TECHNICAL INFORMATION

COMPARISON OF MULTILAYER CERAMIC AND TANTALUM CAPACITORS

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Abstract:

Engineers now have a choice between ceramic and tantalum when it comes to selecting capacitors with values between 0.1 - 22µF. As the ceramic material technology continues to advance, more and more capacitance is realized in the same case sizes compared to previous years. This paper will examine what devices are available and the trade off of using each of the technologies. The goal of this work is to help in selecting the proper device (tantalum versus ceramic) for a specific application.

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Introduction

Although the construction techniques and materials used to manufacture multilayer ceramic and tantalum capacitors are completely different, the basic applications still remain the same. Capacitors in the 0.1 - 22µF range are used mainly for digital circuit decoupling and filtering. Acting as local supplies of charge, capacitors assist power supplies in remaining at a constant DC voltage despite the continuous switching of digital signal circuitry. Capacitors also function as simple, single pole filters and can be used in conjunction with other devices (resistors and inductors) to create higher order filter circuits.

As much as tantalums and ceramics are both capacitors, they do have many different properties. The case sizes and capacitance values available will first be studied. The impedance curves, the parasitic inductance (ESL) and equivalent series resistance (ESR) for each of the technologies will also be outlined. Then the electrical performance under a variety of conditions, such as temperature and DC bias, will be examined.

This work will focus on the surface mount versions of both ceramics and tantalums only, with the knowledge that the only real difference would be the added inductance form the leads themselves for the thru-hole versions. The intent is to also limit the comparison to devices of similar capacitance and size.

Products Available

The following table list the range of devices that will be looked at in some detail. This list includes the extended ranges of both the tantalum and ceramic technologies.

	Ceramics	Tantalums
Case Sizes	0603 (1608M) 0805 (2012M) 1206 (3216M) 1210 (3225M)	R - 0805 (2012M) A - 1206 (3216M) B - 1411 (3528M) C - 2412 (6026M)
Rated Voltage (V)	10 - 500	4 - 50
Dielectric	$BaTiO_2$	Ta_2O_5
Capacitance Range (µF)	X7R - 0.0001 - 3.3 Y5V - 0.022 - 22.0	0.1 - 100
Polarity	Bi-directional	Polar
DC Leakage Current	0.001µA max.	0.5 - 30µA Typical

Table 1

The data shown in Table 1 warrants some comments. First, one should keep in mind that there is a recommended 50% derating of the voltage for tantalum capacitors. That is a 5V application should use a 10 volt rated part. Secondly there is a definite trade off in capacitance and rated voltage for both technologies. On the tantalum side, for example, a C case device rated for 4 volts has a maximum capacitance of 100µF, while a 50V rated part has a capacitance of 1µF. A 10V, Y5V ceramic 1206 chip has a maximum capacitance of 10µF, yet a 50V part has a max. cap of only 0.33µF. The X7R and Y5V dielectrics were chosen because they are widely available and can achieve the capacitance ranges required. Lastly, tantalums are polar devices so one must be careful how much reverse voltage gets applied as in a DC blocking application.

Parasitics

The impedance curve of capacitors can tell a lot about the performance of the device in an actual circuit. Every capacitor has parasitic ESL and ESR, just simply because of the physics involved in manufacturing the devices. Both technologies have a finite length and width of conductor in which the conduction currents flow through, therefore they both have inductance (ESL). The plates of the ceramic capacitor and the tantalum powder have some resistance (ESR). Impedance implies real and imaginary parts, and today's impedance analyzers (such as an HP4194) measure both magnitude and phase and from this one can calculate ESL and ESR. Fig. 1 shows the magnitude of the impedance as well as ESR for 4.7µF, Y5V, 1206, 16V ceramic and a 4.7µF, 16V, B case tantalum.

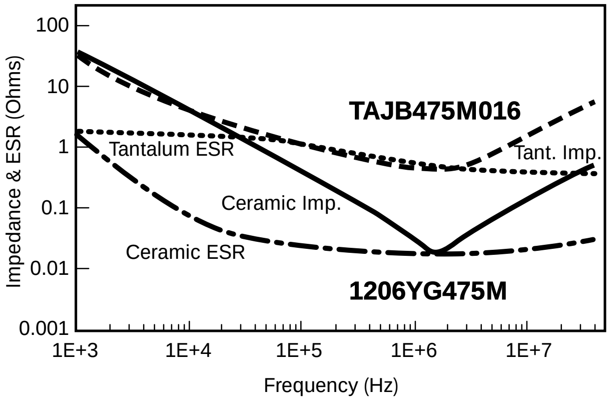

Fig. 1 - Impedance and ESR curves for 4.7µF tantalum and ceramic capacitors.

