

Facedown Termination for Higher C/V - Lower ESL Conductive-Polymer SMT Capacitors

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Abstract

Smaller, thinner power delivery circuits may require slightly reduced capacitance for output filtering, input decoupling, and bypassing, but all in greatly reduced package sizes. Moving the tantalum capacitors from the larger, high capacitance packages to the smaller case sizes has created a disproportionately reduced capacitance per unit volume as the internal connection methods to the leadframe take up a larger percentage of the total volume. Reclaiming some of this lost volume by eliminating some of these internal connections and concentrating the leadframe to the solder attachment points at the bottom face of the chip capacitors allows some case's efficiencies to increase by over 100%. For standard packages, the volume that is dedicated to the leadframe, minimum wall thickness, and connections to the pellet are greater than 90% of the total volume for these small cases. For the smallest of case sizes using the standard leadframe, the volume utilized for the pellet (the active capacitance element) is below 10% of the package volume. By changing the lead frame configuration to terminate the active capacitor element on the bottom of the chip, significant increases in volumetric

efficiency can be obtained. The 'interconnects' between leadframe and pellet are optimized while the plastic thickness required for minimum wall coverage is effectively eliminated on one of the faces (the bottom face).

The elimination of the extraneous leadframe also creates a smaller current loop that easily reduces the ESL of the components by more than 50%. Sub-nanoHenries inductance is now achievable. Additional benefits of lower ESR and higher power dissipation will also be presented while maintaining RoHS and Pb-free compatibility.

Existing SMD Conductive-Polymer Capacitor

The active portion of this capacitor is encapsulated within a plastic package. It consists of a pellet, in block structure, with a riser wire extending from one face of the block structure. The pellet structure is a porous element normally composed of tantalum or a similar valve metal. The fineness of the metal powder and the porosity of the structure results in an enormous surface area of the base metal available for contact. All of the capacitance is contained within the pellet structure and the remaining elements of the package exist to facilitate a high-speed, pick-and-place, surface mount assembly process, and environmental stability.

In an electrolytic fashion, this pellet is immersed in an electrolyte, which penetrates into the pores to contact the open surface area. A circuit is created such that on all metal surfaces an oxide layer is grown. The oxide is grown onto it in extremely thin layers (20 angstroms-per-volt for the tantalum). This capacitor structure is illustrated in Figure 1, with the metal oxide (Ta_2O_5) forming the dielectric of the capacitor while the base metal (tantalum) of the block or pellet creates an anode contact along the inner surface of the oxide film. The cathode contact usually exists in multiple, sequential segments utilizing multiple materials. For the conductive polymer capacitor, the initial contact to the dielec-

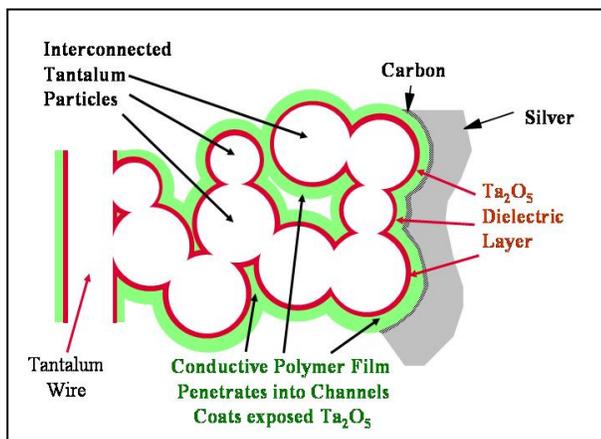


Figure 1. Capacitive structure found inside the pellet structure.

tric surface opposite to the anode contact is by means of a thin film or coating of conductive polymer. The application of this polymer coating on the surface of the dielectric is accomplished in a polymerization process involving a monomer and activating agents. The application of the conductive polymer, as the initial contact, replaces the traditional MnO_2 interface in order to achieve lower ESR (effective series resistance) levels. [1]

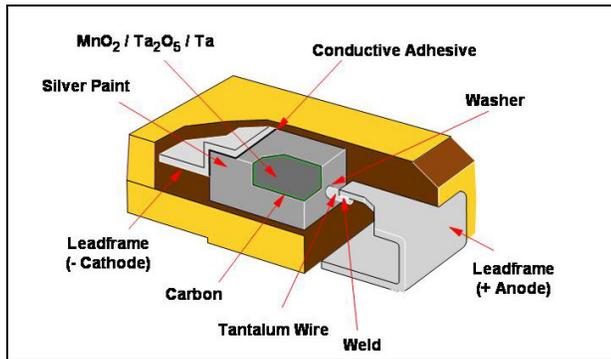


Figure 2. Cutaway view of standard SMD tantalum.

