BME MLCC CAPACITORS FOR SPACE

John Marshall.
marshallj@avxeur.com
Tel +442870340407

Frank Hodgkinson .
hodgkinsonf@avxeur.com
Tel +442870340411

ESCC EVALUATION TEST PROGRAMME

Base Metal Electrode Ceramic Capacitors studies

March 2012

Contract No. 22484/09/NL/CP

ESA BME QUALIFICATION PROGRAM

- **European Space Agency** initiated the program in 2008

- ***Objective:- make BME capacitors available for Space applications***
  - **Take advantage of improved capacitor technology**
  - **Higher capacitance per volume**
  - **Smaller, lighter capacitors (0603, 0402, smaller)**

- AVX Ltd (Coleraine, NI) has been the primary contractor for manufacturing-test. Manufacture of BME Products 15 Years in Europe.

- **AVX Principle Space Guidelines**:

  Use Safe, Conservative Capacitor Designs for best Performance.

  Use Best Materials, Processes (Equipment Capabilities) and Practices.

  Use FlexiTerm as a standard design feature – 10 Yr Europe Manufacture

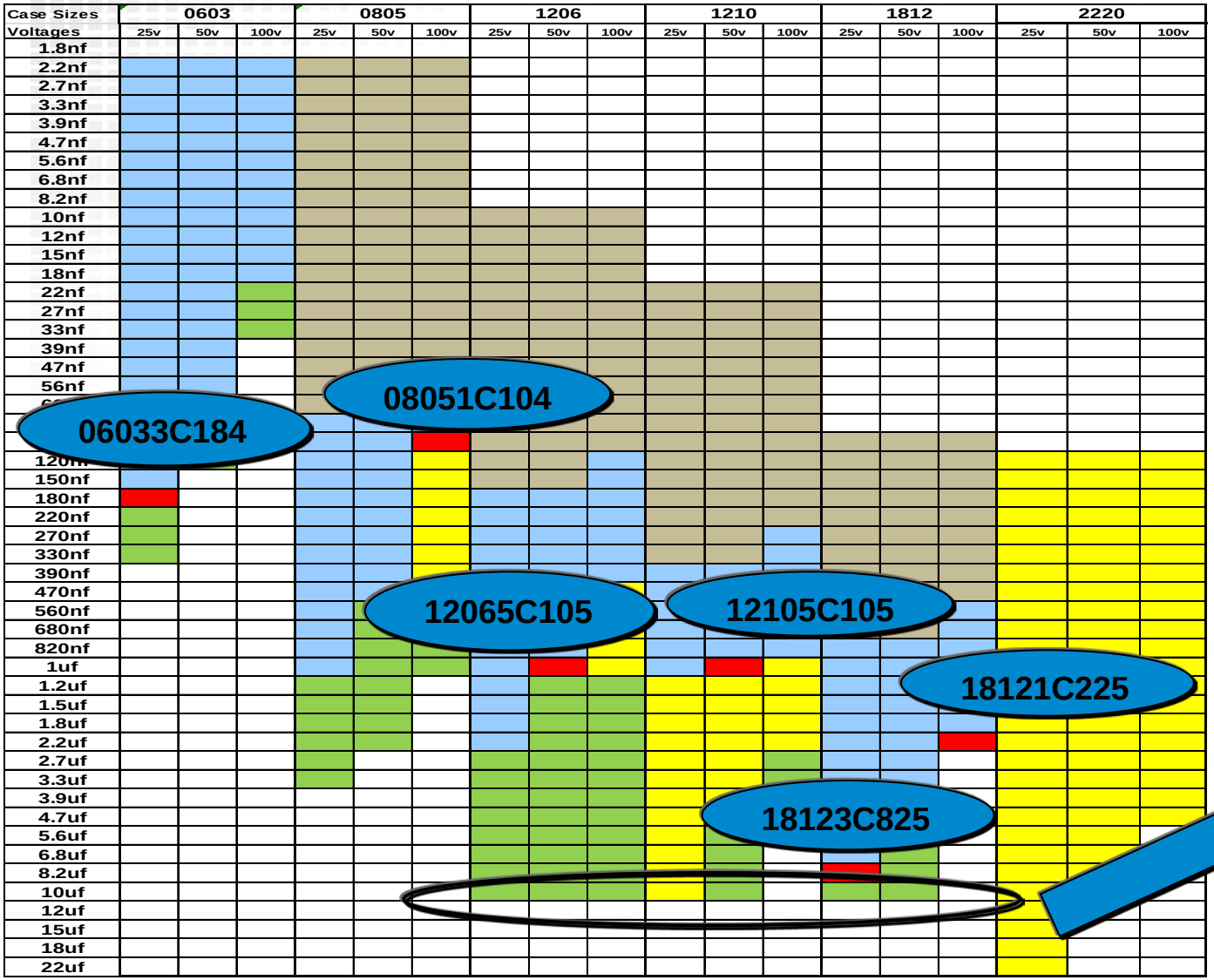
TEST VEHICLE SELECTION

- ***Selection range of test vehicles.***

Reason for this proposed range of part numbers is :

- **At least one sample of each case size is in the proposed range (0603, 0805, 1206, 1210, 1812)**
- **At least one sample of each voltage in the proposed range (25V, 50V, 100V)**
- **The Maximum capacitance in the proposed range (eg. 8.2uF)**
- **The Maximum volts/um in the proposed range (eg. 1812 100V 2.2uF=5.6V/um)**

