TECHNICAL PAPER

C0G High Voltage MLCC in DCDC and OBC Applications

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Abstract

This white paper discusses the advantages of C0G high voltage MLCCs when compared to film capacitors. Capacitance stability is a crucial element when choosing the right resonant capacitor for resonant circuits. Minimum variations with shifts in temperature, voltage, and frequency fluctuation are desirable. Although film capacitors provide a good option for certain applications, advances in MLCC technology have improved the performance of other capacitor dielectrics. In DC-DC/OBC applications, C0G High Voltage MLCCs can represent a more suitable option when compared to film capacitors, maintaining minimal capacitance variation with temperature and low dissipation factor at high frequencies.

C0G HIGH VOLTAGE MLCC IN DCDC AND OBC APPLICATIONS

UNDERSTANDING DC-DC AND OBC LLC CIRCUIT

In a DC-DC converter, the LLC resonant circuit can convert the DC voltage to the desired DC output voltage. When the switching MOSFET is on, the supply voltage is applied to the resonant inductor, causing it to store energy. When the switching MOSFET is off, the resonant inductor releases energy that is transferred to the load through the resonant capacitor. Controlling the on-off time of the switching MOSFET adjusts the output voltage.

In on-board chargers (OBC), the LLC resonant circuit converts the input, alternating current into direct current to charge the battery of an electric vehicle (EV). Similar to DC-DC converters, LLC resonant circuits regulate the output voltage by controlling the on-off time of the switching MOSFET.

The LLC resonant circuit offers the advantage of zero voltage on (ZVS) of the two main MOS switches on the primary side and zero current off (ZCS) of the secondary rectifier diode. The soft switching technology reduces the power supply's switching loss, improving the efficiency and power density of the power converter. In addition, the LLC resonant circuit achieves constant output voltage, improving the stability and reliability of the power supply.

In Figure 1, Lr and Lm illustrate the leakage inductance and excitation magnetic inductance of the transformer, and together with the capacitor Cr, they form a resonant circuit. The LLC converter consists of two inductors (Lr, Lm) and a capacitor (C), in which the resonant capacitor is in series with the transformer. This configuration is also referred to as a series resonance circuit.

The common DC-DC converter adopts pulse amplitude modulation (PAM) mode to obtain the required output voltage by controlling the pulse current amplitude transmitted to the transformer at a certain switching frequency. The LLC converter uses pulse frequency modulation (PFM) mode, maintaining pulse amplitude to control the switching frequency; resonant capacitors, therefore, must exhibit specific characteristics to operate in PFM mode.

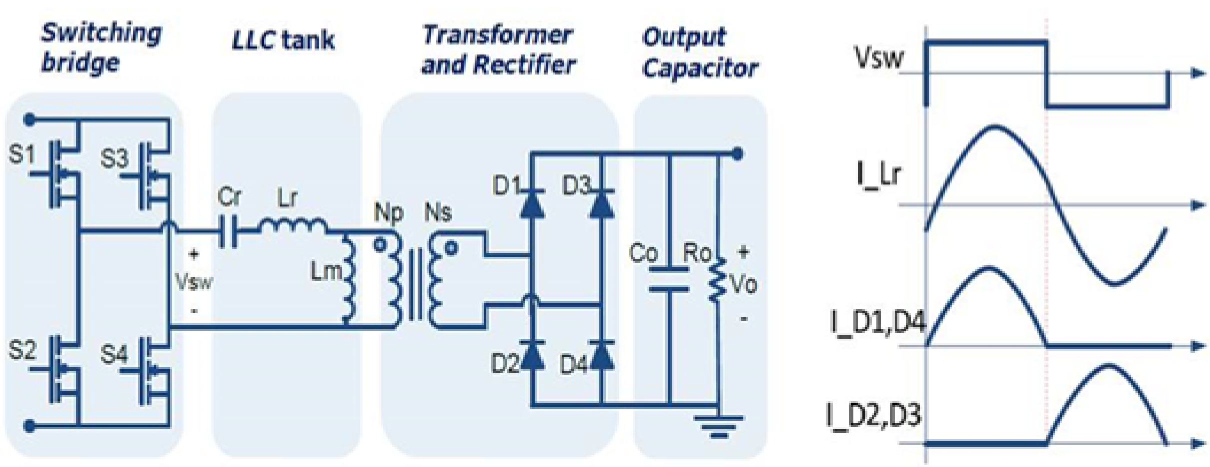

Figure 1. Full-bridge LLC converter with Full-bridge rectifier circuit

C0G HIGH VOLTAGE MLCCS REPLACE FILM CAPACITORS IN DC-DC/OBC LLC CIRCUIT

The usual working voltage in DC-DC/OBC applications ranges from 0-400V, with peak voltage at 450V, and working frequency higher than 100khz.

The capacitance stability is a crucial element when considering the right resonant capacitor for resonant circuits; minimum variations with shifts

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in temperature, voltage, and frequency fluctuation are required.

When subjected to the larger rectangular waveform of voltage, the resonant capacitor must endure a consistent high AC voltage, enabling the LLC converter to transfer power. The high current flowing through the resonant capacitor requires appropriate equivalent series resistance (ESR).

Film capacitors (film caps) have represented the common choice, fitting the requirements when considering voltage, capacitance, ESR value, and temperature, with a rated voltage of 600-1000 V and capacitance of 1-10µf. The common dielectrics for film caps include Polyester, PET (polyethylene terephthalate) and PP (polypropylene).

When choosing film caps, the dv/dt value should be taken into account (Equation 1). Standard values in the industry include AC 50hz/380v with a maximum dv/dt value at 0.027 V/µs. A 0.47µF capacitor under 500v/µs dv/dt pulse generates 235 A current.

Stacked film cap with 5mm lead spacing can handle around 800v/µs dv/dt. The failure mechanism of film caps is not suited for fast dv/dt even with the ESR value at less than 10 mΩ (Equation 2). In some applications, fast spike in high current generates extremely high heat, softening and melting the film cap's dielectrics, contributing to decreased IR and thermal failure.

$$I = C\frac{dv}{dt}$$

Equation 1

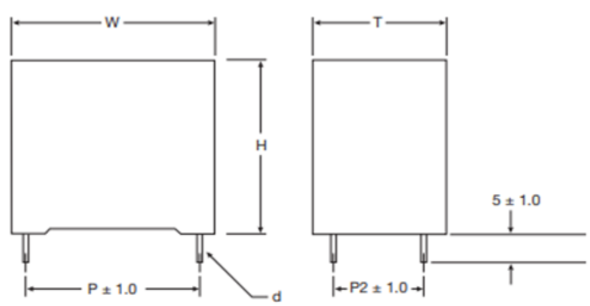
$$W = I^2 \cdot ESR \cdot t$$

Equation 2

Other weaknesses of film caps include:

1. Size: The film cap's box-like shape takes up considerable room on the PCB (typical dimensions shown in Figure 2)

2. Wave soldering: The film cap's leads requires wave soldering during PCBA, potentially interfering with the customer's manufacturing process



millimeters

Case Size	W	H	T	P	P2	d
G	32.0	37.0	22.0	27.5	10.2	0.80
H	42.5	33.5	22.0	37.5	10.2	1.20
J	42.5	37.0	28.0	37.5	10.2	1.20
K	42.5	40.0	20.0	37.5	10.2	1.20
L	42.5	44.0	24.0	37.5	10.2	1.20
M	42.5	45.0	30.0	37.5	20.3	1.20
N	57.5	45.0	30.0	52.5	20.3	1.20
P	57.5	50.0	35.0	52.5	20.3	1.20

Figure 2. Film capacitor typical dimensions

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C0G HIGH VOLTAGE MLCCS REPLACE FILM CAPACITORS IN DC-DC/OBC LLC CIRCUIT

Despite its weaknesses, a replacement for film capacitors proved a challenge in the past. Initially, the C0G (NP0) dielectric was not an ideal candidate due to its low permittivity, which did not allow production of high capacitance capacitors with high voltage. However, with the improvement of MLCC technology, NP0 high voltage MLCC now accommodates higher capacitance and voltage in a compact size, enabling it to replace film caps effectively.

