TECHNICAL PAPER

Smallest and Lowest Profile Tantalum Capacitors

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Abstract:
Tantalum capacitor technology has been recognized for its parametric stability and long term reliability in the most demanding of applications. Unlike some other capacitor technologies, tantalum capacitors do not exhibit significant capacitance change over time and voltage. The other benefit is that due to its mechanical strength it is possible to manufacture flat & thin designs, so why these type of capacitors are the best fit for tasks such as "can you make higher capacitance in the lowest profile? " The paper provides an overview of such tantalum capacitors suitable for most demanding sub millimeter size and low profile capacitors down to 0201 and sub 0.6mm max height.

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 an overall 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. Thirty 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.

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.

Miniaturization is a necessary step forward to increase functionality of the portable consumer systems while this process has to be also economically affordable to move from niche applications to mass production. Despite on-chip integration of many components and advanced circuit configuration the passive discrete components are still occupying majority of board space looking at the recent PCB designs. One of the focus technologies is the embedding of the discrete components into the PCB. A typical thickness of a PCB is 0.8mm, while leaving some space for encapsulation the maximum thickness of a discrete embedded component is 0.5 to 0.6mm depending to embedding technology type. This is a maximum allowable height of components across all PCB layers, if a one single PCB layer is considered than ideal component height is down to 0.15mm.

MLCC capacitors have already been developed and used with miniature 0201 and even 01005 sizes while the smallest tantalum capacitors available on today's market are in 0402 size with maximum height of 0.6-0.7mm. This might be a sufficient to consider for embedding technology nevertheless it does not fully utilize yet the potential benefit of tantalum capacitors – manufacture reliable, mechanically robust thin & flat capacitor. MLCC can be considered as leader in miniaturization of capacitors nevertheless if the design task is to provide maximum capacitance within thin profile such as 0.6mm regardless of footprint - tantalum technology has a potential to provide highest capacitance in large footprint compare to MLCC devices – thus ideal for embedded technology.

MATERIAL AND PROCESS ADVANCES OF SUBMINIATURE TANTALUM CAPACITORS

<u>Low Profile Product Needs</u>

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 utilizing 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 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. Height reduction trend table is provided by IMAPS in figure 1 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.1. Integrated Circuit Height Reduction Trend

MATERIAL ADVANCES

Material 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 more than a ten-fold improvement in CV/gm values (from approximately 15k to 200k). This has permitted the level of capacitance available within a standard case to be increased accordingly.

The ability of tantalum capacitor makers to utilize 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 200,000 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 utilized in commercial mobile electronic circuits where high operational temperatures were not required in the development and release of super high volumetric efficiency series.

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 2.

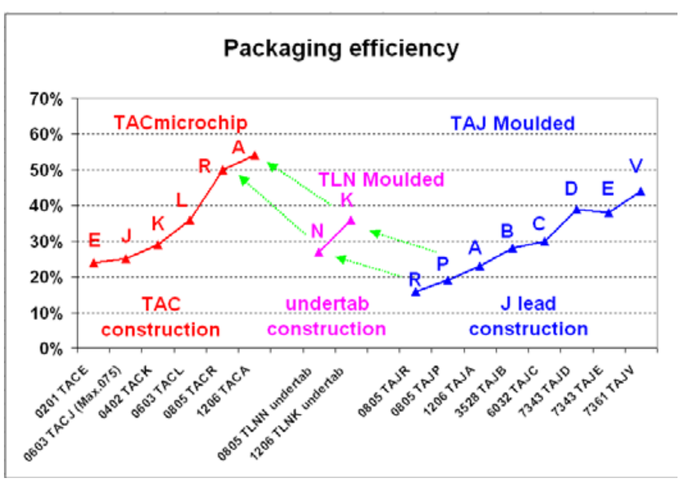

Fig.2. Packing efficiency moulded verses TACmicrochip®.

