Advances in Material Technology Enable Game-Changing MLCC Performance

INTRODUCTION

Although electrolytic capacitors have long been the preferred solution for decoupling applications where capacitance greater than 100µF is required, these devices have intrinsic reliability and service-life issues and are often the first components to fail. Advances in multilayer ceramic capacitor (MLCC) technology now offer designers a high-capacitance alternative to traditional electrolytic capacitors. New high-value MLCCs provide the advantages of lower equivalent series resistance (ESR) and inductance (ESL) than electrolytics, and demonstrated mean time to failure (MTTF) of 10,000 to over 1,000,000 years. Applications for high-value MLCCs include automotive electronics, medical electronics and industrial equipment.

This paper describes the material science behind TAIYO YUDEN's advanced MLCC products. It also presents comparative performance and price data to show how these ceramic capacitors afford significant benefits over polymer capacitors.

HIGH CAPACITANCE MLCCS VS. POLYMER CAPACITORS

High-capacitance MLCCs provide significant improvements over equivalent polymer capacitors. Comparisons of performance and price demonstrate the potential for MLCCs to displace polymer capacitors in designs that require high-capacitance values and/or other system-level improvements.

Performance Comparisons

Aside from the mechanical advantages that the solid-state nature of the MLCC topology provides in comparison to electrolytic devices, a number of significant electrical performance improvements are also evident.

Lower ESR and ESL

Figure 1 shows the lower equivalent series resistance (ESR) and equivalent series inductance (ESL) of 100µF, 220µF and 330µF MLCCs compared with a 330µF polymer capacitor. In addition to the reduced system losses from lower ESR and ESL values, the case size and printed circuit board footprint of the MLCCs are dramatically smaller as well.

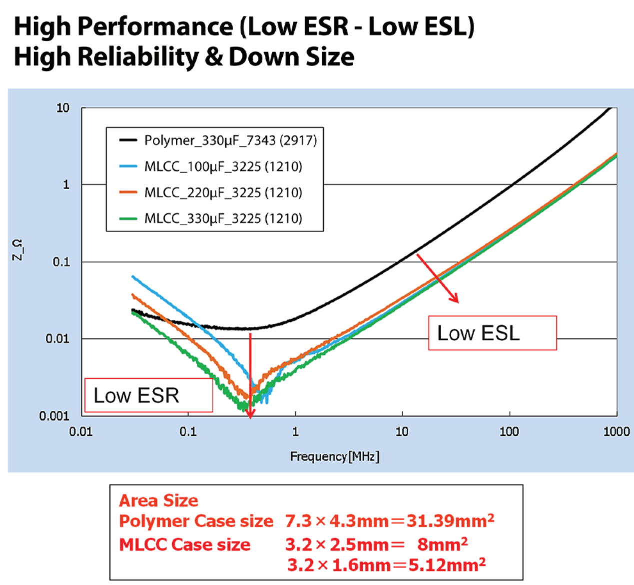
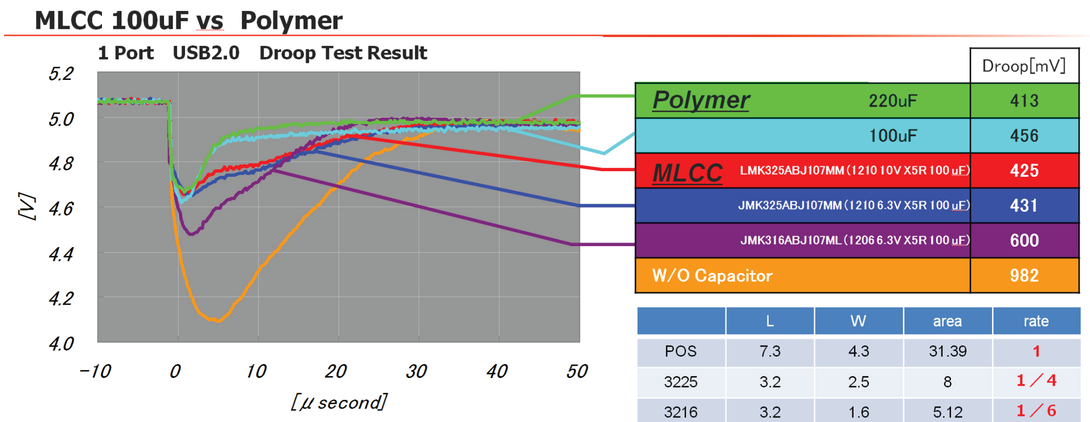


Figure 1. MLCCs of 100µF, 220µF and 330µF compared with a polymer capacitor

Comparable Results in Droop Test with More Compact MLCCs

In a specific application, MLCCs can provide performance similar to polymer capacitors while significantly reducing the mounting footprint. Figure 2 shows the results comparing competitive polymer devices with a selection of 100uF MLCCs in a droop test. (Note how the MLCCs provide similar results with footprints of ¼th to 1/6th the size.)

