APLIKACIJSKI ČLANKI
APPLICATION ARTICLES

TANTALUM CAPACITOR REPLACEMENT WITH CERAMIC CAPACITOR

Iztok Šorli, MIKROIKS, Ljubljana

High Capacitance MLCC

For several years we have been facing periodic variations of availability and price of Tantalum capacitors. In the past this behaviour was due to political and economical strategies.

Today it is the poor supply of Tantalum raw material that drives the Tantalum capacitor crisis. At present we see a price growth of 50% (from 0.2 USD to 1.0 USD) for normal Tantalum capacitors; the forecast is for a further hike in the next year. Murata can help to solve this problem by offering many ceramic capacitors that directly replace electrolytic and Tantalum types.

Before we discuss about electrical characteristics, part numbers etc., let us briefly summarize some basic concepts of high capacitance usage. Figure 1 shows principal circuits that need high capacitance values.

Smoothing

The function of C1 and C2 is to smooth ripple and voltage fluctuations at the input and output of the LDO (Low Drop Out Regulator). C2`s ESR and ESL are most important because they are responsible for the purity of the output voltage. In the past high value Ta capacitors were used; now it is possible to use ceramic capacitors at 1/2 to 1/10 of the Ta values used.

Bypassing

C3 creates a "virtual" ground for the transistor which "believes" it is working at ideal conditions. The static and dynamic parameters are satisfied and the active device is properly used. Also in this case the ESL of the capacitor is of the most importance since a low value avoids self - oscillation problems.

Coupling

In order to link two stages (for example pre amp to power amp) C4 is basic. This capacitor transfers only the signal and does not modify the DC parameters. For the example mentioned, it is the most important that the capacitor is not polarized in order to avoid signal distortion. What better solution than a ceramic capacitor?

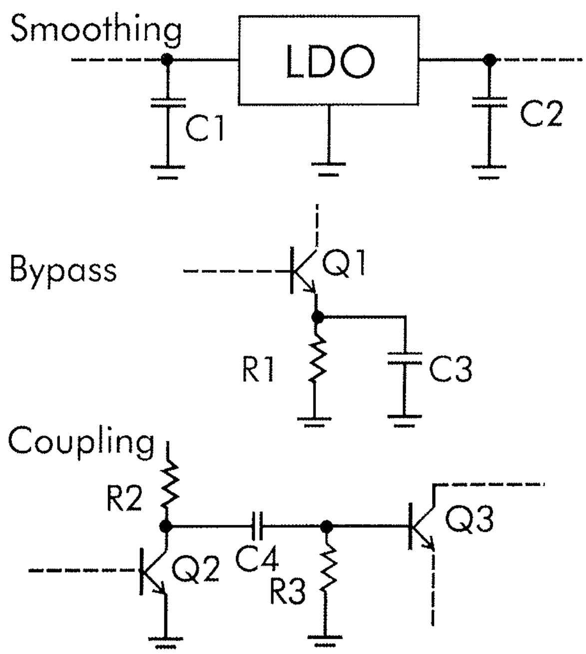


Figure 1: Examples of principal circuits where capacitors with high capacitance values are mostly used

Technical Aspects of Multi Layer Ceramic Capacitors

Despite the simple construction, monolithic ceramic capacitor provides both high-speed response and an excellent high-frequency characteristics; the capacitance range has generally reached just approximately 1μF until now. However, with recent advancements in the thin-layer/multilayer forming technology for dielectrics, as well as the technology for using base metal for internal electrodes, the capacitance range now exceeds 1μF. Moreover, capacitors with capacitance of up to 100μF have been developed and are now being used.

Multilayer Ceramic Capacitors (MLCC) are built as a kind of "sandwich", composed of conductive layers separated by a dielectric (ceramic). Two conductive terminations are added to provide solderability, figure 2.

