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2017

Ceramic Capacitor B.M.E. Technology and future developments for Space, Military Applications

- Development for BME X7R material selection & processing for high reliability capacitors.
- Design rules to assure BME MLCC performance for Space and Military applications.
- BME capacitor development program - Capacitance, Voltage, Size.
- IDC (InterDigitated Capacitors) BME for Space.

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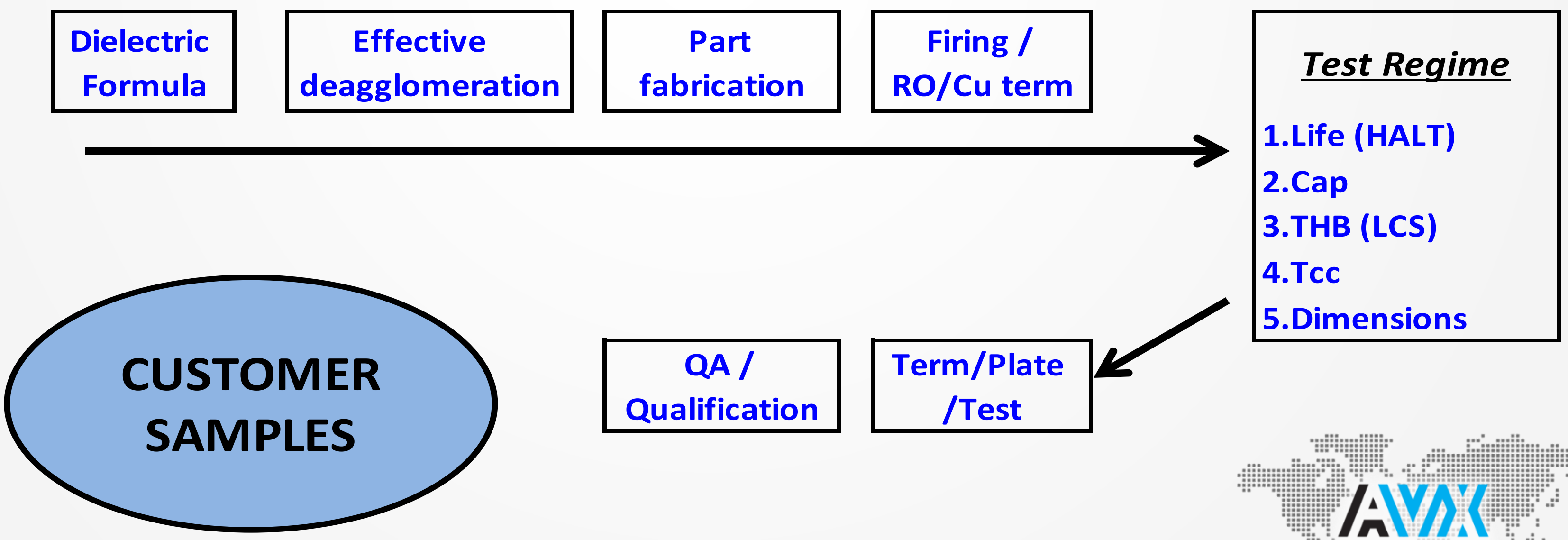
The Product Development Process

- Dielectric improvement has been the primary focus for the last 2 – 3 years development work.
- The electrode is important but designs using 5 to 8um (25 to 50V) dielectric tape thickness do not need major electrode modifications.
- HALT is the key measurable for development success.

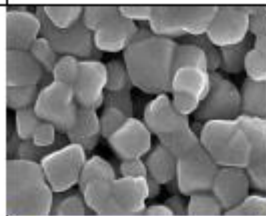
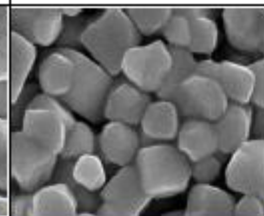
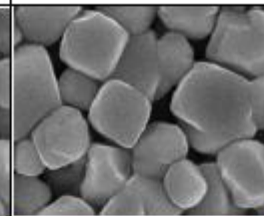
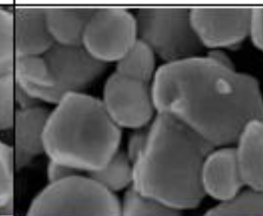
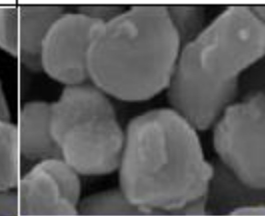
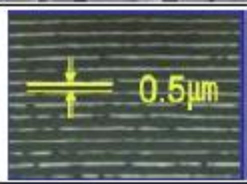
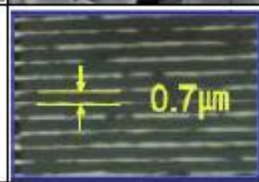
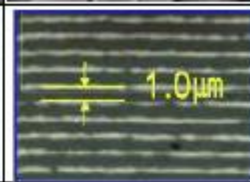
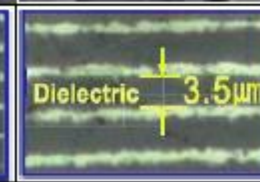


- **Targets**
  - General product range extension → APS range → Mil range
  - 2 – 3 year cycle → 1 year cycle → 3 to 4 year cycle
  - Voltage range : 25 - > 100V
  - Temperature range: X7R
  - Case Size: 0805 -> 1210

- **Development plan initiated in 2014**
  - Focus upon improved Life performance – specifically dielectric capability improvement
  - Develop the lower V/um parts first and work up the degree of difficulty curve as the materials and process capability evolve
  - Accept X7S initially as a qualified option prior to full X7R specification

- **Outcomes**
  - By 2016 - 7x range extension parts supplied customer samples (e.g. 12105C106)
  - Plans in place to deliver the next 3 part numbers (e.g. 12061C225)
  - Commenced TCC and Electrode studies for next phase

Commercial Product – Materials Development

Particle size	100nm under	150nm	200nm	250nm	300nm over
SEM					
Dielectric thickness					