Fig. 1 shows some interesting results. First, one can tell they are the same capacitance value because the impedance curves are the same at low frequencies, i.e. at 1kHz. The ESR of the ceramics is also much lower over most of the frequency spectrum. Lastly, by looking at the upper end of the frequency spectrum, the ESL of the ceramic package is also much lower. This is caused mainly by the lead frames used in the packaging of surface mount tantalum capacitors. The following table lists the measured parasitic inductance for a variety of tantalum and ceramic case sizes. It is interesting to note that capacitance value has almost no effect on the change in inductance. The governing properties are the path length and aspect ratio that the current "sees" flowing through the capacitor.

Case Size	Inductance (pH)
Ceramics	
'0603	850
'0805	1050
'1206	1250
'1210	1020
Tantalum	
R	1600
A	2200
B	2250
C	2800

Table 2

While ESL remains fairly constant with frequency, ESR is very frequency dependent. Both tantalums and ceramics have a dissipation factor (DF = ESR/2πfC) that must be met at 120Hz and 1kHz respectively. The following table lists the required maximum DF that devices are allowed to meet before being able to ship to a customer.

Tantalum	DF	Test Frequency
C <= 1.0µF	4%	120
C > 1.0µF	6%	120
Ceramic, X7R		
50V and 100V	2.5%	1000
25V	3%	1000
16V	3.5%	1000
10V	5%	1000
Ceramic, Y5V		
25V and 50V	5%	1000
26V	7%	1000
10V	10%	1000

Table 3

Unfortunately in the real world, most electronic circuits do not operate at 120Hz or 1kHz. Maximum ESR for tantalum capacitors is specified at 100kHz, as this is fairly close to the switching frequency of most power supplies, while ceramics are typically not specified or are given for resonant frequency only. The following table shows the **typical ESR** at 100kHz and 1MHz for some comparable ceramic and tantalum capacitors.

AVX Part Number	Description	ESR@100kHz (mΩ)	ESR@1MHz (mΩ)
TAJA105M016 1206YC105M	A case, 1µF, 16V 16V, 1µF, X7R	5000 2200	1500 25
TAJA106M010 1206ZG106Z	A case, 10µF, 10V 10V, 10µF, Y5V	1600 600	350 20
TAJB226M010 1210ZG226Z	B case, 22µF, 10V 10V, 22µF, Y5V	1300 4	1000 3
TPSC226M016 1210ZG226Z	C case, 22µF, 10V low ESR tant. 10V, 22µF, Y5V	300 4	250 3

Table 4

As this table demonstrates, ceramics typically do have a much lower ESR, especially at higher frequencies.

DC Bias Dependency

Ceramic capacitors are made with high K (permittivity) materials which exhibit a change in dielectric constant with an applied DC voltage. Tantalum capacitors do not change capacitance with applied DC bias. Since almost all capacitors are operated with a DC voltage involved, this is a very important feature to keep in mind when designing a circuit. Fig. 2 shows the DC bias dependency for Y5V and X7R capacitors up to rated voltage. This dependency is not really voltage related, but rather is a phenomena caused by the electric field between the capacitor layers. A good rule of thumb is a 15 - 20% loss for X7R at rated voltage and 75 - 80% for Y5V, regardless of the rated voltage. A linear fit in between works quite nicely for a first order approximation.

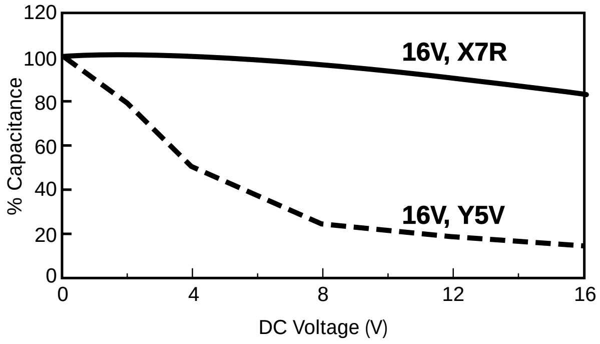

Fig. 2 - % change capacitance vs. DC bias voltage for Y5V and X7R ceramic capacitors.

Temperature Dependency

Once again, by their very nature ceramic and tantalum capacitors change capacitance over temperature. X7R and Y5V EIA are coding sequences that describe how the capacitance changes over temperature. X7R stands for ±15% change from -85°C to +125°C and Y5V +22 to -82% from -30°C to +85°C. Fig. 3 shows the change in capacitance for both tantalums and ceramics. It should be noted that the **temperature and DC bias effects are cumulative** and not exclusively independent.

