COTS-Plus / Alternate Grade bulk capacitor for LEO flight Platforms

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INTRODUCTION

Satellite design is a complex and exacting task with significant time & cost pressure placed on reacting to rapidly changing end customer needs. Customer demands & expectations regarding hardware performance are formed by impressive advances in flight hardware. Powerful semiconductors, with ample amounts of processing power, have transformed small satellites into mission capable, lightweight, efficient packages. Power conversion efficiency and quality for these processing cores is more important than ever and thus great demands are placed on bulk capacitors. The selection of the correct capacitors is critical in present day satellites.

To complicate things further, as new classes of small satellites become more common, designers of those satellites have become more open to consider alternate grade parts. Part of the design consideration transformation is a trend to utilize capacitors that are commercial grade off the shelf – COTS.

COTS components lack the testing and guaranteed reliability of Military performance (MIL-PRF) rated devices, but they offer stable design, proven high volume processes and a performance greatly exceeding consumer or even AEC Q200 expected performance levels. Additional screening can be applied to COTS plus parts to establish an expected performance level of reliability.

Additionally, alternate grade parts might offer lower costs or larger capacitance values, different form factors (e.g. as in the case of 3-terminal MLCCs) and faster delivery.

This paper investigates the construction & screening of TBJ capacitors relative to MIL-PRF-55365 Tantalum capacitors (specification). Test options are highlighted, and performance levels established. The parts applicability to flight power trees is discussed and an example of basic electrical performance is given. The TBJ Space Level Series is a new option for designers in need of alternate grade bulk capacitors.

HISTORY & CONSTRUCTION OF TANTALUM CAPACITORS

The wide use of tantalum capacitors emerged in the 1950s and at the time were associated with transistor bulk capacitor needs. Circuits needed larger capacitance values that were stable in terms of temperature, time and applied voltage. Tantalum capacitors offered great promise of large capacitance values in leaded packages that were compatible with circuit designs of that era.

The design of a tantalum capacitor is based upon creating an oxide dielectric layer between electrodes that are deposited inside the sponge-like structure of Tantalum. This design takes advantage of a large high surface area available for dielectric formation within a tantalum pellet and allows tantalum capacitors to offer a very high capacitance in a significantly smaller package than other capacitor technologies. These features made them ideal as bulk hold up, filtering and power conversion applications.

Up until the early 1980's axial and radial leaded capacitors dominated designs. Then as surface mount technology appeared in the semiconductor world, passive components began to transform into leadless structures. A variety of different case sizes were developed that corresponded to different capacitance ranges, voltage ratings and Equivalent Series Resistance (ESR).

In the case of tantalum capacitors, SMT tantalum capacitors of various sizes were developed and widely adopted. The different case sizes dimensions were generally driven by the size of the tantalum pellet and number of pellets used in a

single packaged part. Multiple tantalum pellet inserts are sometimes used to reduce the Equivalent Series Resistance (ESR) of the capacitor.

Solid tantalum capacitors belong to the electrolytic capacitor family. Electrolytics are devices with polarity ratings. Current will only pass from the positive end (the anode) to the negative end (the cathode).

The construction of a solid tantalum electrolytic capacitor consists of three elements:

- Anode
- Dielectric
- Cathode

Explaining further, the tantalum anode is comprised of particles of pure tantalum powder. The anode is sintered into a pellet. The key to this technology is that the pellet has a very high 3D surface area due to tantalums sponge-like structure.
The pellet will house the capacitors thin dielectric layer and counter electrode. A tantalum wire embedded inside one end of the tantalum pellet and will be welded to a lead frame.

The surface of the anode pellet is processed to have a thin layer of tantalum pentoxide (Ta_2O_5) formed. The tantalum pentoxide functions as the capacitors' dielectric.

The cathode of the capacitor is manganese dioxide (MnO_2) in the case of the TBJ series capacitor – the topic of this paper. Additional layers of carbon and silver are added to ensure a solid connection between the cathode side of the capacitors pellet structure and the other lead frame connection. Once finished, the capacitor insert has its anode welded to one termination of the lead frame[1]. The cathode is connected to the other lead frame with a conductive epoxy. That structure is then over molded with a plastic compound resin and the result is a finished SMT tantalum capacitor. A cross section of a SMT tantalum capacitor is shown in figure 1.

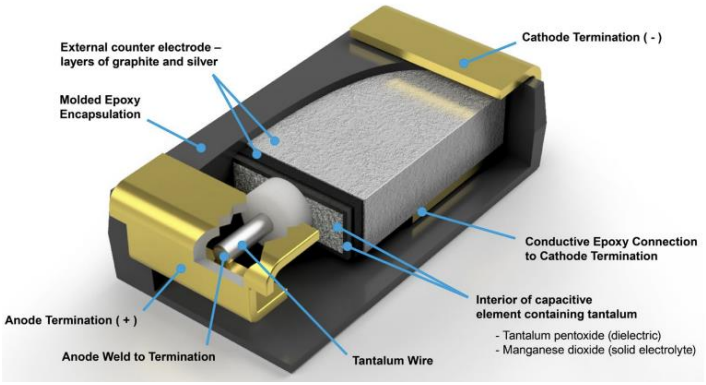

Figure 1: SMT Tantalum Capacitor Cross Section

TANTALUM CAPACITOR PARAMETERS & PERFORMANCE

Tantalum capacitors exhibit many desireable performance features critical to modern circuitry.
First tantalum capacitors have high capacitance per unit volume. Tantalum capacitors also maintain that high capacitance density with a relatively stable capactance variation vs temperature. More importantly tantalum capacitors have zero DC voltage bias effects and no parametric degradation with age. Additionally tantalum capacitors have zero piezoelectric noise and a low ESR. The combination of these features reinforce the use of tantalum capacitors in power conversion applications and signal processing levels. Further, tantalum capacitors exhibit very low leakage levels thereby making them very attractive in low power, battery and energy harvesting applications.Tantalum capacitors additionally exhibit high reliability in circuit applications.

The MnO_2 cathode has a property that significantly contributes to tantalum capacitor reliability[2]. Defects in the Ta_2O_5 dielectric cause local heating at the defect site during capacitor operation, which changes the nearby MnO_2 to Mn_2O_5 — a non-conductive phase of manganese oxide.
This non-conductive site serves to remove that portion of the capacitor from the circuit, effectively correcting the defect. This characteristic is called self-healing, and it allows tantalum capacitors with MnO_2 cathodes to have a declining failure rate over time.

Given the attractive performance of tantalum capacitor technology, a typical recap of commonly accepted reliability grades is in order - see figure 2.

Tantalum capacitors performance grades are divided into commercial reliability and established reliability.
There are two grades of tantalum capacitors within commercial devices. The first group is consumer grade capacitors. These parts are intended for consumer applications ranging from set top boxes to home appliance controls and personal electronics, etc.
The next grade is professional grade capacitors. These devices can be represented by Automotive grade AEC-200 devices or those intended for infrastructure, industrial, data processing applications etc.

Next the established reliability group (including high reliability) is made of 5 different grade capacitors. Each of these grade devices is intended to meet specific quality demands of the end use sector. Our concentration will be on the COTS tantalum capacitors.

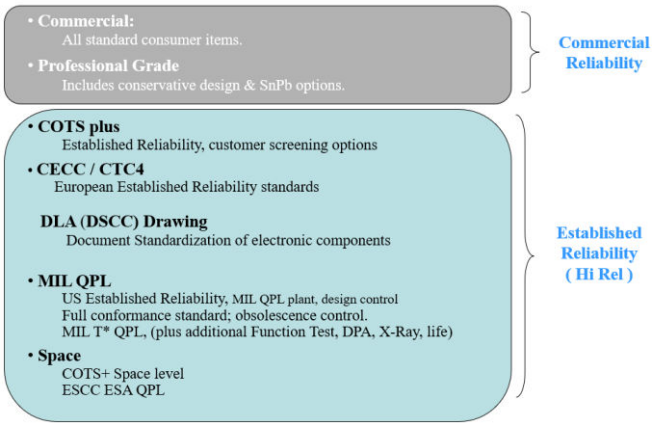

Figure 2: High-level explanation of tantalum reliability grades

COTS TANTALUM CAPACITORS – TBJ SERIES

The TBJ series is based on the CWR11 (MIL-PRF-55365/8) form factor. The TBJ series is ideal to meet the needs of LEO mission flight platforms power conversion & power distribution circuitry because of their low weight and high capacitance value range capacitance options.
TBJ A case capacitors exemplify the smallest & lightest case options available to designers with each device weighing ~0.029grams (100nf / 35v part). The largest case size is the U case. U case size (680uf / 6v part) capacitors weigh 0.738 grams per part.
Capacitance values from 100nf to 680uf are available in an overall voltage range from 6 volts to 50 volts. The derating factor used is obtained from recommendations given by the manufacturers catalog.

The TBJ COTS series came about by first selecting a sub-group of tantalum capacitors deemed suitable for mission critical and space level applications. Those capacitors have a more conservative design approach when compared to other up-screened components utilizing established CV powders and higher dielectric formation ratios. The capacitors chosen typically exhibit a DC current leakage (DCL) that is approximately 25% lower while still offering aggressive ESR values. Further, TBJ COTS capacitors allow end users the flexibility of changing their screening requirements as needed by program requirements.

TBJ capacitors have multiple unique preconditioning stress condition options to choose from. Each of these stress conditions roughly corresponds to different burn in conditions where different stresses initiate the self-healing previously discussed. The various test options remove the weaker parts from the population of parts to be shipped.

From a high-level perspective, the core qualifications of high-performance tantalums are products built and tested to MIL-PRF-55365. Building on that foundation, Kyocera-AVX realized that needs existed for various series of tantalum capacitors each with reliability performance matching specific end use needs. A high-level comparison of high reliability specification requirements comparison is shown in Table 1.

