High-Capacitance MLCCs Fit as Smoothing Capacitors for Power ICs

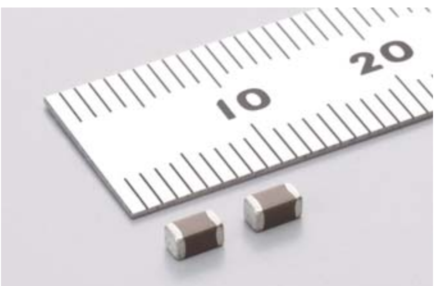


Photo 1: 100µF multi-layer ceramic capacitors (examples of 3.2 × 2.5mm, 330µF capacitors)

Many digital devices use direct voltage generated through an AC adapter as input voltage, and increase or decrease voltage for specific purposes using power ICs. Smoothing capacitors above 100µF are often used, especially when high power consumption semiconductor devices are used. Also, as lower-voltage, higher-speed semiconductor devices are being developed, lower-impedance smoothing capacitors are needed in order to ensure operational stability. Therefore, Murata Manufacturing Co., Ltd, has recently expanded its portfolio of over 100µF, high-capacitance, multi-layer ceramic capacitors (MLCCs) (Photo 1).

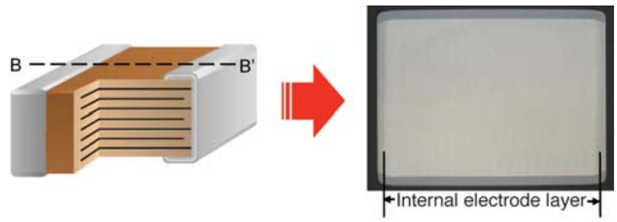


Figure 1: Cross-section of over 100µF multi-layer ceramic capacitor (3.2 × 2.5 mm, 330µF)

Features of Over 100µF MLCCs

Capacitors are classified into several types according to their basic structure and material. Table 1 shows advantages and disadvantages of typical capacitors.

Among the advantages of multi-layer ceramic capacitors include (1) small size, (2) high reliability, (3) high price competitiveness, and (4) low impedance/low ESR (equivalent series resistance)*1/low equivalent series inductance (ESL)*2. However, they also have disadvantages, such as (1) thermal dependence of capacitance and (2) decrease in effective capacitance due to voltage application (DC bias characteristics). Therefore, currently, most small, high-capacitance capacitors are multi-layer ceramic capacitors, while most of the smoothing capacitors, which require over 100µF high capacitance and low impedance, are conductive-polymer electrolytic capacitors.

Meanwhile, technical innovation for increasing the capacitance of multi-layer ceramic capacitors is continuing. Murata Manufacturing has already established technologies that allow stable, mass production of 1000 or more, 1µm or less high-accuracy dielectric layers and reduction of their thickness; thereby it is mass producing over 100µF multi-layer ceramic capacitors. Figure 1 shows a cross sectional diagram of a 3.2 × 2.5 mm, 330µF product.

Semiconductor devices used in recent digital devices use lower voltage, and so tend to cause less reduction in capacitance related to DC bias characteristics. Thus, over 100µF multi-layer ceramic capacitors are becoming ready for use as smoothing capacitors in digital devices.

Table 1: Advantages and disadvantages of multi-layer ceramic capacitors (source: Murata Manufacturing)

Type	Multi-layer ceramic capacitor	Conductive-polymer aluminum electrolytic capacitor (H chip)	Conductive-polymer tantalum electrolytic capacitor	Conductive-polymer aluminum electrolytic capacitor (V chip)	Tantalum electrolytic capacitor (MnO2 type)	Aluminum electrolytic capacitor (electrolyte type)
Appearance						
Maximum capacitance	~330µF	~560µF	~1,000µF	~3,900µF	~2,200µF	~10,000µF
Size	◎	○	○	×	○	×
ESR/Z SRF	◎	○	△	△	×	×
Ripple current heating	◎	○	△	△	×	×
Temperature characteristics	△	◎	◎	◎	◎	○
DC bias characteristics	△	◎	◎	◎	◎	◎
Long-term reliability	◎	○	○	○	△	△
Polarity	Non-polar	Polar	Polar	Polar	Polar	Polar

Portfolio of Over 100µF MLCCs

Murata Manufacturing has commercialized several types of over 100µF multi-layer ceramic capacitors (maximum capacitance: 330µF), while already offering 2.0 × 1.25mm X5R 4V 100µF, 3.2 × 1.6 mm X5R 6.3V 100µF, and 3.2 × 1.6mm X5R 4V 220µF products., Table 2 shows a portfolio of over 100µF multi-layer ceramic capacitors.