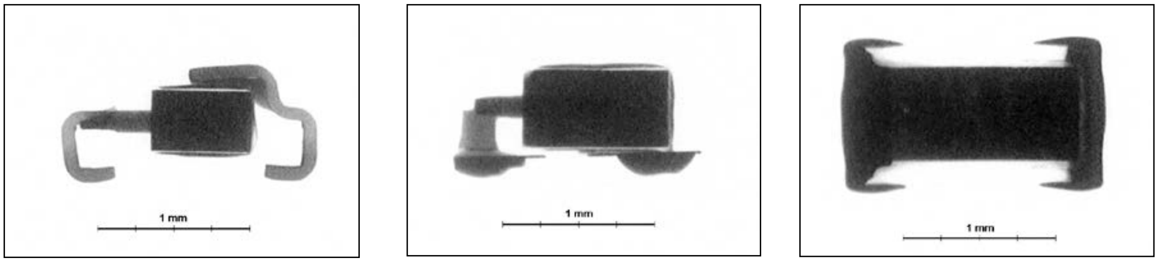

Fig.3. X ray comparison of 'J' lead, Face Down and TACmicrochip® constructions

In figure 3 and 4 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) for cosmetic reasons. 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 2.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 due to its high degree of manufacturing flexibility customizable heights. A good example of this is 10µF 6.3V capacitor in a 0805 format with just a 0402 height of 0.6mm.

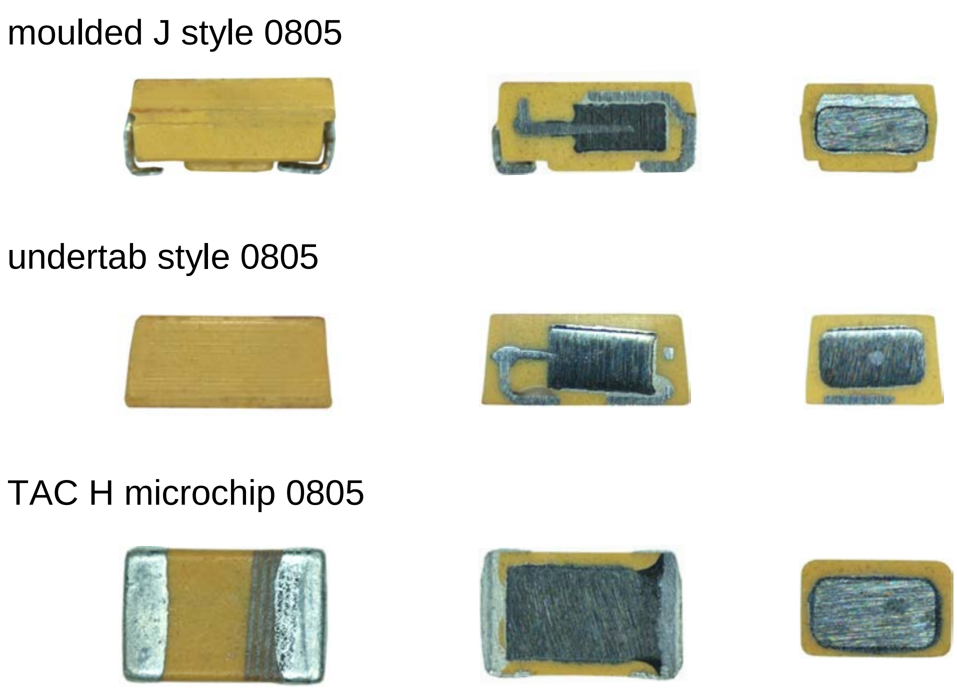

Fig.4. Packing efficiency moulded J style, undertab and TACmicrochip®.

