Tantalum capacitor benefits and recent advances: Product how-to

Charles Pothier - July 13, 2015

Tantalum capacitors offer designers of densely packed, high-performance electronic circuits a reliable high-capacitance solution with stable performance. A historical favorite among design engineers, tantalum capacitors are found in a wide range of applications such as bulk energy storage, filtering, and decoupling. Advancements in tantalum capacitor technology include the maturation of the polymer cathode system, which brings lower effective series resistance (ESR), significant improvements in packaging density, and reductions in effective series inductance (ESL). Herein, we will examine the impacts these developments have had on performance.

Background

Tantalum capacitors have been in use for almost 60 years. Noted for their long-term reliability and capacitance density, tantalum capacitors have been central in the design of military and commercial avionics, implantable medical electronics, notebook computers, smartphones, and industrial automation and control systems.

At the core of their popularity has been their volumetric efficiency, which yields high capacitance per unit volume. Refer to the equation for capacitance:

\[ C = \frac{(kA)}{d} \]

Where:

- \( C \) = capacitance
- \( k \) = dielectric constant
- \( A \) = surface area
- \( d \) = thickness of the dielectric

With an extremely large surface area, high dielectric constant, and a relatively thin dielectric, tantalum capacitors offer the best capacitance density available in the 1\( \mu \)F to 2,200\( \mu \)F range at working voltages up to 50V.

Combining advanced tantalum powders and high-efficiency packaging has kept tantalum capacitors one step ahead of advancements in alternate technologies. For example, today’s tantalum capacitors are able to offer up to 22\( \mu \)F at 4V in the 0402 case size. At the other end of the voltage range, one can find tantalum capacitors of up to 47\( \mu \)F at 50V in a single package, and even higher in through-
Conventional tantalum capacitors utilize manganese dioxide (MnO₂) as the cathode system. This semiconductor material provides a self-healing mechanism that leads to long-term reliability and is relatively inexpensive. However, its oxygen-rich formulation can contribute to ignition under extreme circumstances involving high heat. Since the mid-1990s, the industry has been working to mature conductive polymers, complementing the MnO₂ offering. With significantly higher conductivity than MnO₂, conductive polymers have contributed to the reduction of ESR. This advancement, coupled with the elimination of the ignition risk in sensitive applications, has helped drive investment in this technology.

Advancements in tantalum capacitor design

Manufactures offer solid tantalum capacitors in a wide variety of different series optimized for specific characteristics and targeting different applications and market segments. These varied product series include optimizations such as lower ESR, reduced size, high reliability (e.g., military, automotive, and medical), reduced DC current leakage, lower ESL, and higher temperature. This paper focuses on two of these areas of attention: lower ESR and reduced size.

- Lower ESR – Optimized for lowest ESR, these devices offer higher efficiency in pulsed or AC applications and better filtering in high-noise environments.
- Reduced size – Combining the use of high-CV tantalum powder and highly efficient packaging, these devices offer high capacitance in compact sizes. These are used in space-constrained applications such as smartphones, tablets, and other hand-held consumer electronics.

Low ESR tantalum capacitors

Reducing ESR in tantalum capacitors has been an important area of study in their design. The choice of tantalum powder and the processes used in the application of the cathode material during production have a significant impact on ESR. However, for a given rating (capacitance, voltage, size) these factors are largely a design constraint and are mostly fixed in today's state-of-the-art devices. The most significant reductions in ESR have come from two sources: replacing MnO₂ with a conductive polymer as the cathode and switching from iron-nickel alloys to copper as the leadframe material.

The primary contributor to ESR in conventional tantalum capacitors is the use of MnO₂ as the cathode material. As shown in Figure 1, MnO₂ has a conductivity of ~0.1 S/cm. In contrast, conductive polymers, such as Poly [3,4-ethylenedioxythiophene] (PEDT), have a conductivity in the range of 100 S/cm. This increase in conductivity directly translates to significant reductions in ESR.

