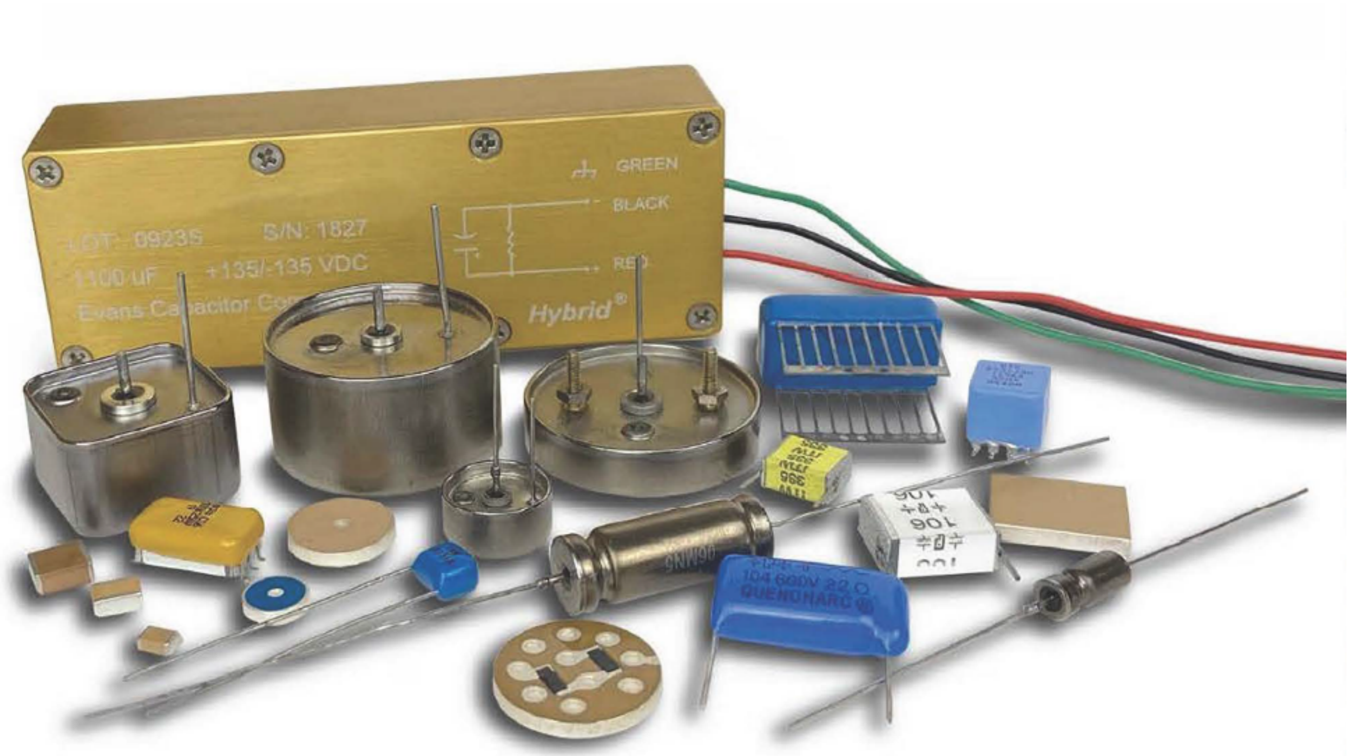
Specifying a Capacitor for Space-Based Applications

White Paper



Introduction:

In 1957 humans launched the first satellite into space. This groundbreaking moment kicked off a new era for those in the science and engineering community. Since then, the way we think about space has continued to evolve. In recent years, that evolution has exponentially increased as the number of space-based applications has risen significantly. Accessing and using space is now a critical part of our day to day lives. From GPS and internet to national defense and the study of our universe, we rely on space-based technologies to keep us safe and improve the quality of our lives.

As the cost to launch objects into space continues to fall, space has become far more accessible. No longer are the days where large government agencies or defense contractors were the only entities who had the means to put something into orbit. Today, small countries' space agencies, universities, researchers, and smaller companies now have access to space. In addition, larger companies and space agencies can easily afford to launch arrays of thousands of smaller "cube satellites" into orbit.