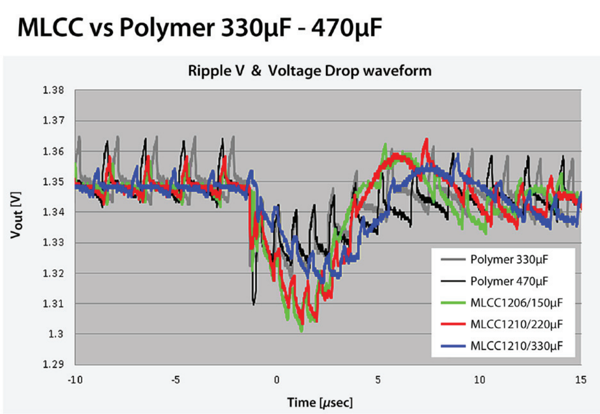


	L	W	area	rate
POS	7.3	4.3	31.39	1
3225	3.2	2.5	8	1／4
3216	3.2	1.6	5.12	1／6

Figure 2. **Droop test performance of MLCCs similar to comparable electrolytics**

Comparable Ripple Performance with Smaller Case Sizes

Figure 3 shows the ripple voltage and voltage drop waveforms of 150μF, 220μF and 330μF MLCCs compared with 330μF and 470μF polymer devices. The ripple voltage of the 150μF MLCCs is similar-to-slightly-improved compared with polymer devices, and with the 220μF and 330μF MLCCs ripple performance is significantly improved. Again, although providing the same or better performance, MLCCs provide a more compact package.



Test Condition PMIC: MAX1717 | Fsw: 550kHz | Vin: 10V | Vout: 1.35V
Light Load: 1A | Heavy Load: 6A | 1.35 V | +5% = 1.42 V | -5% = 1.28

Polymer	MLCC	1206 (3216)	1210 (3225)
2917inch (7343) Case Size: 7.3 × 4.3mm = 31.39mm²	• Nonpolar • Down size • Low ESL • Low ESR	Case Size: 3.2 × 1.6mm = 5.12mm²	Case Size: 3.2 × 2.5mm = 8mm²

Figure 3. **MLCCs of 100μF, 220μF and 330μF compared with a polymer capacitor**

Exceptional Stability over High Frequency Range

One of the more dramatic improvements provided by MLCCs occurs with the reduced change of capacitance over frequency. Figure 4 compares frequency characteristics of MLCCs and polymer designs. Over a frequency range of 100Hz to 100MHz, four MLCCs varied by only 8% to 12%, compared to an 18% to 80% change in six polymer devices.

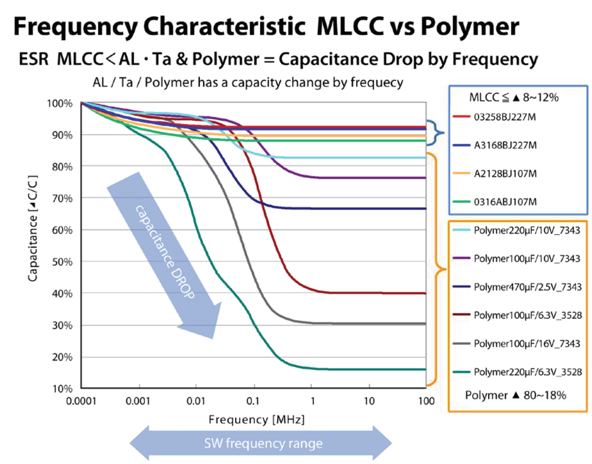


Figure 4. **Frequency impact on the capacitance values of MLCCs compared with polymer capacitors**

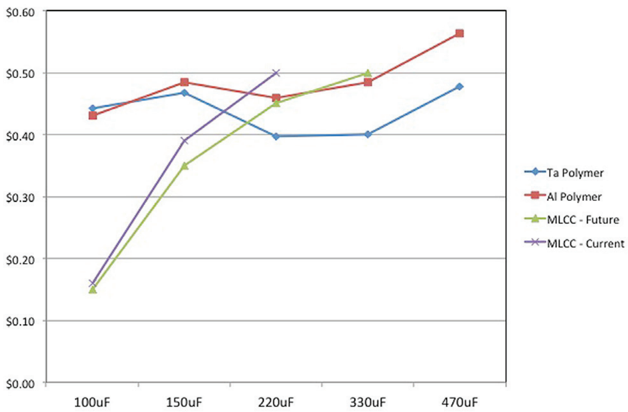


Figure 5. Advantages of MLCCs come at price points comparable to polymer capacitors. (Price comparison based on market study. Actual prices may vary.)