ESA Evaluation Study Range



ESA Range

Test Vehicles

Current Auto Range

2014 Development

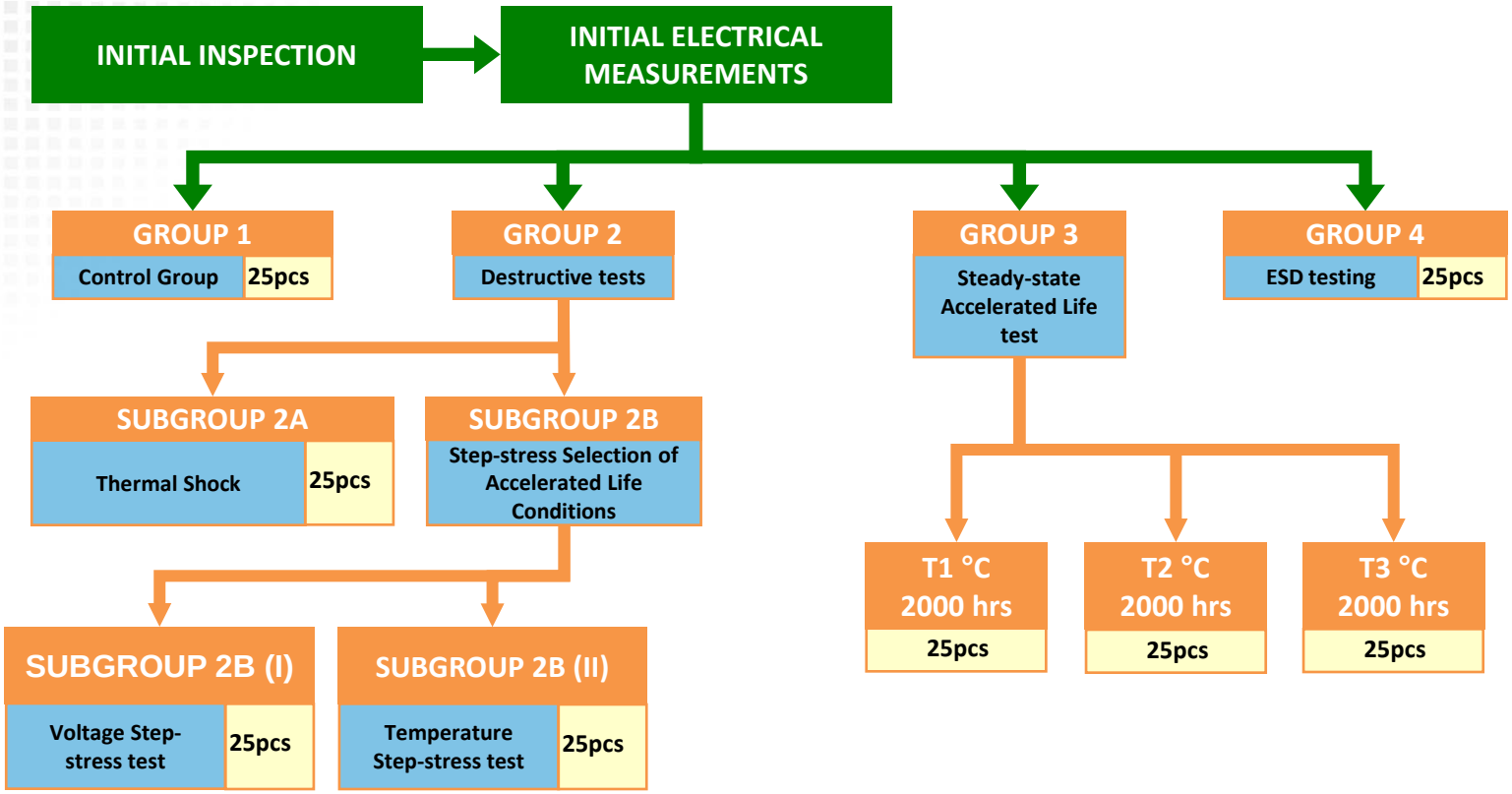
SMD PME X7R Range
AVX- TPC

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
- note an Active layer comprises two electrodes either side of a Ceramic layer

TEST PROGRAMME



- 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)

INITIAL INSPECTION RESULTS

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

PASS

- 25 pcs inspected for external visual performance
- Dimensions measured for length, width and thickness
- Electrically tested for capacitance, and insulation resistance
- All parts were inside specification

2A- 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

PASS

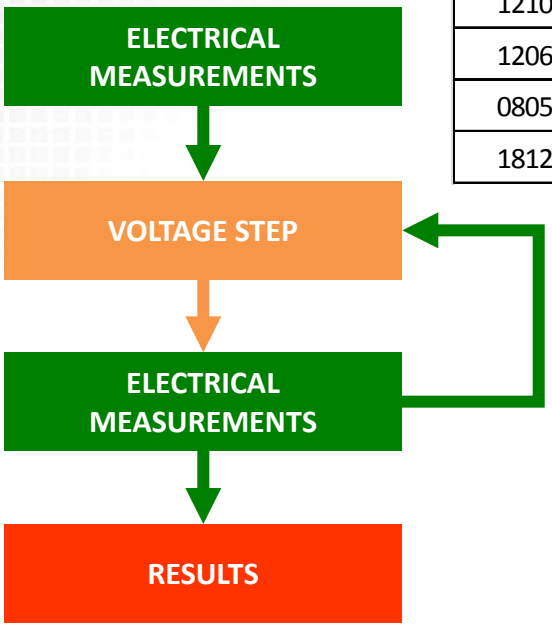
- All parts were electrically tested before and after Thermal Shock: for Capacitance, Dissipation factor and Insulation resistance.
- All parts were inside electrical specification limits.

VOLTAGE AND TEMPERATURE STRESS TESTS

- **Sub Group 2B (ie VSS and TSS) were a series of Destructive tests.**
- **The Voltage/Temperature conditions were ramped up beyond the Expected Working limits of the component to a point where >= 50 % of the components had failed Completely → Short CCT**
- **The components were electrically measured at each test to determine <u>Parametric</u> variation.**
- **On failure Parts analysed to determine mode of failure**
- **After VSS & TSS completion data was analysed to determine life tests conditions for each test vehicle.**
- **Accelerated Life testing to 2000hrs was performed until 50% of the components Failed**

2B(I)- VOLTAGE STEP STRESS

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 specimens 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