With the DC-DC/OBC's downsize trend, customers have been looking for a higher power to density ratio. Engineers value the high voltage C0G MLCC packaged in miniature size when compared to film caps.

C0G MLCCs continue to represent a suitable option as EVs and other areas increasingly adopt wide bandgap (WBG) semiconductor — SiC and GaN — technology. As the typical working frequency of MOSFETs stays around 100-300 kHz, WBG semiconductors operate at higher frequencies: SiC at 500kHz and GaN at 1MHz. C0G MLCCs often perform better than film caps when considering high frequency applications using SiC and GaN semiconductors and temperatures around 150°C.

In resonant circuits, Class 1 ceramic materials like NP0 and U2J dielectric deliver the best outcomes when compared to X7R and other second-class ceramic materials. NP0 and U2J maintain minimal capacitance variation with temperature and low dissipation factor at high frequencies (Figure 3, Equation 3). As the X7R MLCC's DF increases steadily with the increase in frequency, the heat generated can cause it to fail.

$$fr = \frac{1}{2\pi\sqrt{LC}}$$

Equation 3. Series resonance frequency

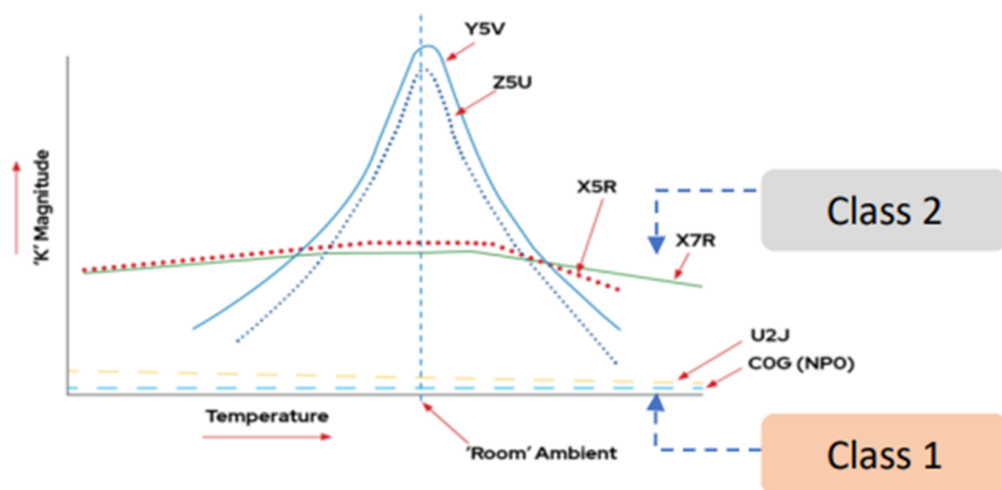

Figure 3. Capacitance stability of different dielectrics

KYOCERA AVX'S C0G HIGH VOLTAGE MLCC SOLUTION

C0G (NP0) ceramic capacitors are ideal for use in applications that require high stability and low losses because of their temperature coefficient of capacitance of 0 ± 30ppm/°C; they remain stable across a wide range of temperatures. The C0G high voltage MLCC is constructed of Strontium Calcium Zirconium Titanate (SCZT), with a permittivity of 20-30.

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KYOCERA AVX'S C0G HIGH VOLTAGE MLCC SOLUTION

In DC-DC/OBC, the common sizes of C0G high voltage MLCC are 1206, 1210, and 2220, with voltages ranging from 630-1000 V, and perform better at larger capacitance.

To determine the best capacitor, customers first need to calculate the total voltage and capacitance. Then, engineers determine how many capacitors, put in series, are needed to reach the target voltage and how many are needed in parallel to gain enough capacitance. To simplify the design, they choose one type of capacitor, such as the 1210CA333J4T2A. Finally, they design and form a network of capacitors to attain the desired voltage and capacitance.