Plots of ESR vs. frequency for several ratings (Figure 2) highlight the advantages of the polymer cathode system in tantalum capacitors. By directly comparing the A-case 6.3V/47µF rating in MnO₂ and polymer, one can see a reduction in ESR with the polymer design of as much as an order of magnitude at 100kHz.
The leadframe material is another area where switching to more highly conductive materials improves ESR. As shown in the capacitor cross-section in Figure 3, the leadframe provides the electrical connection from the internal capacitor element to the exterior of the package.
Iron-nickel alloys (such as Alloy 42) have been the traditional choice of leadframe material. The benefits of these alloys include a low coefficient of thermal expansion (CTE), low cost, and ease of use in manufacturing. Significant advancements in the processing of copper as a leadframe material enable its use in tantalum capacitor design. With an electrical conductivity of 100 times greater than Alloy 42, its use has a measurable impact on ESR. To illustrate, Vishay’s 100µF/6.3V T55 polymer tantalum capacitor in the A case (EIA 3216) with a traditional leadframe has a maximum ESR specification of 70mΩ at 100kHz and 25°C. By switching to a copper leadframe, the maximum ESR specification can be reduced to 40mΩ.

**Compact tantalum capacitors**

The two main contributors of improving volumetric efficiency (capacitance density) in tantalum capacitor designs are the evolution of tantalum powder and improvements in packaging.

The figure of merit of tantalum powder used in capacitor designs is equal to C×V/mass (CV/g). The evolution of tantalum powder used in mass production is shown in Figure 4. These increases in CV/g are related to smaller particle sizes and improved purity of the powder. The utilization of these in capacitor designs is itself a complex field of study requiring significant investment in R&D.
Another significant contribution to size reduction in tantalum capacitor designs is the development of ultra-efficient packaging technologies. The most common packaging technology used throughout the industry is the leadframe design. This construction is very efficient in manufacturing, providing low cost and high throughput. For applications that are not subject to space constraints, these devices continue to offer a viable solution.
However, in many electronic systems where increased density is the primary design criteria, the ability to reduce component size is a key advantage. In response to this need, manufacturers have developed several advances in packaging technology. As shown in Figure 5, leadframeless designs provide an improvement in volumetric efficiency over the standard leadframe construction. By reducing the size of the mechanical structure required to make the outside connections, these devices can make use of this extra available space to increase the size of the capacitor element, thereby increasing capacitance and/or voltage.

In the latest generation of packaging technology, Vishay’s patented multi-array packaging (MAP) construction further improves volumetric efficiency by making the external connections using metalized layers applied on the ends of the package. By altogether eliminating the internal anode connection, the size of the capacitor element can be maximized within the available volume. To further illustrate the improvement in volumetric efficiency, consider Figure 6. Here an increase of over 60% in the volume of the capacitor element is evident. Such an increase can be used to optimize the device for increases in capacitance and/or voltage, reductions in DCL (DC leakage), and increased reliability.
An additional benefit of Vishay MAP construction is the reduction in ESL. By eliminating the enveloping mechanical leadframe, the MAP construction significantly reduces the size of the established current loop. By minimizing the current loop, a significant reduction in ESL can be realized. As shown in Figure 7, this reduction can be in the order of 30% when compared to the standard leadframe construction. A reduction in ESL corresponds to an increase in the self-resonant frequency which extends the useful frequency range of the capacitor.

Conclusion

Advancements in tantalum capacitors have resulted in lower ESR, lower ESL, and reduced size. The maturation of the processes and materials used in the conductive polymer cathode system has resulted in stable, repeatable performance. This has spurred significant design-in activity beyond the confines of tantalum’s traditional uses. And improvements in packaging technology have led to higher capacitance density and reductions in ESL.

When combined, these two advancements provide design engineers with greatly improved electrical performance with low parasitic effects and increased packaging density.

Also see:

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