2B(I)- VOLTAGE STEP STRESS

Results Summary

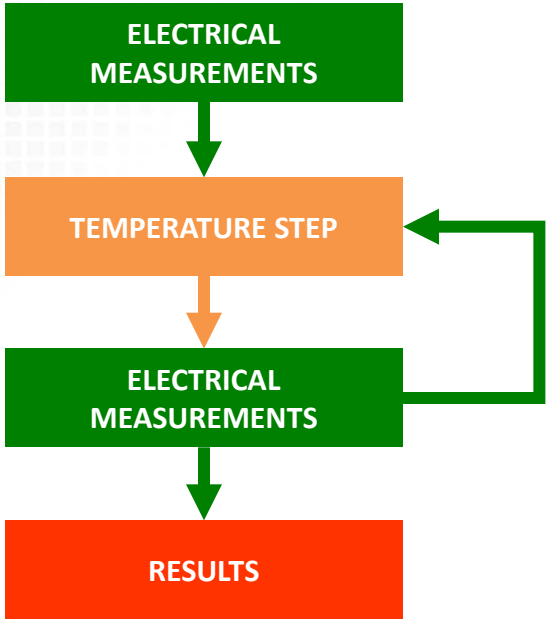
AVX Partnumber	Rated Voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Rated voltage Multiplier 125DegC,168hrs (Number of fails / 25pcs)							
					4x	5x	6x	7x	8x	9x	10x	11x
18123C825	25	1812	8.2	2.7	0	0	0	0	5	0	4	9
06033C184	25	0603	0.18	3.1	0	0	0	0	2 3	13		
12105C105	50	1210	1	3.8	0	0	0	0	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 :**
- **The higher the Voltage Stress the earlier 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 showed fails around 7 x Rated Voltage and have Volts /um = between 2.7 and 3.1**

2B(II)- TEMPERATURE STEP STRESS (TSS)



