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New Capacitors Offer Better Balance Of Performance, Reliability And Cost For LEO Satellites

by Ron Demcko, Daniel West and Ryan Messina, KYOCERA AVX, Fountain Inn, S.C.

The low-Earth-orbit (LEO) satellite market continues to change rapidly and is driven by multiple trends, the most impactful of which is a significant increase in the production of LEO satellites. End-user demand for LEO satellites is growing due to the expansion of newer, single-satellite applications, like Earth observation missions, as well as the growing use of LEO satellite constellations, which offer reduced latency, broader coverage, improved reliability, and potentially even lower costs compared to geostationary satellite platforms.

Another trend fueling the growth of the LEO satellite market is the evolution of their design. Today's LEO satellites have been turbocharged with technologies ranging from cutting-edge semiconductors and advanced passive components to off-the-shelf, flight-tested subsystems ready for integration into end-user designs. Launch delivery service options are also expanding, enabling the reliable delivery of hardware into orbit.

As a result of these trends, the global LEO satellite market has morphed into a reasonably sized market with the promise of solid growth over time, and more LEO satellites than ever are being built worldwide. This in turn has led a growing number of passive component manufacturers to dedicate research and development (R&D) efforts to producing components specifically optimized for LEO satellite designers.

Two such capacitor developments are high-capacitance-per-unit-volume (high-CV) multilayer ceramic capacitors (MLCCs) and enhanced-reliability commercial off-the-shelf (COTS) bulk capacitors. In this article, we'll discuss these developments with a focus on two recently introduced series.

To begin, we'll review the benefits of high-CV MLCCs in satellite applications and the development of the MIL-PRF-32535 specification to define their requirements. Then we'll look at the trend in satellite development of using consumer- or automotive-grade capacitors in satellite applications during the prototyping phase to save cost before implementing MIL-PRF-32535 MLCCs in the final design.

As we'll explain, the differences between these various component grades can create problems and have inspired development of a new series of lower-cost, pre-flight-grade/prototype MLCCs (the EM series). The characteristics of this series will be described and differences in testing between the EM series capacitors and MIL-PRF-32535 MLCCs will be identified.

Then, we'll turn our attention to bulk capacitors, tantalums specifically. While MIL-PRF-32535 versions are available, as with the MLCCs, COTS versions are being requested to save cost. We'll share details of a new series of space-grade tantalums (the TBJ series SRC8000) and outline the testing differences between these capacitors and MIL-PRF-55365 tantalums.

High-CV MLCCs For LEO Flight Designs

MLCCs with larger capacitance values, or high CV, are attractive to the flight community since they typically offer low equivalent series resistance (ESR) and are thus capable of delivering higher peak currents to the load with less heating. High-CV MLCCs are also beneficial to flight system designs since they weigh less than other options and take up less board space.

The Defense Logistics Agency (DLA) and the user community both realized the value that high-CV MLCCs can provide for next-generation flight-rated semiconductors. In response, a combined user and supplier committee drafted a high-reliability, high-CV specification proposal and submitted the draft to the DLA.

The DLA reviewed this document, considered broad manufacturer and end-user comments, and eventually issued the military performance specification MIL-PRF-32535. This spec is similar to European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) specifications for parts built with the same material systems in slightly different configurations.

The MIL-PRF-32535 specification is maintained by the DLA and defines the functional requirements and predictable quality levels of capacitors manufactured to the specification. The DLA maintains a qualified product list (QPL) and defines requirements for component manufacturing and quality assurance (QA) processes.

This agency also mandates that qualified manufacturers conduct subsequent lot basis testing in order to maintain their qualification and that qualified product designs are not allowed to change without extensive testing, documentation, and DLA approval.[1] As such, MIL-PRF-32535 is used widely in the satellite community, regardless of the class of satellites.

Component-Level Rapid Development Flight Design Challenges

When developing lower-priority satellites, designers often seek out low-cost alternate-grade components (i.e., *not* flight grade). That's because this segment of the market faces significant and increasing pressure to rapidly complete satellite designs, build the hardware, perform terrestrial debugging, and accommodate any necessary redesigns before manufacturing new flight hardware. So designers need parts fast and there are cost pressures to consider. As a result, designers are often encouraged to use lower-cost components for building terrestrial evaluation systems.

Although it's understood that all preflight hardware must be based upon individual components with the exact electrical and physical versions of flight hardware in all respects, the lower-cost parts should be close enough for hardware prototyping, right? Well, that's often not the case.

For example, hardware designers might select consumer-grade MLCCs for debugging and test systems, only to learn that consumer-grade components frequently change electrode counts, which negatively affects ESR and ripple current ratings. Additionally, consumer-grade MLCCs can come from multiple factories within a suppliers' manufacturing network, and different factories can have different process materials and methods, which can open the door to potential variations in MLCC height, weight, and inductance.

Other designers might choose automotive-grade MLCCs to achieve the necessary design consistency that consumer-grade MLCCs lack in this context, only to discover that the flight-grade parts are based upon a totally different design.

Further, consumer- and automotive-grade MLCCs might have different termination materials that require different processing temperatures and solder types for end use. Plus, there is little to no component lot traceability available for either, and traceability could be very significant if individual part failures occur or if there's a requirement to use parts with known lot and date codes.

New High-CV MLCCs For Rapid LEO Satellite Development

A new approach to cost control in the rapid development of flight hardware was recently released to market. Highly experienced capacitor manufacturer engineering teams worked with flight hardware manufacturers worldwide to develop the new engineering module series, or EM series, MLCCs from KYOCERA AVX.

The EM series MLCCs help designers reduce initial prototype costs and component lead-time by offering a series of parts featuring the same dielectric materials, case sizes, voltages, capacitance values, capacitance tolerances, and terminations as flight-grade MLCCs—in addition to full lot traceability.

EM series MLCCs are based on the ESCC 3009/041 and NASA G311/P838 X7R base metal electrode (BME) space MLCCs and MIL-PRF-32535 BME MLCCs. All parts look physically identical to agency- and DLA-specified components (see Fig. 1) and are available with no minimum order quantities to support the rapid development of nonflight prototype designs. As such, once a design engineer confirms that the EM series part number works in the design, they can then cross reference the EM part to the matching MIL-PRF-32535, NASA G311/P838, or ESCC 3009/041 specification for flight-grade hardware.

However, the testing differences between the new EM series MLCCs and MIL-PRF-32535 MLCCs are significant and are summarized in Table 1 below.

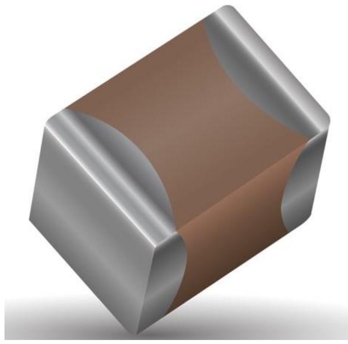


Fig.1. The KYOCERA AVX Engineering Module series (EM series) MLCCs[2] are designed to satisfy growing demands for rapid development in the space flight industry. These high-CV components are currently available with ratings spanning 16 to 100 V, 2.2 nF to 22 µF (X7R), 4 V to 100 V and 68 pF to 1,500 pF (NP0).

Table 1. The applied testing differences between KYOCERA-AVX EM series MLCCs and MIL-PRF-32535 MLCCs.

Applied testing	EM series	MIL-PRF-32535	
		Group A	Group B
Visual inspection	X	X	X
Capacitance	X	X	X
Dissipation factor	X	X	X
Insulation resistance	X	X	X
Thermal shock		X	X
Nondestructive internal examination		X	X
Voltage conditioning		X	X
Destructive physical analysis (DPA)		X	X
Solderability testing		X	X
Bond strength testing		X	X
Shear stress testing		X	X
Board flex		X	X
Resistance to soldering heat		X	X
Temperature humidity bias			X
Thermal shock life test			X
Dielectric voltage breakdown			X
Voltage-temperature limits			X

New COTS Bulk Capacitors For LEO Satellites

As previously alluded to, flight platforms, like LEO satellites, are using a growing range of IC types in their designs, many—if not most—of which require larger bulk capacitance values to support applications ranging from power conversion to voltage hold-up.

Tantalum capacitors offer designers high reliability and high capacitance in combination with low inductance and small SMT packages. Variants compliant with the MIL-PRF-55365 specification are commonly utilized in satellite designs. However, the user community recently requested COTS-grade parts to address cost concerns in less demanding end systems.

The new TBJ series SRC8000 COTS-Plus space-level tantalum capacitors from KYOCERA AVX are especially designed for LEO satellite applications—including internet satellite systems integration, military and defense observation, surveying and imaging Earth, and space research and testing—and are exclusively comprised of commercially upscreened ratings that have been deemed suitable for mission-critical and space-level applications.

The capacitors selected as part of this TBJ series subseries have a more conservative design approach than other up-screened components that utilize established CV powders and higher dielectric formation ratios. So, their dc leakage current (DCL) is typically 25% lower than competing solutions while still offering aggressive ESR values. They also exhibit stable parameters over time with no wear-out mechanism and emit no noise.

These new space-level components are available in standard SMT case sizes equipped with a UL94 V-0 molding compound (Fig. 2). They come standard with Weibull reliability level "C" and surge current option "C" testing per MIL-PRF-55365 Rev. G and are also available with radiation effects test data upon request. Table 2 compares the test differences between the proprietary KYOCERA AVX SRC8000 specification used to upscreen the new TBJ series parts and the MIL-PRF-55365 specification.

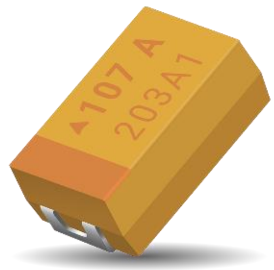


Fig. 2. The KYOCERA AVX TBJ series SRC8000 COTS-Plus space-level tantalum capacitors are currently available in six case sizes spanning EIA metrics 3216-18 to 7361-43 with ratings spanning 6 to 50 V and 0.10 to 680 µF.

Table 2. Test comparison between the TBJ series SRC8000 COTS-Plus space-level tantalum capacitors and MIL-PRF-55365 tantalums.

Parameter/Test	COTS+	MIL-PRF-55365	
	SRC 8000	MIL Weibull B, C. D	MIL T Level
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)	(0.01 to 0.1)%/1000 hrs/90% conf	(0.01 to 0.1)%/1000 hrs/90% conf	0.01%/1000 hrs/90% conf
Environmental (humidity)	65°C/(90 to 95)% RH/500 hrs	(10 to 65)°C/(90 to 95)% RH/20 cycles	(10 to 65)°C/(90 to 95)% RH/20 cycles
100% reflow	✓	✓	✓
100% thermal shock	✓	✓	✓
100% voltage aging	Optional Weibull	Mandatory Weibull	Mandatory-Weibull-Grace C. min.
100% surge current	Optional	Optional A, B or C	Mandatory - C surge
Surge voltage		✓	✓
100% electrical testing (capacitance, DF, ESR, Z, DCL)	To specification limits only	To specification limits only	+3 sigma limits
100% visual and mechanical	Sample test	Sample test	✓
100% x-ray	Sample test		✓
Simulated mounting, rework, and lot conformance	✓		
Solderability test (8-hour steam age)	Mandatory – 90% coverage	Mandatory – 90% coverage	Mandatory – 90% coverage
Hot dc leakage	✓		
Visual and mechanical	✓	✓	✓
DPA – 1580 destructive physical analysis			✓
Temperature stability	Mandatory	Mandatory	Mandatory

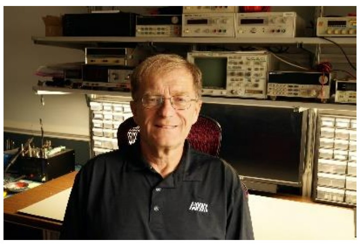
Summary

The global LEO satellite market is experiencing significant growth fueled by technology trends, including the use of advanced ICs that require high-performance capacitors to deliver expanded functionality, and rapidly increasing demand for flight-ready products with reduced development cost and delivery times. In response, experienced passive component manufacturers have released new versions of high-CV MLCCs, like the EM series MLCCs, and enhanced-reliability COTS bulk capacitors, like the TBJ series SRC8000 COTS-Plus space-level tantalum capacitors, especially designed to address the unique demands of this market. They are also continuing to expand on these product series in an attempt to keep pace with rapidly evolving IC needs.

References

1. "Microelectronic Component Engineering for the 2020s" tutorial by Ron Demcko, Trevor Devaney, Jon Rhan and Thomas J. Green, Components for Military & Space Electronics (CMSE) Conference, Los Angeles, California, May 1, 2024.
2. KYOCERA AVX Engineering Module Series (EM Series) MLCCs, product page.
3. KYOCERA AVX TBJ Series SRC8000 COTS-Plus Space-Level Tantalum Capacitors, product page.

About The Authors



Ron Demcko is a KYOCERA AVX senior fellow at KYOCERA AVX headquarters in Fountain Inn, South Carolina. This role centers on projects ranging from simulation models for passive components to product support, new product identification, and applied development. Prior to this role, Ron was the EMC Lab Manager at AVX in Raleigh, North Carolina. This lab concentrated on subassembly testing and passive component solutions for harsh electrical and environmental applications. Before that, he was an AVX application engineer for products including integrated passive components, EMI filters, and transient voltage suppression devices.

Prior to joining AVX, Ron worked as a product engineer and, later, a product engineering manager in the electronics division at Corning Glass Works. In these roles, he supported the development, production, and sale of pulse-resistant capacitors, high-temperature capacitors, and radiation-resistant capacitors, developed high-frequency test methods, and co-developed high-temperature test systems. Ron earned his BSEE from Clarkson College of Technology (now Clarkson University). He can be reached at ron.demcko@kyocera-avx.com.

Daniel West is the lead technical applications engineer at KYOCERA AVX where he is responsible for engineering support across North America for multiple KYOCERA AVX products and regularly conducts training at end customer locations, internally, or for distribution, in addition to creating technical sales tools. Daniel spent two years as a connector FAE, and over four years as a generalist FAE.

He has published various papers from connectors to capacitors among other passive electronic components. Daniel is a combat veteran of the 82nd Airborne, and resides in Greenville, S.C. with his wife and two children. He received his BSEE from Mercer University. Daniel can be reached at daniel.west@kyocera-avx.com.

Ryan Messina is a technical applications engineer at KYOCERA AVX headquarters in Fountain Inn, S.C. where he provides support services for internal R&D, product development, marketing, and QC groups. His roles range from working with IC companies supporting next-generation passive component design and selection for advanced integrated circuits to internal engineering database support and analysis. Ryan provides support for high reliability and flight electronics part selection worldwide and serves on the organizing committee for the Components for Military and Space Electronics conference. He joined KYOCERA AVX in June 2022.

Previously, Ryan served five years as an Infantry Squad Leader in the United States Marine Corps. He resides in Greenville, SC with his wife and child. Ryan graduated from Clemson with a B.S. in electrical engineering. He can be reached at ryan.messina@kyocera-avx.com.

For more on capacitor selection for power design, see How2Power's Design Guide, see the "Component" category and select "Capacitors". For more on power design for space, see How2Power's Space Power section.