Price Comparisons

Higher value MLCCs are comparable in cost to polymer capacitors, as shown in Figure 5. As capacitance values increase, MLCCs continue to be highly competitive with polymer capacitors. Yet, at all price points, MLCCs improve designs by offering a nonpolar design approach that simplifies manufacturing processes, decreases ESR, ESL and reduces footprint.

MLCC APPLICATION EXAMPLES

MLCCs offer improvements in performance over electrolytics that include both physical size and electrical advantages. Additionally, in some applications, comparable performance can be achieved with a lower capacitance (and even smaller) MLCC.

Power Supply Output Voltage Stabilization

To achieve improved efficiency, today's digital products are increasingly equipped with switching-type power supplies. These power supply circuits use combinations of high-value capacitors to smooth the output and ensure the stable operation of other circuitry within the end product. Figure 6 shows an example of using MLCCs to improve the waveforms in a step-down converter.

The important benefits of high-value MLCC technology in this application are the significant reduction in component size and the reduction in both ESR and ESL when compared with electrolytics. Figure 6 depicts low ESR and ESL of capacitors contribute to reduced ripple currents.

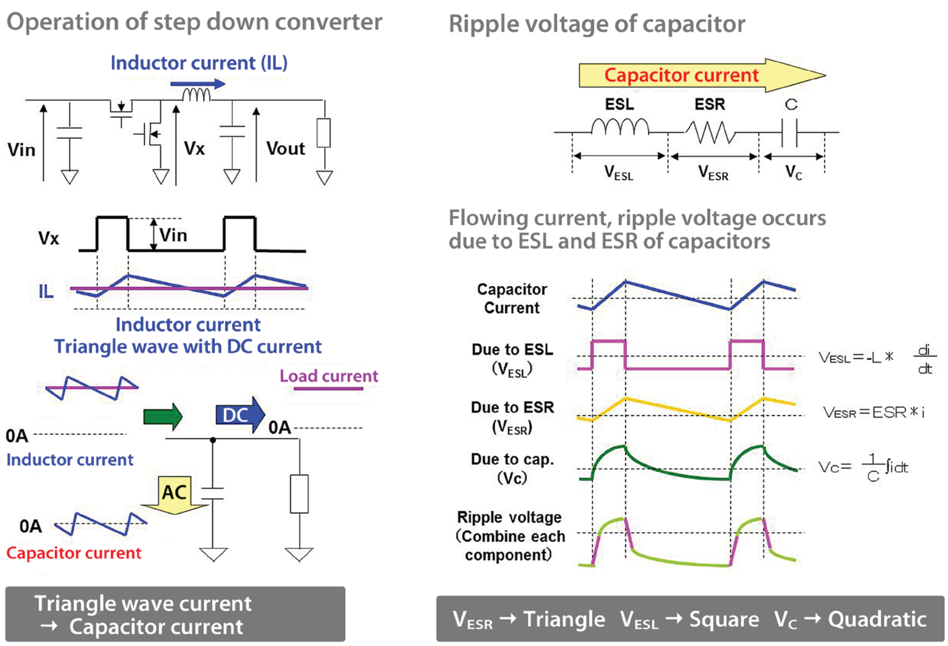


Figure 6. Ripple voltage occurrence mechanism in a step-down converter due to ESR and ESL of capacitors

Noise Filtering

At high frequencies, an MLCC can filter RF noise and minimize the disruptive impact of high frequency spikes on other circuitry. Figure 7 shows an example of this application. The MLCC's better performance over a wider frequency range combined with low ESR and ESL make it well-suited for this application.