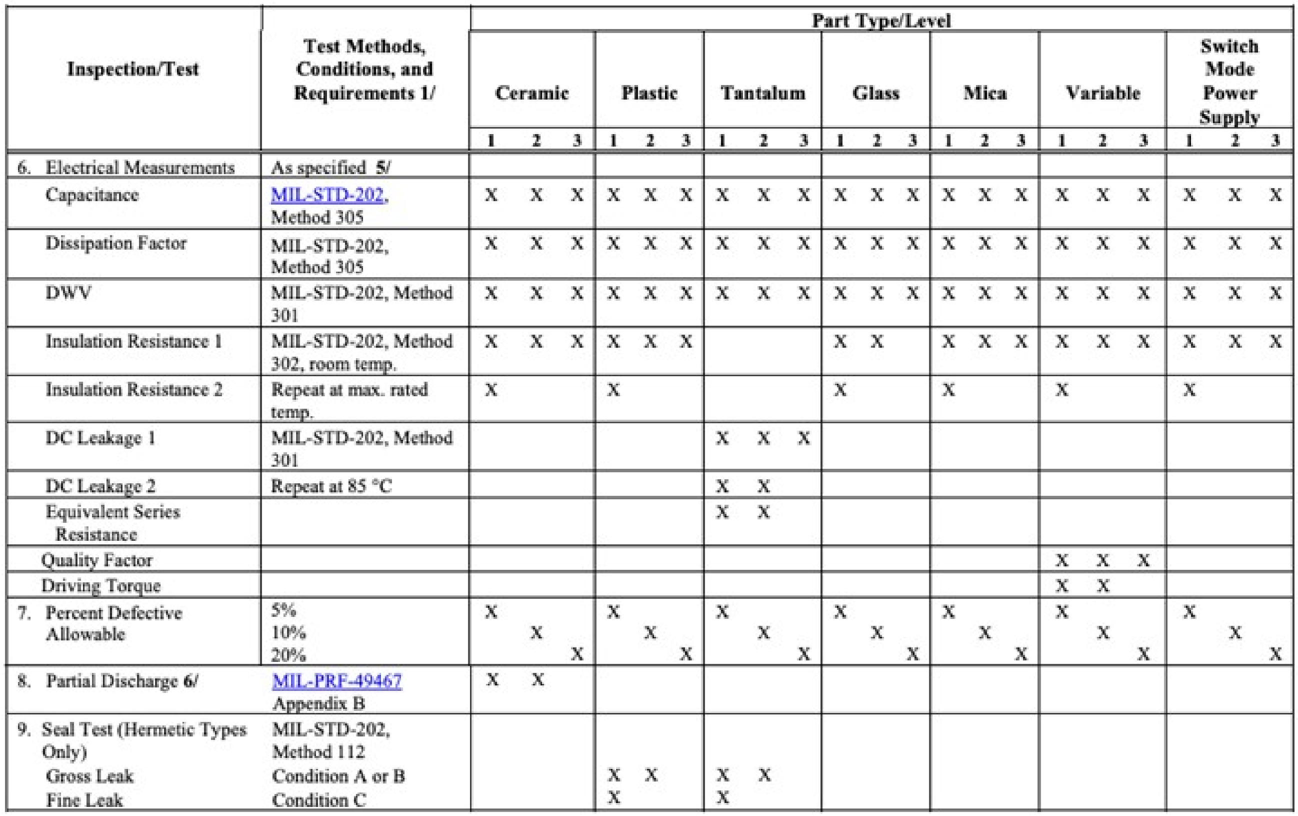
As the designs of these modern space technologies are being developed, several key factors need to be considered when selecting critical electronic components. Capacitors play a major role in countless critical systems including propulsion, power management, communications, RADAR, LIDAR, filtering, and many more. The way capacitors are specified for use in space is very different than was done as recently as 10 years ago. This whitepaper will serve as a guide that will highlight important design criteria to consider when selecting a capacitor for any space application, from large high-profile missions to smaller cost sensitive projects.

