

Small Case Size Polymer Now Comes in Ultra Low ESR

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Abstract

Manufacturers of solid electrolytic Tantalum Polymer capacitors continue to make significant advances in producing ultra low ESR capacitors to meet the increasing demands of decoupling solutions for microprocessors and other applications. Until recently the focus of the development was on larger footprints such as the EIA 7343 case size. Progress in this area has led to the development of tantalum capacitors with 4 milliohm ESR. The demand for smaller capacitors for applications in wireless hand sets and notebook computers is increasing with growing demand for lower ESR and higher capacitance in smaller footprints such as the EIA 3528 case size. The need to achieve low ESR in smaller packages presents a new challenge to component suppliers. This paper will describe advances in material and process technologies required to develop these ultra low ESR small case size tantalum polymer capacitors.

Introduction

Miniaturization of portable electronics continues to drive circuit designers to demand smaller and smaller case sizes with more functionality than components with more than twice the volumetric size. The drive towards miniaturization and the industry trend towards low circuit voltages at higher frequencies fuels the demand for low ESR and high capacitance capacitors in small case sizes for applications in laptops, cell phones, digital camera, MP3 players and other portable devices. Low ESR values combined with a smaller footprint allow for greater efficiency in signal processing applications, while requiring less board space.

Application of intrinsically conducting polymer materials such as the cathode for tantalum capacitors resulted in significantly lower ESR when compared to MnO₂ cathode systems. Two orders of magnitude higher conductivity when using conductive polymers reduces the resistance contribution from the cathode resulting in lower ESR. The lower ESR and enhanced capacitance retention at higher frequencies of the conductive polymer capacitors enables circuit designers to reduce the number of capacitors resulting in lower cost design

solutions. In addition to lower ESR, the conducting polymer based capacitors also offer higher volumetric efficiency, high reliability, and reduced propensity for ignition. These critical attributes of polymer capacitors enhance their demand for applications in portable consumer electronics.

The development of conductive polymer based cathode systems resulted in the offering of valve metal capacitors in the 7343-43 footprint (KEMET X case) with ESR as low as 4 milliohm. Extension of these cathode systems to smaller case sizes also resulted in a dramatic reduction in ESR. These innovations enabled KEMET to continue to expand its lead in small case size low ESR solutions with the addition of B Case (3528-20) offerings available with ESR values of 25milliohms. The 25milliohm B Case product offerings included voltage ratings from 2.5V to 6.3V with capacitance values ranging from 47uF to 220uF. These products have been requested throughout the portable electronics industry. In addition to application in portable electronics, B case products also offer other industry segments a small case size substitution option for larger low ESR D Case (7343-31) and V Case (7343-20) products. Last year KEMET introduced a 15mohm B case to the market. Continued effort toward improving small case sizes resulted in the development of 12 mohm and 9 mohm B cases. This paper will describe strategies used in developing these ultra low ESR small case parts.

Advances in ESR

Since the introduction of polymer tantalum capacitors in 1999, KEMET Corporation has continued to make significant advances in reducing their ESR (1). Figure 1 shows the ESR reduction in 7343 and 3528 case sizes developed by KEMET over the last 20 years.