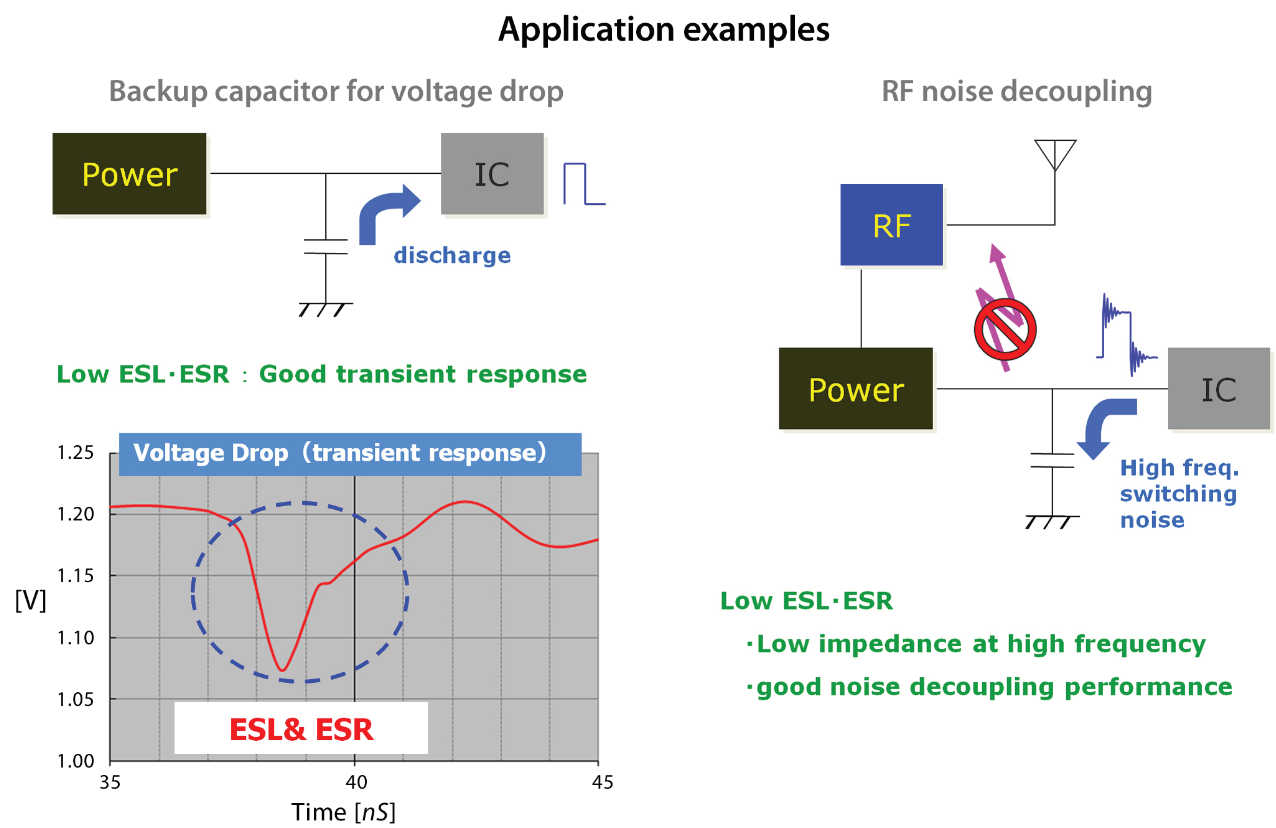


Figure 7. **RF noise decoupling benefits of using MLCCs**

TAIYO YUDEN MLCC PRODUCT EVOLUTION AND TECHNOLOGY

Figure 8 illustrates the evolution of mass-produced, high-capacitance MLCCs in various industry-standard packages. As is shown, the trend in MLCCs has been toward higher capacitance and shrinking form factors. TAIYO YUDEN is the industry leader in providing increased capacitance, multilayer ceramic capacitors.

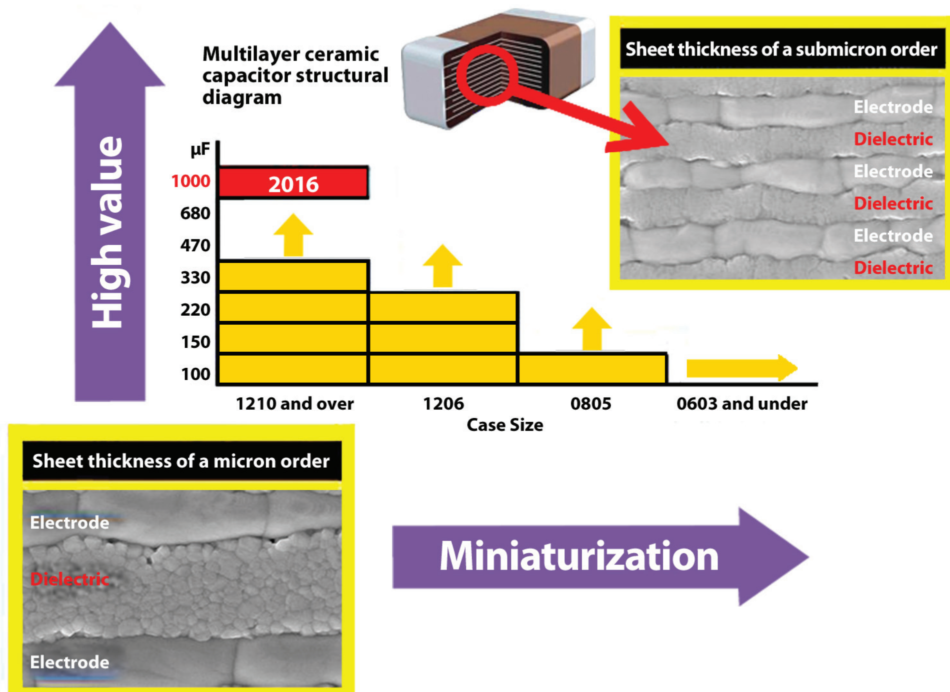


Figure 8. **The trend in MLCC technology toward smaller size and higher capacitance**