The first expansion of the TBJ series capacitor was that of Commercial Off the Shelf (COTS) performance grade. These products generally offered smaller sizes, higher capacitance & possibly lower ESR. They also offered faster lead times and potentially lower costs.

COTS tests include 100% test of the following: reflow, thermal shock, surge, Weibull and electrical parameters. Optional tests include enhanced visual/mechanical, solderability and temperature stability tests with a 100% surge current option.

Knowing that certain classes of LEO Sats have a need for up-screened components beyond COTS grade parts, the SRC8000 specification was created. The TBJ Space Level series is based upon components that have been selected from COTS-Plus products and deemed suitable for additional up-screened tests. The typical applications targeted are those classified as mission critical for space LEO - Low Earth Orbit specification use.

Two different screening matrices are used once termed SRC8000 for LEO applications and the other test set is intended for high priority space applications (SRC9000 and T Level).

TBJ SRC8000 processed components have all the tests of COTS parts plus:

- 100% electrical testing to 3 SIGMA Kyocera-AVX DCL/ESR/DF limits
- Simulated Mounting, Rework and accelerated life test
- Standard solderability on a sample basis
- 100% Xray on a sample basis
- Hot DCL leakage on a sample basis

TEST		Series	100% Reflow	Vibration	Shock	100% Thermal Shock	RTSH	Moisture Resistance	OperatingLife	100% Weibull	100% Surge Current	100% Electrical Testing	Visual & Mechanical	Sim Mounting, Rework, Life	Solderability	100% X-Ray	DPA - 1580	Surge Voltage	Hot DC Leakage	Temperature Stability	Adhesion Shear
COTS-Plus	COTS-Plus	TBJ	0			0				0	1	0	0 3		1 3					1 3	
Space Level	SRC8000	TBJ COTS	0			0				0	1	0 5	0 3	0 3	0 3	0 3			0 3	0 3	
Space Level	SRC9000	TBJ COTS	0	1 3	1 3	0	1 3	1 3	4 0/1 3	0	0	0 5	0	0 3	0 3	0	0 3	0 3	0 3	0 3	1 3
MIL-PRF-55365 QPL	T Level	CWR09,11,15,19,29	0 2	2 3		0 2	2 3	2 3	0 2 3	0 2	0 2	0 2 6	0 2		2 3 1	0 2	0 3	2 3		0 2 3	
KEY:																					
0 = Standard Test 1= Optional Test 2 = Qual and/or Grp C	5 = KAVX Std DCL/ESR/ DF 3 Sigma	6 = DLA STD DCL/ESR/ DF/ESR 3 Sigma																			
3 = Sample Test 4 = COTS Upscreen 1000 hr @125c																					

Table 1 – High Reliability Specification Requirements Comparison Chart

This comparison highlights the differences between the product grades. The reduced testing requirements of the SRC8000 products is a major reason for improved lead time deliveries of TBJ LEO class capacitors.

TBJ LEO SAT DEVICE USE

Satellites have a complex power conversion chain starting with solar panels and battery management circuitry then progressing to a primary power supply that in turn powers multiple low noise Point of Load (POL) power supplies that are powered by isolated power supplies converting main power bus levels POL input levels[3]. Further, there are multiple points of feedback/monitoring power levels, power quality and general circuit health.

Reliability, weight, power quality and efficiency are all design targets. Those targets are becoming more difficult to meet as high-power levels required by processor boards (for example) and voltage regulation requirements become more stringent.

TBJ LEO Sat capacitors offer the high capacitor density and low ESR needed to achieve low ripple voltage to powerful flight processors, ADCs etc. TBJ LEO Sat capacitors low weight, low ESR and low inductance make combining multiple TBJ capacitors in parallel as an output filter a very practical design solution. Table 3 provides a summary of weight and inductance by case size.

Component Type	Series	Case Size	Approximate Average Weight (g)	Inductance (nH)
Tantalum	TBJ	A	0.029	1.8
		B	0.068	1.8
		C	0.166	2.2
		D	0.290	2.4
		E	0.512	2.5
		U	0.738	2.4

Table 3 TBJ LEO Sat Grade Capacitor weight and inductance by case size

SUMMARY

The LEO Sat sector is expected to experience continued and accelerated growth due to the cost, speed of development and mission efficiency that these spacecraft exhibit. Further, the practicality of LEO Sat solutions is expected to improve as dedicated semiconductors provide high levels of integration and functionality at attractive costs.

The power distribution of advanced flight grade ICs used in LEO Sats is a critical design concern within the satellite. Power levels will increase along with IC processing advances and power quality/signal integrity will become a much more important design goal in flight platforms. TBJ capacitors offer stable parameters in signal level processing. These capacitors build upon past component design success and offer designers enhanced reliability and electrical performance in a small, lightweight package. TBJ capacitors provide designers with a practical compromise between full space grade and uncontrolled commercial grade capacitors. These devices will enable designers to expand LEO circuit optimization.

REFERENCES

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[3] Texas Instruments, Satellite Electrical Power Products Reference Design, Satellite electrical power system (EPS) design resources | TI.com