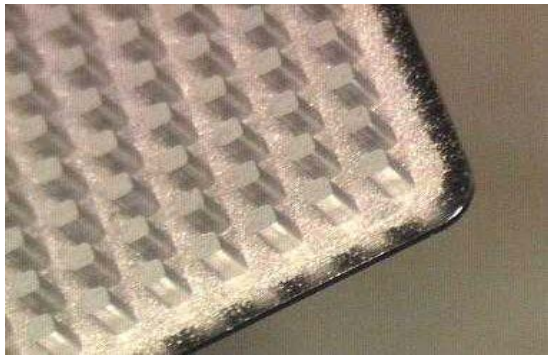

Fig.5. Wafer based tantalum anode carrier system

CAPACITOR FORMATS

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 meters 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 [4].

One of the negative features of BaTiO dielectric used by 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 [3].

A clear development trend that continues is the need for ever smaller standard case sizes. Thirty 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 commercialization of the R (TAJR 0805), the L (TACL 0603) and 0402 K case (TACK 0402) in 2005. With the development of the manufacturing processes and technology shown in this paper AVX has successfully demonstrated its capability to manufacture the next step in miniaturization – the world smallest 0201 capacitor.

DEVELOPMENT OF THE WORLD SMALLEST 0201 TANTALUM CAPACITOR

AVX has developed the world smallest tantalum capacitors starting with a 0805, 0603 then a 0402 in 2005 and the technology advancements allowed demonstrating manufacturing capability to produce the next level in miniaturization – 0201 tantalum capacitor (TACmicrochip® case size “E”).

The internal 0201 parts structure follows conventional TAC design. Focus is to utilize maximum volume efficiency together with effort to get max anode CV/g. Conventional tantalum substrate thickness widely used for TAC series is 0.010". This wafer thickness is unacceptable for 0201 dimensions and it presence a crucial challenge for further miniaturization. The thinner wafer and leadframe materials will allow to increase anode length so higher anode volumetric efficiency is also achievable.

Another key area is to increase tantalum powder CV/g and minimize capacitance loss during manganese dioxide based cathode creating. Newly developed anode pellets pressing, sintering and manganising techniques allows to use very high CV/g tantalum powders (>200kCV/g) and it allows to utilize maximum tantalum pentoxide dielectric surface. All those procedures provide enhanced capacitance/leakage performance. The first trials confirm the expectations to achieve above 20% of active volume within the 0201 case size that corresponds to about 0.47uF 6.3V tantalum capacitor.

A next 0201 development challenge is related to a mechanical handling during assembly. Completely new assembly techniques processes and manufacturing jigs / equipments are to be introduced. Basic principles are already known from MLCC manufacturing practice, but it has to be adjusted for tantalum TAC series specifics.