The 1210CA333J4T2A example (Figures 4-7) highlights the quality of KYOCERA AVX's C0G high voltage MLCC.

In DC-DC/OBC applications, this process for choosing capacitors makes C0G high voltage MLCC an attractive option because other resonant capacitors may require the use of balance resistors, increasing costs and complicating circuits. Guaranteeing the quality and reliability of resonant capacitors is critical to costumers. The KYOCERA AVX C0G high voltage MLCC not only represents a suitable choice in DC-DC/OBC applications, but also ensures customers high-quality, reliable capacitors.

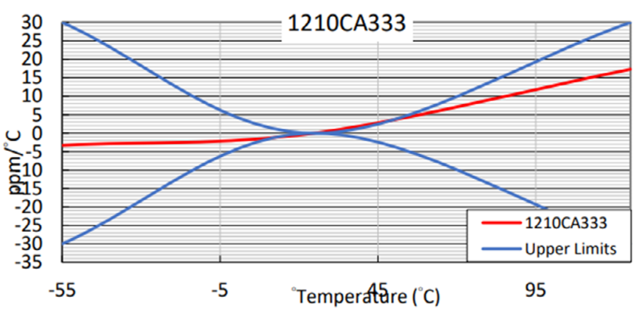


Figure 4. The TCC performance of 1210CA333

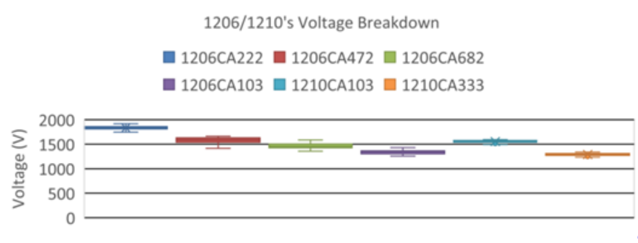
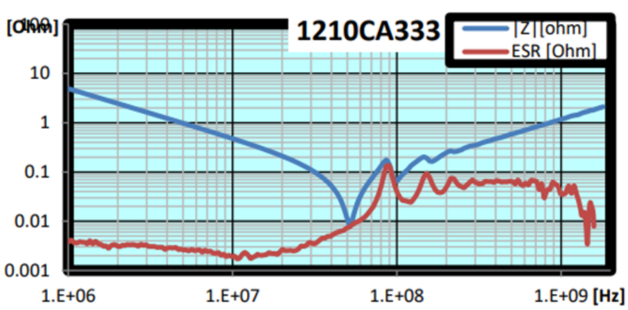


Figure 6. Breakdown voltage of 1210CA333:1290 V, dielectric thickness: 12.2μm



Part	Resonance frequency (MHz)
1210CA333	51

Figure 5. Impedance/ESR of 1210CA333

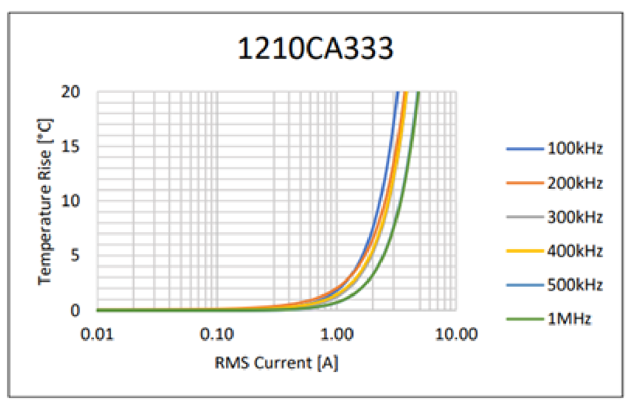


Figure 7. Ripple current specification (100khz:3.25A, 200kHz:3.72A, 300kHz:3.87A, 400kHz:3.84A, 500kHz:4.76A, 1000kHz:4.83A)

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