Electrical contact (cathode) to the polymer is accomplished through a thin coating of graphite, then an overcoat of the outside of the pellet structure with a silver paint. The cathode contact then utilizes a conductive epoxy to create a connection between the silver paint and the leadframe. Electrical contact for the anode element is accomplished with a weld connection of the leadframe to the riser wire. The block-type pellet structure and riser wire may have considerable dimensional variations within a production batch. This variation and the materials presented prohibit the direct circuit contact to the riser wire as the anode contact, and the silver paint surface of the pellet as the cathode contact, as these would require special handling and treatment to allow only the true capacitive element to be mounted in any circuit. Encapsulating the fragile wire and pellet structure within the plastic body and using a leadframe to bring the capacitor contacts to the outside world, creates a robust and dimensionally consistent package, which is reflow or wave solderable (Figure 2). This mechanically consistent device is optimized for the high-speed, pick-and-place, surface mount assembly.

The volume of the active portion of this capacitor is a fraction of the total package volume. As depicted in Figure 3, the right half of the device is where the riser wire and leadframe are welded together and the leadframe then extends horizontally out of the plastic package. Once the leadframe is out of the package, it is bent down and under the package to create the anode's solder-pad terminal for contact to the PCB. On the left in Figure 3, the leadframe is applied to the top and end

faces of the pellet structure with a conductive adhesive, where it then extends out of the plastic package, horizontally aligned at the mid height point with the leadframe at the opposite end. It again is bent down and under to create the cathode's solder-pad terminal. Looking at the arrangement in Figure 3, the best efficiency of this package might be in the range of only 70% of the total volume being used by the true capacitive element (pellet), while the remaining 30% deals with wall margins and interconnects.

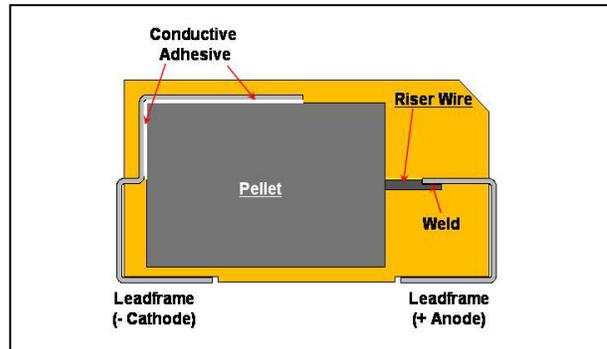


Figure 3. Cross-sectional view of pellet within plastic package.

Applying this same structure to a smaller case size may require the same wall margins around the pellet structure, but the proportional volume allocated to the weld contact would increase dramatically, as shown in Figure 4. Allowances here are dictated by minimum riser wire extensions, weld length and amount of leadframe encased within the plastic. Here the pellet structure comprises less than 50% of the cross-sectional area resulting in a volumetric efficiency of less than 50%. As we will show later, the efficiencies for the smaller, low profile cases decrease to less than 10%.

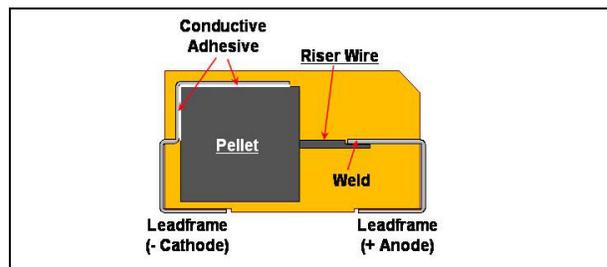


Figure 4. Smaller case has lower volumetric efficiency.

The solid electrolytic capacitors have always been the most volumetrically efficient capacitors available, with large gaps separating competing technologies. With the extended growth of capacitance capabilities with multi-layer ceramic (MLC) capacitors, that differentiation is being challenged. The standard leadframe assembly

needs to be changed to eliminate the inactive volume and increase volumetric efficiency.

