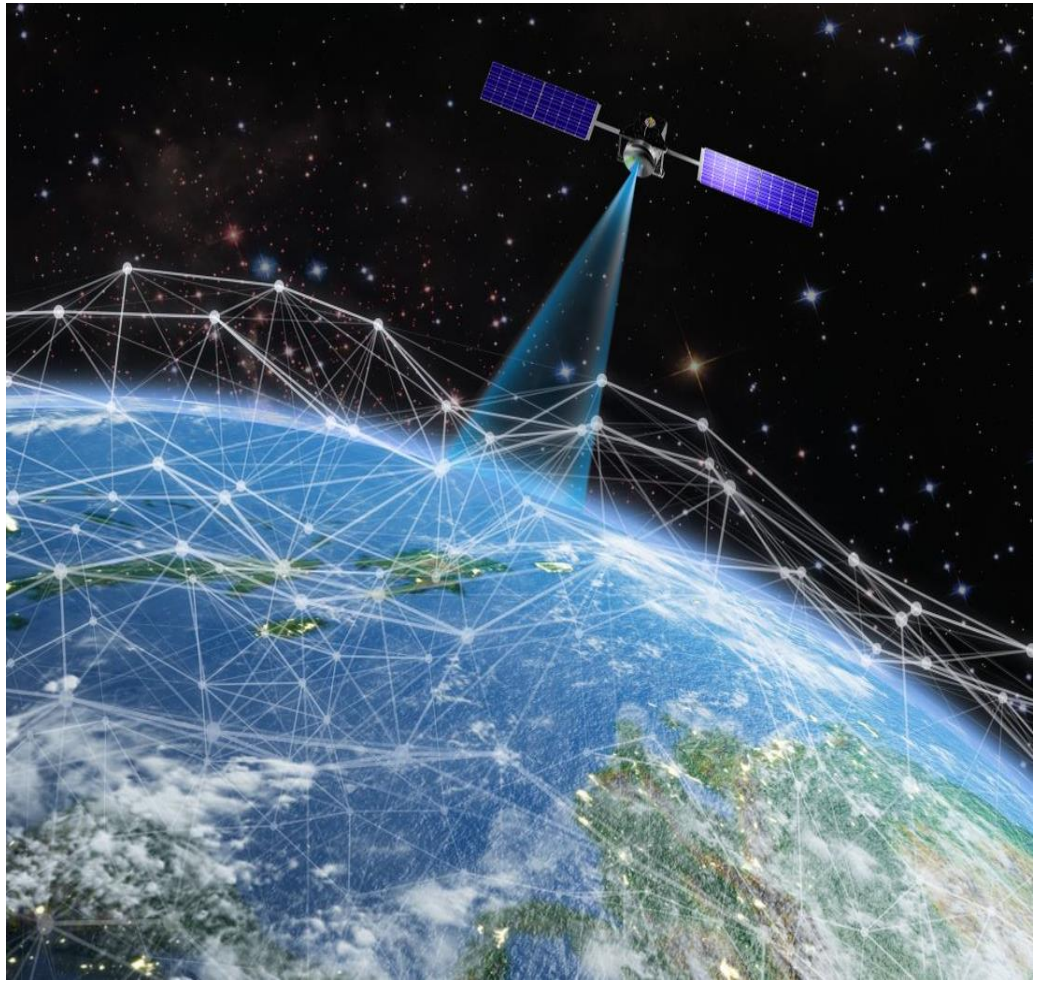
A Comparison of Commercial, Automotive, and Aerospace Capacitors



Daniel West
daniel.west@avx.com
1 AVX BLVD. Fountain, Inn SC 29644

Introduction
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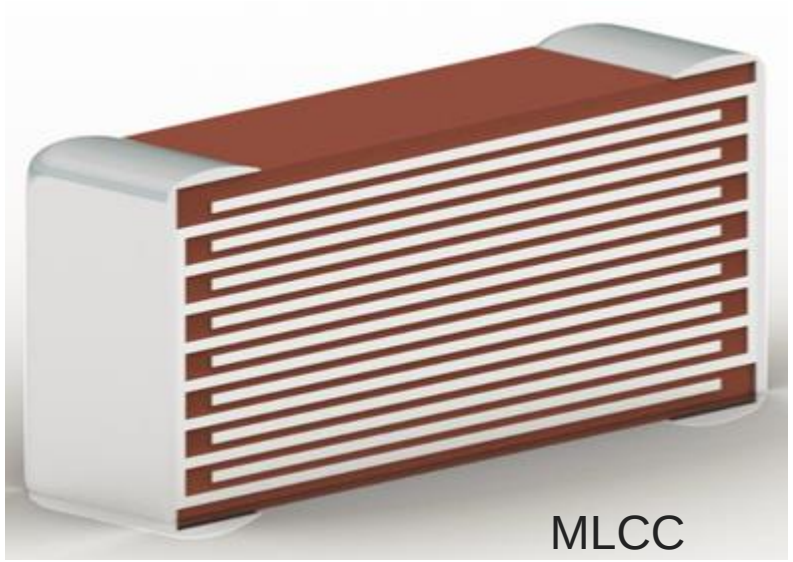
Introduction