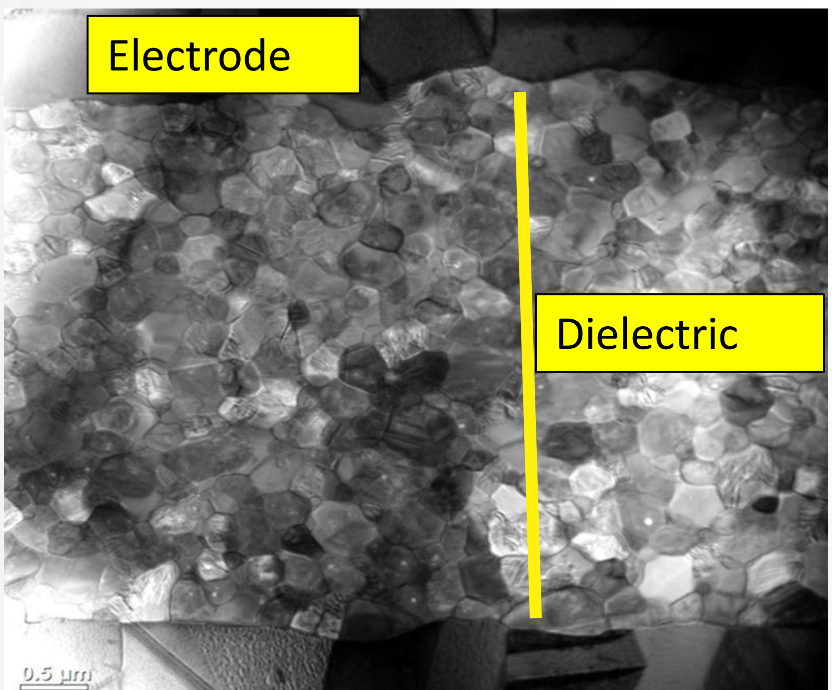
Voltage Rating 4 – 6V ← 10/16V ← 16/25V ← 25/50V ← 50V /100V

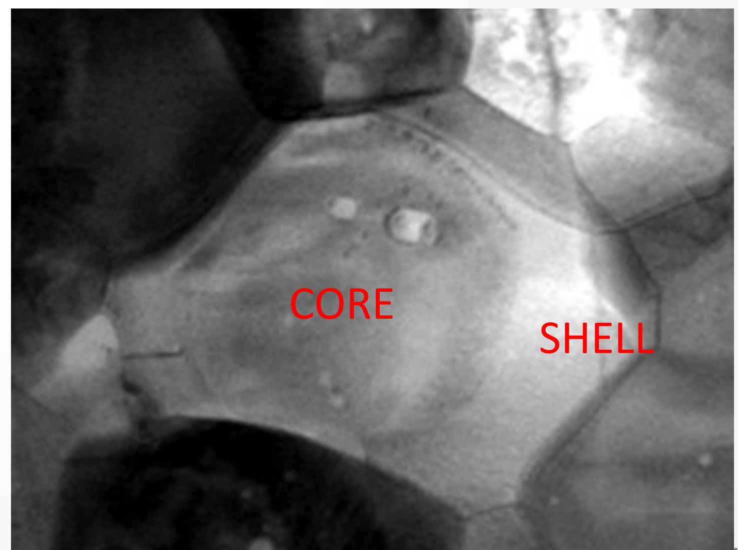
Very thin Dielectric Layers need finer particle Ni powders to deliver thin Electrode

Driver is to use V/um Dielectric Improvement Program to achieve range extension

The ideal microstructure for improved performance is:

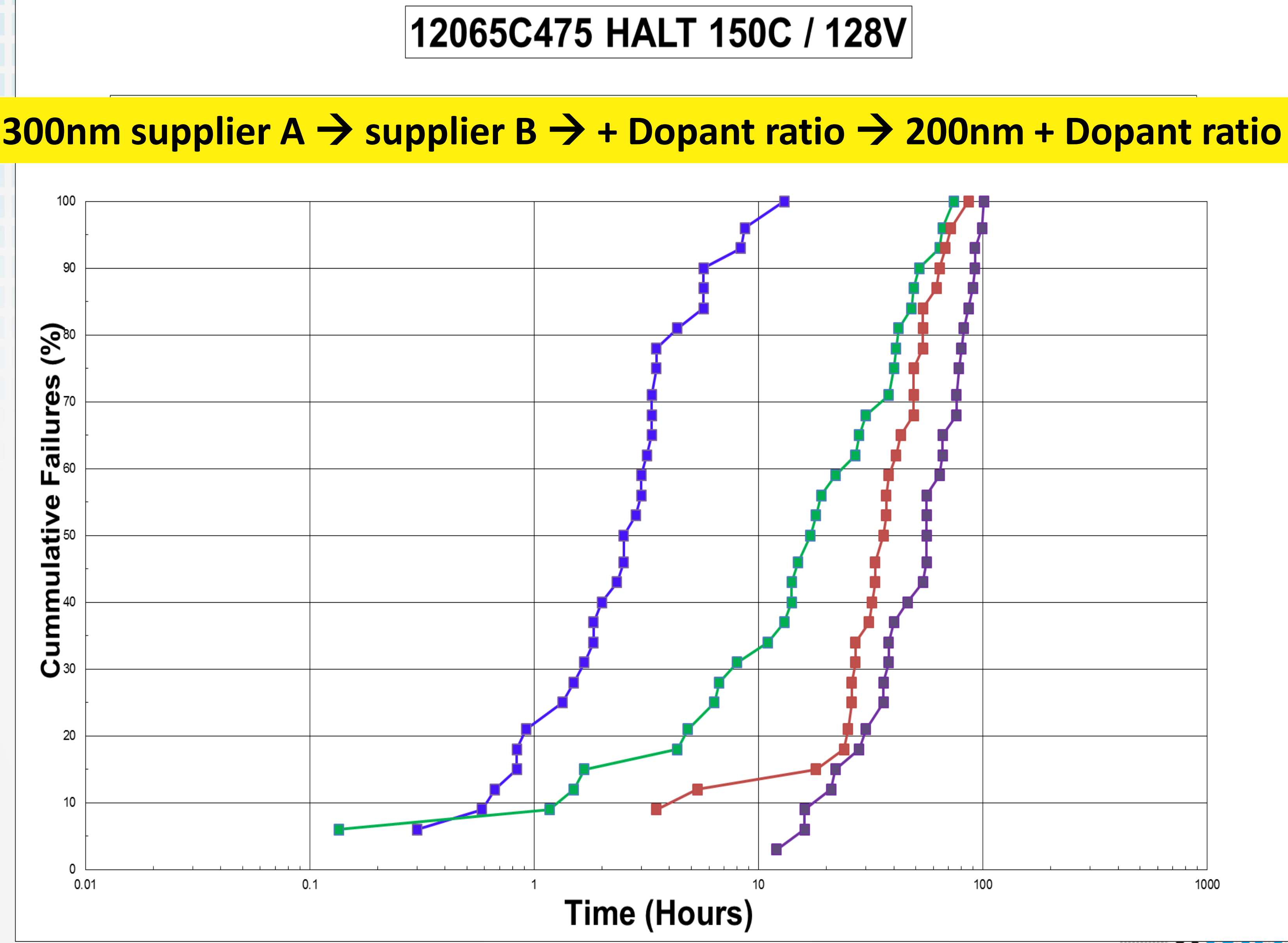
- **Densification without any abnormal grain growth**
- **Dopants evenly diffused around cores (as far as possible)**
- **Highly resistive grain boundaries to minimise electronic conduction and the migration of 'Vo' under applied field**