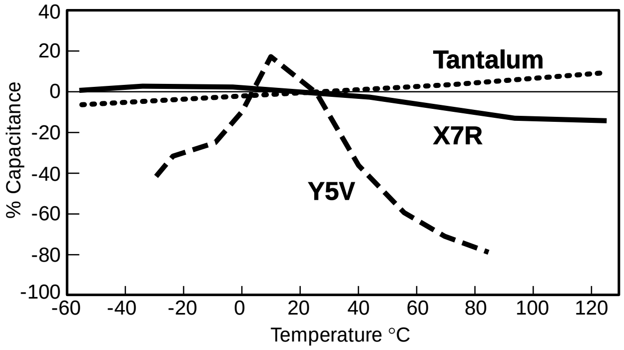

Fig. 3 - Typical temperature dependency for tantalum and ceramic capacitors.

Ripple Current Capability

Power supply designers are often concerned about the ripple current capabilities of capacitors on both the input and output sides of converters. The biggest concern is the internal temperature rise caused by the I^2R power consumption of the capacitor. Since tantalums are a polar device, this ripple should always be accompanied by a DC bias. Since ESR is so dependent on frequency and temperature, the power ratings listed should be viewed as rules of thumb and not laws written in stone. The tantalum capacitors have a published data set for a 10°C rise above the ambient. The experimental set-up used to arrive at this number was emulated and done for a series of ceramic capacitor chips. It should be noted that different mounting techniques can alter the thermal conductivity greatly (see Ref. 1). The following table lists the empirical data from this experiment.

Case Size	Dielectric	Max. power dissipation (W) for 10°ΔC
Tantalum		
A		0.08
B		0.09
C		0.11
Ceramics		
1206	X7R	0.27
'0805		0.24
1206	Y5V	0.2
'0805		0.18

Table 5

From table 5, the power handling of the ceramics is typically much better than the tantalums. Keep in mind that the ESR of ceramics is also typically lower (see table 4), so more current can be driven through the capacitor ($P=I^2R$).

Microphonic Effects

Of much less concern, yet still important, especially in audio applications, is the microphonic or piezoelectric effect. Barium titinate which is the base ceramic material for most dielectric systems will exhibit microphonic effects. It is not very difficult to take a Y5V capacitor and put a DC bias with a small signal 1kHz sine wave and get the capacitor to “sing”. Tantalum capacitors exhibit no microphonic effects. The experiment done by AVX involved the opposite phenomena whereby the part was shaken while under bias and the resulting generated voltage was measured. This was done for a series of 1µF devices and the results are shown in Fig. 4. While this experiment does not give an empirical number, the resulting relative voltage generation tells the story. This experiment confirms that the higher the K of the ceramic capacitor, the worse the microphonic effect becomes.

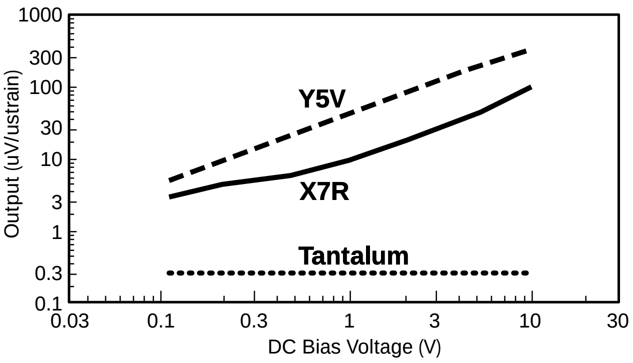

Fig. 4 - Microphonic effect of surface mount capacitors.

Conclusions

There is no simple answer to the question of when one can replace a tantalum with a ceramic, or visa versa. The parameters that the capacitor will see during its lifetime need to be examined carefully. The benefits and highlights are listed in the table below.

Important Parameter	**Tantalum**	**Ceramic**
ESR/Output ripple		X
Volumetric efficiency	X	
Wide temperature range	X	
Low inductance		X
DC bias	X	
Microphonic	X	
High frequency filtering		X

Table 6

One cannot just blindly replace one type of capacitor technology with another and expect equal performance offer all conditions. General knowledge of what the circuit will see must be taken into consideration.

References

(1) I. Salisbury, “Thermal management of surface mounted tantalum capacitors”, *AVX Tech. Bulletin*, Nov. 1992.

(2) J. Cain, “Parasitic inductance of multilayer ceramic capacitors”, *AVX Tech. Bulletin*, June 1997.

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