The mathematical formula that relates all the mechanical and electrical parameters to the capacitance values is as follows:

$$C = \frac{\varepsilon \times \varepsilon_0 \times S \times n}{d}$$

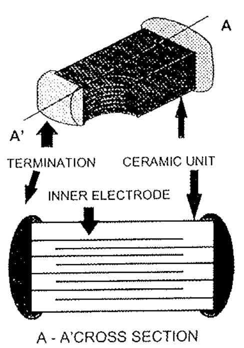
where

* ε_0: dielectric constant of vacuum
* ε: dielectric constant of ceramics
* S: active area per layer
* n: number of ceramic layers
* d: thickness of a layer

With this equation in mind, the means of obtaining high value multilayer ceramic chip capacitors are:

* thinner dielectric layers
* increased number of dielectric layers
* increased active area
* increased dielectric constant

A



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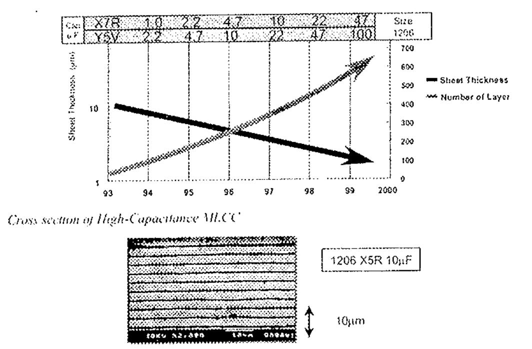


Fugure 2: Structure of a ceramic capacitor

A) device cross section

B) physical cross section as seen on electron microscope; the graph is showing how higher capacitances of X7R and Y5V ceramic capacitors can be obtained by thinning dielectric layers and by increasing their number

The most important parameter that can enable an increase in the capacitance of monolithic ceramic capacitors is the thickness of the dielectric element. Year by year, the dielectric element thickness becomes ever smaller. Currently, products with a dielectric element of 2 ~ 3 μm thick are on the market, and recent products with dielectric elements only 2μm thick or less have been developed. The core technologies for supporting thin-layer products include technologies for ultra-fine graining and low-temperature firing of ceramics, non-reduction material technology, and technologies for graining and dispersing the electrode material, as well as using base metal for the electrode material. These technologies are much advanced compared to more conventional ones.

Consequently, the delicacy of a MLCC design is clear. A good capacitor is the result of a good balance between materials, thickness and dimensions.

This demonstrates the difficulties to be overcome in order to obtain small, high value capacitors with good temperature performance and high working voltages.

Reliability Superiority of Ceramics over Tantalum

Breakdown voltage

In figure 3 there are two important points that must be observed:

* considerably higher actual breakdown voltage of ceramic capacitors compared to tantalums
* enormous safety factor between stated working voltage and actual breakdown voltage of ceramic capacitors

This only means that the ceramic capacitor is more reliable and that can safely operate at the stated working voltage; it would also seldom fail due to overvoltage spikes which would kill tantalum capacitor.

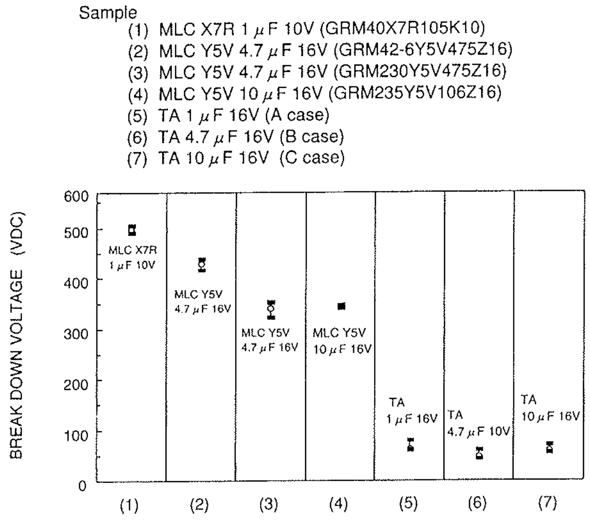


Figure 3: *Comparison among measured breakdown voltages of ceramic and tantalum capacitors*

ESL & ESR vs Frequency

Unique features of ceramic capacitors are their low Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL) especially at high frequencies. This is clearly demonstrated in figure 4 where differences among two types of ceramic (X5R and Y5V) capacitors and tantalum capacitors are shown.

The superior performance of the ceramic is extremely clear, allowing optimization of final circuit. Because of this effect, in most cases it is even possible to reduce the capacitance values of ceramic capacitor compared to tantalum, while filtering very effectively.

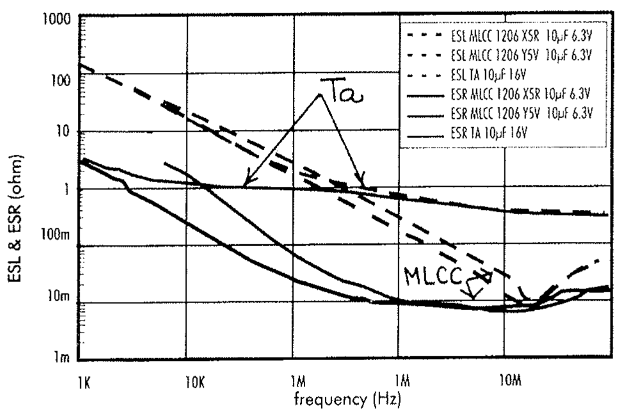


Figure 4: *ESL and ESR of ceramic versus tantalum capacitors*

Allowable Power

The low ESR is the feature of MLCC that allows high peak current. This guarantees very fast response to high speed current transients.

The low ESR (at medium/high frequencies) also causes low self-heating when ceramic capacitor is under stress at high frequencies and under high voltage.

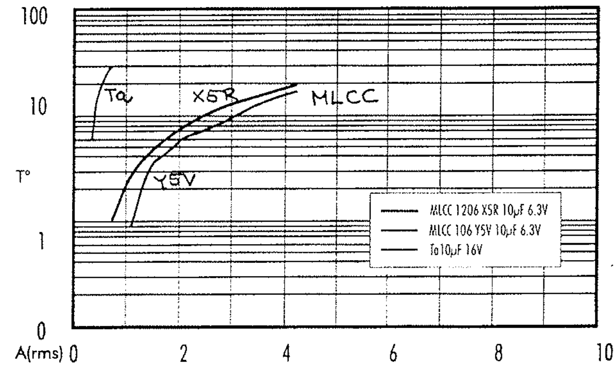


Figure 5: *Temperature rise of different capacitors working at 100 kHz*

Attention

When designing circuitry with ceramic capacitors two important things must be taken into consideration: capacitance versus temperature behaviour of different ceramics, as well as capacitance versus bias voltage dependence, as summarized in figures 6 and 7. In these two specific cases only the performance of X7R ceramics is comparable to tantalum, while Y5V is inferior.

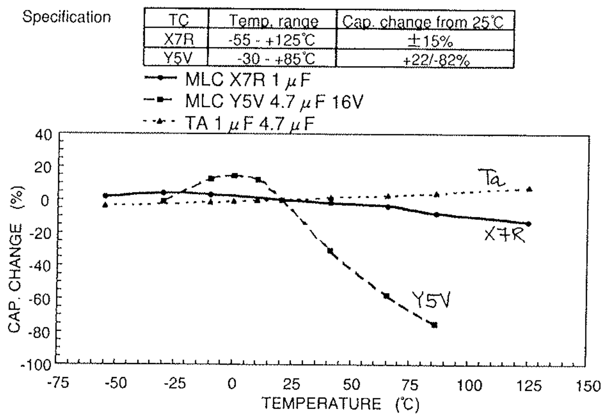


Figure 6: *Capacitance versus temperature behaviour of different capacitors*

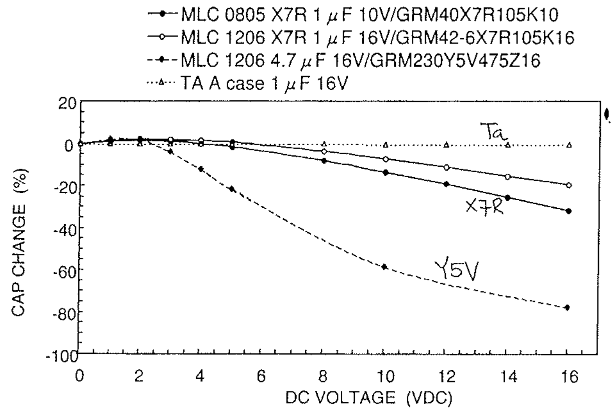


Figure 7: Capacitance versus DC voltage behaviour of different capacitors

Measurement results

Figures 8, 9 and 10 present some measurement results from which we can compare performance of ceramic to Ta/Al capacitors in pulse response, noise absorption and smoothing applications.

This data shows clearly that in noise bypass applications the value of MLCC capacitance can be 1/2 to 1/10 of the tantalum for the same bypass effect. This is due to lower ESR and ESL of MLCC compared to tantalum capacitor.