In September 2013, the company was the first to produce 330μF MLCCs and, a year later, 470μF devices were announced. With accelerated development, the company promises to add even higher capacitance devices in the near future. TAIYO YUDEN's developments in MLCC technology, including best-in-class micro-fabrication technology as well as world-leading, high-precision layering techniques have yielded a ten-fold increase in capacitance in just the past five years. Figure 9 illustrates the history of TAIYO YUDEN MLCCs over the past 30 years.

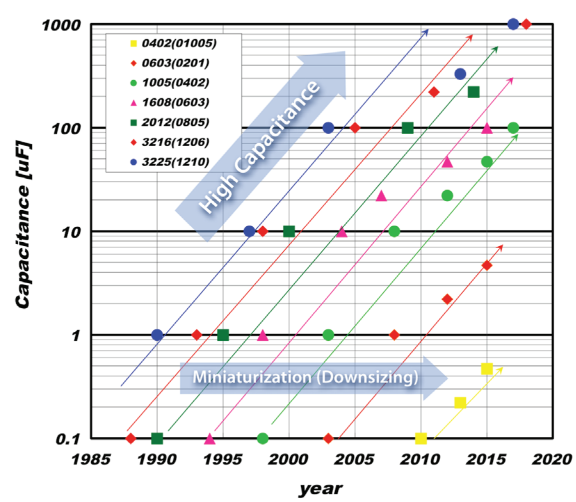


Figure 9. **TAIYO YUDEN history of MLCC mass production**

MATERIAL SCIENCE DRIVES IMPROVED PERFORMANCE

MLCCs require a variety of key technologies to achieve increasingly higher values. As shown in Figure 10, these technologies include:

- Super-fine powder technology
- Core-shell structure
- Thin layer technology
- Printing technology
- Multilayer technology
- Simulation technology

Advances in each of these areas contribute to TAIYO YUDEN's ability to achieve the highest value MLCCs in the industry.