NASA EEE-INST-002 is the gold standard and a great starting place for understanding what a capacitor should be designed to withstand in order to be suitable for use in space. While EEE-INST-002 covers a variety of components including connectors and resistors, section C1 focuses specifically on capacitors.

In section C1, a screening protocol (Figure 1) is outlined. Screening tests are intended to remove nonconforming parts (parts with random defects that are likely to result in early failures, known as infant mortality) from an otherwise acceptable lot and thus increase confidence in the reliability of the parts selected for use.

NASA EEE-INST-002 requires that all flight and qualification tests capacitors from the same production lot must be screened 100%. This includes a visual inspection, thermal shock, voltage burn-in, and hermetic seal test to name a few. Qualification requirements are outlined based on the capacitor technology (ceramic, tantalum, plastic, glass etc).

Figure 1:



Inspection/Test	Test Methods, Conditions, and Requirements 1/	Part Type/Level Ceramic			Plastic			Tantalum			Glass			Mica			Variable			Switch Mode Power Supply		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
6. Electrical Measurements	As specified 5/																					
Capacitance	MIL-STD-202, Method 305	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dissipation Factor	MIL-STD-202, Method 305	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DWV	MIL-STD-202, Method 301	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Insulation Resistance 1	MIL-STD-202, Method 302, room temp.	X	X	X	X	X	X				X	X		X	X	X	X	X	X	X	X	X
Insulation Resistance 2	Repeat at max. rated temp.	X			X						X			X			X			X		
DC Leakage 1	MIL-STD-202, Method 301							X	X	X												
DC Leakage 2	Repeat at 85 °C							X	X													
Equivalent Series Resistance								X	X													
Quality Factor																	X	X	X			
Driving Torque																	X	X				
7. Percent Defective Allowable	5%	X			X			X			X			X			X			X		
	10%		X			X			X			X			X			X			X	
	20%			X			X			X			X			X			X			X
8. Partial Discharge 6/	MIL-PRF-49467 Appendix B	X	X																			
9. Seal Test (Hermetic Types Only)	MIL-STD-202, Method 112																					
Gross Leak	Condition A or B				X	X		X	X													
Fine Leak	Condition C				X			X														

The qualification section goes a step further. Qualification testing consists of mechanical, electrical, and environmental inspections, and is intended to verify that materials, design, performance, and long-term reliability of the part are consistent with the specification and intended application, and to assure that manufacturer processes are consistent from lot to lot.

The rigorous and thorough screening and qualification guidelines required in NASA INST-002 give designers of these capacitors hard targets to design for and give users of these capacitors' high confidence of their performance when in service. The costs to conduct these tests will significantly add to the components costs though. For many years, designers of high profile/high-cost defense and commercial space missions have and continue to require adherence to NASA INST-002 guidelines. Some designers even specify extra tests of their own to eliminate every possible risk.

These NASA requirements have given capacitor designers years of experience in optimizing the performance of their products for use in space. In fact, when seeking low risk ways to reduce cost, it is common practice for engineers and designers to simply require that all flight parts only undergo the screening process (as specified in Figure 1) so long as the manufacturer can confirm that the component has a history of being reliably used in space. A request for a previously completed NASA INST-002 report for the same part number or product series can also be requested as evidence of reliability. Several designers have simply required that a capacitor must be designed to meet automotive standards in order to be used in space (typically with a confirmation of space heritage or a specific part number or product series.

There are a variety of different capacitor technologies for use in space available today, but not all are created equal. If a capacitor is advertised as “space grade” that’s a great start, however it may not necessarily be the most efficient solution. Minimizing the volume and weight of anything being launched into space is a critical design consideration that has a significant impact on cost and performance. By selecting the best capacitor solutions for any given application, designers can meet their SWaP savings goals.

Aluminum polymer capacitors are often used in space. They can withstand the demanding environments of space and have good electrical performance characteristics. Although they can environmentally and electrically meet common space level applications needs, other solutions offer distinct SWaP advantages. Let’s step through a case study as an example.