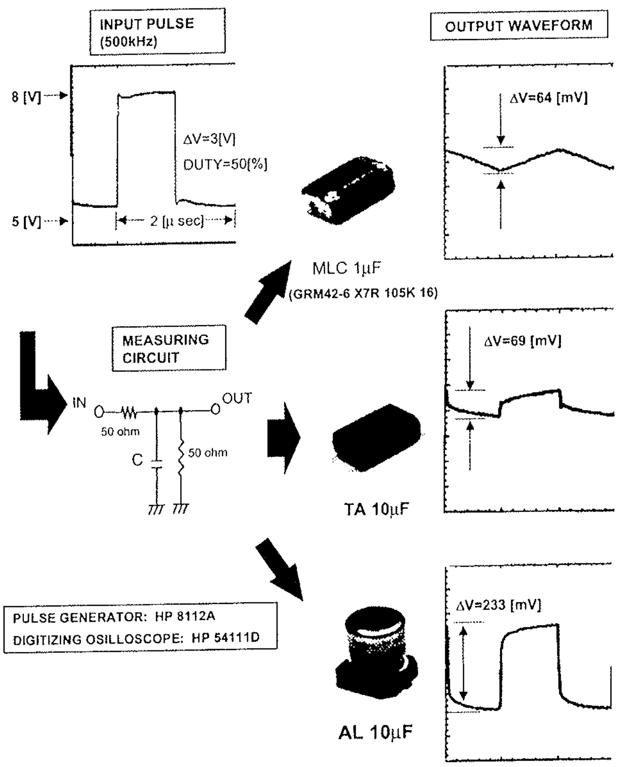


Figure 8: Pulse response of MLCC versus Ta/Al capacitors

Input Pulse Freq	Input Pulse Voltage	Output ripple voltage (mV)		
		AL	TA	MLCC
10kHz	2V	534	204	196
100kHz		336	64	16
500kHz		346	38	12
1MHz		332	30	3

FFT Analysis result shows MLCC's superiority in terms of noise absorption in High Frequency range.

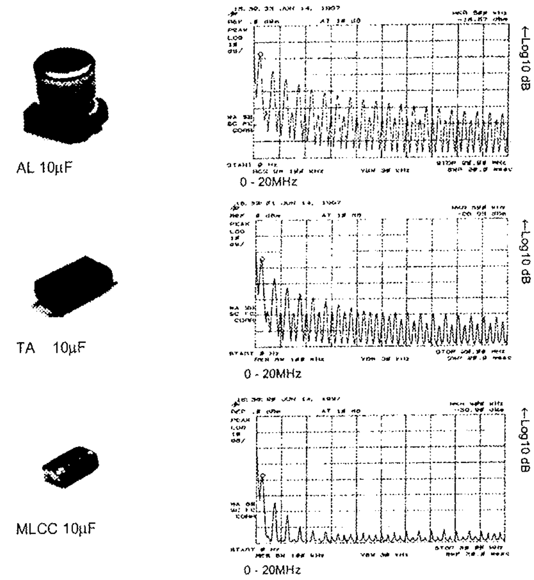
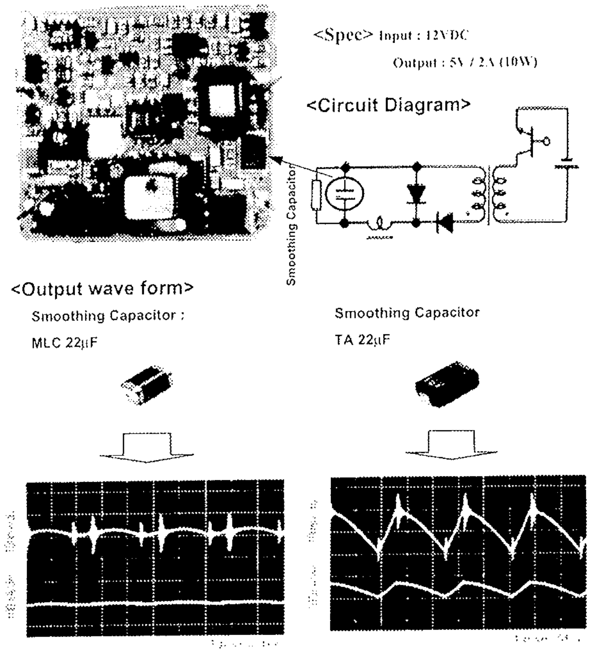


Figure 9: General noise absorption comparison data

Non resonance type forward method DC - DC converter.



Comparing MLCC and TA . MLCC can reduce ripple noise by 1/3 in Forward method DC - DC converter.