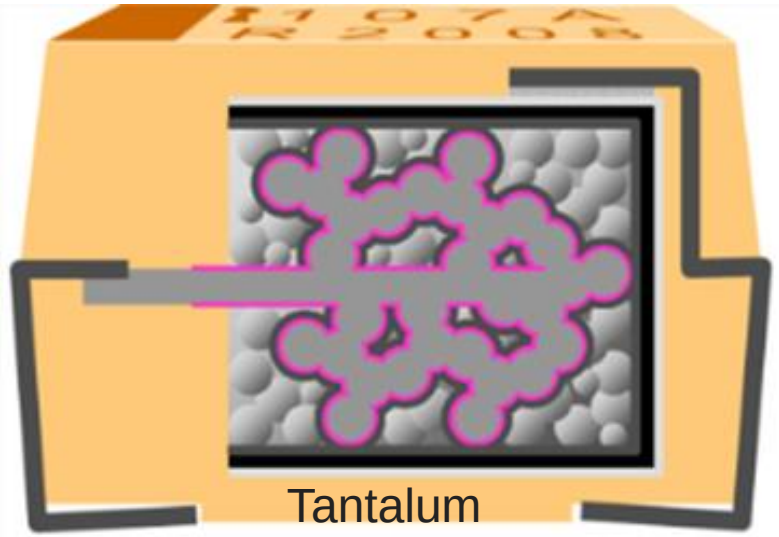
Dielectric Formulation & Optimization

Capacitor Design Constraints: capacitance, voltage, materials, size, processes



MLCC

$$C = \frac{kA}{d}$$



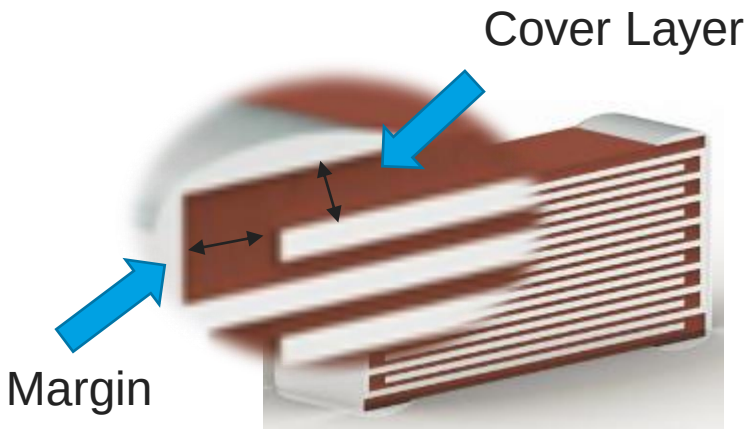
Tantalum

Other Design Constraints: High reliability, AEC-Q200, cost

Space, Aerospace, Military	Automotive	Commercial
Unique conservative design + “heritage” material set	Standard design model and several material sets	Multiple designs, multiple material sets

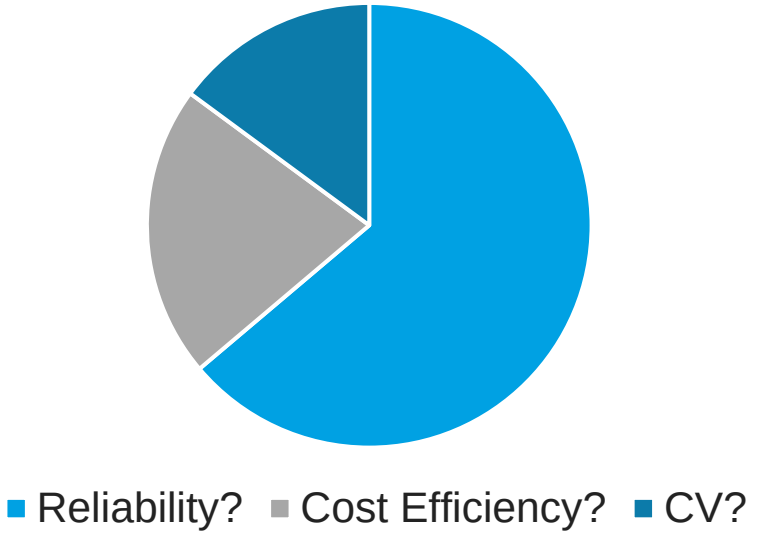
Design Protocols | MLCC (X7R)