The Facedown Termination

This device still needs the plastic packaging to create the mechanically robust and dimensionally consistent structure for surface mount applications. The problem is the positioning of the leadframe. Consider the drawing of Figure 5. In this cross sectional view, the leadframe is replaced with a “Terminal Plate” because there are no free vertical or horizontal elements on this plate. It may be of the exact same material and structure as the leadframe, but all extraneous elements of the leadframe have been removed – it may be confusing to be referred to as a leadframe without these free vertical or horizontal elements.

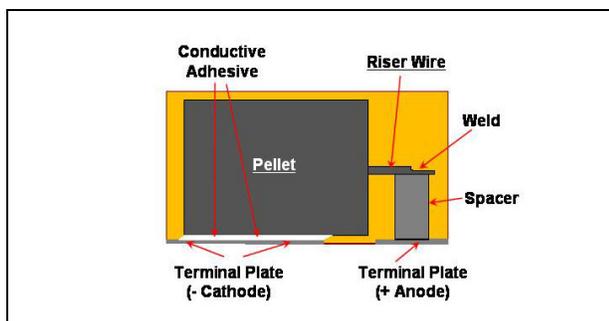


Figure 5. Cross-sectional view of facedown device.

The serpentine connection from the bottom of the chip, up to the midway point in the plastic, followed by an entry into the plastic, and vertical span to the top of the pellet has been removed from the cathode contact. The terminal plate is attached to the bottom of the pellet through a conductive adhesive, and the wall margins along the sides and top faces of the pellet are minimized, as they contain no additional allowance for the leadframe thickness or attachment. The riser wire is in contact with a spacer that extends the electrical connection of the anode down to the terminal plate along the bottom of the chip. The solder attach for this device is along the bottom surface of the terminal plates to solder pads on the surface of the PCB that are mirrored dimension of the terminal plates.

Figure 6 illustrates the improvements in volumetric efficiency of this design for the smaller capacitor cases. From left to right, the alpha case code designations are “R(or P),S,T,A and B” or the metric EIA designations shown (LLWW-HH in mm x 10). The initial offering for the facedown package is for the “T,” or the 3528-12 case (3.5 mm length x 2.8 mm width x 1.2 mm height). The volumetric efficiency doubles by moving the design from the standard construction to the facedown package. The initial offering for the facedown capacitor is of the

conductive-polymer structure; but, because of this pure capacitance increase, these packages will be expanded to include the tantalum-MnO₂ product offerings, where the ESR is a minor concerns but bulk capacitance is a major concern.

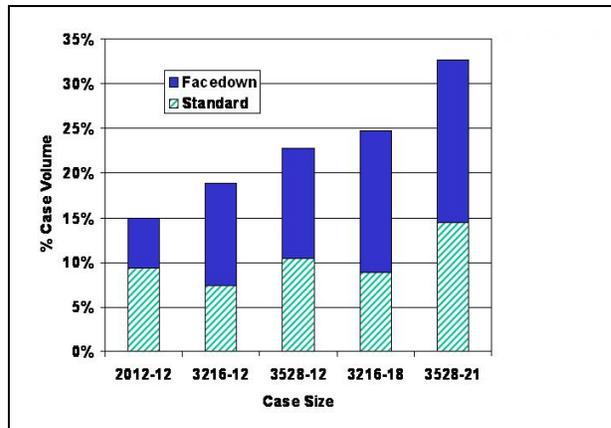


Figure 6. Chart of efficiency versus case size and facedown versus standard leadframe.

Secondary Benefits

The increase in volumetric efficiency and low profile has demanded that we pursue this package for applications demanding smaller packaging, yet with still higher capacitance requirements. This package geometry reveals additional benefits. With the elimination of the extraneous leadframe, the current and thermal paths are reduced (Figure 7). The reduced current paths will include a reduction in ESR and ESL, while the reduced thermal paths will allow for higher thermal transfers (power dissipation) out of the package.

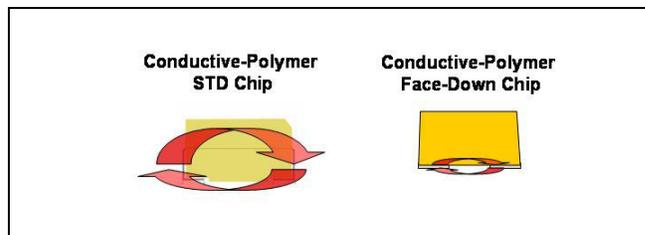


Figure 7. Reduced current loops achieved with facedown terminations.