In addition to X5R capacitors suitable for general consumer products (operating temperature range: -55 to 85°C), Murata Manufacturing has launched X6* capacitors for high power consumption, high temperature applications (operating temperature range: -55 to 105°C). The development of other higher-capacitance products is also being planned.

Impedance Comparison

The power lines of low-voltage high-speed semiconductor devices used in today's digital devices need to reduce voltage fluctuation associated with ripple voltage and load fluctuation in order to ensure operational stability. This requires smoothing capacitors with both 100µF or more capacitance and low impedance, and so conductive-polymer electrolytic capacitors have been mainly used. Now, the expanded portfolio of over 100µF multi-layer ceramic capacitors has allowed replacement of the conductive-polymer electrolytic capacitors.

If multi-layer ceramic capacitors replace conductive-polymer electrolytic capacitors, the former can have a lower capacitance than the latter. This is because multi-layer ceramic capacitors have lower impedance and ESR and so have higher responsiveness to voltage changes. Figure 2 shows the impedance and ESR-frequency characteristics of typical conductive-polymer tantalum electrolytic capacitors and multi-layer ceramic capacitors. The figure indicates that in the frequency range over 100kHz, which is a switching frequency for power ICs used in digital devices, multi-layer ceramic capacitors have lower impedance and ESR than conductive-polymer tantalum electrolytic capacitors, even if the former have a lower capacitance than the latter.

Also, multi-layer ceramic capacitors are effective in suppressing high-frequency noise because at frequencies higher than the resonance frequency, they have much lower impedance than conductive-polymer tantalum electrolytic capacitors.

Table 2: Portfolio of over 100µF multi-layer ceramic capacitors (as of August 2015)

(X5R : -55 to 85ºC)

Legend: red = Under development; green = New product; blue = In mass production

Size (Inch)	Rated Volt (V)	Capacitance (µF) 100	150	220	330	470
2012 (0805)	4	In mass production				
	6.3	New product				
3216 (1206)	2.5			In mass production	Under development	
	4	In mass production	New product	In mass production	Under development	
	6.3	In mass production	New product	New product		
3225 (1210)	2.5				New product	Under development
	4			New product	New product	Under development
	6.3	In mass production		New product		

(X5R : -55 to 105ºC)

Legend: red = Under development; green = New product; blue = In mass production

Size (Inch)	Rated Volt (V)	Capacitance (µF) 100	150	220	330	470
2012 (0805)	2.5	In mass production				
	4	New product				
3216 (1206)	2.5		New product	New product		
	4	In mass production	New product	New product		
3225 (1210)	2.5			New product	New product	Under development
	4	In mass production		New product		
	6.3	In mass production				