Basic Design Protocols:
Dielectric Formula
Dielectric Thickness
Electrode Patterns
Cover Layer
Margin
Terminations



Impact of Design Protocols:
Flexure
Voltage Coefficient
Breakdown Voltage
Ripple Current Capability
ESR
Dissipation Factor
Temperature Stability
CV Range
Cost

Design Protocol Trade-Offs

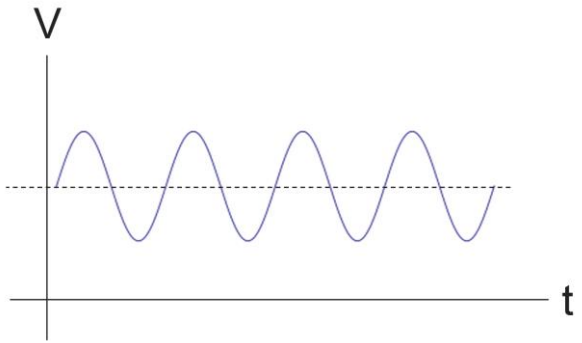


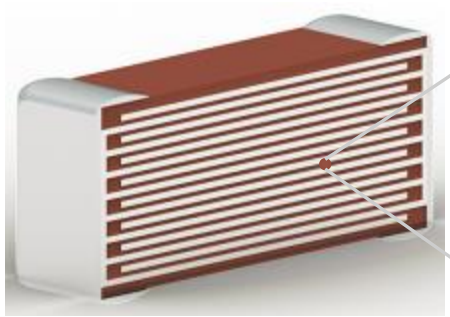
Design starts here and priorities based on end application

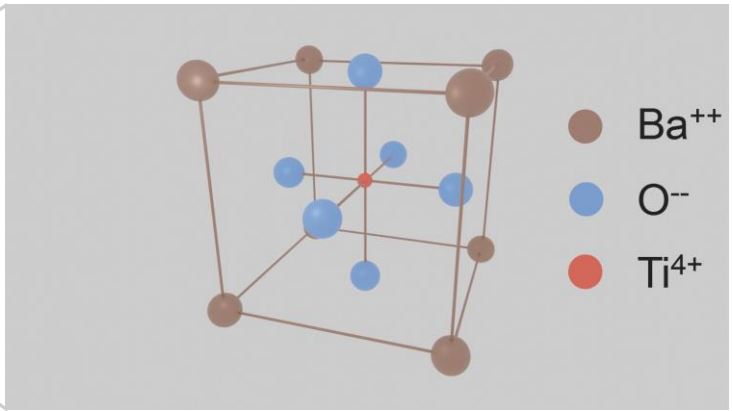
Design Protocols (X7R)

Dielectric Formulation Trade-Off Example

Example: V_{AC} & V_{DC} Bias







Designing dielectrics for high reliability:

- Thick dielectric layers for higher voltage capability (V/µm) and enhanced reliability performance
  - Trade-off: capacitance or size
- Ceramic grain uniformity and size for improved repeatability
  - Trade-off: additional refinement and firing requirements
- Conservative k formulas for increased stability
  - Trade-off: capacitance, R&D

Crystal deforms from:

- Voltage
- Temperature
- Ageing

Characteristics Comparison | MLCC (X7R)

	Commercial	Automotive	Space
Mechanical	2mm board flex. Smallest margins and cover layers.	2mm board flex. Superior material set. Balanced dimensions for performance and cost.	5mm board flex (standard). Conservative designs employ largest margins / cover layers, and thick dielectric layers.
Electrical	Highest CV range per case size. High voltage coefficient (VC). Voltage breakdown closer to $V_{R.}$	Consistent temperature and voltage characteristics. Reasonable CV range.	Lower CV Range. Good ripple current handling. Higher breakdown voltage. Best VC performance.
Reliability	Assumed performance. 1000 hr life test for small sample. No PCN process.	Ratings based on 1000 hr life test and generic data for a family of parts. PCN process.	Ratings based on 4000 hr life test and Lot Group B test (100hrs). No changes-Full Qualification.