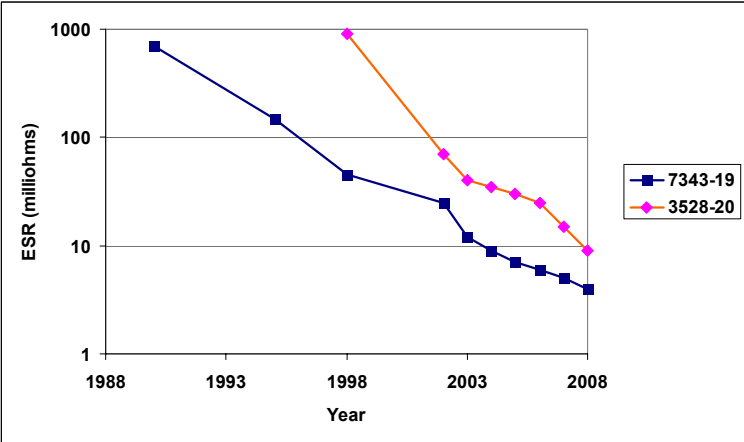


Figure 1. Decrease in ESR for 7343-19 and 3528-21 case sizes since 1990

ESR Advances in Large Case Size

Research strategies utilized to develop and manufacture ultra low ESR tantalum capacitors have been described previously(1,2). KEMET Corporation introduced the industry's first and only single anode 6 mohm ESR products in a 7343 foot print in 2006. This leading edge technology involved the development of fluted anode designs with multiple wires in a single anode (3). Continued innovations in anode designs, material advancements, and process improvements resulted in further reductions in ESR. Recently KEMET developed T520V capacitors in a 7343-19 footprint with ESR as low as 4 mohm. In addition, a low Equivalent Series Inductance (ESL) version (designated as the T528Z Face Down) was developed in a 7343-17 footprint to further improve the performance of the 7343 design by expanding its performance capabilities to even higher frequency ranges(5). Figure 2 shows the ESR probability distribution of 7343 case sizes in low (ESL) and standard ESL package designs.

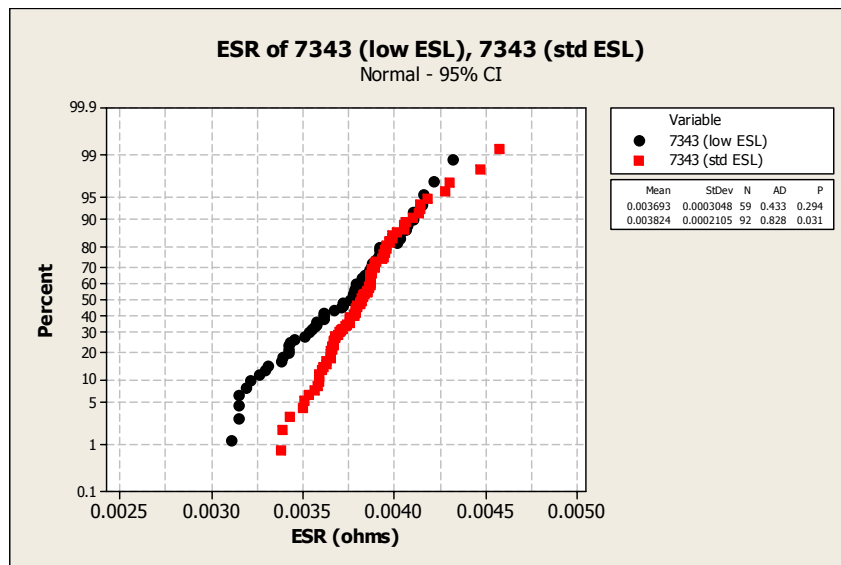


Figure 2. Probability distribution of ESR for 7343-19 (standard ESL) and 7343-17 (low ESL)

ESR Reduction Strategies for Small Case Sizes

KEMET's approach to developing a low ESR 3528 case was similar to the strategy used in developing 7343 footprint capacitors (1). Conceptual application of the general equation of resistance to the various elements in the capacitor gives general direction for new strategies.

$$R = \square L/A$$

where R= Resistance, ρ = Resistivity, L= path length, A= cross sectional area.

This general equation enabled a better understanding of the resistance contribution from various materials systems in the capacitor and aided in the development of improved material, design, and process solutions.

Conductivity of Cathode

As mentioned before, emergence of conductive polymer technology enabled capacitor manufacturers to dramatically reduce ESR. Table 1 shows a comparison of the ESR contribution from a 3528 footprint case size with MnO₂ and conductive polymer as the cathode. It can be seen that the conductive polymer, due to its higher conductivity, significantly reduces the resistance contribution from the external cathode layer. The conductivity of the conducting polymer is determined by the type of polymer system, polymerization (electrochemical, in-situ, polymerized dispersion, etc) reaction rate, and reaction conditions. The ability to form a uniform coating both inside the Tantalum pores and outside the anode also determines the final ESR contribution from the cathode. There have been ongoing efforts to attain the theoretically possible conductivity of the conducting polymer to achieve further ESR reduction.

