Tantalum Capacitors Bring Micro-Miniaturisation to Electronic Devices

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Abstract
The trend toward portable electronics is a major driving force in the need for miniaturisation of electronic components. This must be achieved without loss of performance and reliability. Indeed the transition from the home and office environment to the outside world subjects these devices to a much greater level of stress. These stresses are not just in the mechanical shock, bump and vibration arena but also operational and storage temperature-humidity range and rapid temperature-humidity changes. For this reason tantalum capacitors are becoming once again a product of first choice where high electrical and mechanical stability along with long service life and volumetric efficiency are demanded. Until recently tantalum devices in the 0603 and 0402 form factor were rare and provided little in the way of capacitance and voltage range. The latest generation of ultra-high surface area tantalum powders in combination with a super efficient constructional and encapsulation system provides a new solution to many old problems.

Introduction

As integrated circuit technology has advanced, its developers have incorporated the aim of lessening their customers' reliance on passive components. This has had the effect of diminishing the demand for passives in certain areas. However, as the deployment of electronics has grown enormously, and passives are still a vital element of so many designs, the net effect has been a growth in their use. Perhaps the most dramatic discontinuity in the way passives are manufactured and used occurred with the emergence of surface mount technology. Twenty years ago, the move to surface mount was gathering momentum, a transition that really gained traction with the growth of the portable electronics market. The adoption of surface mount processes placed capacitor manufacturers under pressure to develop new materials and forms of device construction. One challenge was the need to equip parts to withstand high temperatures of soldering, a task made further more difficult with the need for lead-free assemblies. The magnitude of the task varied with the type of device and the component materials chosen. Tantalum and ceramic devices have made the transition easily but there were more headaches to resolve with other devices. For example, products based on the use of the use of plastic-film dielectrics often had to completely revised, often with the development of new materials. 'Wet' aluminium foil materials were particularly difficult to match with surface-mount processes and remain problematic today.

The rise of the portable appliance changed the baseline reliability requirements for all kinds of components. It created a need for parts with levels of mechanical robustness against shock, longevity and temperature-withstand previously familiar only to developers in the military or ‘hi-rel’ arenas. At the same time, these parts had to adapt to fit product developers aspirations for small, light and inexpensive systems.

Engineers have been able to radically alter their reliability expectations for passives in the past 20 years. While back then it was standard practice to express capacitor product failures in terms of ‘acceptable levels of failure’ and percentage values, nowadays, failures are framed in ‘parts per billion’ terms.

Material Advances

Materials advances have offered improvements with respect to many aspects of capacitor performance. In the portable arena, a key priority is volumetric efficiency (the amount of capacitance that can be provided in a given volume), which is often addressed most effectively with tantalum parts. This property is frequently quantified in terms of ‘CV’ values (where C and V are the capacitance and voltage). Since the mid-80’s, manufactured tantalum powders has exhibited around a ten-fold improvement in CV/gm values (from approximately 15k to 150k). This has permitted the level of capacitance available within a standard case to be increased accordingly. See below figure 1.