Test Protocols

MLCC X7R Dielectric

Test	Commercial	Automotive	M32535 T-Level
Operating Temperature	-55°C to 125°C	-55°C to 125°C	-55°C to 125°C
Capacitance	Within specified limits	Within specified limits	Within specified limits
Dissipation Factor	≤ 10% (≥ 50 RV), ≤ 12.5% (< 50 RV)	≤ 10%(≥ 50 RV), ≤ 12.5%(< 50 RV)	≤ 3% (≥ 50V), ≤ 5% (16-25V), ≤ 7.5% (10V), ≤ 10% (4-6.3V)
Insulation Res. (+25°C)	100,000MΩ or 1000MΩ-µF	MIL-STD-202	MIL-STD-202
Hot IR (+125°C)			MIL-STD-202 (100%)
Dielectric Withstanding V	250% of RV for 1-5 seconds	250% of RV	250-400% of RV for 5 +1 seconds
Board Flex	2mm deflection for 30 seconds	AEC-Q200-005, 60 seconds	2mm min. for 60 seconds
Solderability	≥ 95% coverage	J-STD-002	MIL-STD-202
Solder Heat Resist.	C ≤ +7.5%. DF, IR, DWV meets IL	J-STD-002	MIL-STD-202
Thermal Shock	C ≤ +7.5%. DF, IR, DWV meets IL, 5 cycl		MIL-STD-202, 100 cycles
Operational Life	C ≤ 12.5%, DF ≤ 2x IL, IR ≥ 0.3x IL, (1.5x or 2x RV) 1000 hrs	MIL-STD-202, 1000 hrs	MIL-STD-202, 4000 hrs, C ≤ 20%, DF ≤ IL, IR/Hot IR ≥ 0.3x IL
Temp. Humidity Bias	C ≤ 12.5%, DF ≤ 2x IL, IR ≥ 0.3x IL, (85/85) 1000 hrs	MIL-STD-202, (85/85) 1000 hrs	MIL-STD-202, (85/85) 1000 hrs
DPA		EIA-469	EIA-469

Test Protocols

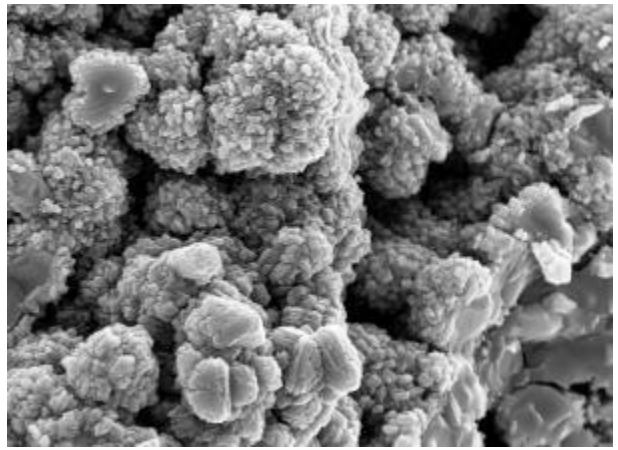
MLCC X7R Dielectric

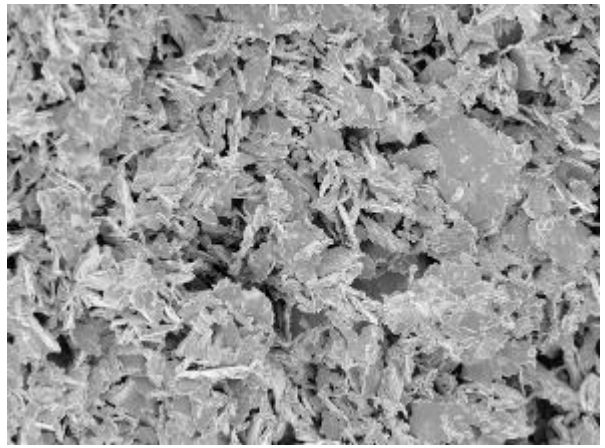
Test	Commercial	Automotive	M32535 T-Level
Physical Dimension	Within specified limits	JESD22	MIL-PRF-32535 Appendix B
Visual Examination		MIL-STD-883	MIL-PRF-32535 Appendix B
Material			MIL-STD-790
Design			MIL-PRF-32535 Appendix B
Construction		MIL-STD-883	MIL-PRF-32535 Appendix B
Marking		MIL-STD-883	MIL-PRF-32535 Appendix B
Workmanship		MIL-STD-883	MIL-PRF-32535 Appendix B
Terminal Strength		MIL-STD-202 (leaded), AEC-Q200-006 (SMD)	MIL-STD-202
High Temp. Exposure (storage)		MIL-STD-202	MIL-STD-202
Shear Stress		AEC-Q200-006	MIL-PRF-32535, 60 seconds
CSAM			2x Acoustic Micro Inspection (100%)
Voltage Conditioning			2x RV for 168-264 hrs @125°C
Dielectric Voltage Breakdown			6x Rated Voltage or 1,200V_{DC}, whichever is less