HALT Analysis of 4 different Ceramic formulations

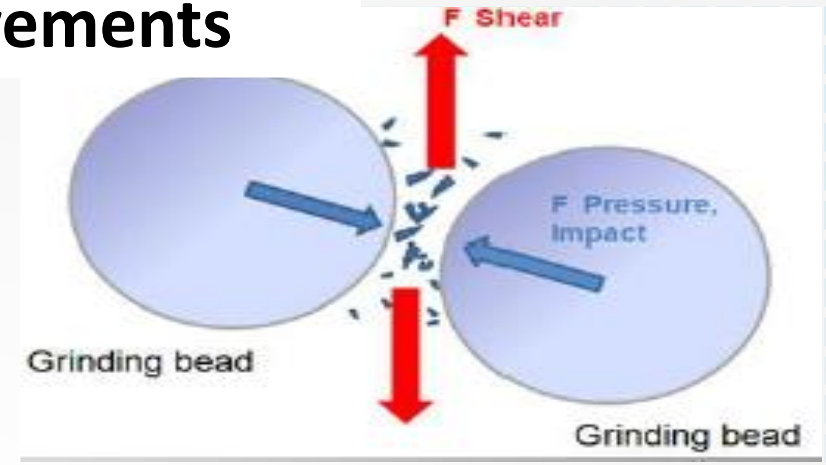
300nm supplier A → supplier B → + Dopant ratio → 200nm + Dopant ratio

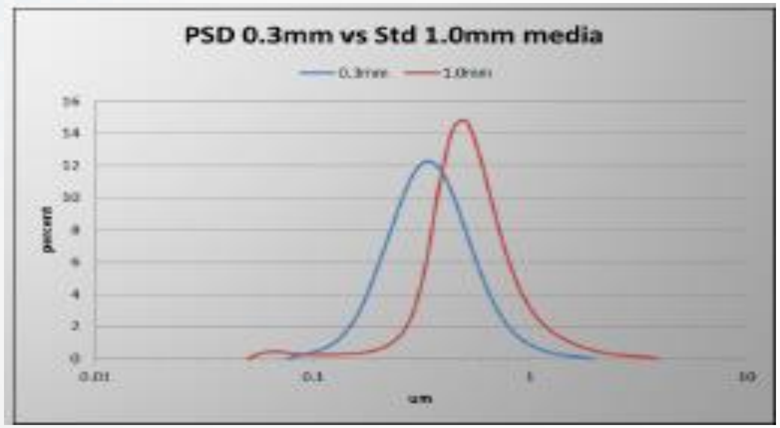


Materials Processing Improvements

DIELECTRIC PROCESSING

Goal – To separate the BT agglomerates without causing damage, to ensure each grain has the ability to form a shell