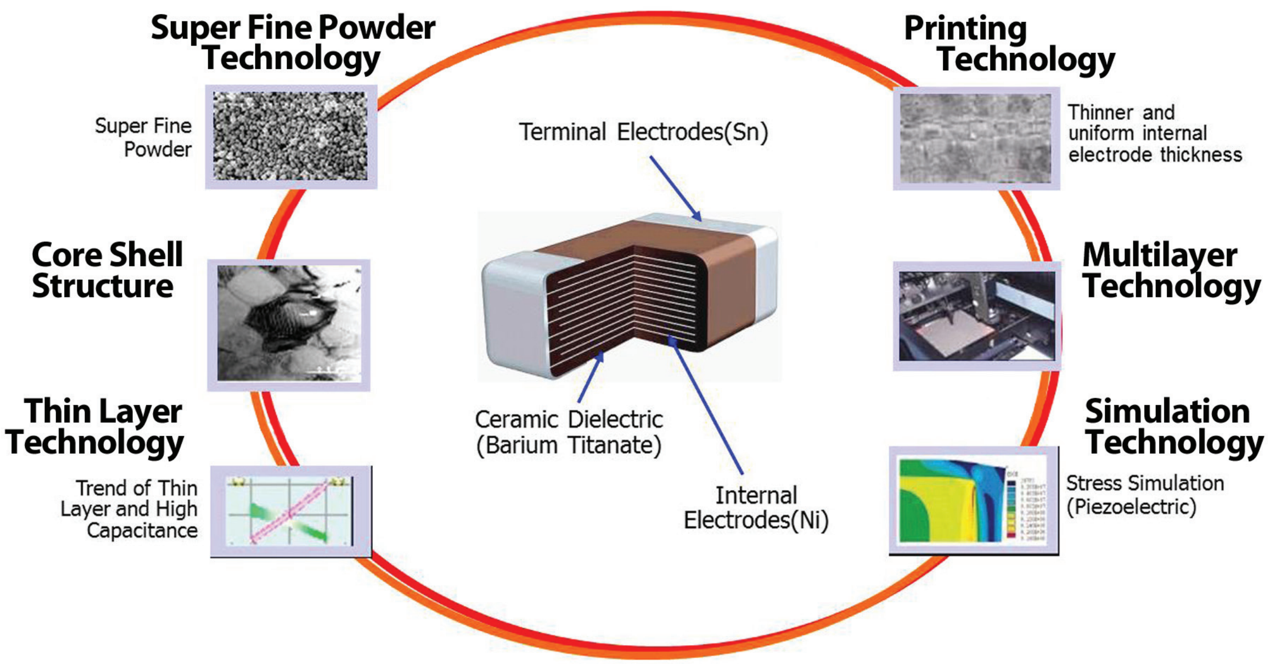


Figure 10. **Key technologies for MLCCs to achieve high capacitance values**

TAIYO YUDEN MATERIAL TECHNOLOGY

The thickness of the sheet of a single layer material used in super high-end products has shrunk from microns to submicrons. TAIYO YUDEN'S near-term target for the next technology innovation is to produce a 1000µF ceramic capacitor by 2016. With the recent successes of introducing the 330µF in 2013 and a 470µF in 2014, significant progress is being made toward this goal.

Barium titanate is the key raw material that allows TAIYO YUDEN to continue its quest to provide the market with small-size, high-volume and high-value products from the raw material level through all phases of manufacturing. Figure 11 shows the manufacturing method and the element-level technology of the EIA Class 2 MLCCs.

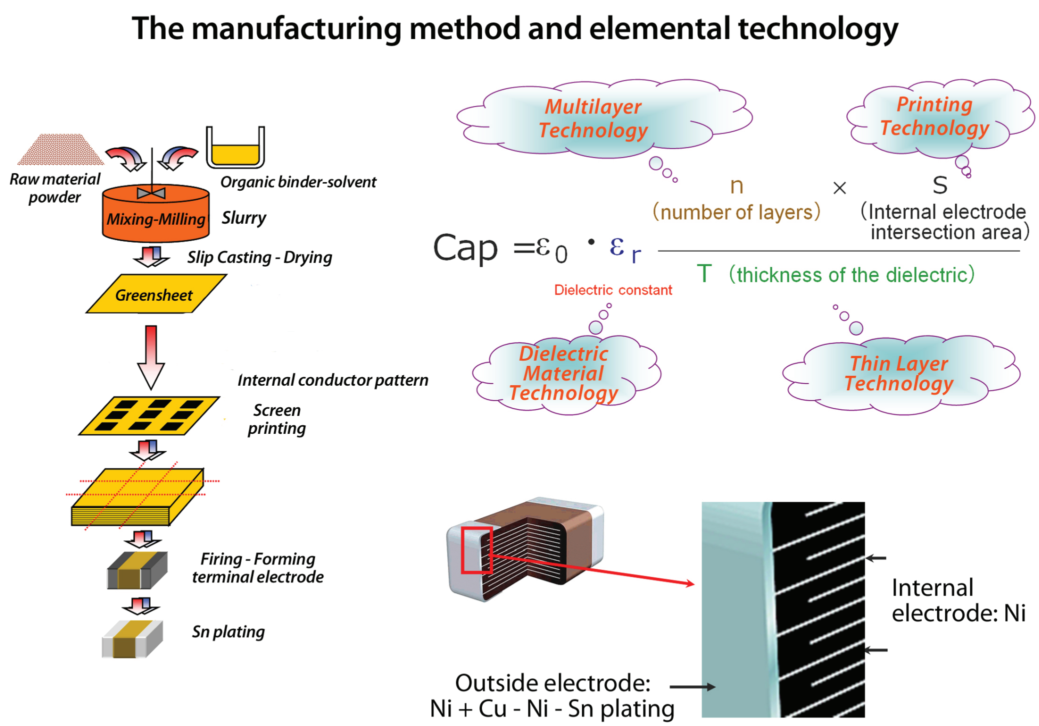
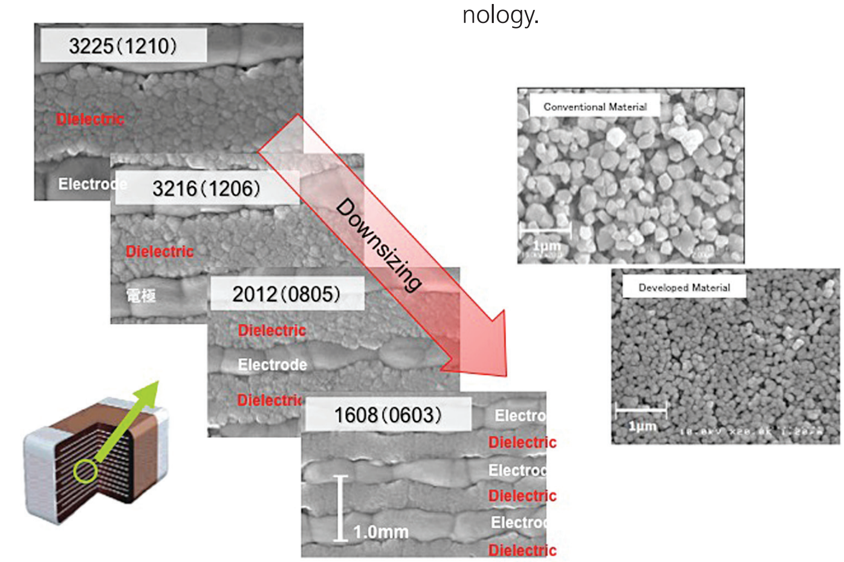