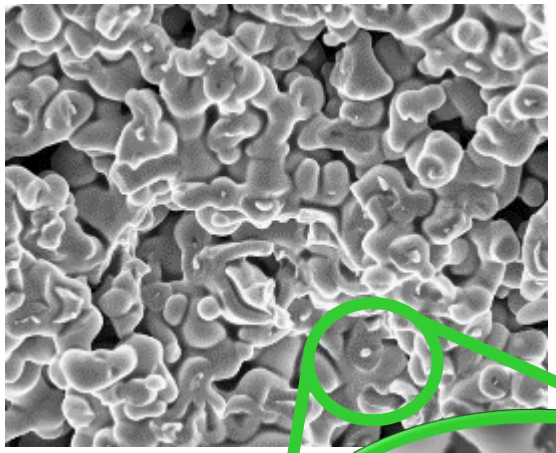
Design Protocols (Tantalum)

Dielectric Formulation & Optimization

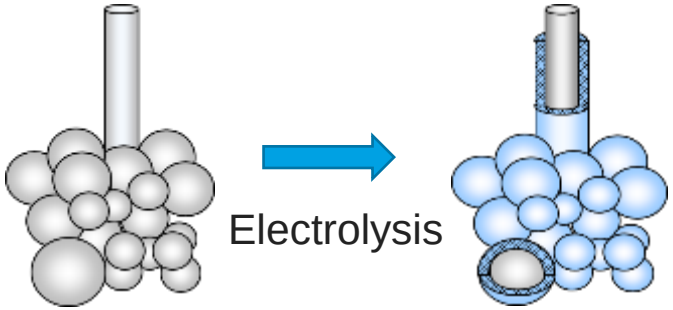
Tantalum Grain Structures





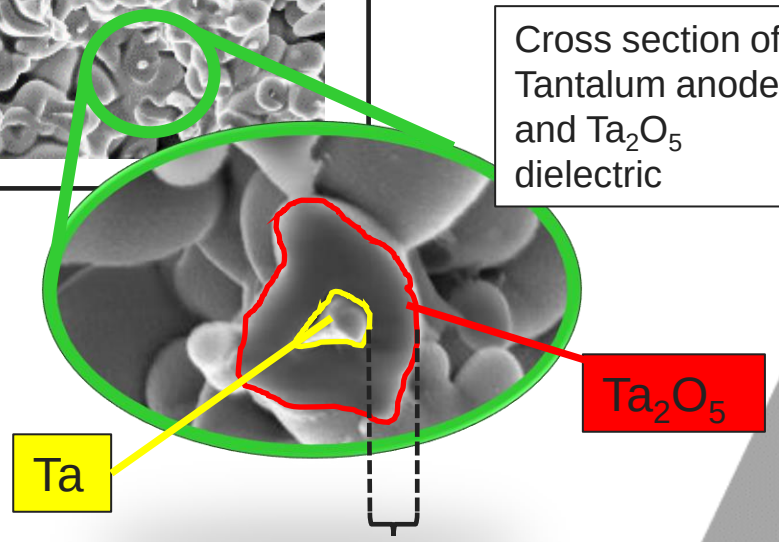


Tantalum Dielectric Formation



- Formation voltage (V_F) determines Tantalum consumption rate
- Rated voltage (V_R) spec. determines ratio
- High V_F:V_R contributes to optimal neck patterns

Tantalum Anode Tantalum Pentoxide Dielectric



Cross section of Tantalum anode and Ta_2O_5 dielectric

Dielectric thickness directly affects reliability, and is related to V_F:V_R

Characteristics Comparison | Tantalum MnO_2

	Commercial	Automotive	Space
Mechanical	Lowest formation ratios. Use of high CV/g Ta grain.	Balanced formation ratios.	Largest formation ratios.
Electrical	Highest CV range per case size. Derating rules are significant.	Improved performance. Higher current handling.	Lowest DCL. Resilient to surge voltage.
Reliability	Base rating of 1% failure rate (1000hrs, 60% conf)	Up to 0.5% failure rate from base commercial reliability levels	Base rating of 0.001 to 0.01% failure rate (1000hrs, 90% conf)