Table 1: Effect of various cathode materials on resistance contribution from cathode layer

Cathode Material	Conductivity (S/cm)	Resistance contribution from external cathode layer (mohms) for 520B (3528 footprint)
MnO ₂	0.1-1	54-200
Conductive Polymer (PEDT)	5-100	0.3-5

Case Size and Surface Area

Reducing the ESR of small case capacitors is significantly more challenging due to the reduced surface area available for current flow. The cross sectional area (A) for current flow is essentially equal to the external surface area of the anode. Resistance increases as the bulk resistivity (ρ) of the element in the capacitor increases and the cross sectional area for current flow decreases. The carbon layer is the highest resistive element in the cathode layer and thus the ESR of the part is limited by the theoretical conductivity of the carbon layer. The theoretical limitations by carbon conductivity show a dramatic effect on ESR in small case size capacitors. Efforts to improve the conductivity of the carbon layer by optimizing both the type of conductive particles and the binder system used in these materials are ongoing. KEMET has also developed carbon nanotube based carbon system for improving

the conductivity of the carbon layer (4). Table 2 shows the effect of case size on the resistance contribution from cathode layer and carbon layer.

Table 2: Effect of case size on resistance contribution from cathode layers

Material	Resistance contribution from external layer (mohms)	
	520V(7343)	520B(3528)
Case Size (footprint)	520V(7343)	520B(3528)
Conductive Polymer (PEDT)	1 - 2	2 - 3.5
Carbon Coating	2 - 3	5 - 8.5

Anode Designs

Fluted anode designs have been used to increase the surface area (A) available for current flow. This has been successfully used in several 7343 footprint part types in the past. Although the flute dimension options are limited in the small case size, we have developed new anode designs with 4 and 8 flutes. Figure 3a shows the effect of increased surface area on ESR using fluted parts compared to non fluted parts. Another area of ESR reduction is in the use of large diameter wires. KEMET and other capacitor manufactures use large diameter wire to increase the cross sectional area of current flow from the lead frame through the anode body. The effect of wire diameter on resultant theoretical resistance is described elsewhere (1). Successful application of large diameter wires in small case size presents more challenges during processing. Figure 3b shows the effect of wire diameter on ESR of small case size T520B.

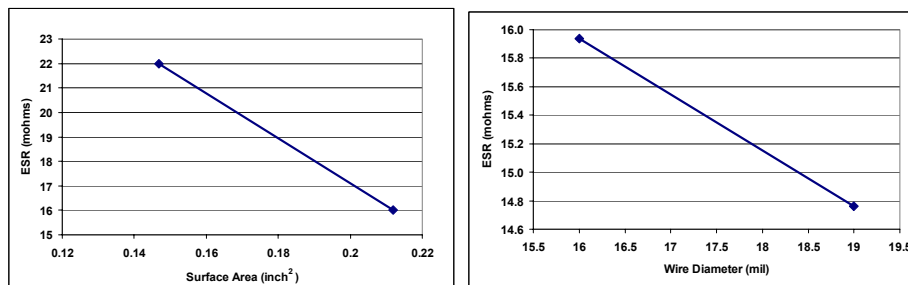


Figure 3. Effect of surface area (a) and wire diameter (b) on ESR

Conductive Polymer Processing

Progress has been made in improving conducting polymer processing so as to have a good buildup of polymer in the internal anode pores and uniform coating on the external anode. The impregnation of the internal anode also depends on anode density and sintered anode porosity and distribution. Figure 4 shows the ESR of 3528 case size as a function of polymerization cycles. A reduction in ESR was obtained by increasing the polymer buildup in the internal surface and by uniform continuous coating on the external surface.

