress cracks, Stress Fails or dielectric breakdowns
🟦	No defect found but minimum margins observed
⬜	Passed, 0 defects

- **Within the 25 and 50 V rated failures occurred earlier with higher Volts/Micron stressing**
- **For life test parts are normally subjected to 2*rated voltage**
- **For 25 volt rated → life test voltage was 6* rated voltage**
- **For 50 volt rated → life test voltage was 4* rated voltage**
- **For 100 volt rated → life test voltage was 3*rated voltage**

Table 9. T_2 – Results Summary

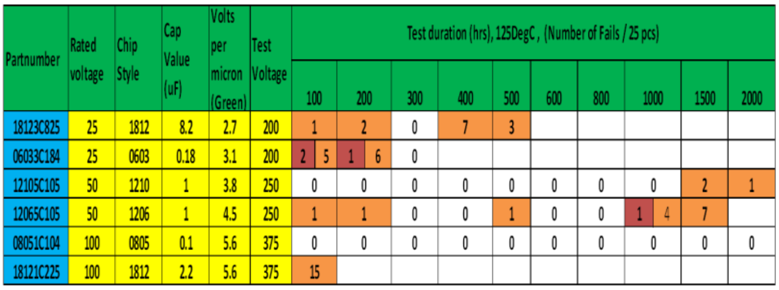


Partnumber	Rated voltage	Chip Style	Cap Value	Volts per micron	Test Voltage	Test duration (hrs), 150DegC , (Number of Fails / 25 pcs)									
						100	200	300	400	500	600	800	1000	1500	2000
18123C825	25	1812	8.2	2.7	150	0	0	0	2 2	0	11				
06033C184	25	0603	0.18	3.1	150	0	1	0	23						
12105C105	50	1210	1	3.8	200	0	0	0	0	0	0	1	2	2	9
12065C105	50	1206	1	4.5	200	0	1	0	1 2	0	2 8				
08051C104	100	0805	0.1	5.6	300	0	0	0	0	0	0	0	0	0	2
18121C225	100	1812	2.2	5.6	300	0	2	0	2	0	0	0	0	1	7 2

Colour coding vs Failure mode

🟥	1 or more manufacturing defects detected
🟧	100% Over stress cracks, Stress Fails or dielectric breakdowns
🟦	No defect found but minimum margins observed
⬜	Passed, 0 defects

Table 10. T_3 – Results Summary



Partnumber	Rated voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Test Voltage	Test duration (hrs), 125DegC , (Number of Fails / 25 pcs)									
						100	200	300	400	500	600	800	1000	1500	2000
18123C825	25	1812	8.2	2.7	200	1	2	0	7	3					
06033C184	25	0603	0.18	3.1	200	2 5	1 6	0							
12105C105	50	1210	1	3.8	250	0	0	0	0	0	0	0	0	2	1
12065C105	50	1206	1	4.5	250	1	1	0	0	1	0	0	1 4	7	
08051C104	100	0805	0.1	5.6	375	0	0	0	0	0	0	0	0	0	0
18121C225	100	1812	2.2	5.6	375	15									

- **Compared to Test 1 -T3 used the same Temperature 125C but much Higher Voltage levels**

Colour coding vs Failure mode

🟥	1 or more manufacturing defects detected
🟧	100% Over stress cracks, Stress Fails or dielectric breakdowns
🟦	No defect found but minimum margins observed
⬜	Passed, 0 defects

- **For 25 volt rated parts life test voltage = 8* rated voltage**
- **For 50 volt rated parts life test voltage = 5* rated voltage**
- **For 100 volt rated part life test voltage = 3.75*rated voltage**

- **4 x Part numbers all showed early failures**
- **The 08051C104 had no Defects on the test .**
- **The 12105C105 had 3 x fails at >= 1500 hrs**

RESULTS AND DISCUSSION

T1 Test Group - Tested at 125^{o}C and 4 to 6 x rated voltage

Within the 25 and 50V rated parts there were more /earlier failures at the highest V/µm design parts.

There were no fails on the 100V parts and these were tested at 3 x rated voltage and had the highest design dielectric thickness 18 µm.

T2 Test Group - This used the same voltage as T1 but higher temperature 150^{o}C

All parts showed earlier failures between 200 to 2000 hours. Also within each voltage rating the parts with the higher V/µm stress had more/earlier failures.

These earlier failures could be attributed to the extra thermal energy, making the conductive mobile species within the barium titanate structure move more easily.