Figure 11. The manufacturing method and elemental technology for TAIYO YUDEN MLCCs

The core technology that enables the high-volume manufacturing of compact and high capacitance products is the ability to make both thin and uniform dielectrics. By controlling the thickness of dielectrics, TAIYO YUDEN currently has technology that exhibits insulation properties in regions less than one-micron thick.

Figure 12. TAIYO YUDEN'S core technology results in more compact and higher capacitance MLCC products.



Refining and advancing the technology to manufacture thin and uniform sheets occurs by controlling the powder from the synthesis of the raw materials to dispersion, and the total process of laminating, firing and then finishing these sheets. Figure 12 shows the decreases in dielectric and electrode that result from increasing finer powder and uniform-sheet technology.

Producing MLCCs with values well above 100µF requires extensive research in laboratory and manufacturing technology. This knowledge is essential for achieving accurate laminations as well as for overcoming the challenges of firing an increasing numbers of layers.

TAIYO YUDEN MLCC ENHANCEMENTS

Acoustic Noise Suppression

The ferroelectric ceramic materials commonly used in high capacitance-type MLCCs can result in mechanical distortions when an electric field is applied. With an AC voltage, the capacitor vibrates and transmits this vibration to the substrate creating an audible sound. In response to this issue, TAIYO YUDEN has developed acoustic noise-suppression dielectric materials that are used in commercialized capacitors to reduce the acoustic noise.

These acoustic noise-reducing products also provide a small capacitance decrease due to the DC bias voltage, making them ideal for use in the power circuits of notebook PCs. For example, in measurements using a voltage waveform across an actual circuit, it was confirmed that there is a sound pressure reduction effect compared with products with regular X5R characteristics, as shown in Figure 13.

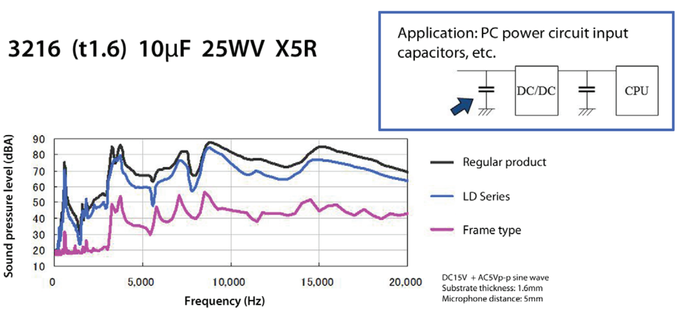


Figure 13. MLCCs with acoustic noise-reduction measures to reduce sound pressure levels

Soft Termination

Figure 14 shows the design elements of the external electrodes for MLCCs, including soft-termination aspects. A soft termination provides heat cycle resistance and resistance to substrate bending.

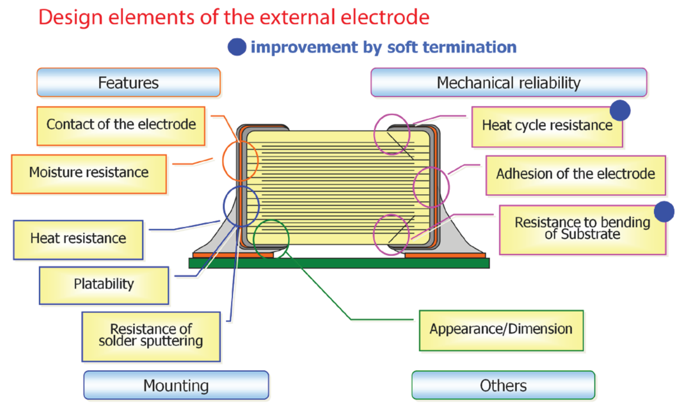


Figure 14. MLCCs' soft-termination provides heat-cycle resistance and resistance to substrate bending.