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 specimens 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

2B(II)-TEMPERATURE STEP STRESS (TSS)

Results Summary

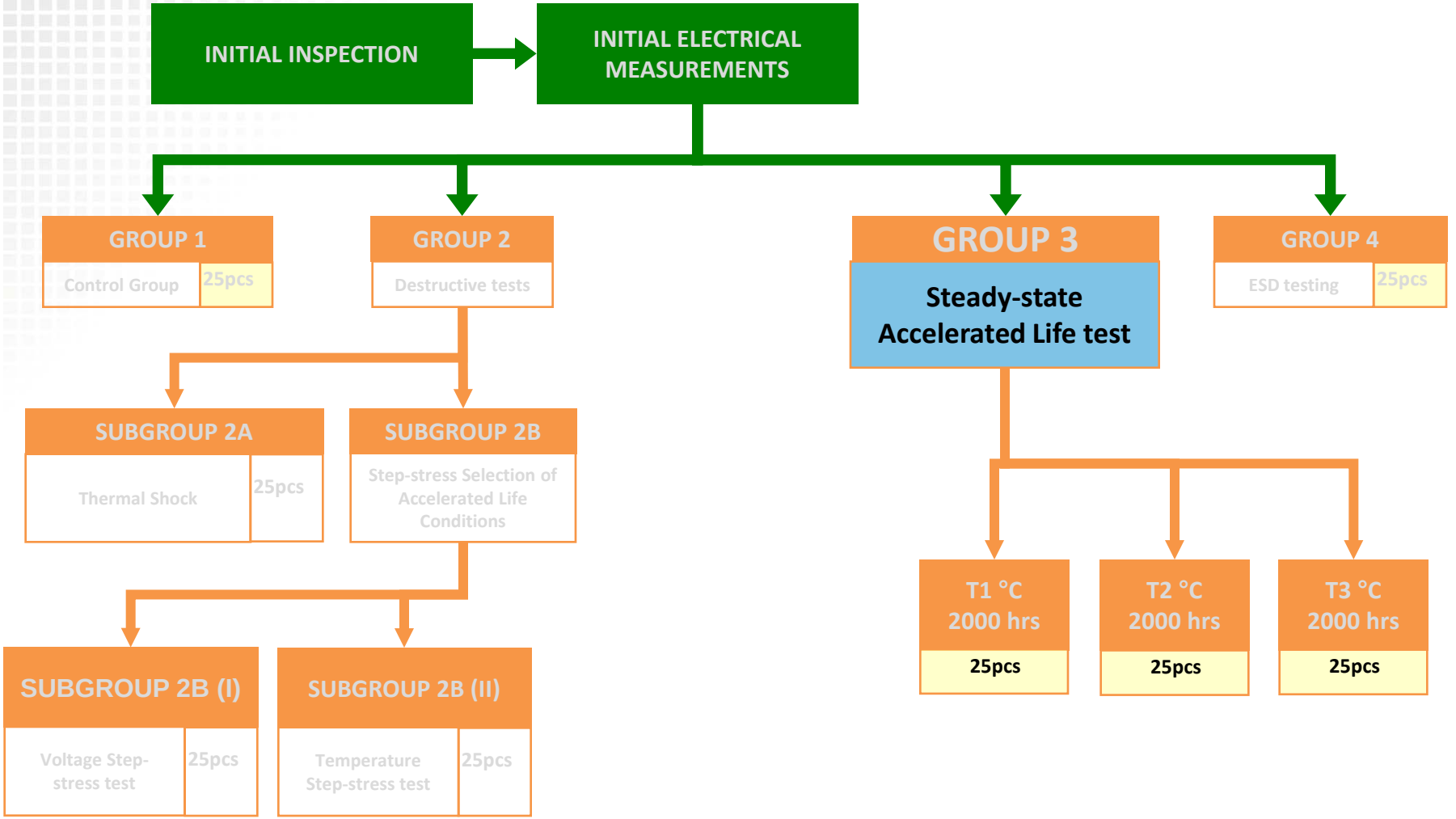
Partnumber	Rated voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	Temperature, 2 xRated voltage, 168hrs (Number of Fails / 25 pcs)					
					100^{0}C	125^{0}C	150^{0}C	175^{0}C	200^{0}C	225^{0}C
18123C825	25	1812	8.2	2.7	0	0	0	0	0	1
06033C184	25	0603	0.18	3.1	0	0	0	1	4	17
12105C105	50	1210	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 150DegC.**
- **Generally within each rated voltage higher Temperature Stress leads to earlier failures.**
- **The >=1210 Sizes showed the best performance at the highest Temperatures .**

TEST PROGRAMME - GROUP 3



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

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 Formula recommended by Propokowicz and Vaskas**
- **T_o refers to standard life testing conditions.**

- **Example the 18123C825K tested at standard life conditions for 168 hours =→ 8 years field use*.**
  Vs the 18123C825K tested at 200Volts and 125 C conditions for 168 hours=→ 3629 years field use*.

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

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**
- **Both 100V part numbers had No Fails to 2000 hrs**

- **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**

T_2- RESULT 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

- **Compared to Test T1 → T2 uses the same Voltage Levels But Higher temperatures 150C vs 125C**
- **All Parts show Failures but at earlier times 200 to 2000hrs**
- **Best Performance was on the 08051C104 with no failures until 2000 hrs .**
- **Higher V/um stress parts fail earlier**

T_3- RESULT 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									

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

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

- **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**

AVX
A KYOCERA GROUP COMPANY

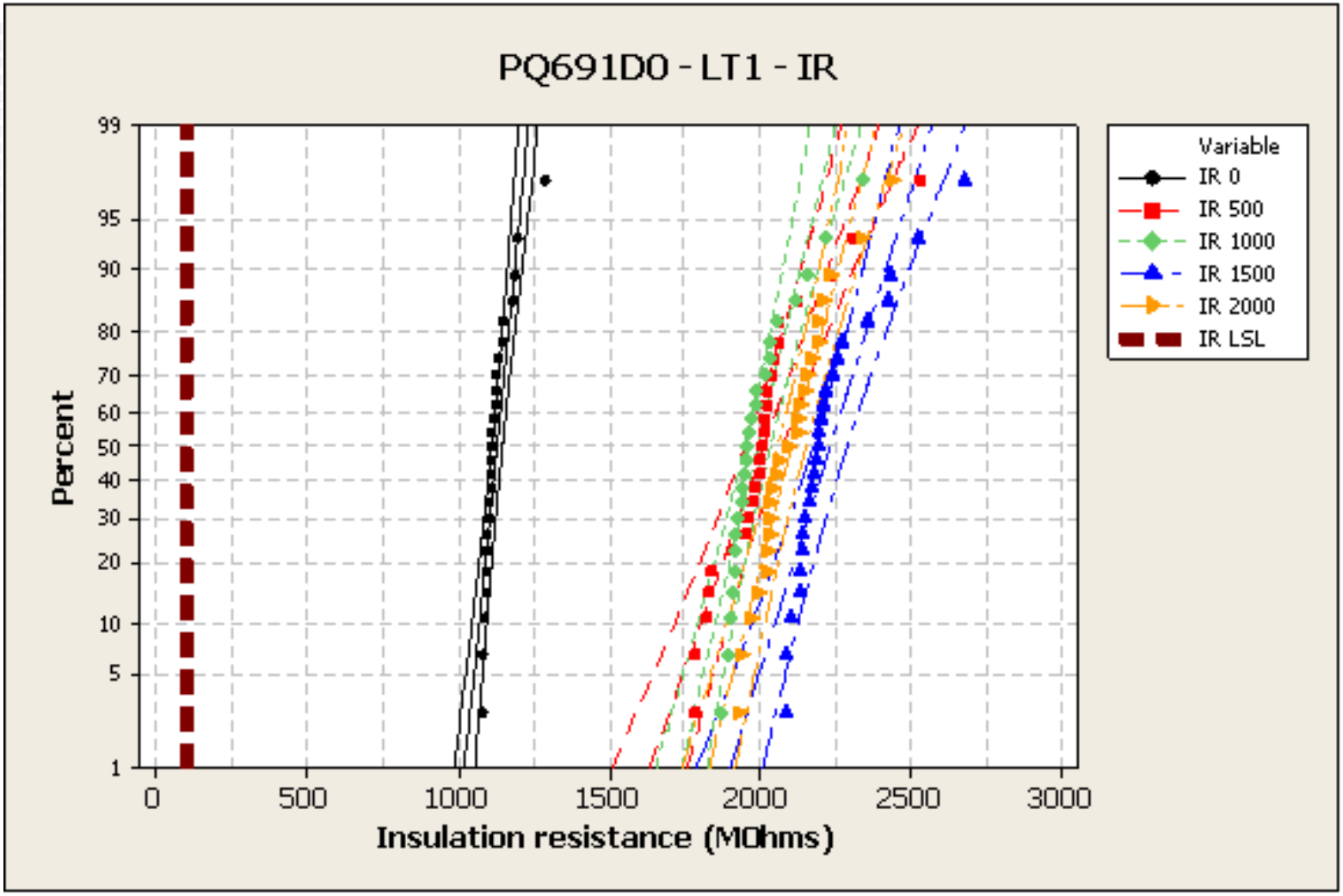
ACCELERATED LIFE TEST DATA

1210, 50 V, 1.0 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)

ACCELERATED LIFE TEST SUMMARY

- The results of Accelerated Life Test in the ESA evaluation were good overall, including these examples
- **1210, 50 V, 1.0 µF**
  - 2000 hours at 4xRV, 125°C, no failures
  - Equivalent to 16,000 hours at 2xRV, 125°C, or
  - 26,000,000 hours at 0.5xRV, 85°C
- **0805, 100 V, 0.1 µF**
  - 2000 hours at 3.75xRV, 125°C, no failures
  - Equivalent to 13,000 hours at 2xRV, 125°C, or
  - 22,000,000 hours at 0.5xRV, 85°C
- These results show that BME caps are capable of excellent performance in long term Accelerated Life Test

LONG TERM LIFE TEST

	LIFE TEST 2 x UR	Temp 125C	Sample Size	125 pcs
AVX Partnumber	1000 Hr	2000Hr	3000 Hr Sept 23	4000 Hr Nov
18123C825	PASS	PASS	PASS	
06033C184	PASS	PASS	PASS	
12105C105	PASS	PASS	PASS	
12065C105	PASS	PASS	PASS	
08051C104	PASS	PASS	PASS	
18121C225	PASS	PASS	PASS	

ESD TESTING - RESULTS

Test results Summary Table.