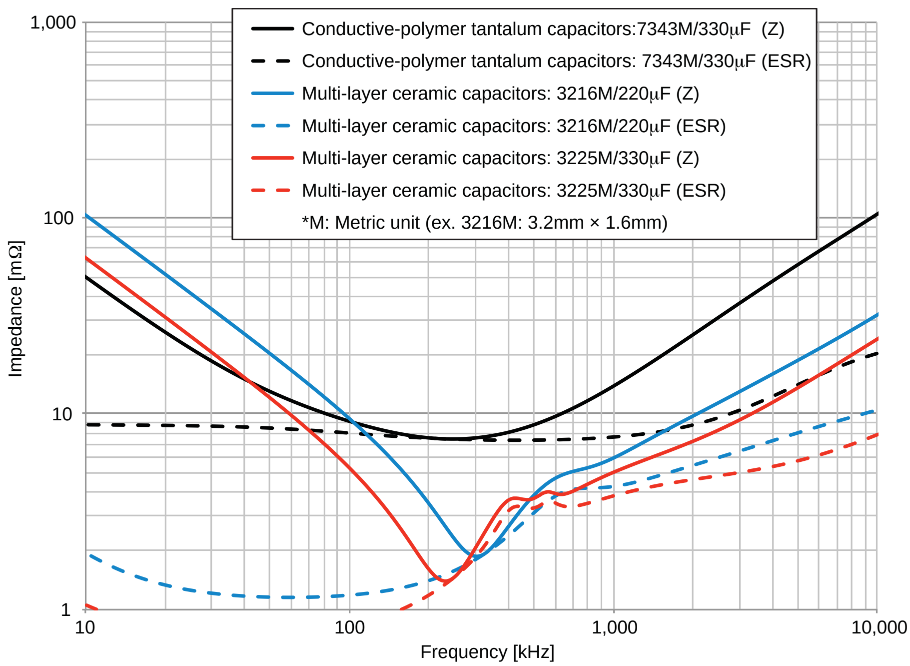


Figure 2: Comparison in impedance/ESR-frequency characteristics

Capacitor Replacement Test

An examination was carried out on capacitor replacement using an evaluation board for double data rate (DDR) power ICs for PCs. Figure 3 shows the evaluation circuit and the examination results. In this evaluation board, DC 1.4V voltage was used, and two conductive-polymer tantalum electrolytic capacitors (7.3 × 4.3mm, 2.0V, 330µF, M tolerance) were initially used as smoothing capacitors. Then, these capacitors were replaced with 150µF and 220µF multi-layer ceramic capacitors (3.2 × 1.6mm, 6.3V, M tolerance) to examine voltage fluctuation associated with changes in ripple voltage, spike voltage, and load. Before this examination, phase adjustments were made to ensure the stability of the evaluation board.

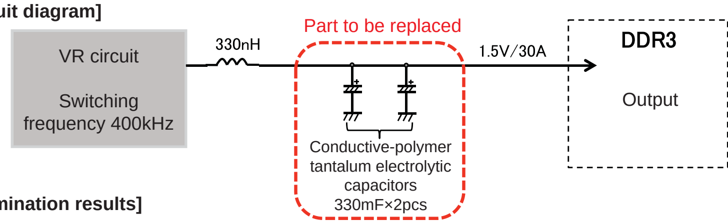
The results showed that multi-layer ceramic capacitors tend to have a lower ripple voltage even though they have a lower nominal capacitance than conductive-polymer tantalum electrolytic capacitors. This is probably because at the switching frequency, multi-layer ceramic capacitors have low impedance and ESR, and so cause voltage fluctuation to decrease. The results also showed that multi-layer ceramic capacitors tend to have a lower spike voltage in a similar manner. This is probably because they have low ESL, and as a result, suppress high-frequency noise.

However, in a load change test where current was changed significantly, there was a large voltage fluctuation when 150µF multi-layer ceramic capacitors were used. This is probably because the load change test has a correlation with the effective capacitance of capacitors obtained when voltage is applied. The multi-layer ceramic capacitors used in this test have a lower nominal capacitance than the conductive-polymer tantalum electrolytic capacitors, and their effective capacitance is decreased by DC bias characteristics; this is the reason for the large voltage fluctuation in this test. However, voltage fluctuation was able to be reduced by using 220µF high-capacitance capacitors.

Conclusion

As the use of low-voltage semiconductor devices has been rapidly increasing, conductive-polymer electrolytic capacitors featuring high capacitance and low ESR have been widely used as smoothing capacitors for power ICs that supply DC power to the semiconductor devices. Size reduction and long-term reliability, however, are considered more important for other devices that use these semiconductor devices, such as server computers, and they are also important for smoothing capacitors. There is, therefore, a demand for expansion of over 100µF multi-layer ceramic capacitors that can be more easily miniaturized, are more reliable, and feature low impedance, ESR, and ESL. As there have been a number of business inquiries about such capacitors, Murata Manufacturing is confident that further expansion of the portfolio in the future will contribute to development of the electronic component market.

[Circuit diagram]



[Examination results]

Examination item	Stability			Ripple/spike		Load change
	Phase margin (deg)	Gain margin (dB)	Crossover frequency (kHz)	Ripple voltage (mVpp)	Spike voltage (mVpp)	0A→20A→0A Overshoot/ Undershoot (mV)
Initial state Conductive-polymer tantalum electrolytic capacitors 330µF × 2pcs	58.3	−10.2	44.7	**12.8**	**169**	**162**
Case 1 Multi-layer ceramic capacitors 3.2 × 1.6mm/150µF × 2pcs	51.0	−8.07	75.0	10.8	149	173
Case 2 Multi-layer ceramic capacitors 3.2 × 1.6mm/220µF × 2pcs	49.1	−8.43	72.4	9.74	147	155
Target values	≧45deg	≦−7dB	≦80kHz (≦1/5fsw)	≦Initial	≦Initial	≦Initial

Figure 3: Examination on replacement of conductive-polymer tantalum electrolytic capacitors

End Notes:

*[*1.] ESR: A numerical component of the impedance of a capacitor*

*[*2.] ESL: A small inductance component of a capacitor that will dominate impedance in a frequency range above the resonance frequency.*

*[*3.] SRF: Frequency obtained when the reactance of a capacitor is 0.*

About This Article:

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