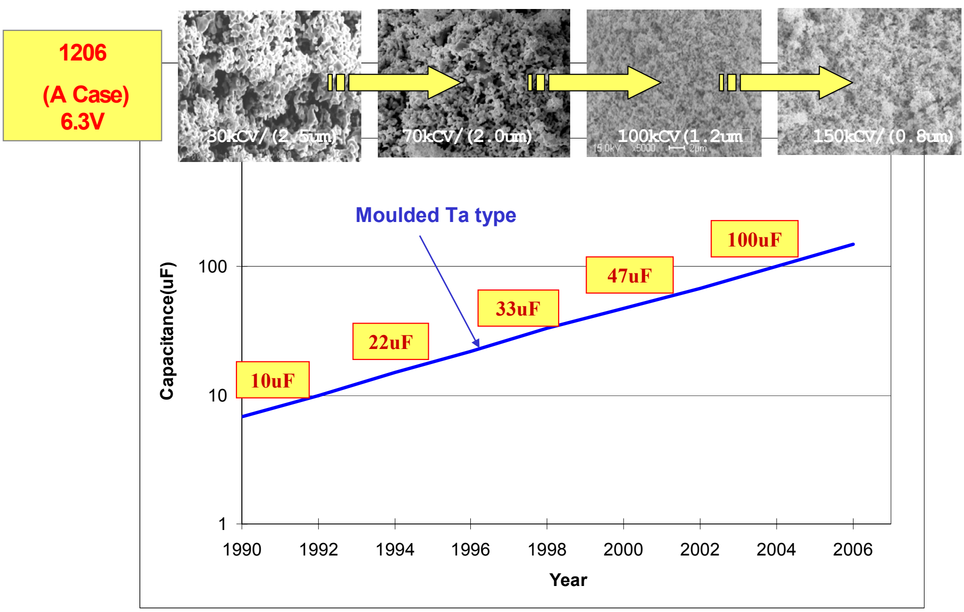


Fig.1. Time evolution of A (1206) case10μF 6.3V to 100μF 6.3V.

Apart from its ability to allow higher levels of capacitance to be achieved within a case size it also can be used to provide a similar level of capacitance in a smaller package, called ‘downsizing’. See figure 2. An additional benefit was the ability for component count reduction programmes since the available capacitance that could only be achieved previously by putting multiple capacitors in parallel and was now available in a single part. This saved PCB space and improved overall system reliability not to mention cost savings.

The ability of tantalum capacitor makers to utilise the very highest CV/gm powders has also been given a boost by the general lowering of power voltage rails over the years. As the power line voltages have dropped from 5v to 3.3v and even lower than 1.5v it has been possible for powders in excess of 150,000 CV/gm to become useful.

Customers have also taken advantage in the improving reliability of tantalum capacitors to reduce the need for a minimum of 50% voltage derating (e.g. a 10v capacitor on a 5v power rail) and it is now common for circuits of high impedance to run tantalum capacitors up to 80% of their rated voltage [1].

These super high CV powders could also be better utilised in commercial mobile electronic circuits where high operational temperatures were not required in the development and release of super high volumetric efficiency series.

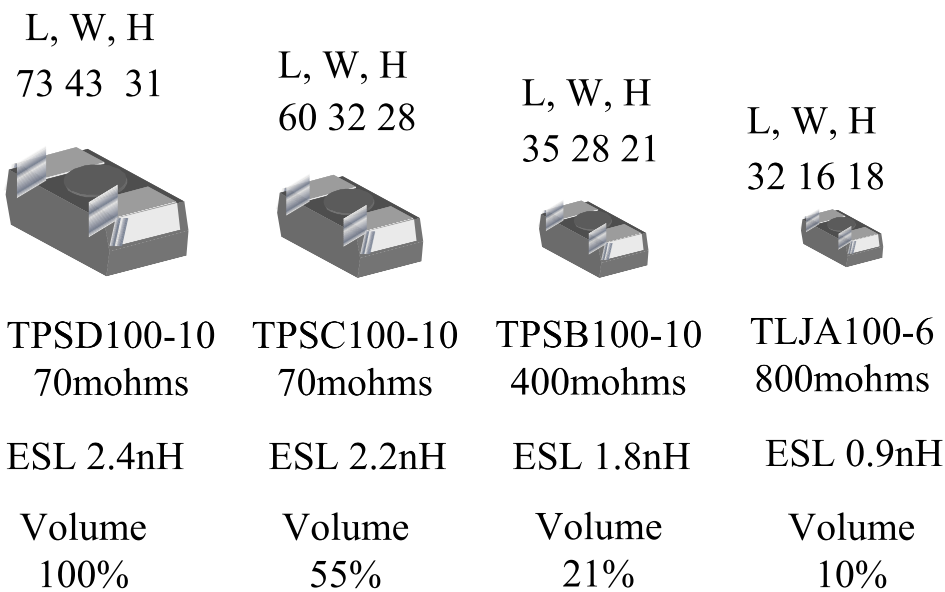


Fig.2. Case size evolution or ‘downsizing’ from D case to A case.

One unfortunate trait of tantalum capacitors is their tendency to give rise to proportionately higher levels of Equivalent Series Resistance (ESR) values with each successive generation of 'downsized' device geometry. This may be a cause for concern with high-frequency digital circuitry. One way to avoid this ESR increase is to use a capacitor based on a conductive polymer cathode. It is 10 to 100 times more conductive than the manganese dioxide it replaces, resulting in lower ESR. This has become a commercially-viable manufacturing process in recent years (albeit one that is more expensive than that used for conventional tantalums). See figure 3.

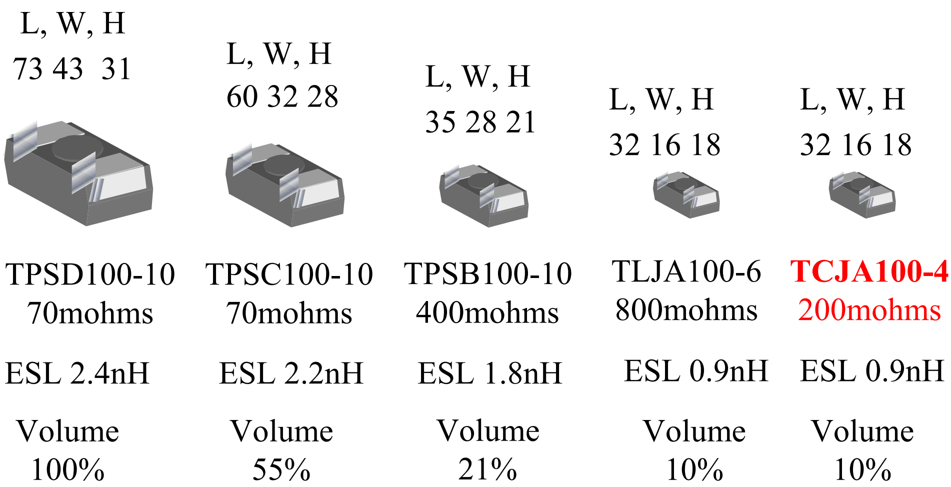


Fig.3. Impact of polymer on ESR of downsized parts

Another tantalum-substitute to have become commercially feasible in recent years is niobium oxide capacitors. These offer a number of advantages over tantalums, including a safer failure mechanism (failed tantalums can overheat), lower weight and a less expensive base material. Furthermore, they do not require the same degree of voltage derating to achieve high reliability in low impedance circuits. One commercially available product is the niobium oxide OxiCap™ range [2, 3]. Although a relatively new capacitor technology, it to can illustrate the rapid improvement in volumetric efficiencies called for by the industry users. See figure 4.

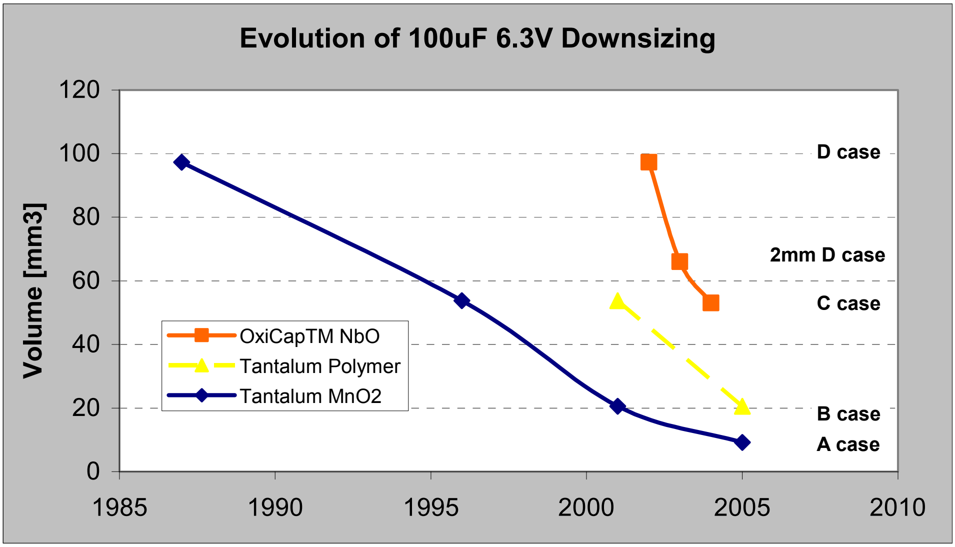


Fig.4. Downsizing trend for polymer, tantalum and niobium oxide technologies

Device Geometries

Alongside a requirement to squeeze in greater amounts of capacitance, application needs have required that capacitors support higher levels of current and signal integrity. The ability of the capacitor to support high-current and high-speed signals (as required in many modern digital systems) is often characterized by the values for ESR and Equivalent Series Inductance (ESL), respectively. These values should be low, ideally. A high value of ESL will tend to impede high-frequency signals while a high value of ESR will cause large power loss to be incurred when high-current signals are present.

Multilayer ceramic capacitors are often preferred for their low ESL and ESR values. Further improvements with this technology include the use of inter-digitated arrays, as for example the Inter-Digitated Capacitor (IDC) products, introduced in the late 1990's. With the IDC device design, the capacitor is connected with a series of vias to the power and ground planes, arranged in alternating (or inter-digitated) pattern. With this construction, the polarity of these elements is alternated, cancelling out any self generated inductance (which tends to impede the propagation of high frequency signals). Another way in which passive developers are supporting the goal of miniaturisation is with the employment of new packaging technologies borrowed from the IC arena. The use of the flip-chip is relatively new here, for example. AVX and IBM have worked together to develop flip-chip for the passives arena, as featured in the Low Inductance Capacitor Array (LICA™) device range.

One noticeable development since the 1980s has been the increasing closeness and interdependence of the worlds of passives and ICs. Their supply and demand needs have grown increasingly intertwined and they are being used in increasingly close proximity to each other on the PCB. For example, many IC packages provide developers with the opportunity to save board space by soldering the passives directly onto the top of the package, as opposed to congesting the surrounding PCB area. Similarly, it is becoming more common for passives to be mounted underneath ICs, on the PCB.

Fabrication processes from the semiconductor world have also been increasingly borrowed to support some of the most advanced capacitor designs. For example, in the smallest tantalum TACmicrochip™ range of capacitors the parts are handled on a tantalum substrate or wafer using diamond cutting wheels to 'singulate' devices to high levels of mechanical tolerance required for ever smaller devices. Its development was driven from analysis of the volumetric efficiency of the regular moulded tantalum body showing a very high degree of packing inefficiency. See figure 5.

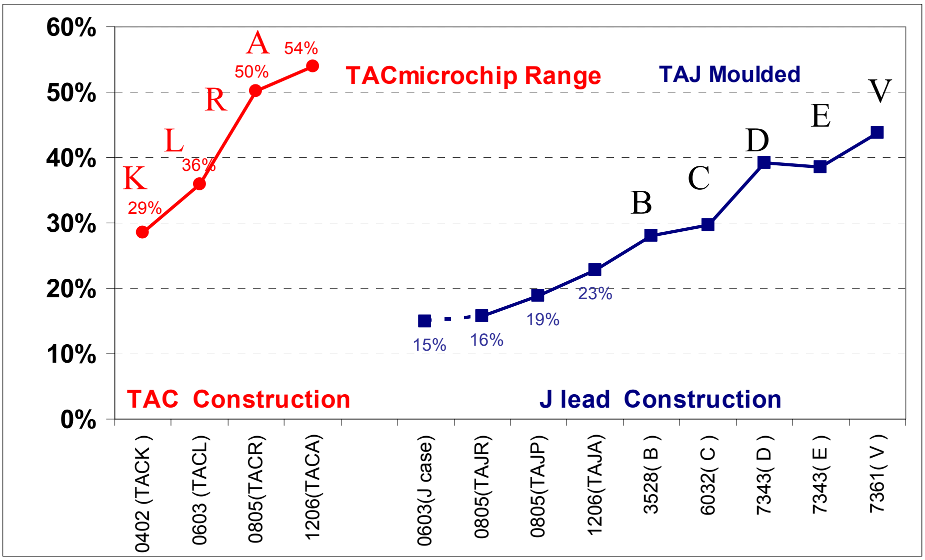


Fig.5. Packing efficiency moulded verses TACmicrochip.