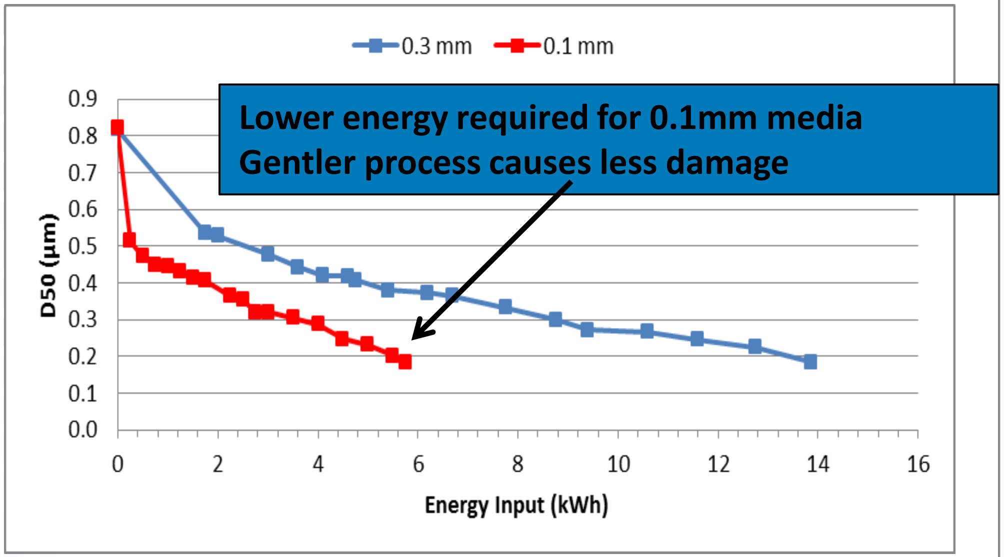


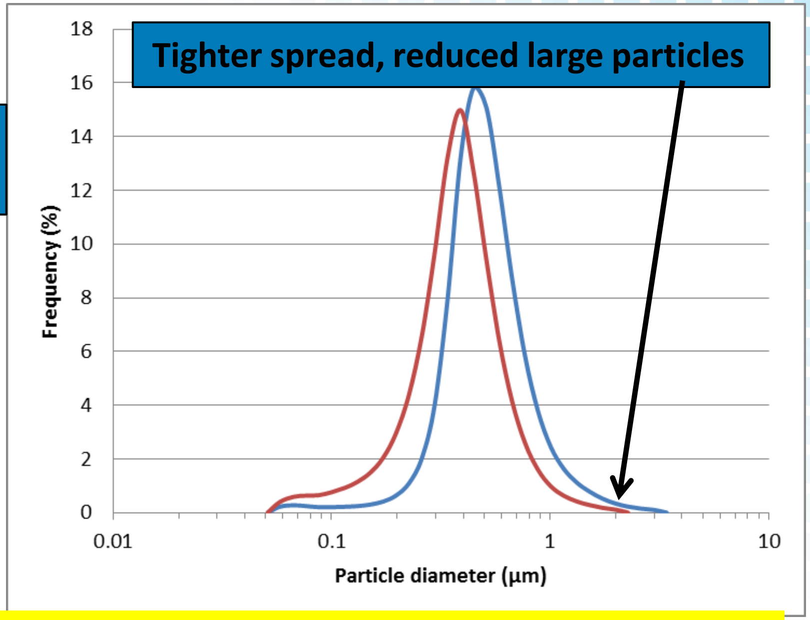
- 2 level factorial DOE & ANOVA statistical analysis completed

Factor	Low Level	High Level
Media size (diameter)	0.3 mm	1.0 mm
Media loading in chamber	60 vol. %	80 vol. %
Agitator tip speed	1000 rpm (2.6 m/s)	5000 rpm (13.1) m/s

- **Most desirable outcomes were achieved using**
  - Smaller diameter media
  - Higher impeller speed
  - Higher media fill in chamber

Finer Powder Milling - Recent Work with 300nm BT





- The product performance data indicates that the improved particle de-agglomeration process improves HALT significantly T50 27 (hrs) → 60 (hrs)
- Absolute IR Improvement 650 MegOhms → 816.
- The mechanism for electrical performance improvement is thought to be better core/shell formation. Follow up SEM / TEM work underway.

MEDIA SIZE	PN	HALT T50 (hrs)	Mean Cap (µF)	Mean Df (%)	IR (MΩ)
0.3 mm	12065C475	27	4.8	2.2	650
0.1 mm	12065C475	60	4.7	2.6	816

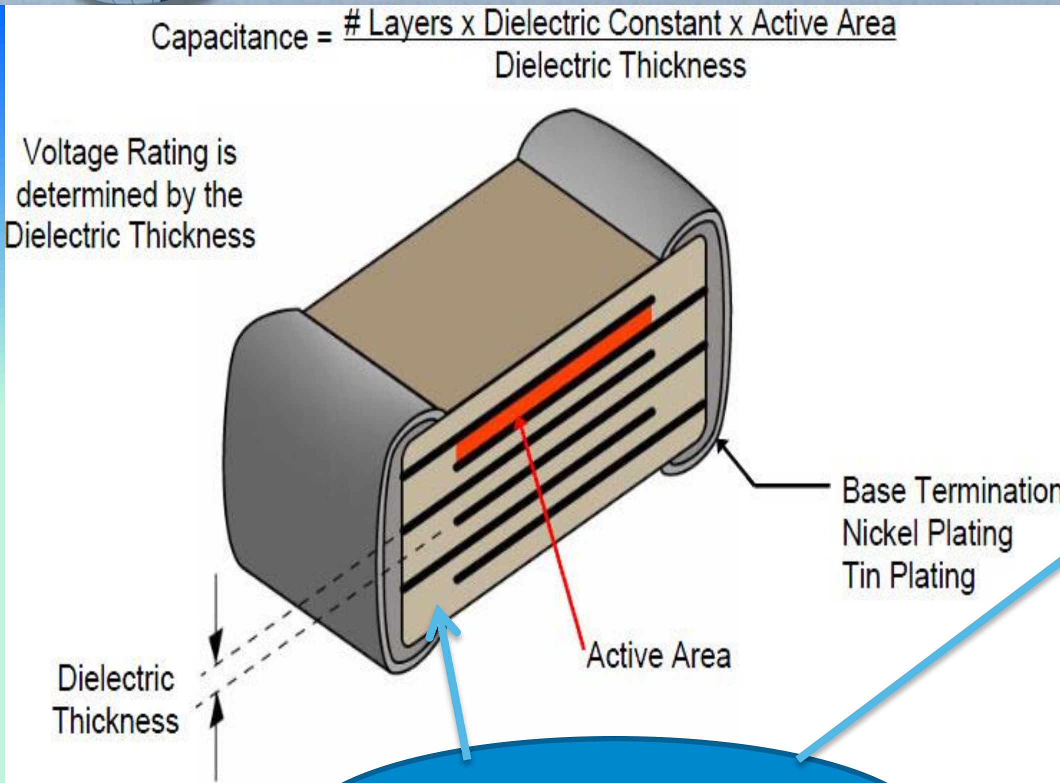
Factors affecting Performance Parameters

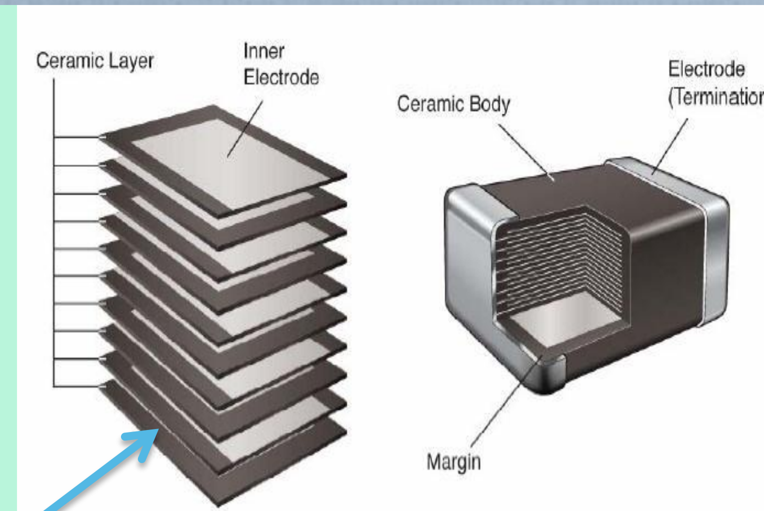
Parameter	Barium Titanate • Type (HT,SS etc.) • PSD • c/a	% Glass	Deagglomeration process	Dopant ratio	Firing process
Life / HALT	✓	✓	✓	✓	✓
Cap / Df	✓	✓	✓	✓	✓
THB	×	?	?	×	✓
Tcc	✓	✓	✓	✓	✓