Test Protocols

Tantalum MnO_2

	Test	Commercial	Automotive	Aerospace
Performance Specifications	Min Operating Temperature	-55°C	-55°C	-55°C
	Max Operating Temperature	+85°C	+85°C	+85°C
	Max Category Temperature	+125°C / derated 33%	+125°C / derated 33%	+125°C / derated 33%
	Base Reliability (FR)	1% / 1000hrs / 60% conf	(0.5 - 1)% / 1000hrs / 60% conf	(0.001 - 0.01)% / 1000hrs / 90% conf
	Environmental (Humidity)	65ºC / (90-95)% RH / 500hrs	65ºC / (90-95)% RH / 500hrs	(10-65)ºC / (90-95)% RH / 20 cycles
Preconditioning	100% Reflow	✓	✓	✓
	100% Thermal Shock	✓	✓	✓
	100% Voltage Aging	(2 - 4)hrs	(2 - 4)hrs	Mandatory - Weibull - Grade C min (0.01%/1000hrs)
	100% Surge Current	(1 - 2) Cycles / 25°C	(2 - 4) Cycles / 25°C	Mandatory C Surge
	Simulated mounting (reflow)	✓	✓	✓
	Surge Voltage			✓

Test Protocols

Tantalum MnO_2

	Test	Commercial	Automotive	Aerospace
100% Test	100% Electrical Testing (Cap, DF, ESR, Z, DCL)	To specification limits only	Custom test limits available	+ 3 sigma Limits or custom
	100% Visual & Mechanical			✓
	100% X-Ray			✓
Lot Conformance	Simulated mounting, rework and Lot Conformance.			✓
	Solderability Test - 8hr Steam Age			Mandatory - 90% Coverage
	Hot DC Leakage			✓
	Visual & Mechanical			✓
	DPA - 1580 Destructive Physical Analysis			✓
	Temperature Stability			Mandatory

Test Protocols

Tantalum MnO_2 COTS+/MIL-PRF-55365

	Test	COTS+	MIL-PRF-55365	Aerospace
Performance Specifications	Min Operating Temperature	-55ºC	-55ºC	-55ºC
	Max Operating Temperature	+85ºC	+85ºC	+85ºC
	Max Category Temperature	+125ºC / derated 33%	+125ºC / derated 33%	+125ºC / derated 33%
	Base Reliability (FR)	(0.01 - 0.1)% / 1000hrs / 90% conf	(0.001 - 0.1)% / 1000hrs / 90% conf	(0.001 - 0.01)% / 1000hrs / 90% conf
	Environmental (Humidity)	65ºC / (90-95)% RH / 500hrs	(10-65)ºC / (90-95)% RH / 20 cycles	(10-65)ºC / (90-95)% RH / 20 cycles
Preconditioning	100% Reflow	✓	✓	✓
	100% Thermal Shock	✓	✓	✓
	100% Voltage Aging	Optional Weibull	Mandatory Weibull	Mandatory - Weibull - Grade C min
	100% Surge Current	Optional A, B or C	Optional A, B or C	Mandatory C Surge
	Simulated mounting (reflow)			✓
	Surge Voltage			✓

Test Protocols

Tantalum MnO_2 COTS+/MIL-PRF-55365

	Test	COTS+	MIL-PRF-55365	Aerospace
100% Test	Electrical Testing (Cap, DF, ESR, Z, DCL)	Custom test limits available	To specification limits only	+ 3 sigma Limits or custom
	Visual & Mechanical	Sample	Sample	✓
	X-Ray			✓
Lot Conformance	Simulated mounting, rework and Lot Conformance.			✓
	Solderability Test - 8hr Steam Age	Optional - 75% Coverage	Mandatory - 90% Coverage	Mandatory - 90% Coverage
	Hot DC Leakage			✓
	Visual & Mechanical	✓	✓	✓
	DPA - 1580 Destructive Physical Analysis			✓
	Temperature Stability	Optional	Mandatory	Mandatory

Conclusion

Guidelines for Selecting Capacitor Grades

- Commercial
  - Should not be used for high rel. applications
- Automotive
  - Programs with highest risk acceptance
- Aerospace
  - Critical Applications
  - Operational payload
  - Medium to Low-risk acceptance

THANK YOU.