In figure 6 we compare by cross sectional view the constructional styles of the conventional moulded 'J' leaded device with that of the TACmicrochip and the packing efficiency differences becomes clear.

In a conventional moulded 'J' lead type, the lead frame and anode positioning within the package is extremely critical in order to prevent 'show through' (where the anode body is exposed through the case). Manufacturing tolerances are more exacting and this can lead to production difficulties and will limit the size of the anode that can be accommodated and still generate a high yielding cost effective product. These issues become progressively worse as the case size becomes smaller. In the case of the TACmicrochip instead of the conventional tantalum wire to each capacitor anode body, a matrix of anodes is pressed onto a tantalum wafer – see figure 7.This acts as a common carrier throughout the processing stages and subsequently becomes part of the capacitors external termination system and the exact tolerances required maintained.

The resultant internal construction is simple and possesses very low parasitic electrical losses (ESL) and in addition eliminates several of the 'space consuming' elements such as the anode wire, lead frame and need for larger wall thicknesses. This wafer approach to manufacturing has also allowed even smaller devices to be made a commercial reality such as the 0402 size and further due its high degree of manufacturing flexibility customisable heights. The U case is an example of a custom product that creates high capacitance for an extreme height constrained application. A good example of this is 10µF in a 0805 format with just a 0402 height of 0.6mm.

Constructional Comparison (0603)

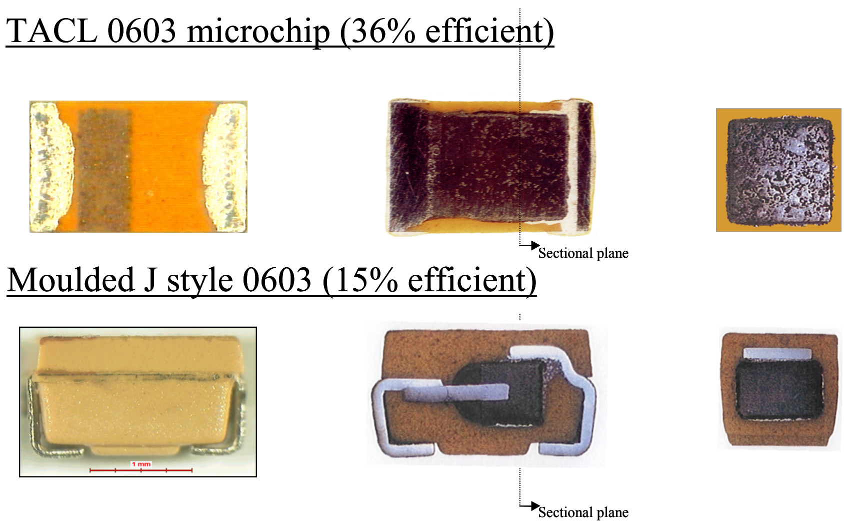


Fig.6. Packing efficiency moulded verses TACmicrochip.