TAIYO YUDEN HIGH-VALUE MLCC PRODUCTS

Using proprietary technologies and extensive development of raw material, TAIYO YUDEN continues to introduce small-size, high-volume MLCCs. A multi-layered structure with more than 1200 layers has resulted in a capacitance of 470µF in a EIA 1812 case size. Tables 1 and 2 show the specifications of the newest MLCCs with values above 100µF.

In addition to the capacitance value, the other important characteristics required when specifying an MLCC include: maximum voltage rating, thickness, EIA/JIS case size and temperature rating, and temperature coefficient (capacitance change). The temperature coefficient identifies how much the MLCC will change over the operating temperature range. Popular ratings include: X5R (-55°C to +85°C with ±15%), X6S (-55°C to +105°C with ±22%), X7R (-55°C to 125°C with ±15%), and X7S (-55°C to 125°C with ±22%).

TABLE 1 HIGH VALUE MLCCS FOR GENERAL APPLICATIONS

Capacitance	Case Size EIA	Rated Volt. (Vdc)	Temperature Characteristics	Capacitance Tolerance	Part Number
100 µF	0805	2.5	X5R	±20%	PMK212BBJ107MG-T
100 µF	1206	4	X5R	±20%	AMK316ABJ107ML-T
100 µF	1206	4	X6S	±20%	AMK316AC6107ML-T
100 µF	1206	6.3	X5R	±20%	JMK316ABJ107ML-T
100 µF	1210	6.3	X5R	±20%	JMK325ABJ107MM-T
100 µF	1210	6.3	X7S	±20%	JMK325AC7107MM-T
100 µF	1210	6.3	X6S	±20%	JMK325AC6107MM-T
100 µF	1210	10	X5R	±20%	LMK325ABJ107MM-T
150 µF	1206	4	X5R	±20%	AMK316BBJ157ML-T
150 µF	1210	4	X5R	±20%	AMK325ABJ157MM-T
150 µF	1210	4	X6S	±20%	AMK325AC6157MM-T
150 µF	1210	6.3	X5R	±20%	JMK325ABJ157MM-T
220 µF	1206	2.5	X5R	±20%	PMK316BBJ227ML-T
220 µF	1210	2.5	X6S	±20%	PMK325AC6227MM-T
220 µF	1210	4	X5R	±20%	AMK325ABJ227MM-T
220 µF	1210	4	X6S	±20%	AMK325AC6227MM-T
220 µF	1210	6.3	X5R	±20%	JMK325ABJ227MM-T
330 µF	1210	2.5	X6S	±20%	PMK325AC6337MM-T
330 µF	1210	4	X5R	±20%	AMK325ABJ337MM-T
470µF	1812	2.5	X6S	±20%	PMK432AC6477MM-T
470µF	1812	4	X5R	±20%	AMK432ABJ477MM-T

TABLE 2 HIGH VALUE MLCCS FOR HIGH-RELIABILITY APPLICATIONS – AEC-Q200 QUALIFIED

Capacitance	Case Size EIA	Rated Volt. (Vdc)	Temperature Characteristics	Capacitance Tolerance	Part Number
100 µF	1206	4	X5R	±20%	AMK316ABJ107MLHT
100 µF	1206	6.3	X5R	±20%	JMK316BBJ107MLHT
100 µF	1210	4	X5R	±20%	AMK325ABJ107MMHT
100 µF	1210	6.3	X5R	±20%	JMK325ABJ107MMHT
220 µF	1210	4	X5R	±20%	AMK325ABJ227MMHT

In addition to ultra-small capacitors and high-volume capacitors, the TAIYO YUDEN portfolio includes special types of capacitors such as low ESL capacitors, capacitors for high-frequency applications, high-voltage capacitors and array-type capacitors.

CONCLUSION

Due to the advantages provided by multilayer ceramic capacitors, MLCC devices have proven their ability to replace polymer capacitors in many consumer, industrial and automotive applications. Increasingly higher-value MLCCs are poised to bolster this trend. With demonstrated leadership in turning laboratory breakthroughs into high-volume production, TAIYO YUDEN is setting the pace in the evolution of high-value MLCCs. Today, the company recognizes critical market need for super-high-end technologies. Its goal is to complete and make available a 1000μF ceramic capacitor in 2016 by developing even more advanced microstructures that enable higher capacitance values in MLCC products.

REFERENCES

High Value Cap landing page
http://www.yuden.co.jp/ut/solutions/mlcc/

TAIYO YUDEN Starts the Commercialization of the World's First 470μF Multilayer Ceramic Capacitor, http://www.yuden.co.jp/ap/cms/wp-content/uploads/2014/09/25131679f6a431f5a509e0761b462c59.pdf