The ESL of any device can be viewed as a current path constrained over a prescribed duration. It is directly proportional to duration (length) and inversely proportional to constraint (width and thickness or cross-sectional area). If the current loop for this package is compared to the standard package, the difference is readily apparent. The standard package forces the current duration through vertical elements of the leadframe that are actually beyond the extreme edges outside the plastic package. At the mid height layer, the leadframe

then must penetrate into the plastic package to the points of anode and cathode contact to the riser wire and pellet. Joining the entry and exit points of current flow together reveals a current loop with substantial area – defining the large ESL for the standard package.^[2]

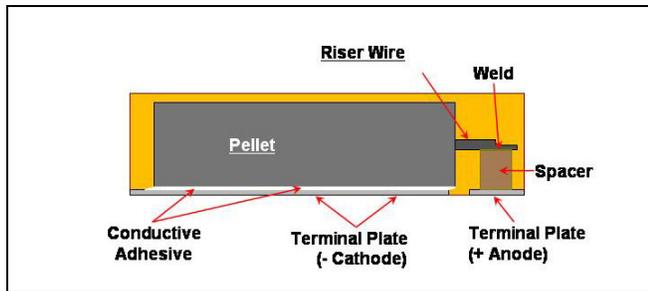


Figure 8. Low-profile device optimizes smaller current loop.

For the facedown package, the loop is reduced to the very small area involving the inner path from cathode plate, to pellet, to riser wire, then spacer and finally the anode plate (Figure 8). Reductions greater than 50% in ESL from the standard to facedown package are typical.

Optimizing ESL

This reduction can be optimized further still. Again, the initial offerings were targeted for the smaller case devices and concentrated on increased volumetric efficiencies. Typically, these smaller devices have ESR values that are many times greater than the larger packages, and decreases in ESL may be obscured by the higher ESR related to these devices. As these were envisioned as alternative designs with higher capacitive volumetric efficiencies, they were designed to fit the existing solder pad geometries for the same case sizes of the standard leadframe packaging. In order to optimize the ESL still further, the gap between the anode and cathode terminal plates needs to be minimized as this gap may define the width of the loop area. The height of the riser wire needs to be reduced as this may define the height of the loop area. In order to allow this improvement in ESL to be utilized by the circuit, the ESR must also be minimized as achieved with the larger, low-profile capacitors.

There is a device already on the market that utilizes these optimizations: the Sanyo TPL Series.^[3] This de-

vice is in a 7343 footprint, with the gap between cathode and anode terminal plates set at 1.1 mm.. The gap for the standard 7343 package utilizing the standard leadframe is 3.8 mm. (Remember that the leadframe forces the current loops well beyond the gap and actually beyond the extremes of this package). We targeted the full ESL optimization on this device without the constraints afforded by the standard solder pad designs. We can already achieve between 220-uF and 560-uF capacitance, with ESRs below 9 milliohms, in packages with heights below 2.0 mm. The ESL for the standard leadframe package in this case size is around 1.8 nH. With the low impedance created with these capacitance and ESR levels, the impact of the reduced ESL should be very distinguishable.

A three-plane drawing of the device is shown in Figure 9. Our low-profile 7343 facedown has a height of 1.7 mm maximum (7343FD-Z) and unlike the Sanyo offering, there are two terminal plates instead of three. The pellet is bonded, electrically and mechanically, to the cathode terminal plate using a conductive epoxy. The anode terminal plate is connected to the riser wire through a spacer element. The small gap between anode and cathode terminal plates, the small vertical travel through the thin pellet and spacer create a very small loop area in this device. Recorded ESL measurements of approximately 500 pH are consistent with this design.

The recommended number of solder pads for this device is three – one anode contact and two cathode contacts as shown in Figure 10. This split cathode pad is necessary because of the effects that one small anode pad and one very large cathode pad would have on the soldered component. Consider that a large amount of solder applied to the one large pad may create enough constraining horizontal tension during solder reflow that it could vertically lift the chip, well above the solder pad. This action could lead to an equal lift of the anode terminal above its solder pad and, being of little solder volume, could result in a contact break or “open circuit” condition.