Our Data indicates that the best performance to date is:

- **200nm Solid phase BT with high crystallinity**
- **Lower Dopant ratios + less glass formula**
- **De-agglomerated close to primary grain size**
- **Fired at 1286C with a % H2 (x)**

SPACE B.M.E. CAPACITOR DESIGN
Dielectric layer design >= 8.5um 25v to 18um 100v





Larger Margins ends and sides

A capacitor is a device capable of temporarily storing electrical energy for release in a controlled manner at a predetermined time

SPACE BME Design Model TTP ESCC and NASA

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 originally chosen for min dielectric thickness to meet TC X7R requirement – modified to 8.5um to comply with NASA spec.**
- **Number of active layers range from 43 to 215.**
- **V/um stress 2.7 to 5.6**

Mil 32535 Designs for Space

Part Number	No Actives	Active thk green (um)	Cover layers thk green (um)	Min active thk green (um)	Min Design Side Margins green (um)	Min Design End Margins green (um)	Min Cover Layers green (um)	Volts per Micron (Green)
04021C682K	19	18	96	18	170	170	96	5.6
04025C273K	37	9	96	9	170	170	96	5.6
04023C333K	42	8.5	96	8.5	170	170	96	2.9
06031C183K	23	24	96	18	170	170	96	4.2
06035C124K	58	9.5	96	9	170	170	96	5.3
06033C184K	73	8.5	96	8.5	170	170	96	2.9
18121C225K	131	18	96	18	200	200	96	5.6
18125C475K	173	12	96	9	200	200	96	4.2
18123C825K	219	9	96	8.5	200	200	96	2.8
22201C475K	137	18	96	18	200	200	96	5.6
22205C106K	172	11.5	96	9	200	200	96	4.3
22203C226K	264	8.5	96	8.5	200	200	96	2.9

* Highlighted Blue is all from our TTP spec. for Space/Mil.

- Number of active layers range from 19 to 264.
- V/um stress 2.9 to 5.6

DESIGN AND MATERIAL RULES FOR HIGH RELIABILITY BME MLCC

Description	Commercial	Auto / APS	ESCC - Space
Material	No restrictions, frequent changes	Change Notice required PCN	No change allowed - requalification / readudit
Chip Dimensions	No restrictions	Minimum thickness constraint	Minimum Thickness No change allowed – requalification
Design	No restrictions, frequent changes	Major change requires PCN	No change allowed – requalification / Reaudit
Margins	>= 75um	>= 100um	>=170um
Cover Layers	>= 75um	>= 100um	>=112um
Dielectric Thickness	No restrictions, frequent changes	Major change requires PCN	No change allowed – requalification

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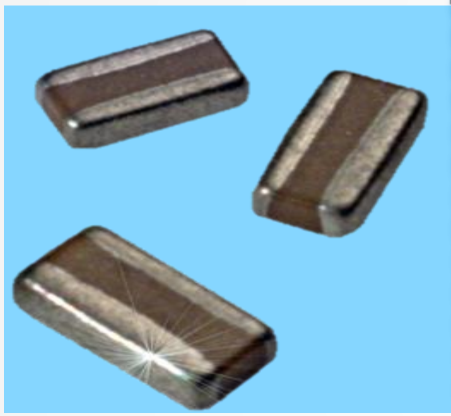
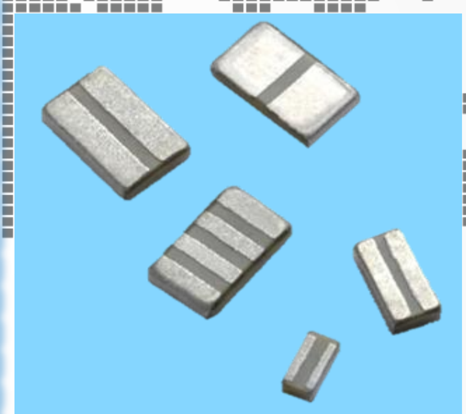
New product Roadmap

PN	Fired Dielectric /um	Life Test V	V/um Stress	Samples	MP
12065C225	6.8	75	11	✓	✓
08055C105	5.5	75	14	✓	✓
12063C475	4.5	37	8	✓	✓
12105C106	4.5	75	17	✓	Q1 - 17
12065C475	4.5	75	17	✓	Q1- 17
12061C225	6.8	150	22	✓	Q2 - 17
12101C475	6.8	150	22	✓	Q2 – 17
08053C225	3.8	37	10	Q1 - 17	Q2 - 17
08051C105	5.5	150	27	Q2 - 17	Q3 – 17
12061C335	5.7	150	26	Q2 - 17	Q3 - 17

LOW INDUCTANCE LINE-UP

LICC	IDC	LGA	LICA®
"Reverse Geometry"	"Inter-Digitated"	"Land Grid Array"	"Cap-Array"