Case Study:

A designer has a space-based application requiring a 63V / 8900uF capacitor. An aluminum polymer capacitor solution can be considered to meet this need as these types of capacitors have plenty of space heritage and meet miscellaneous space level requirements. One solution for consideration could be Kemet’s PHA226 series. A capacitor within this series is rated to 63V and 560uF per cap. In order to meet the 8900uF requirement, the designer would need 16 capacitors connected in parallel. This would consume a volume of 12.64in3 and weigh in at 320g.

Another solution to consider with be Quantic Evans’ TDD series. These are hybrid wet tantalum capacitors that have a long space heritage and are well suited to meet the demanding environment of space. One capacitor within this series has a rating of 63V / 9400uF and would routinely pass the screening and qualification requirements as specified in NASA INST-002. The Quantic Evans capacitor solution would consume a volume of 0.9in3 and weigh 86g, thus providing significant volumetric and weight savings compared to our aluminum polymer solution.

In the vacuum of space, hermetic capacitors are common a requirement. Although it’s commonly thought of as meaning “airtight”, hermetic really means that gasses and moisture cannot penetrate the capacitor, nor can they escape from the capacitor. There are some circumstances where the capacitor will be placed within a hermetic enclosure, therefore an engineer or designer may be able to relax their capacitor hermeticity requirements in those instances. If not, a hermetically sealed capacitor a typically a must.

In space, radiation levels are much higher than on earth, since earth’s atmosphere shields us. Radiation can impact the performance or cause damage to some capacitors, but there are capacitors that carry a radiation hardened designation, otherwise known as “rad-hard”. This means that their performance is not impacted by high radiation conditions. Citing the capacitor example from the case study, Quantic Evans capacitors are designed in a tantalum case. Tantalum provides shielding from radiation, therefore Quantic Evans capacitors are rad-hard. If “radiation vulnerable” capacitors are considered for use in a design, radiation shielding options usually need to be designed in.

Thinking of a satellite in orbit, one may not think that shock and vibration needs particular consideration, but this is usually only true during operation. There are events during a system’s launch and deployment when shock and vibration withstand capability are important. During initial launch, the electronics on the satellite or spacecraft are exposed to varying level of vibration conditions. Once in orbit, there is a deployment event which can result in a high shock condition. Despite the fact that the few high shock and high vibration events may occur during a mission, the specified capacitor must be rugged enough to withstand these events.

The lifespan of the mission typically dictates the needed lifespan of a capacitor. Typical derate criteria are defined in various MIL standards. 50-60% voltage derate is typical but can vary depending on the individual mission profiles. Primary factors that impact capacitor life includes the capacitor’s duty cycle, operating temperature and operating voltage. The lower the operating voltage and temperature are the longer the capacitor will last.

Storage life/shelf life come into consideration in certain applications as well. Some defense applications my sit dormant for years and when used are very short in operating life. In deep space missions where the travel time is measured in years, designers will need to be mindful of the storage life of the individual components as it may be several years before the capacitor is energized and in use. It’s always a good idea to plan for the unknown. Despite a designer’s best efforts, failure happens. Capacitors can fail, but the way a capacitor fails should be something to keep an eye on. Solid tantalum capacitors are routinely used in space applications, however when they fail, they can fail open and catastrophically (by catching fire).

This can and will often impact other subsystems around it and could render the entire vehicle useless. Citing our previous example, Quantic Evans' capacitors fail short, providing a level of protection to the circuit or subsystem.

As the new variety of space-based applications continue to grow, the way capacitors are designed in has changed. Keeping low cost and high reliability in mind, there are many capacitor manufactures whom have plenty of experience and heritage in designing the right capacitor for any unique space based application.

About Quantic Evans:

Quantic Evans manufactures high power density capacitors for demanding defense and aerospace applications. Quantic Evans capacitors are hybrid wet tantalum capacitors that offer significant savings on space, weight, and power (SWaP) when compared to other capacitor technologies. For over a decade, Quantic Evans has been a preferred supplier for several Tier 1 Aerospace and Defense contractors and is ISO9001/AS9100 certified.

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