T3 Test Group - this uses the same temperature as T1 but higher voltages from 3.75 to 8 times rated voltage

The 25V parts tested at 8 x rated voltage showed both part numbers with early fails and the parts with the highest V/µm reached the 50% failure point first.

The 50V parts had earlier failures on parts with the highest volts/µm stress.

The 100V parts showed earlier failures on the larger case size part the 1812, although it has considerably more electrode area than the 0805 part. This is the same trend seen with voltage overstress test of Group 2.

The voltage is driving the failure mechanism in the T3 series and these failures can be attributed to the voltage stress exceeding the "dielectric's voltage capability" of the fired ceramic causing the ceramic to wear out. This is influenced by a number of factors, dielectric thickness, the number of grains within each ceramic layer, the grain core/core-shell characteristics [5].

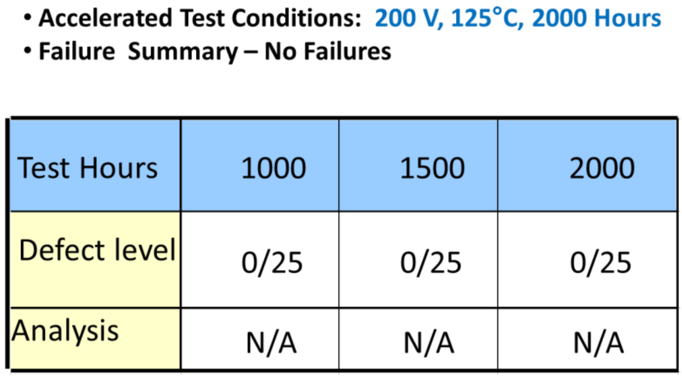
HIGHLY ACCELERATED LIFE TEST DATA FOR 1210 50V 1.0 uF PART

This example has been selected to show how the accelerated testing relates to life time MTTF values. The 1210 50V 1.0uF part showed no fails at 4 x rated voltage with 125^{o}C to 2000 hours of test time see Table 11.

This is equivalent to an MTTF value of 16,000 hours at 2 x rated voltage and 125^{o}C or 26,000,000 hours at 0.5 x rated voltage at 85^{o}C.

The actual parametric value trends for IR on this part are shown graphically below at the time intervals where the IR values were measured and recorded between 0 to 2000 hrs, Fig.7.

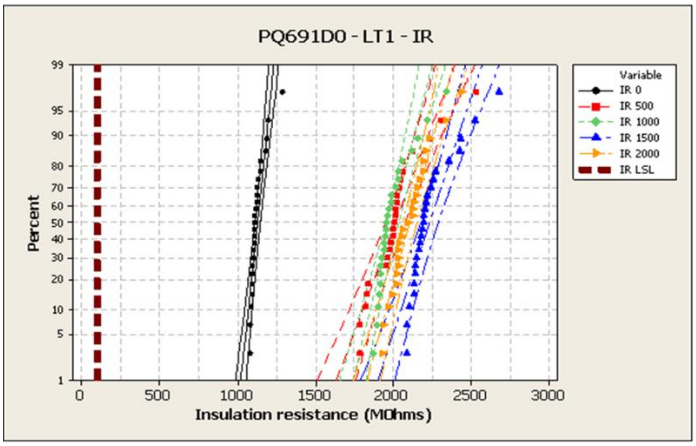
Table 11. Accelerated Life Test 1210 1 µF



- **Accelerated Test Conditions: 200 V, 125°C, 2000 Hours**
- **Failure Summary – No Failures**

Test Hours	1000	1500	2000
Defect level	0/25	0/25	0/25
Analysis	N/A	N/A	N/A

1210, 50V, 1.0 µF – IR



IR Stable at 2 GΩ (2x initial requirement)

Fig. 7. IR Distribution Data for 1210 1③F

CONCLUSIONS

The evaluation program described in this paper for the BME capacitors has shown that the long term reliability performance of these devices under highly accelerated conditions is excellent and would comply with the performance expectations for space applications. The product samples have been deliberately "over stressed" with voltage and temperature to generate long term data for life performance evaluation.

The product design model used has been conservative compared to the present BME range of capacitors available for the automotive and commercial markets. These designs have incorporated larger dielectric layer thickness between opposing polarity electrodes and greater margins/cover layers surrounding the electrode stack for added protection to the devices.

The products tested here have been the maximum values within their corresponding size/voltage/cap category so the lower values would be expected to at least meet and likely exceed the long term accelerated life data seen here.

The actual accelerated life performance for some typical parts tested here to 2000 hours shows MTTF values of >=26,000,000 hours or around 3,000 years.

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