Conditions : RC combination 150pF, 2kOhms

Test ID	Rated Voltage	Chip Style	Cap Value (uF)	Volts per micron (Green)	ESD at 1250V (Number of fails/25)	ESD at 5000V (Number of fails/25)	ESD at 18750V (Number of fails/25)
691F	25	1812	8.2	2.7	0	0	0
691A	25	0603	0.18	3.1	0	0	0
691D	50	1210	1	3.8	0	0	0
691C	50	1206	1	4.5	0	0	0
691B	100	0805	0.1	5.6	0	0	0
691E	100	1812	2.2	5.6	0	0	0

Hand Solder of Surface Mount Components:

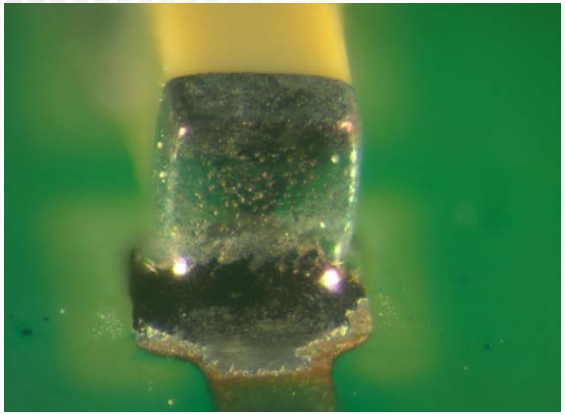
- Components were hand soldered by an AVX Space Customer
- A small and large component were chosen (0603 and 1812)
- Components were retuned to AVX for visual inspection - long term stress tests

Job No.	Part No.	Ceramic	Test No.	Hand Solder	TCY	HUM			HUM		
					rated voltage	rated voltage			rated voltage		
					10 cycles	168	500	1000	168	500	1000
				200	100	100			100		
D808210	06035C223KACB5Z	X7R	VR31120	2	0	0	0	0	0	0	0
D938420	12101C105KACGEZ	X7R	VR31150	0	0	0	0	0	0	0	0

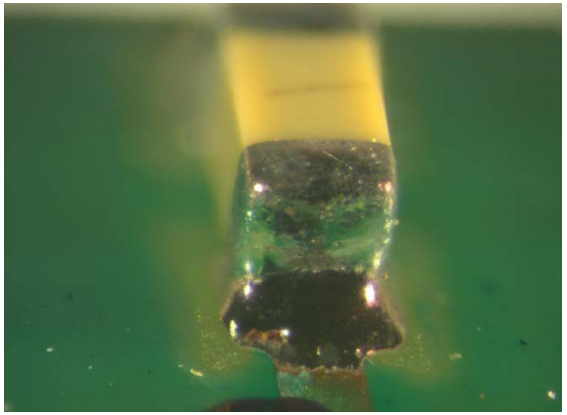
- No Electrical Failures on either Size.
- 2 pcs of the 0603 had small Fillets after Soldering.

Test Results

Analysis of 2 Visual Failures:



Non Wetting



Non Wetting: small solder fillet

- **Conclusions :**

- **0603 Smallest Size had 2 parts with small Fillets**

- **Soldering Capabilities are Limited when using Manual Soldering with Small Components**

BME Product Groups

	Commodity	Automotive	APS/H Series	Space
Voltage Rating	4-100V	16-100V	16-100V	25-100V
Dielectric Thickness	<2-10um	4.5-12um	4.5-12um	8-18um
QA	Sampling focused on max caps	Batch release, large samples, A0R1	Batch release, largest samples, A0R1	100% CSAM 100% B- in, PID, PDA limit
Fabrication	Wet and Dry	Wet and Dry	Wet and Dry	Dry
Margin and Cover Layer Sizes	Small as possible	Increased Margins	Increased Margins	Largest Margins

SUMMARY AND FUTURE PROGRAM

1. BME Space Product has High Reliability under Accelerated Life Test conditions . Normal Life Test tests on all 6 selected parts passed 3000 hrs – No Failures → 4000hr data Nov 2013.

2. Promote BME Products to the Space and Aerospace Industry Scheduled Customer Visits Europe and USA 2013, 14.

3. Provision of Samples and Additional Test Data Packs 2013,14.

4. Status EPPL 2 → ESCC 3009 /039 Nov. → QPL 2014 .

5. Develop BME components for Leaded Space Products.
   Single Chip " Straight , J, L " Leads
   Multi Stacks with Leadframe .

6. Design and manufacture smaller sizes - 0402, 0201

Thank You