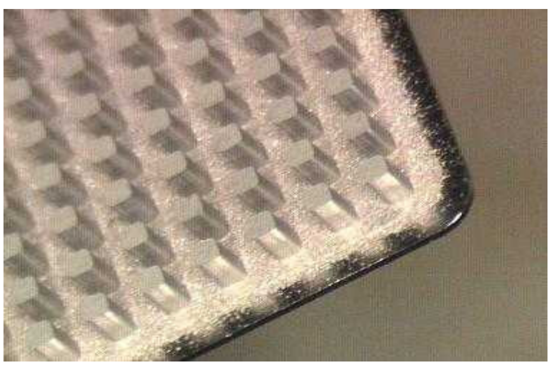


Fig.7. Wafer based tantalum anode carrier system

Capacitor Formats

As can be seen in figures 5 and 6 the volumetric efficiency worsens considerably as the case size reduces and a great deal of time and attention has been paid by the capacitor manufactures to maximise the volume occupied by useful tantalum powder whilst minimising the volume taken by encapasulant and terminations. It must always be borne in mind that it is the board space and height occupied by the capacitor once mounted on the board that has to be considered and not purely the component size itself. Thus the ability of the capacitor to be mounted onto the smallest pads or pads that do not extend far beyond the capacitor footprint is also a very important feature. In the case of such 'five-sided' termination product as in the example of MLCC and TACmicrochip this provides a very high degree of flexibility in choosing the actual PCB pads that the part can be accommodated onto and hence larger opportunities to save valuable real estate. Equally, the more defined the product in dimensional tolerances the closer such products may be mounted adjacent to themselves and other parts on the board. It is in this area that the 'conformal coated' tantalum style can be prone to problems associated with an irregular shape and to date no supplier have ventured smaller than 0805 or below 1mm height.

Once mounted consideration also has to be given to the flexure of the PCB. The degree of board flexure has increased as the PCB boards themselves have become thinner, another requirement for portable electronics. The need for portable electronics to survive multiple drops onto concrete floors from heights of 1 to 2 metres is well established and is representative of actual use conditions. The older style of conventional moulded tantalum capacitor handled this very well in having compliant 'J' lead terminations. The newer style capacitor formats now are more directly mechanically connected and must have a 'flexible' termination system to prevent such board flexure or twist from causing mechanical and electrical damage.

This was developed within the TACmicrochip as flexible silver glue that permitted high degrees of bend without transfer of stress to the capacitor anode body. A similar conductive polymeric contact layer within the capacitor termination system has also been adopted by MLCC Flexiterm™ product which is ideally suited to locations and applications where high degrees of bending may occur such as automotive and consumer electronics [5].

One unintended consequence of the development of MLCC technology toward very high CV (reduced dielectric thickness) has been the immergence of 'piezo' or 'microphonic' noise. This is where the passive capacitor acts as an active device and can actually generate electrical signals as a result of board bending or the part causing the board to vibrate as a result of electrical excitation. It has even been noticed that multiple MLCC parts on boards can actually 'chatter' amongst themselves. Clearly, not a desirable feature. This phenomenon does not occur within tantalum and niobium oxide capacitor technology [4].

A clear development trend that continues is the need for ever smaller standard case sizes. Twenty years ago the smallest commercially available tantalum capacitor was the A case (1206). In the preceding years AVX was the first to develop and bring to commercialisation of the R (TAJR 0805), the L (TACL 0603) and in recent years the worlds only K case (TACK 0402) which in combination with the newly available tantalum powders provided huge improvements in volumetric efficiency and downsizing opportunities.

Low Profile Products

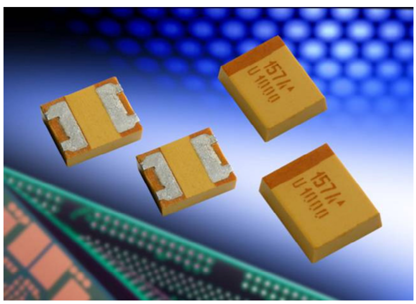
One very key trend driven exclusively by IC technology is the maximum height that is acceptable for passive components. Thinner smaller end-products with increasing functionality, intense focus on time-to-market and cost pressures are the background to the development trend for ICs and ultimately drive the requirements for passives. Whilst integration of functions will ultimately reduce the need for passives the time necessary to provide these complex application-specific solutions is still sufficiently long that a solution utilising numerous individual discrete passive components remains. Package proliferation continues at a pace but with a common constraint – height. Early low profile series of tantalum capacitors were defined as less than 1.2mm driven by CABGA (Chip Array BGA) devices which are now giving way to requirements of less than 1mm driven by VFBGA (Very-thin fine pitch BGA) and now less than 0.8mm for WFBGA (Very very thin fine pitch BGA) packages with UFBGA (Ultra-thin fine pitch) at less than 0.65mm finding favour. This has driven the development of a new series of conventional moulded tantalum capacitors and spurred the introduction of new styles and reformatting of older ones. One forecast for the reducing height is provided by IMAPS in figure 8 below.