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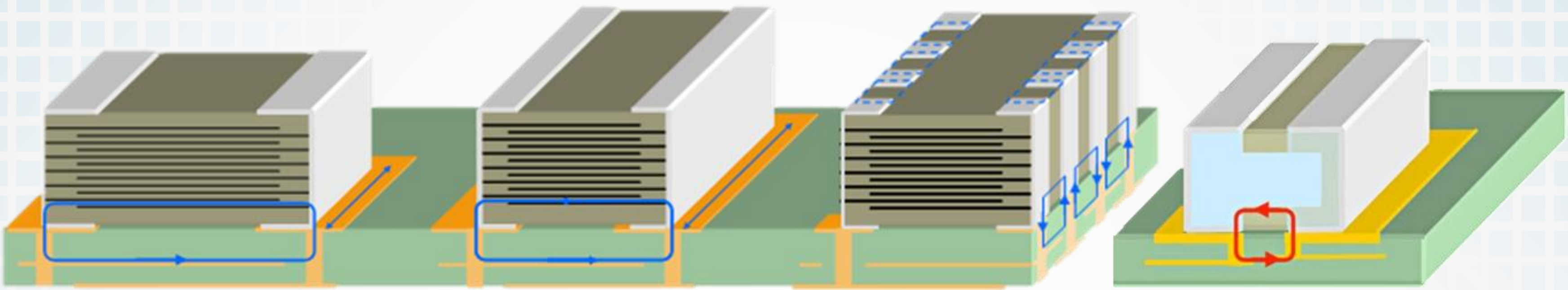
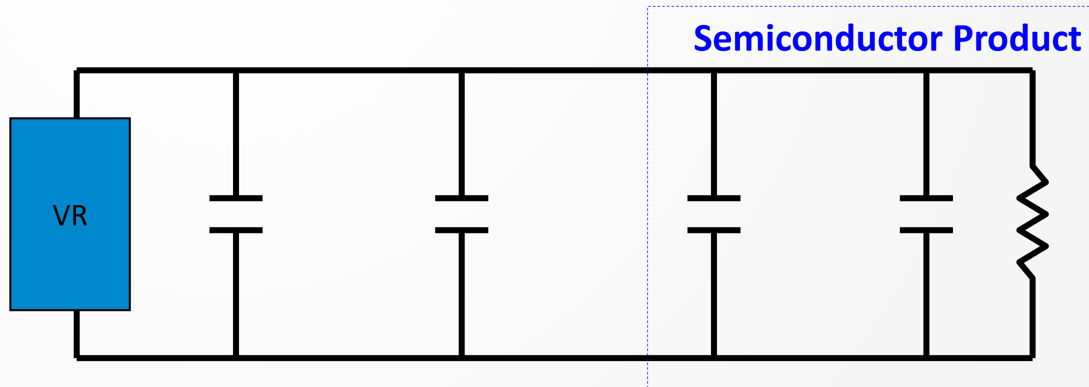
Low Inductance Capacitors

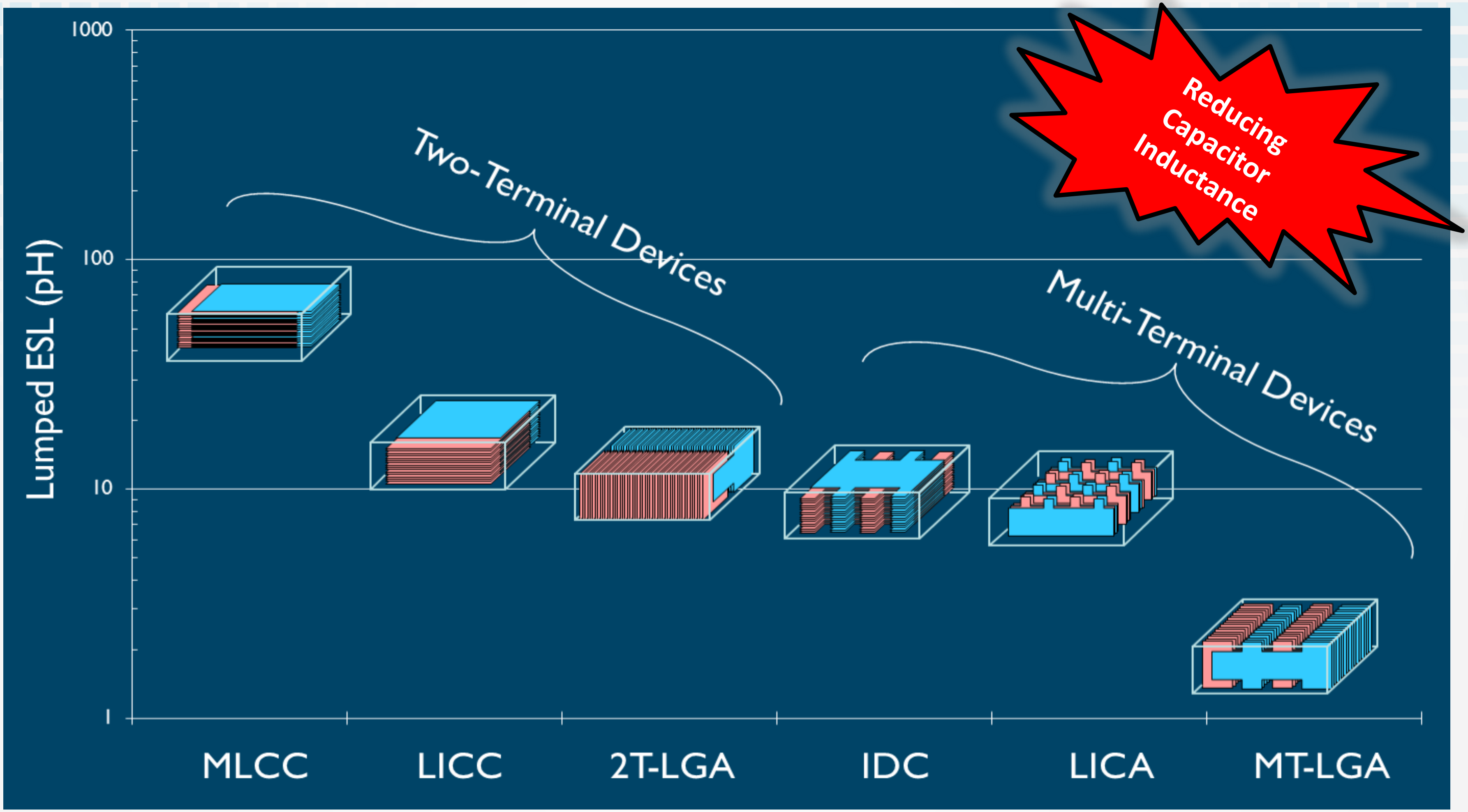


0805 MLCC	0508 LICC	0508 IDC	0508 LGA
ESL ~600pH	ESL ~130pH	ESL ~45pH	ESL ~27pH

Low Inductance MLCCs provide power to the semiconductor (IC) until slower bulk capacitors and Voltage Regulator (VR) 'catch up' to the speed of the IC