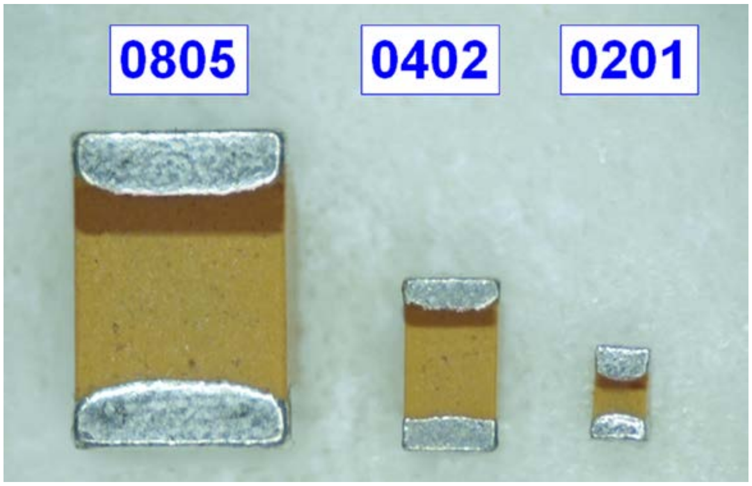

Fig.6. TACmicrochip® tantalum case size comparison

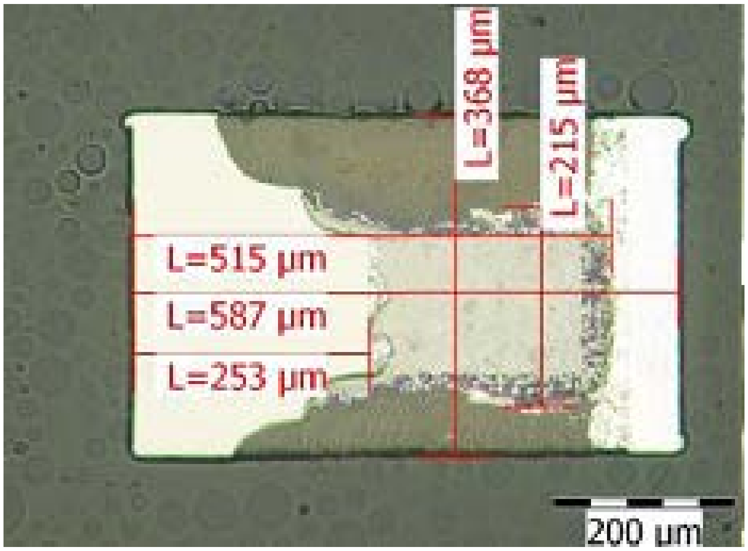

Fig.7. cross section through 0201 TACmicrochip® tantalum capacitor

Fig 6 is showing relative case size comparison of 0201, 0402 and 0805 case sizes and Fig 7. cross section through 0201 TACmicrochip® capacitors. The outer 0201 case dimension are just 0.6±0.12mm in length, and 0.3±0.06mm in width and height.

Electrically stable capacitance and ESR of TAC E 0.33µF 6.3V have been measured on ten units as shown below on Fig.8. Capacitance tolerance is within +/- 20% and ESR at 100kHz is about 35Ohms which is an expected value for such small capacitor.

