

Applying Ceramic Tech to Achieve High Power Density (Part 1)

Capacitors, especially ceramic, are now strongly being considered in electronic design because of their excellent potential to increase efficiency, which ultimately leads to higher power density.

Two primary characteristics of a capacitor are its energy density and [power density](#). In Part 1 of this two-part series, we will focus on power density. Capacitor power density can be calculated as a quantity per unit volume or per unit mass.

We'll also look at the characteristics and technology of Class I versus Class II multilayer ceramic capacitors (MLCCs) to determine which class will have the best performance for high-power-density applications. Some key applications can include snubbers, dc-link, and resonant converters.

Semiconductor devices that use a switching technology are the prime drivers for increasing efficiency and power density because they significantly contribute toward lower

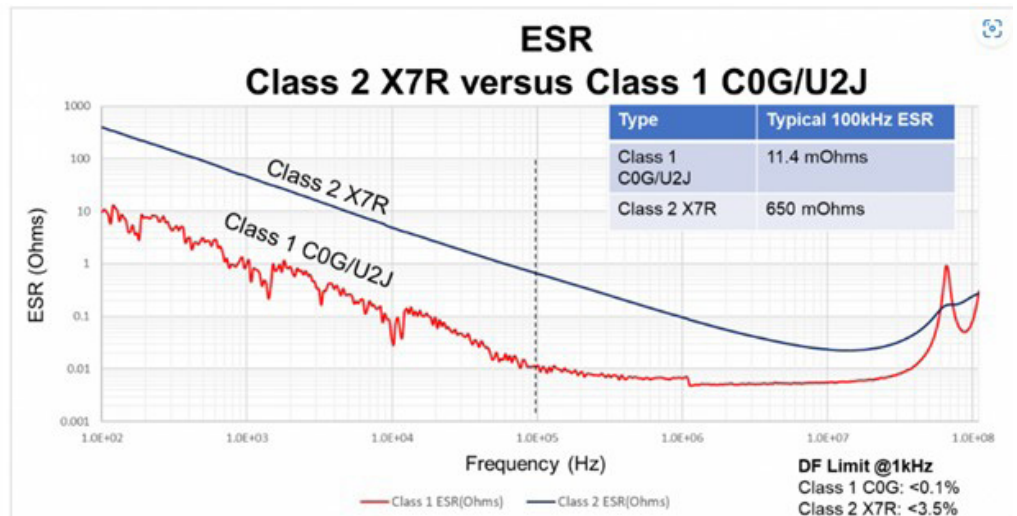
dynamic and static losses in power systems. However, designers are finding it more expensive and challenging to achieve incremental improvements. Capacitors are becoming better recognized for having the potential to improve efficiency, leading to better power density.

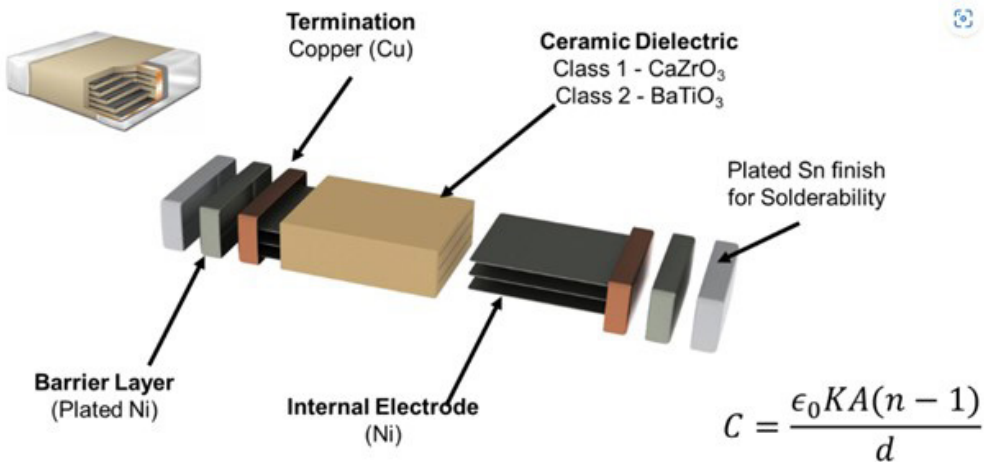
Capacitors and Efficiency in a System Design

In power design, there are three key applications in which capacitors positively impact the efficiency of an electronic system. In each area, the capacitor will have a bit of a different requirement:

1. In a dc-link, high voltages, high temperatures, high frequencies, and high ripple current will be essential.
2. With a snubber design, the requirement will be high

1. This plot compares ESR between Class II X7R and Class I COG/U2J. (Image courtesy of Reference 1)





2. This is an exploded view of a base-metal-electrode capacitor. (Image courtesy of Reference 1)

dv/dt, high voltage, high ripple current, high temperature, and low inductance.