Decoupling capacitors evolution



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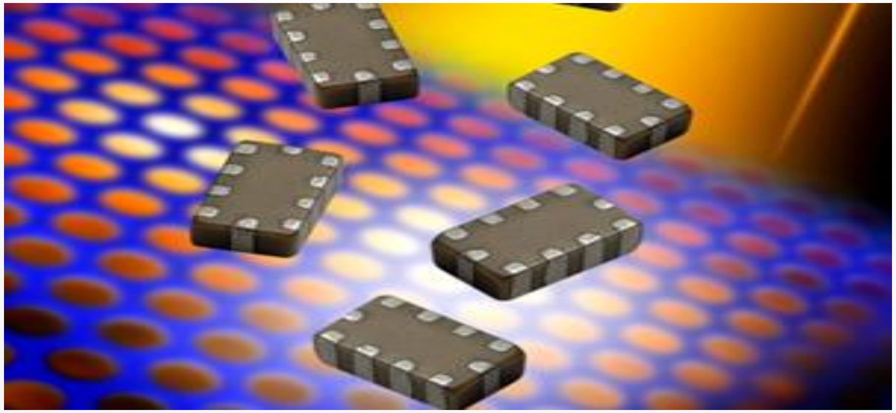
Mechanical Compatibility

- Capacitors are constructed to match assembly processes:
  - Terminal type
  - Terminal metallization
- TCE of capacitor dielectric is ~ 6 ppm/°K for use conditions
- Mismatch of cap-package TCE introduces strain in solder joint

Technology	LICA	LICC / IDC	LGA
Internal Electrodes	Pt / Ni	Ni	Ni
Terminal Configuration	Area Array	Side terminals	Area Array
Base Termination	Evaporated	Thick Film	Plated
Finished Termination	BGA	Plated	Plated
Termination Type	PbSn (C4) / SnAgCu	Sn or SnPb	Sn / Cu / Au / SnPb

IDC (Inter Digitated Capacitors)

- **Sizes:** 0306, 0508, 0612
- **Capacitance Range:** Min (0.01µF) – Max (3.3µF)
- **Voltage Ratings:** 4, 6.3, 10, 16, 25V
- **Available Dielectrics:** X7R, X5R, X7S
- **Available Tolerances:** M = ±20%
- **Number of Terminals:** 8
- **Termination options:** Ni/Sn, Sn/Pb (L_L series)



0306

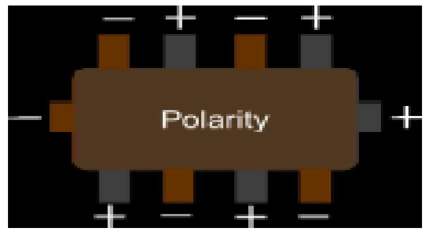
X7S

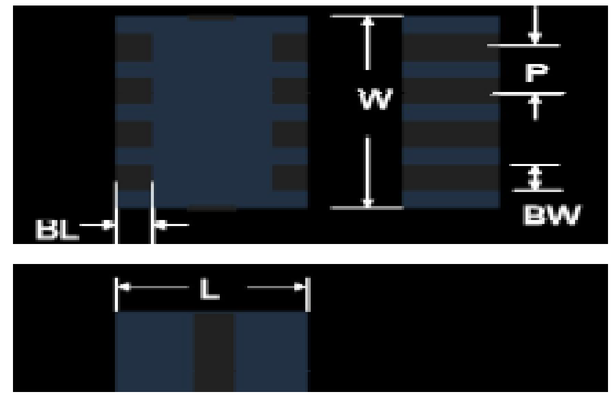
PERFORMANCE SPECIFICATION SHEET

CAPACITORS, CHIP, MULTIPLE LAYER, FIXED, CERAMIC DIELECTRIC (GENERAL PURPOSE), STANDARD RELIABILITY AND HIGH RELIABILITY, STYLE IDC 0306 (Interdigitated Capacitor)

This specification sheet is approved for use by all Departments and Agencies of the Department of Defense.

The requirements for acquiring the product described herein shall consist of this specification sheet and MIL-PRF-32535.





4V - 1uF

TABLE I. Style IDC 0306 capacitor characteristics.

Part or Identifying Number (PIN) 1/	Capacitance (pF)	Capacitance tolerance	VTL/TC	Rated voltage (Vdc)	Electrode Material
M3253511E3-104---	100,000	M	X7S	4	B
M3253511E3-224---	220,000	M	X7S	4	B
M3253511E3-334---	330,000	M	X7S	4	B
M3253511E3-474---	470,000	M	X7S	4	B
M3253511E3-105---	1,000,000	M	X7S	4	B

0508 - Thin

PERFORMANCE SPECIFICATION SHEET

CAPACITORS, CHIP, MULTIPLE LAYER, FIXED, CERAMIC DIELECTRIC (GENERAL PURPOSE), STANDARD RELIABILITY AND HIGH RELIABILITY, STYLE IDC Thin 0508 (Interdigitated Capacitor)

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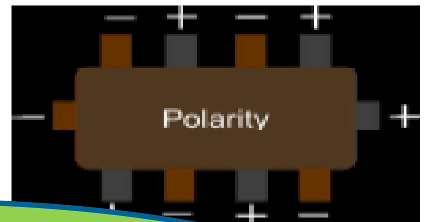
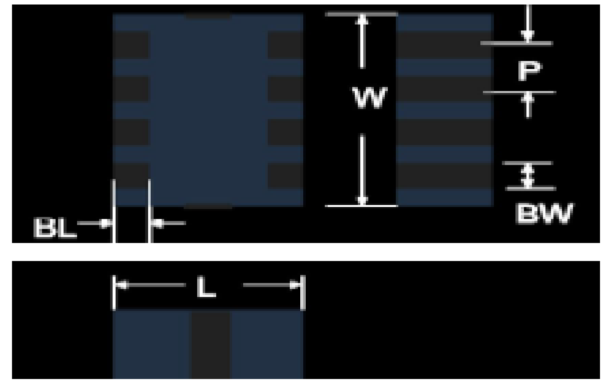
X7R & X7S





4V 0.47uF X7R
4V 2.2uF X7S

TABLE I. Style IDC Thin 0508 capacitor characteristics.

Part or Identifying Number (PIN) 1/	Capacitance (pF)	Capacitance tolerance	VTL/TC	Rated voltage (Vdc)	Electrode Material
M3253512E2-334---	330,000	M	X7R	4	B
M3253512E2-474---	470,000	M	X7R	4	B
M3253512E3-684---	680,000	M	X7S	4	B
M3253512E3-105---	1,000,000	M	X7S	4	B
M3253512E3-225---	2,200,000	M	X7S	4	B

0508

PERFORMANCE SPECIFICATION SHEET

CAPACITORS, CHIP, MULTIPLE LAYER, FIXED, CERAMIC DIELECTRIC (GENERAL PURPOSE), STANDARD RELIABILITY AND HIGH RELIABILITY, STYLE IDC 0508 (Interdigitated Capacitor)

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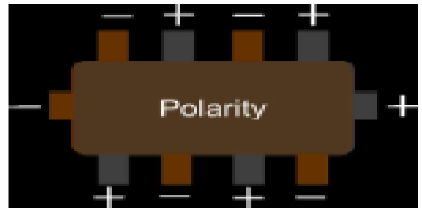
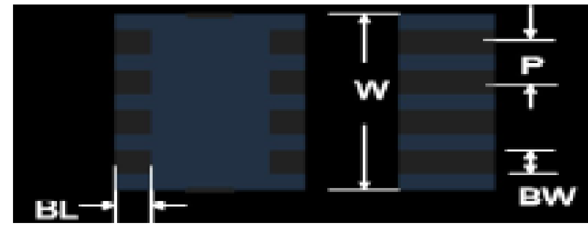
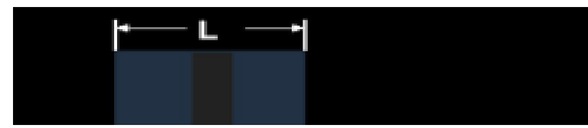
X7R







6.3V - 0.47uF

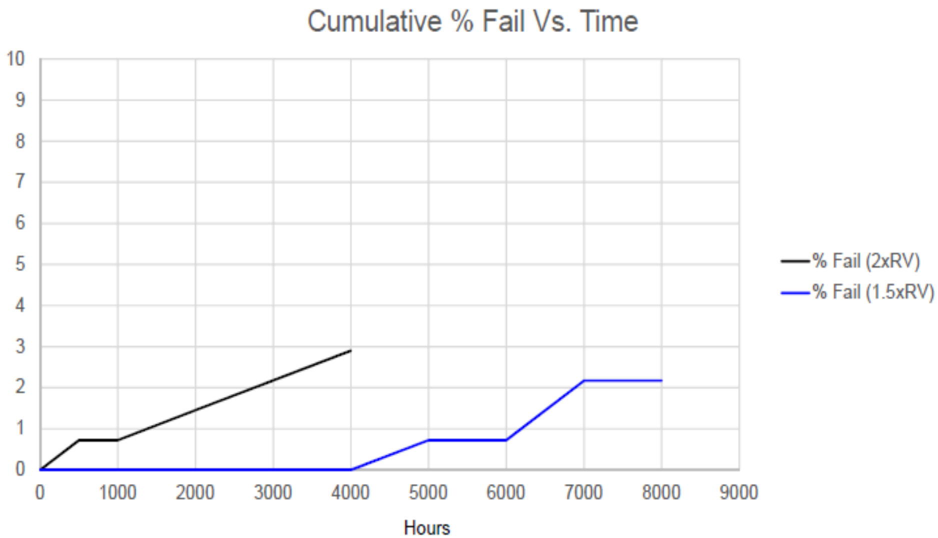
4V - 1uF

Part or Identifying Number (PIN) 1/	Capacitance (pF)	Capacitance tolerance	VTL/TC	Rated voltage (Vdc)	Electrode Material
M3253513E2-104---	100,000	M	X7R	6.3	B
M3253513E2-224---	220,000	M	X7R	6.3	B
M3253513E2-334---	330,000	M	X7R	6.3	B
M3253513E2-474---	470,000	M	X7R	4	B
M3253513E2-684---	680,000	M	X7R	4	B
M3253513E2-105---	1,000,000	M	X7R	4	B

Reliability Performance Testing for IDC Product

- AVX recommends Life Test at 1.5xRV and 125°C for Qualification and Group B test of the IDC X7S PN's
  - 1.5xRV is aligned with industry standards for X7S
- Life Test at 2xRV & 125°C for 4000 hours produced some level of failures
  - Low IR due to "point defects" that reduce the local dielectric thickness
  - IR distribution of general population did not degrade
- Life Test performance at 1.5xRV & 125°C for 4000 hours has been good
- These PN's also exhibit higher values for voltage and temperature acceleration
  - The higher acceleration factors tend to offset the effect of lower life test V for reliability estimates

L2L26Z684MHB1S – 0508 IDC 6.3V X7S 0.68 µF



We agreed with our customer to use 1.5xRV for X7S IDC

- **Life Test at 2xRV and 125°C is not recommended for IDC X7S PN's**
- **AVX recommends Life Test at 1.5xRV and 125°C for Qualification and Group B tests**
- **1.5xRV is aligned with industry standards for X7S**

Reliability Performance Testing for IDC Product

- Results for n and e_a are shown in the table below

AVX PN	Size	RV	C (µF)	DT (µm)	n	ea (eV)
L2L16Z684MAB1S	0508	6.3	0.68	4.0	4.9	1.4
L2L14Z225MAB1S	0508	4.0	2.2	2.9	4.4	1.5
L4L14Z105MAB1S	0306	4.0	1	1.3	4.5	1.2

- These values are considerably higher than the accepted values for MIL BX capacitors
  - Accepted values for MIL BX: n = 3.0, e_a = 1.0 eV
- The table below includes the same comparison extrapolated to operation at lower V and T (0.5x Rated V & 85°C)

			Life Test Conditions			Operating Conditions		Acceleration Factors		
Capacitor Type	n	ea	V	T (°C)	Hours	V	T (°C)	AF_V	AF_T	Equivalent Hours
MIL BX	3.0	1.0	2xRV	125	4000	0.5xRV	85	64	26	6,656,000
IDC X7S	4.4	1.2	1.5xRV	125	4000	0.5xRV	85	126	50	25,200,000

- At these conditions the equivalent hours for IDC X7S at 1.5xRV are 3.8x higher than for MIL BX at 2xRV

- **These PN's exhibit higher voltage and temperature acceleration factors.**
- **The higher acceleration factors offset the effect of 1.5x RV for reliability estimates.**

SUMMARY

- BME capacitor development continues with material and process modifications.
- Special designs and material selections are used for High Reliability devices, conservative approach.
- Delivery of New High CV Discrete capacitors 25 to 100V rating e.g. 1210 50V 10uF.
- New range extension includes 0402 and 2220 sizes max cap 22uF.
- Low Inductance IDC products being qualified for Mil Approval.