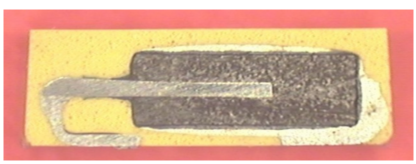
Forecast	Time - year	1997	1999	2001	2003	2006	2009	2012
Schedule	IC technology	250nm	180nm	150nm	130nm	100nm	70nm	50nm
Package [mm]		0.8 - 2	0.5 - 1.5	0.5 - 1.5	0.5 - 1.2	0.5 - 1.2	0.5 - 1.0	0.5

Source: IMAPS

Fig.8. Forecast Trend of Integrated Circuit Height over time

Another approach to improving the packaging efficiency and reducing the foot print area required for mounting is shown in the recent development whereby the 'J' leads are replaced by terminations that do not protrude outside of the outline of the case. This saves internal construction space by up to 50% but also permits the PCB pads to be little more than the outside dimensions of the part. This also allows for a very close packing of similar parts. One such approach in device construction and physical appearance is shown in figures 9a and 9b.





Figs.9a and 9b. Low Profile High Volumetric Efficiency Construction

Placement and Assembly issues with microminiaturised sizes.
The conventional 'J' lead type format works extremely successfully on 0805 and with careful control of the lead shape and co-planarity the 0603 can avoid the earlier issues of 'tombstoning'. This is also true of the 5 faced termination system adopted by MLCC and TACmicrochip. The new construction format shown in figures 9a and 9b does have the disadvantage that the solder joints are almost entirely beneath the part and can not be easily assessed. This is however an increasingly common approach in integrated circuits and should not preclude its adoption.

One area of weakness that can exist in these constructions is that the terminations now have little flexibility or compliance. As in the case of MLCC parts the active internal elements are mechanically connected to the PCB and board flexure can unless appropriate design considerations made, cause internal damage to the capacitor element. The differences in construction and level of volume occupied by the tantalum anode in each style of the three different capacitor formats are shown in figure 10 through X ray pictures.

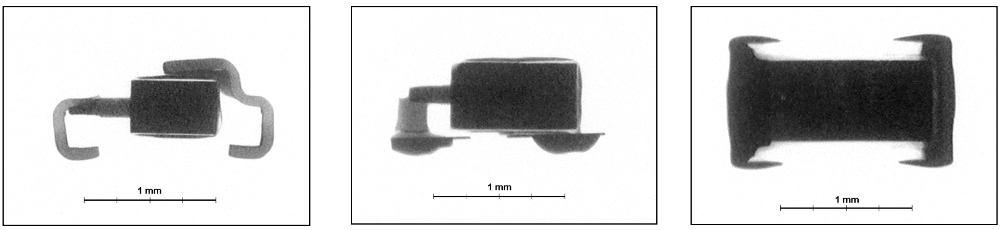


Fig.10. X ray comparison of 'J' lead, Face Down and TACmicrochip constructions

Improvements in volumetric efficiency
We have seen that with the improvements and adoption of alternate material and constructional approaches tantalum capacitors have dramatically improved their volumetric efficiency. It is also possible to forecast future likely improvements and these are displayed in figure 11.