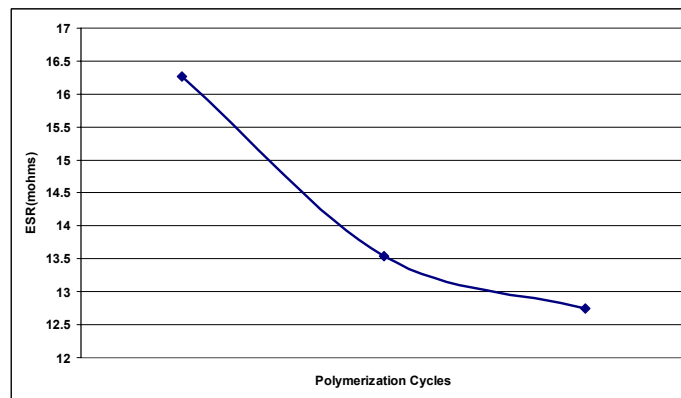


Figure 4. Effect of polymerization cycles on ESR

New Carbon and Silver Systems

A carbon layer is required to prevent any chemical incompatibility between the cathode layer and the silver layer. The binder of carbon layer is chosen such that there is good interfacial electrical contact between the carbon layer and the two adjacent layers separated by the carbon layer. This intimate contact achieves enhanced interfacial conductivity from each layer to the next. In addition to the reduced interfacial gap between the carbon layer and adjacent layers, the carbon layer also needs to have good chemical adhesion to the adjacent interface. Figure 5 shows the ESR reduction obtained by the use of a new carbon and silver system.

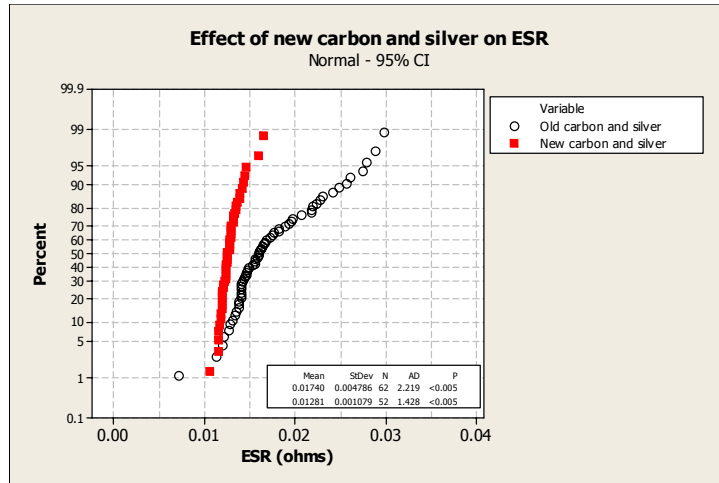


Figure 5. Effect of carbon and silver type on ESR

Multiple Anode Tantalum (MAT)

Multiple anode assembly to reduce ESR has been used by KEMET and others to achieve very low ESR (2). As the case size decreases, processing of MAT anodes becomes more challenging. We have successfully developed small case MAT anodes to achieve ultra low ESR. Figure 6 shows the ESR reduction obtained by using MAT anodes.