Figure 10: Example of Ta/Al replacement in smoothing application

Table I: performance comparison among MLCC, tantalum and aluminum capacitors

		MLCC		TA	AL
Hihg freq.	Capacitance - frequency	Exelent		Fair	Poor
	Imedance - frequency	Exelent		Fair	Poor
Reliability	Break down Voltage	Exelent		Fair	Fair
	Life	Exelent		Fair	Fair
	Temp. rise	Exelent		Fair	Poor
Other	Noise absorption	Exelent		Fair	Poor
	Polarity	Exelent		Poor	Poor
	Size	Exelent		Good	Fair
	Temp. Capacitance	X7R X5R	Y5V	Good	Fair
		Good	Fair		
	Voltage Capacitance	X7R X5R	Y5V	Good	Good
		Fair	Fair		

The Murata answer

In figure 11 you will find the most important values of MLCC that Murata is able to supply. The dielectric types, the capacitance values, the working voltages and the sizes of capacitors currently in production are shown. Please, note that this list is being constantly updated as new capacitor types are being added on the regular basis.

As well, figure 12 allows you to find the right MLCC size to match the existing land pattern of the Ta being replaced. On the left there are the most common Ta pad designs for reflow soldering, on the right there are basic MLCC sizes for those pads. To find equivalent size of MLCC just drag its symbol over the Ta land pattern.

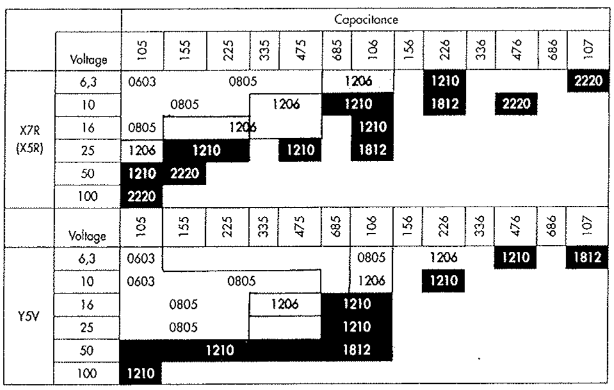


Figure 11: List of high capacitance MLCC that can be supplied by muRata

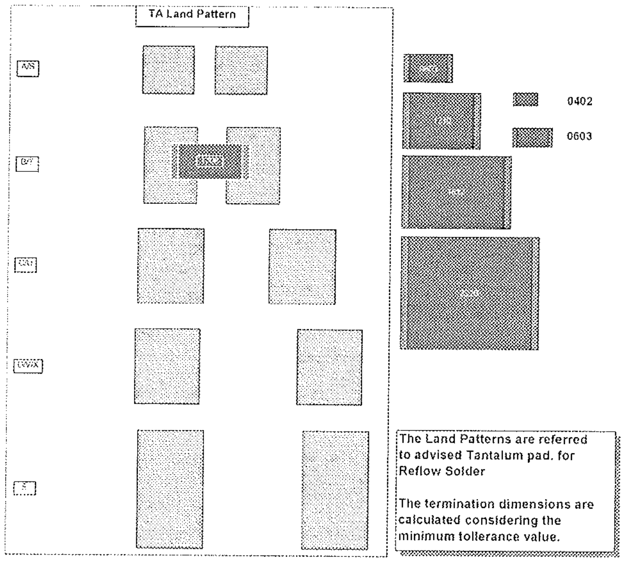


Figure 12 . MLCC to Ta matching sizes

Continued development will see continued decreases in the thickness of the dielectric element. Using thin-layer forming technology allows ceramic capacitors to be further reduced. With increased semiconductor density, semiconductor components use lower voltages. Accordingly, electric and electronic circuits are driven at lower voltages. If a ceramic capacitor appears with a rated voltage of 4 V or 2.5 V, there is a great possibility that applications will be found for it. The current situation is favorable especially for thin-layer monolithic ceramic capacitors.

Likewise, the technology has grown enough to meet the needs for products with more than 100 μF, 220 μF, or higher capacitance.

In addition, low-profiled products that can be used in thinner equipment are available. Step by step, product thickness of 1.35 mm or more will be reduced to 1.35 mm or less (1.25±0.1 mm), to 0.95 mm or less (0.85 mm±0.1 mm), and then to 0.7 mm or less (0.6 mm±0.1 mm).

As described above, it is expected that high-capacitance monolithic ceramic capacitors will be further developed in a variety of directions – through downsizing, upsizing, capacitance increase, rated voltage increase, and more – all based on the ceramic thin-layer forming technology.

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Iztok Šorli
MIKROIKS d.o.o.
Stegne 11, 1521 Ljubljana
Tel.01 5112 221, fax.01 5112 217