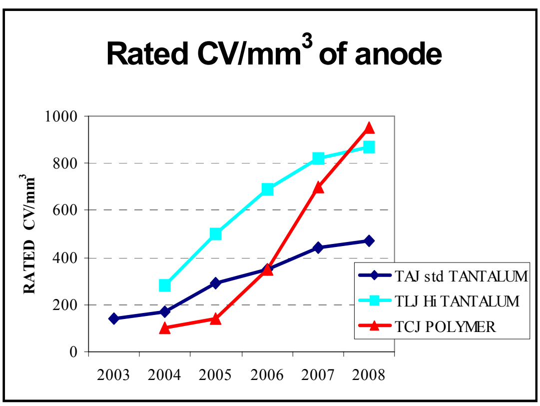


Fig.11. Road Map of Volumetric Efficiency over

Usage Trends in Applications

The relative insensitivity to capacitance change over a wide range of temperatures, time and applied voltages make them ideal candidates for portable electronics and when combined with these new formats providing high capacitance in very small devices make them ideal as a 'fit and forget' solution in many applications [4]. Such an application is in audio circuits in MP3 players where the provision of high capacitance over the audio spectrum produces a discernable superior audio fidelity and thus is a very attractive feature having merit over competing technologies. Another is the elimination of 'piezo noise' as described earlier as tantalum and niobium oxide technology does not suffer from this phenomenon. Since many of these consumer applications rely on battery power and Lithium Ion cells then suitable design and test criteria can be applied to enable these components to be used with high levels of performance for their size and weight. One such example is the need for 150µF 10v in as small a package as possible. The trend in product size and now increasingly important height can be seen in figure 12.

The reduction in the level of capacitance required from 220 to 150µF also reflects improvements made in reducing the demand for power by the IC's makers. Lower power consumption equates to long service life on a single charge which is an important consideration for portable devices.

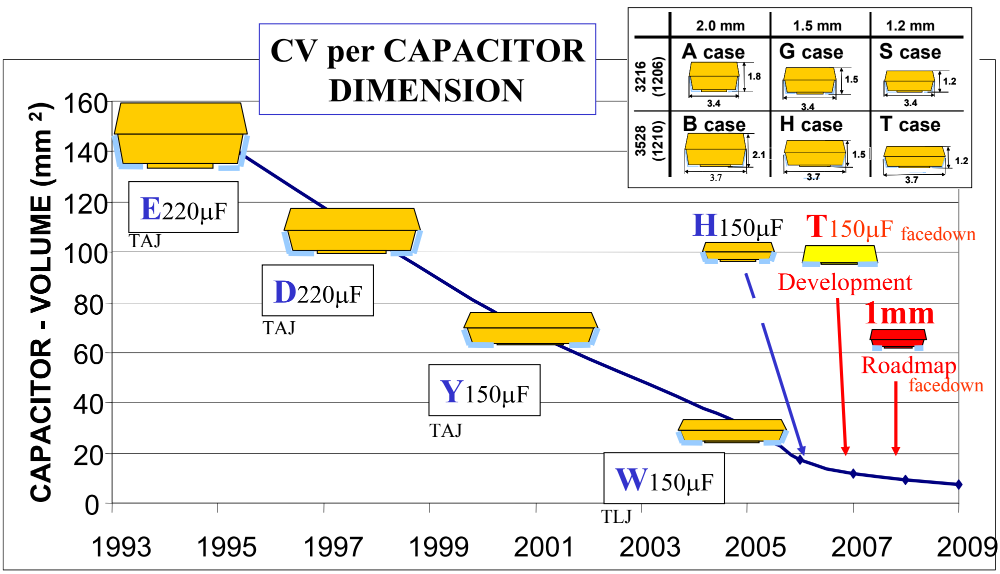


Fig.12. Power line solution trend over time.

Summary

With the continuing development of higher CV MLCC types of capacitors, new challenges face the tantalum capacitor makers to maintain their volumetric and performance advantages but in smaller and lower profile cases. The general trend in reduction in rail voltages and demands from portable electronic devices provides opportunities whereby a new range of alternate material and constructions have delivered major new advances. In addition, the trend towards use of ever thinner IC packages below 1mm, passive components will be required to follow the same trend.

From today's range of competitive capacitor technologies available in miniaturised form, the wafer based tantalum capacitor approach is still well placed to adapt to these particular market needs. It maintains the highest level of volumetric efficiency as case sizes and heights reduce whilst retaining user friendly assembly and mounting features needed for reliability and long service lives in the a portable world.

Acknowledgment

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