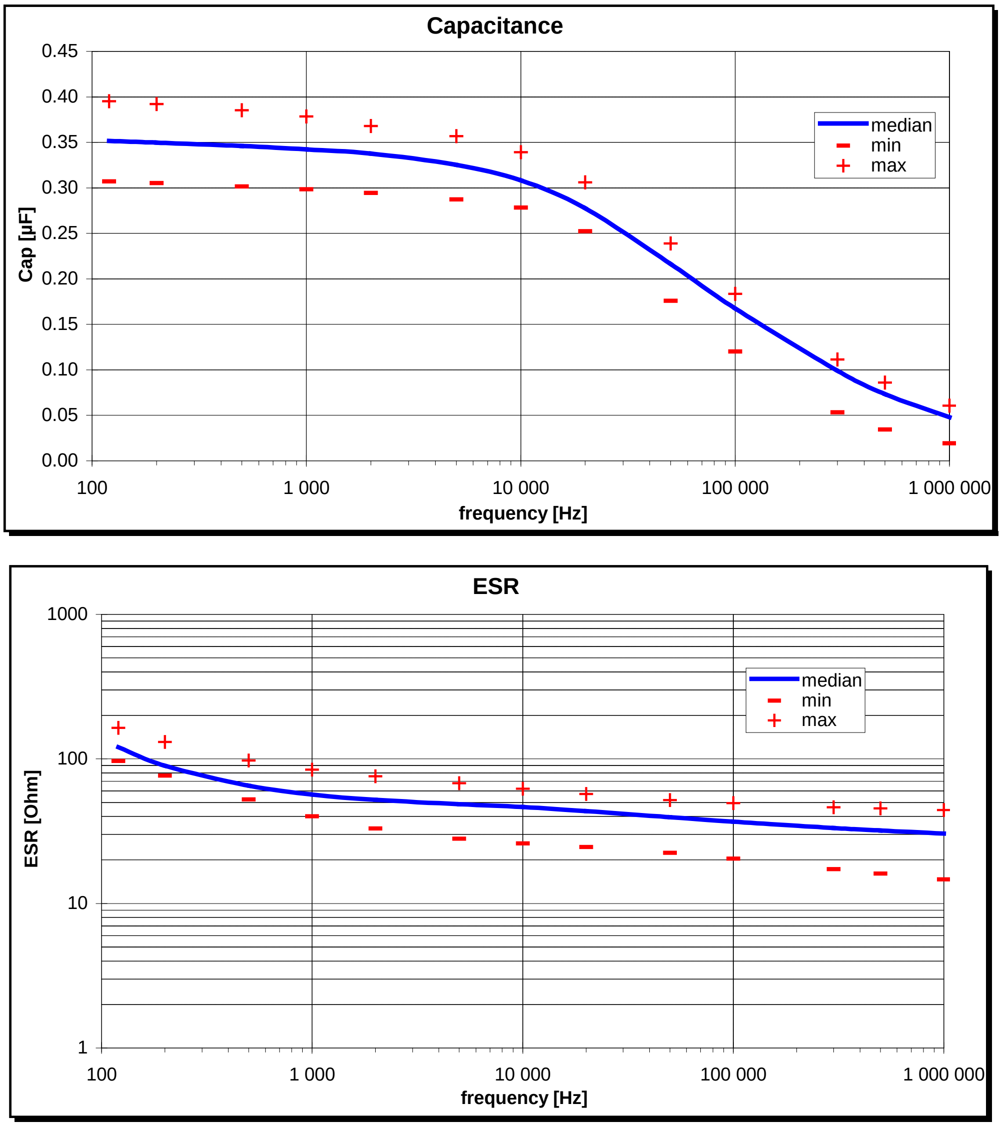

Fig.8. Capacitance and ESR with frequency of 0201 TAC E 0.33µF 6.3V (10 units)

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. Such an application is a power amplifier module of portable cellular phones.

Another positive feature versus HiCV MLCC capacitors is the elimination of ‘piezo noise’ as tantalum and niobium oxide technology does not suffer from this phenomenon [4]. The downsizing capability to 0201 together with the no-piezzo clear filtering and stability of parameters makes such small capacitors ideal choice for applications such as medical hearing aids.

0201 case size tantalum capacitor that has been demonstrated is indeed a suitable solution for embedding into a PCB and thus the way forward for further miniaturization and further expansion of the embedded technology to mass manufacturing technique.

The unique mechanical robustness capability of tantalum technology pose even much wider potential to prepare a sub 0.6mm height large capacitor in value of tenth micro farads that can be embedded into a PCB and used in applications such as electronic SIM card or a banking card that it can enable to memorize information or wireless communication.

SUMMARY & CONCLUSION

The data presented in this paper has demonstrated that based on the latest advancements and developments we can state that tantalum capacitor technology is ready to address the demands of the new challenging application needs – microminiaturization and embedding.

AVX has demonstrated and manufactured the World smallest 0201 tantalum capacitors with dimensions as small as 0.6x0.3x0.3mm. The expected “CV” that can fit into this package is on a level of 0.47µF 6.3V capacitors. This addition widens the component list ready for embedding technology by some unique features of tantalum capacitors. We are entering a new age in the way of parts are assembled. Embedding has already proved its potential for cost saving in some areas, and also has the ability to add new functionality and features to end devices. This is especially true in consumer electronics where smaller, higher function and more reliable products have emerged using the technology. It may still be some while - even a decade - before embedding technology will start to dominate the assembly processing. However manufactures’ attitudes are changing and moving towards acceptance of the technology, which will result in modifications within the supply chain such that ‘embedded-ready’ components are widely available.

The presented advancements in tantalum technology are also bringing capability to produce sub 0.6mm capacitor with large footprint and thus embed quite large capacitance values not achievable up to date.

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 miniaturized 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.

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