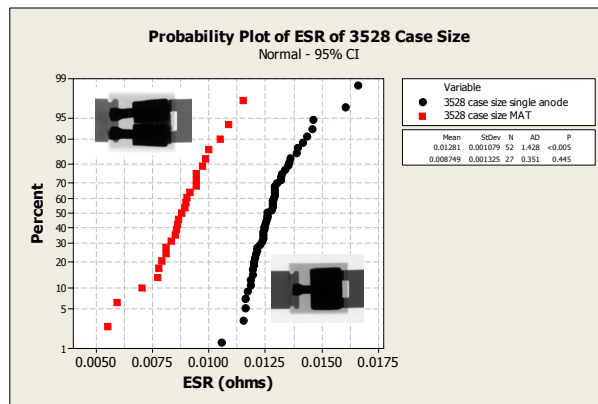


Figure 6. ESR distribution of 3528 case size single anode and MAT anode

Advantages in Design

As noted earlier, the 7343-20 case size represents the most commonly used case size for tantalum polymer chip capacitors in the portable computer market segment. The 2.0mm case height in combination with capacitance values of 100uF to 470uF and ESR values below 15mOhms make this component configuration ideally suited for microprocessor and peripheral decoupling in notebooks. Recently, designers of smaller portable computers such as ultra mobile personal computers (UMPCs) and netbooks have reported that these footprints are not well suited for the board constraints of these devices and have begun requesting even smaller component sizes in order to increase the overall functionality of their systems without increasing overall size.

Today, a miniature notebook may require as many as twenty polymer tantalum chip capacitors with up to nine locations requiring components with ESR ratings below 15mOhms. Until recently, designers had little option but to use 7343 case sizes for components requiring ESR values less than 15mOhms. With board space becoming a critical factor, we can compare the advantages of the commonly used 7343-20 case size to that of an advanced 3528-20 case size design with a comparable ESR value to determine what gains can be achieved with the use of these smaller devices.

Using the recommended land pattern dimensions for the given case size in conjunction with the maximum case dimensions, a component placement courtyard can be determined and compared for each case size. As shown in Figure 7, the mounting pad geometric of a 3528 component is 5.0mm x 2.5mm compared to a 8.9mm x 2.7mm pad geometric for the 7343 component. By accounting for the maximum allowable length and width of each component type and allowing similar margins for placement, an accumulative layout can be calculated for each component size. As shown in Figure 8, by converting the nine components requiring a sub 15mOhm ESR value from the larger 7343-20 case size to the smaller 3528-20 case size, the designer will achieve a space savings of approximately 238mm² (63% reduction).

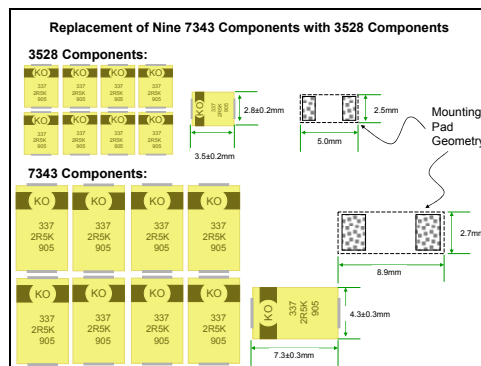


Figure 7: Comparison of 3528 Components vs 7343 Components

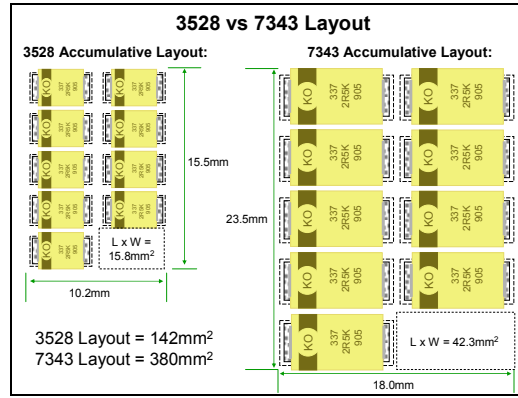


Figure 8: Board Space Comparison of 3528 Footprint vs 7343 Footprint

Conclusions

KEMET Corporation has made significant progress in developing ultra low ESR capacitors in small case sizes, thus being able to meet the demands of circuit designers looking for miniaturization. Using a theoretical framework of ESR contribution from various elements in the capacitor and systematic approaches towards developing those materials and processes resulted in a 3528 foot print with ESR as low as 9 mohm. Our investigations suggest that the improvement in conductivity of cathode materials and carbon systems could offer further ESR reduction for 3528 and other low profile small cases.

Acknowledgment

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