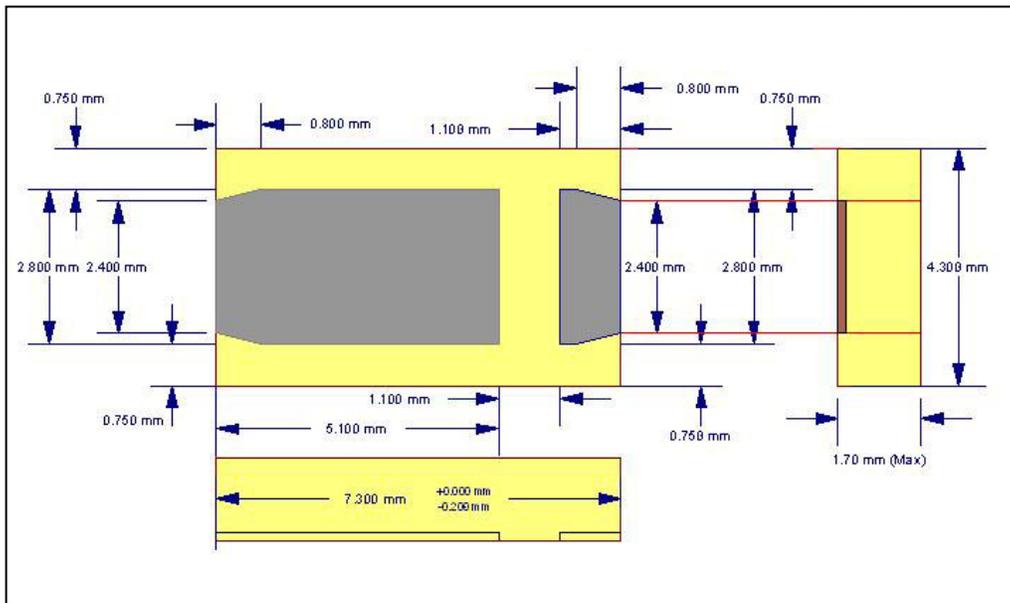


Figure 9. Optimized 7343-17 facedown terminations (~500 pH inductance).

By splitting the cathode contact into two smaller plates, the solder mass is reduced, thereby eliminating any lift mechanism created with one large cathode contact.

The benefits of reduced thermal paths will allow for higher power dissipation in these devices, but testing is still in progress, which will establish that capability.

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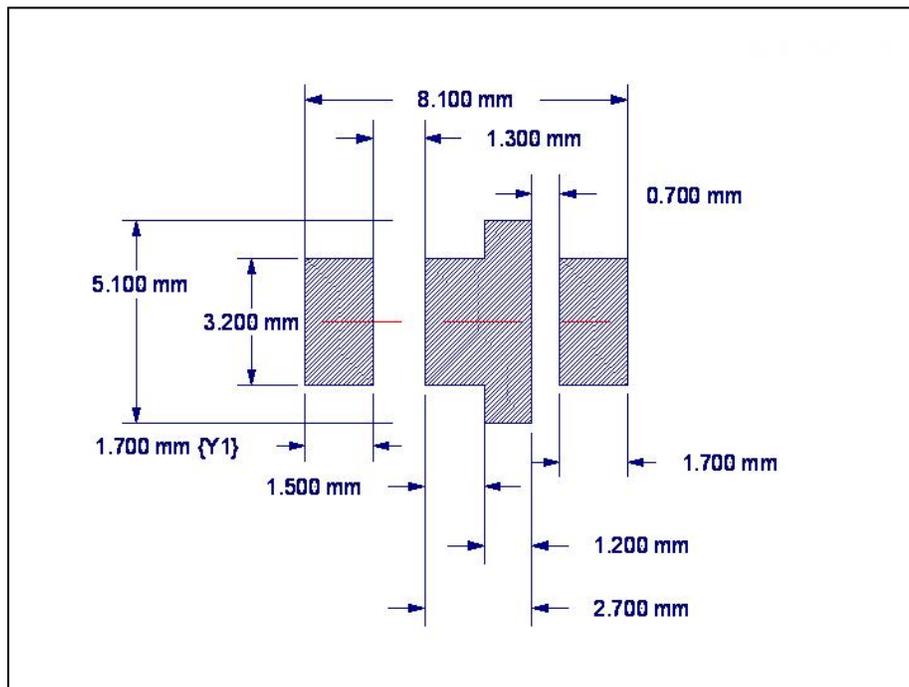


Figure 10. Solder pads (3) required for 7343-17FD device.