3. A resonant power converter will need to satisfy high ripple currents, wide operating voltage ranges, as well as capacitance stability maintained over temperature plus dc and ac voltages.

When we combine these above requirements, the design will necessitate a capacitor with very low loss and maintain high ripple-current handling. It must also have the ability to withstand high voltages and handle higher operating temperatures while maintaining a stable capacitance and high mechanical stability. The next section examines capacitor packages that can deliver the above requirements.

Class I MLCC Capacitors

Class I MLCCs, including [COG](#), [NPO](#) and [U2J](#), are at the top of the list to readily meet the above requirements.⁸ These capacitor types have been shown to be ultra-stable with high temperature stability, low loss, and a high ripple-current capability. These features make them a designer's first choice for high-power-density applications.

Capacitor dielectrics are typically classified by their capacitance stability over temperature. Class I COG, NPO, and U2J exhibit the best temperature stable dielectrics. However, this class of capacitor has the lowest dielectric constant (K). A higher volume is necessary to achieve the same capacitance as Class II MLCC types.

Class I dielectrics are much more stable than Class II. As a result, they're an excellent option for resonant applica-

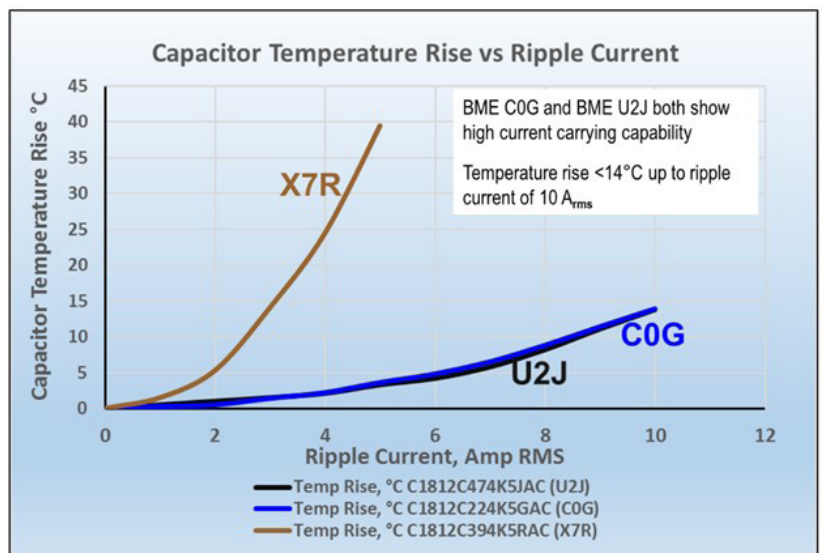
tions like LLC resonant converters and wireless-charging circuits.

For example, COG has a very small capacitance shift of 30 ppm/°C, or 0.3% at 125°C. U2J has 750 ppm/°C or 7.5% at 125°C and is predictable and linear. Both COG and U2J exhibit a negligible capacitance change versus dc bias and virtually no change versus time—in essence, exceptionally low aging.

Equivalent Series Resistance

Equivalent series resistance (ESR) is quite a vital characteristic that must be considered for capacitors in power applications due to i^2R losses.⁸ Barium titanate (BaTiO₃) is a ferroelectric material that can create domain regions within the capacitor dielectric and domain wall heating with a higher ESR as compared to Class I dielectrics.

It's very common for Class II MLCCs to have an ESR up to



3. Ripple current is compared between a Class I COG/U2J and a Class II X7R capacitor. (Image courtesy of Reference 1)

two orders of magnitude higher than Class I MLCCs. *Figure 1* shows an example of ESR for Class I COG/U2J MLCCs and Class II X7R.

Class I vs. Class II MLCC Construction

MLCC capacitors have some excellent properties that prove to be ideal for resonant, snubber, and dc-link applications. They're built with alternating layers of ceramic dielectric and metal electrodes, which are primarily fabricated using base metal electrodes (BMEs).

MLCC devices will usually have a nickel electrode and a calcium-zirconate (CaZrO_3) dielectric for Class I or Ba-TiO₃ dielectric for Class II (*Fig. 2*).¹

How Critical is ESR in Capacitors?

I²R losses in capacitors can lead to unnecessary and excessive heating, especially when coupled with a high ac current in power designs. *Figure 3* shows how an X7R capacitor can increase its temperature by as much as 40°C, even with only 5 A rms.

However, U2J and COG dielectric capacitors will have a self-temperature increase of about 15°C at 10 A rms.

Class I Capacitor Technology Excels in High-Power-Density Apps

Class I BME dielectric-based MLCCs, such as U2J and COG, are the best choice in applications requiring high power density. These types of capacitors have a predictable performance and circuit designers can rely on getting an excellent tolerance.

Summary

This article discussed the power-density characteristics of Class I and II multilayer ceramic capacitors, including efficiency in electronic system design, equivalent series resistance, and Class I vs. Class II MLCC construction. Part 2 will take a closer look at energy density.

References

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Captions: