

MLCC Technology Advances Open New Market Opportunities

INTRODUCTION

Until recently, the multilayer ceramic capacitor (MLCC) market has been driven primarily by consumer electronics devices such as televisions, personal computers and peripherals, digital still cameras, camcorders, mobile phones, and smartphones. However, the emergence of the Internet of Things (IoT) is creating new and diverse markets for electronic components.

High-capacitance MLCCs are an ideal solution for IoT devices because of their intrinsic reliability and long service life. They have a demonstrated mean time to failure (MTTF) of 10,000 to over 1,000,000 hours and provide low equivalent series resistance (ESR) and inductance (ESL). MLCC demands will continue to grow in these emerging markets, but with needs and requirements that are different from the conventional consumer electronics industry.

Applications for high-capacitance MLCCs include automotive electronics, medical electronics, and industrial equipment. This paper describes the advantages of TAIYO YUDEN's highly-reliable MLCC products in these new, emerging products.

RELIABILITY GRADES

TAIYO YUDEN offers three different MLCC reliability grades to address customers' varying product needs and requirements:

- General Environment
- Industrial / Automotive
- High Reliability

General Environment

MLCCs with a *General Environment* reliability grade are used in applications that typically have a life expectancy of three to ten years and operate in environments with a modest ambient temperature. Such applications can include PC servers, indoor wireless access points, surveillance cameras, and other consumer electronics devices.

Industrial / Automotive

MLCCs with an *Industrial / Automotive* reliability grade are used in applications that have a life expectancy of more than ten years and operate in harsher environments, with ambient temperatures that can reach 85°C. The applications often require very low component failure rates. Typical applications can include telecom networking systems, factory automation equipment, outdoor wireless access points, and automobile navigation systems.

High Reliability

MLCCs with a *High Reliability* grade are used in applications that have the highest life expectancy, sometimes more than fifteen years. They often have the harshest operating environments, with ambient temperatures that can reach 125°C, and also have strict requirements for low failure rates. Typical applications can include medical devices that are used for medical operations, and automobile electronic control units that are critical to vehicle operation and performance. These parts come with a certificate of conformance.

INDUSTRIAL GRADE REQUIREMENTS

As mentioned above, consumer electronics devices typically have modest operating requirements whereas industrial, automotive, and medical applications have much longer operating lives, are deployed in harsher environments, and require lower failure rates. Table 1 shows some examples of operating requirements for various applications. *General Environment* reliability grade MLCCs meet the requirements of the first two applications. *Industrial / Automotive* or *High Reliability* grade MLCCs are required by the last three applications.

Table 1. Typical Application Operating Requirements

Applications	Operating Life	Field Lifetime	Environmental Temperature
Desktop PC	13000 Hours	5 Years	10 – 30°C
Telecom hand-held device	43800 Hours	5 Years	-40 – 40°C
High-end server	94000 Hours	11 Years	10 – 30°C
Telecom uncontrolled environment	131000 Hours	15 Years	-40 – 85°C
Telecom controlled environment	131000 Hours	15 Years	0 – 70°C

Source: JESD-94, published by JEDEC (Joint Electron Device Engineering Council)

Figure 1 shows an example of the required failure rates over time in consumer devices compared with industrial / automotive devices.

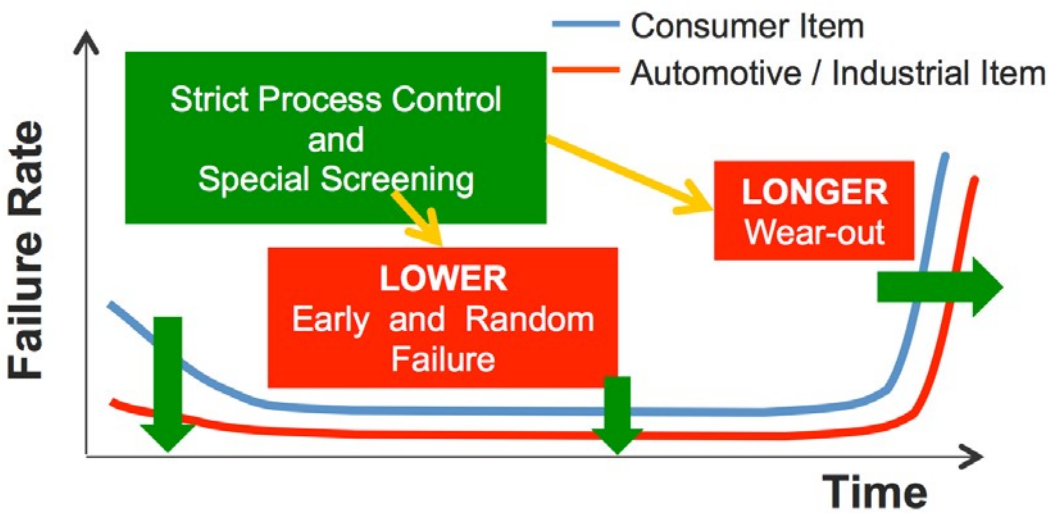


Figure 1. Comparison of Failure Rate over Time

Failure Types

There are three general causes for product failure:

- *Early Failure* is often caused by defects introduced during the manufacturing process. It can also be caused by latent design flaws. Refining the design, improving manufacturing quality, and performing additional product screening after manufacturing can reduce this type of failure.
- *Random Failure* usually results from environmental stresses encountered during operation. Designing with a greater environmental stress margin can lower the random failure rate.
- *Wear-Out Failure* gradually increases over time due to operational “wear and tear”, such as the number of power on/off cycles. Designing for sufficient operational and environmental margin can lengthen product life.

TAIYO YUDEN's *Industrial / Automotive* reliability grade products are designed to minimize the three general causes of product failure. The manufacturing process is strictly controlled to produce highly reliable products, and post-manufacturing screening helps ensure the products meet the quality objectives.

MANUFACTURED FOR INDUSTRIAL-GRADE RELIABILITY

There are several different types of MLCC products and their use in an electrical circuit depends on several application requirements, including the frequency range and circuit voltage. These are shown in Figure 2.

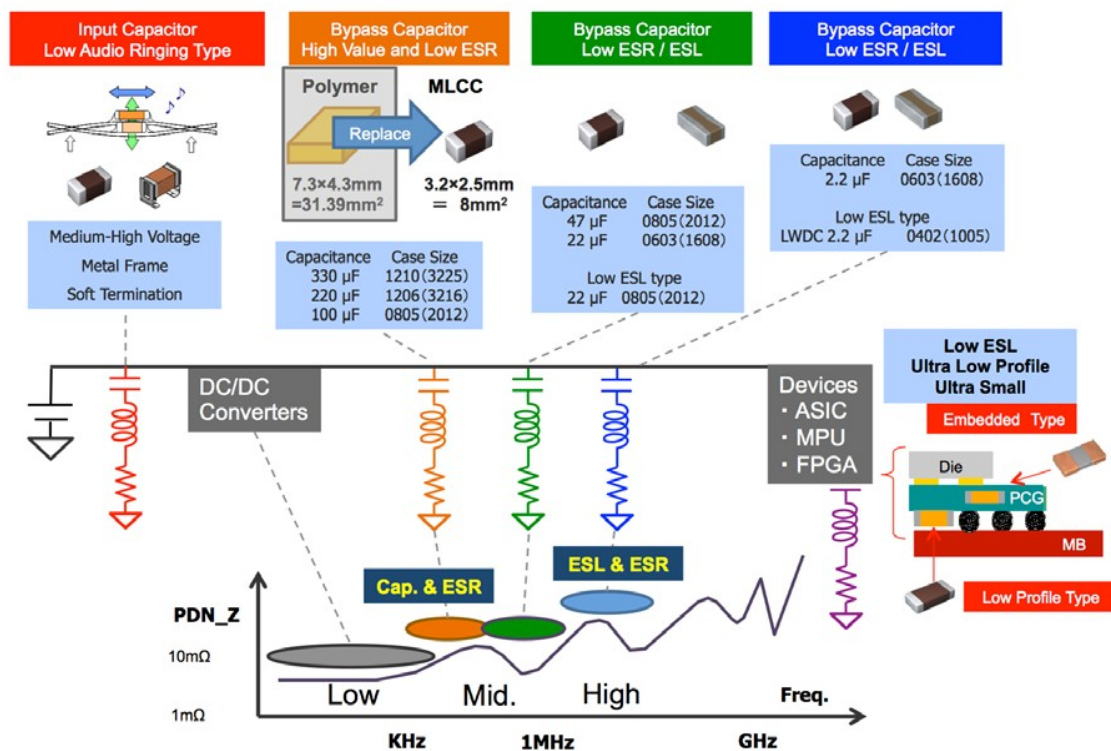


Figure 2. MLCC Product Types

Bypass capacitors with high capacitance values of 100 μF to 330 μF are used in low-frequency applications, such as power supplies. These bulk capacitors are used as supply backup, preventing the supply output from dropping too low when current is not available. Bypass capacitors in middle-frequency decoupling applications have capacitance values of 22 μF to 47 μF . Higher-frequency decoupling applications requiring bypass capacitors for effective current supply and noise suppression have capacitance values of around 2.2 μF . Ultra low-profile, low ESR/ESL capacitors are ideal for applications requiring decoupling capacitors embedded within the package.

Industrial and automotive applications often use higher supply voltages (e.g. 48V) than consumer electronics applications. Medium-high voltage capacitors are used in these circuits. MLCCs with fail-safe features that protect against mechanical stresses are used on the input voltage side to reduce the catastrophic effect of a short circuit failure on the high-power circuit. Frame-lead MLCCs and the addition of a soft termination layer on the MLCC external electrode are two fail-safe features.

MLCC Manufacturing Technologies

A variety of technologies, shown in Figure 3 and Figure 4, are required to manufacture a small, high-value capacitor while maintaining the high quality required by industrial and automotive applications. Dielectric materials are key to making industry-leading MLCCs because they have an effect on both the dielectric constant and reliability. TAIYO YUDEN develops proprietary dielectric materials for each MLCC product to meet the exacting product specifications. For example, thinner dielectric layers enable higher capacitance values but reduce the MLCC's ability to withstand higher voltages. To solve this problem, TAIYO YUDEN uses powder miniaturization technology to produce dielectric material that can withstand higher voltages. Other industry-leading manufacturing technologies are used to produce flat dielectric layers, accurately print electrodes, and precisely stack multiple layers. These are key to producing high-capacitance MLCCs with high reliability.

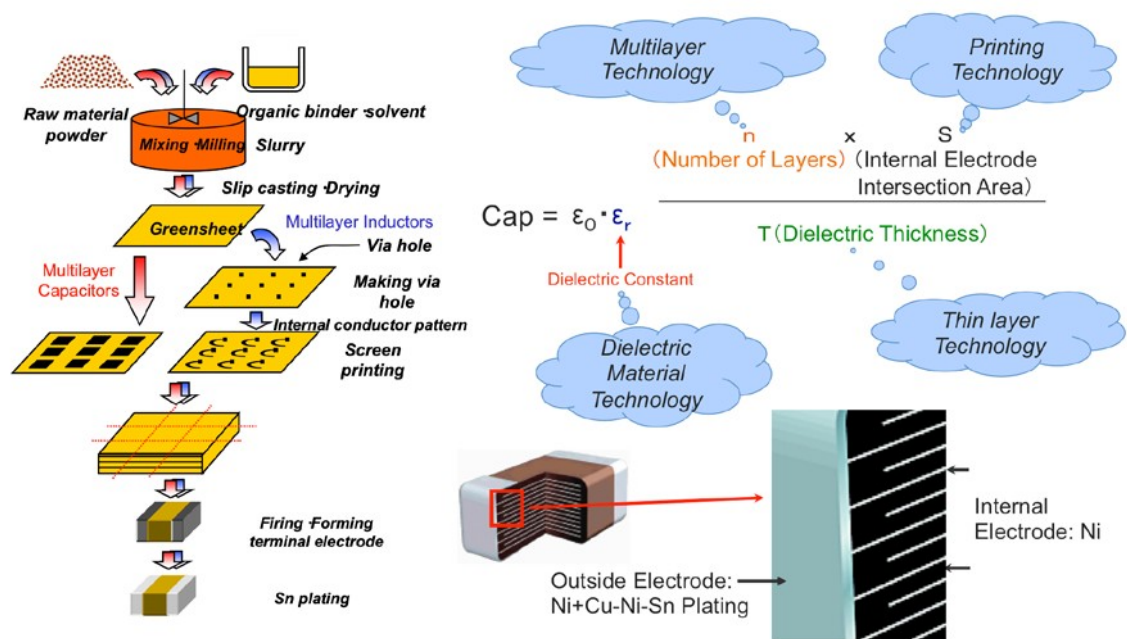


Figure 3. MLCC Manufacturing and Component Technologies

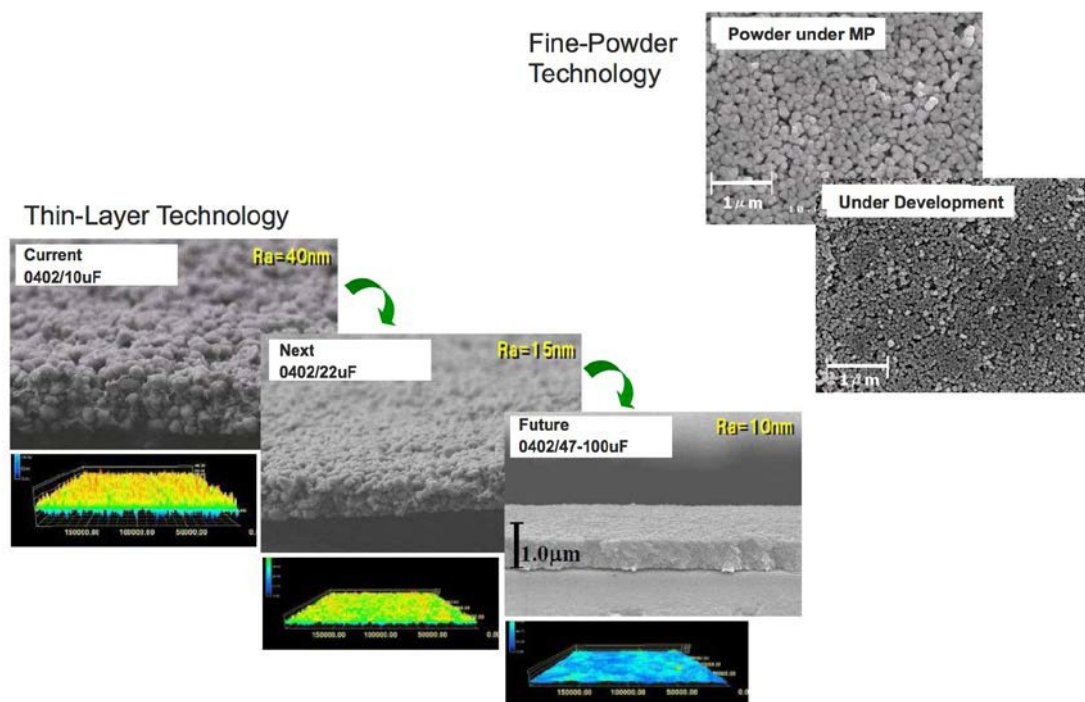


Figure 4. High Capacitance MLCC Thin Layer and Fine Powder Technologies

Small MLCC Form Factors

TAIYO YUDEN is an industry leader in developing and producing high-capacitance MLCCs in small packages. Production of 100 μF MLCCs in 0805 packages and 470 μF MLCCs in 1812 packages is underway. Production of 1000 μF MLCCs in 1812 packages is targeted for 2018. Figure 5 shows the available MLCC form factors and capacitance values. Figure 6 shows the characteristics of the AMK432BJ477MM-T MLCC.

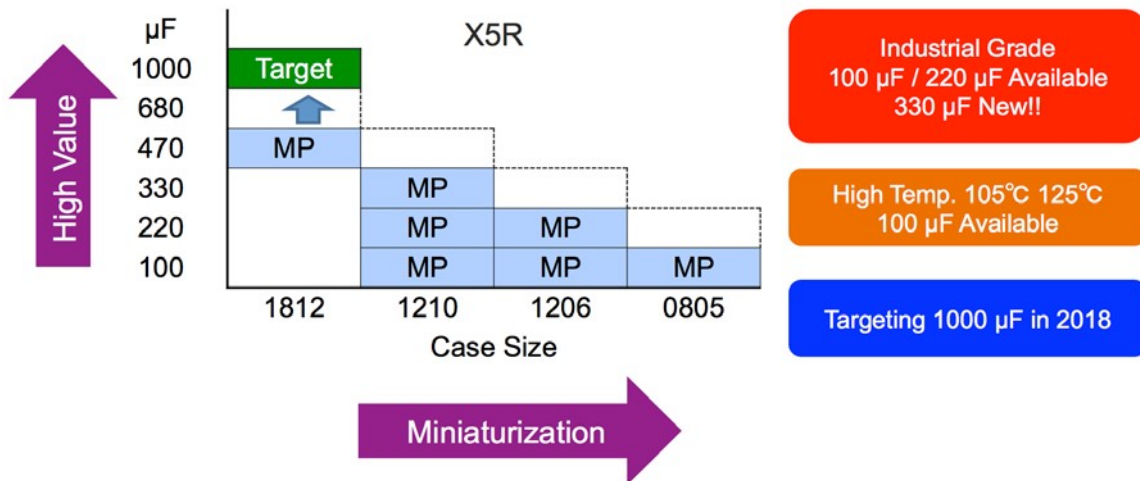


Figure 5. MLCC Form Factors

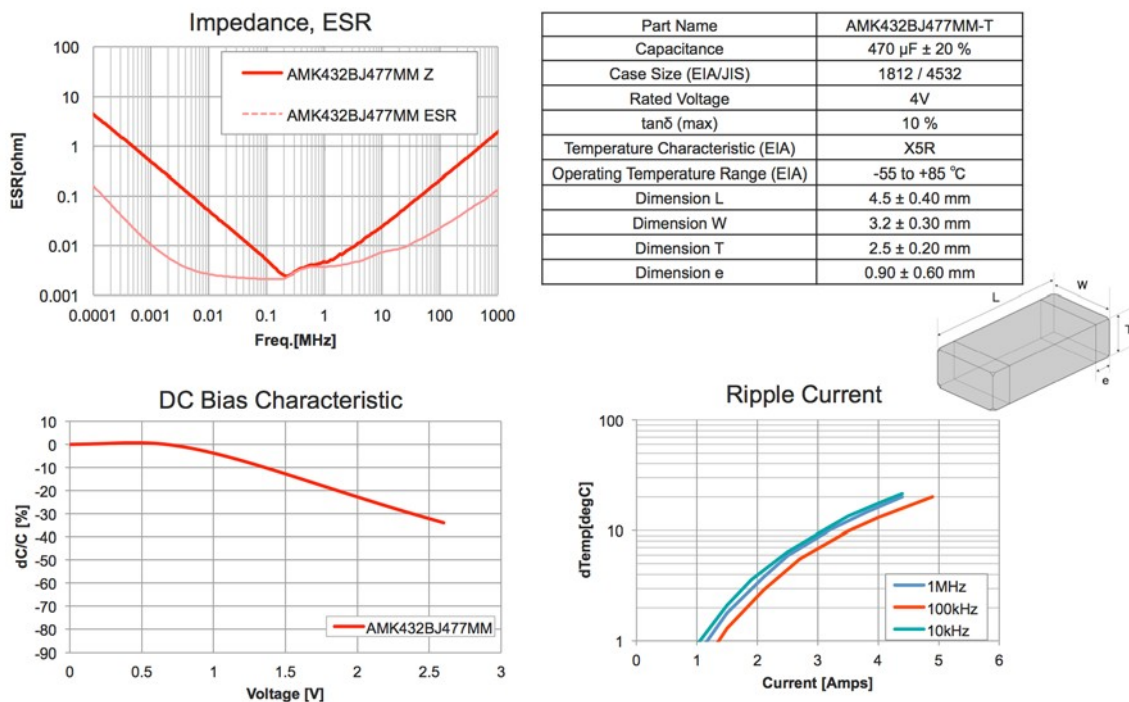


Figure 6. Industry-Leading High Capacitance

Replacing Polymer Capacitors

High-speed signal processing circuits requiring large capacitance have typically used polymer capacitors. Because recent technology advances have increased the capacitance capacity of MLCCs, they are starting to replace polymer capacitors. The smaller MLCC can reduce ripple voltage over certain frequencies more effectively than polymer capacitors, as shown in Figure 7. The 25mΩ in Figure 7 reflects the maximum ESR of a polymer capacitor. There is some variation in ESR and the result in Figure 7 might change with each comparison.

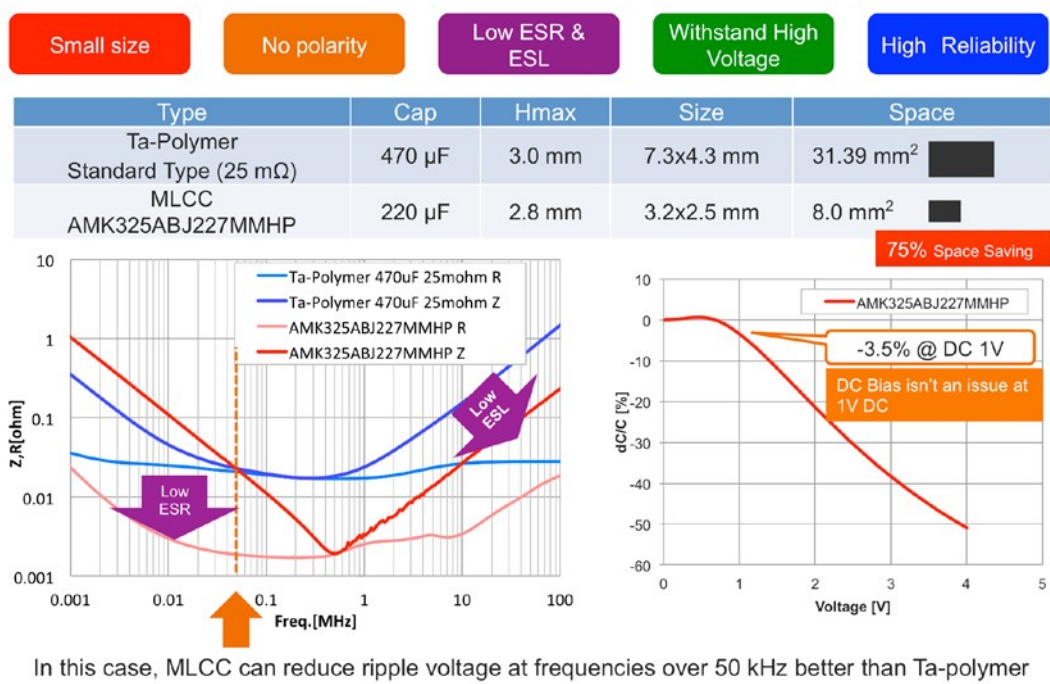


Figure 7. Polymer Capacitor Replacement

Medium-High Voltage and kV Applications

A Power over Ethernet (PoE) circuit that transmits power over an Ethernet cable to network equipment such as a surveillance camera uses many 100V MLCCs on 48V power rail. This application is shown in Figure 8. In addition to PoE circuits, many industrial equipment applications require medium-high voltage MLCCs because of the presence of high-voltage power lines.

TAIYO YUDEN is balancing a number of technical issues in developing MLCCs capable of handling over 1 kV. The primary application of such a device is as an isolation capacitor for an isolated DC/DC power converter. With current technology deployed in the application, increasing the number of internal series

capacitors improves the ability to withstand surge voltages. However, the capacitance is decreased due to the smaller package size. Also, the distance between electrodes is important to prevent unnecessary discharge. The 1 kV MLCCs under development and shown in Figure 9 address these issues.

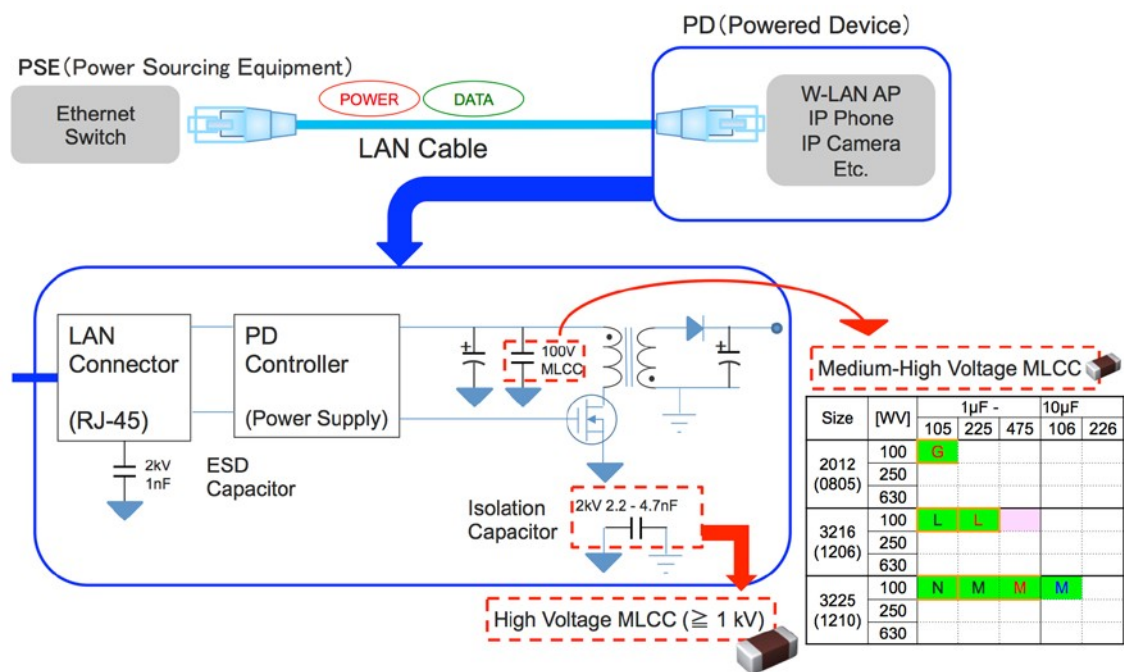


Figure 8. Power over Ethernet Application

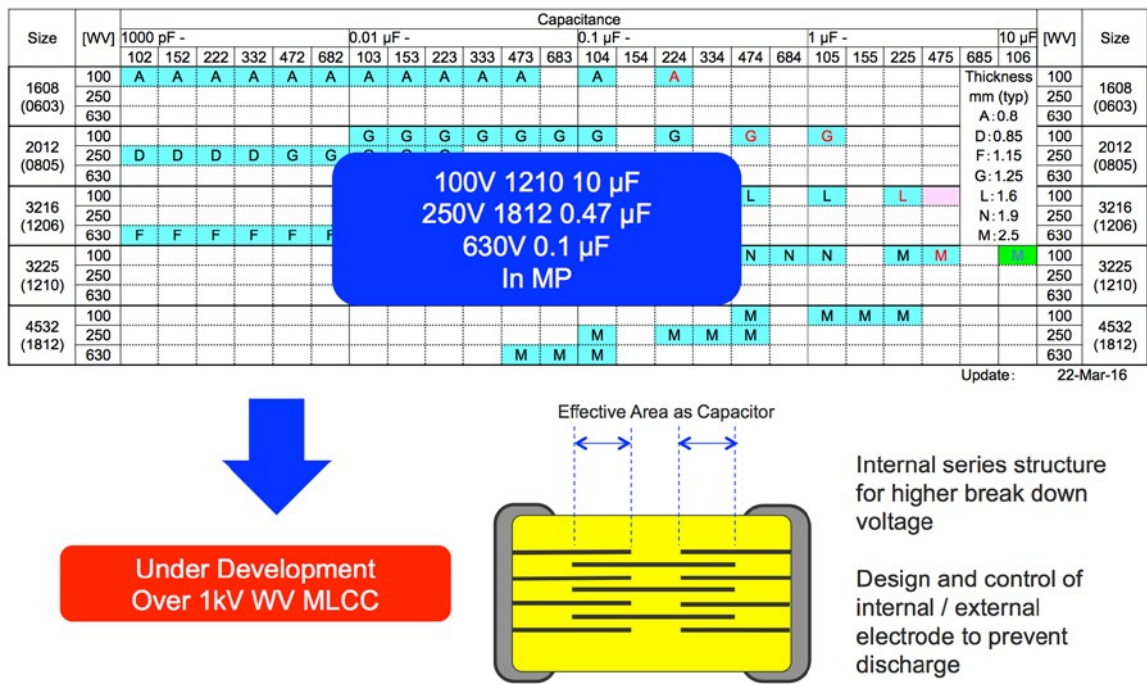


Figure 9. Technology for High Voltage MLCC

250V High-Q MLCC

In high-frequency applications, particularly ones with a large high-frequency current running through the MLCC, a high-Q factor is required to reduce power dissipated by the MLCC. Applications for high-Q MLCCs include cellular base stations, telecommunication networks, TV set-top boxes, and GPS devices. Figure 10 shows a base station application. TAIYO YUDEN offers high-Q MLCCs supporting voltages up to 250V and are the best choice for high-performance, high-power RF applications.

The high-Q MLCCs use a copper internal electrode instead of nickel, and they use a copper terminal electrode plated with nickel and tin. The internal copper electrode is much thicker than the typical internal nickel electrodes in standard MLCCs. Because of copper’s high conductivity and the thicker electrode size, the high-Q MLCCs are very resistant to frequency, reducing power dissipation in high-frequency applications.

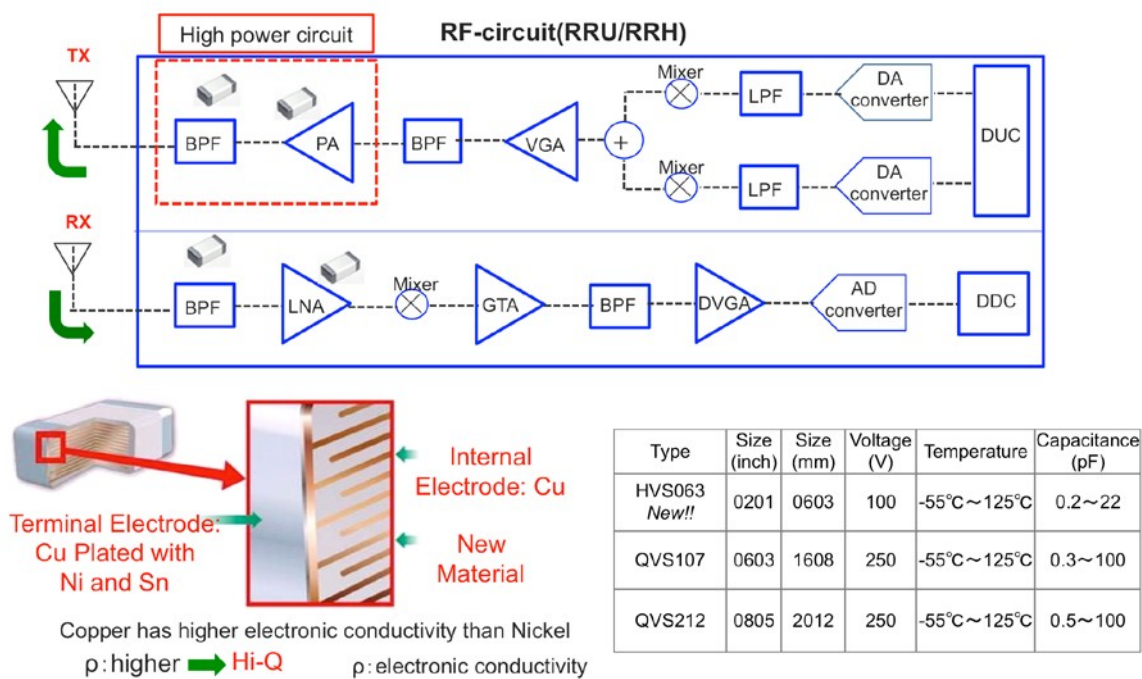


Figure 10. High-Q MLCC Base Station Application

LW Reversal Decoupling Capacitors (LWDC™)

The LW reversal decoupling capacitors are MLCCs that have low ESL characteristics and higher capacitance values. They are ideal for use in high-speed circuit applications and are available in the Industrial / Automotive reliability grade.

The lower ESL is achieved by reversing the length and width dimensions of an LW reversal capacitor relative to those of a standard MLCC. This means the distance between electrodes is shorter and the internal conductor's inductance is lower. The ESL of an LW reversal capacitor is nearly equal to that of two standard MLCCs in parallel.

An added benefit of using an LW reversal capacitor is that component and chip mounting costs are reduced if one such device can replace two standard MLCCs. Also, noise reduction characteristics are better in an LW reversal capacitor than a standard MLCC of the same size. The characteristics and benefits of LW reversal capacitors are shown in Figure 11.

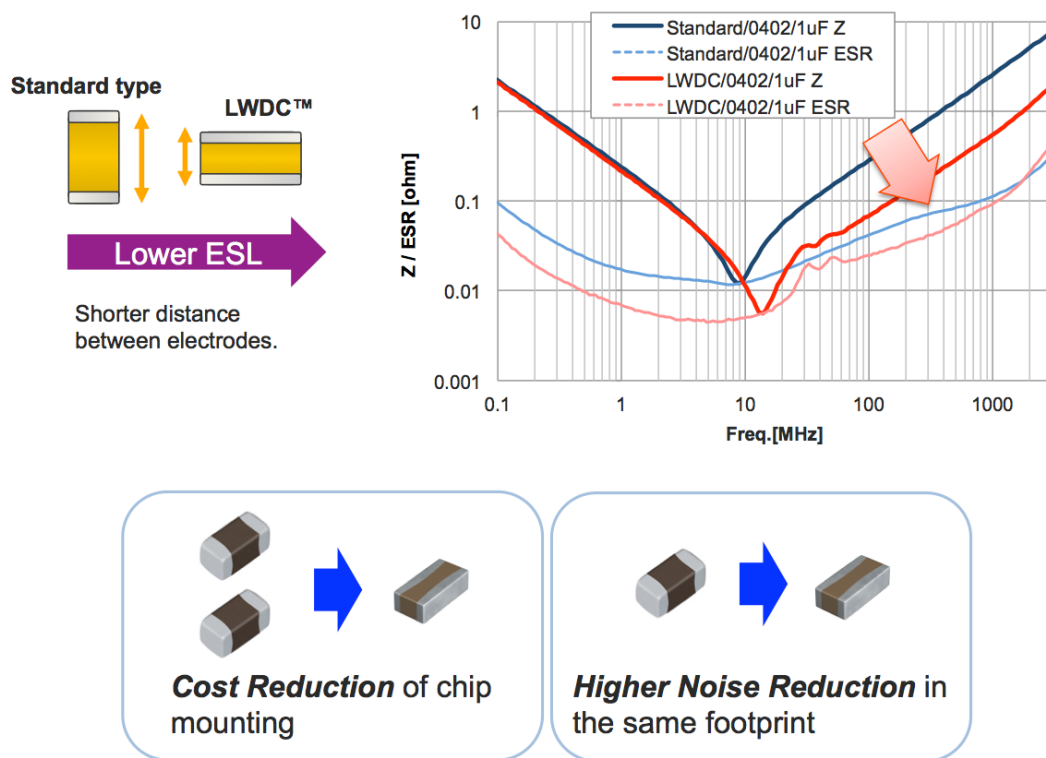


Figure 11. LW Reversal Decoupling Capacitor (LWDC™) Characteristics and Benefits

FAIL-SAFE TECHNOLOGIES

Circuit boards in industrial and automotive applications often undergo frequent physical stresses. For example, the boards might be attached to equipment that vibrates. When this happens the board can bend or flex enough to cause a crack to occur in the MLCC near the solder joint, causing the circuit to fail.

The application could also experience wide changes in temperature, causing the board to expand and contract. MLCC's are susceptible to cracking due to a mismatch in the coefficient of thermal expansion of the various components on the PCB. The thermal mismatch causes stresses on the board and components when they are subjected to temperature cycling or thermal shock. When this occurs the solder connecting the board and MLCC can degrade over time due to these stresses.

MLCC Soft Termination

Termination materials used in conventional MLCCs are inflexible. Vibration, shock, and thermal expansion can crack or shear the solder joint between the component and the circuit board.

Soft termination MLCCs are designed for use in automotive / industrial applications where board flexion can occur. Their exposure to shock, vibration, and extreme temperature swings makes them susceptible to higher failure rates than typical consumer applications. Typical automotive applications include headlight controls, window controls, and navigation systems. They can also be used in outdoor equipment, machine tools, and high-end network equipment when the applications use thicker PCB substrates.

MLCC soft termination is used to mitigate these problems, as shown in Figure 11. With soft termination, a conductive polymer is added to the MLCC's external electrodes. This polymer absorbs the bending and vibration forces to help prevent the MLCC from cracking. Soft termination also provides protection in high-temperature and high-moisture environments. The polymer absorbs the forces that occur during heat cycles, helping to reduce solder degradation. See Figure 12.

TAIYO YUDEN's Industrial / Automotive reliability grade MLCCs include a variety of parts that support soft termination to prevent cracking in applications deployed in severe environments.

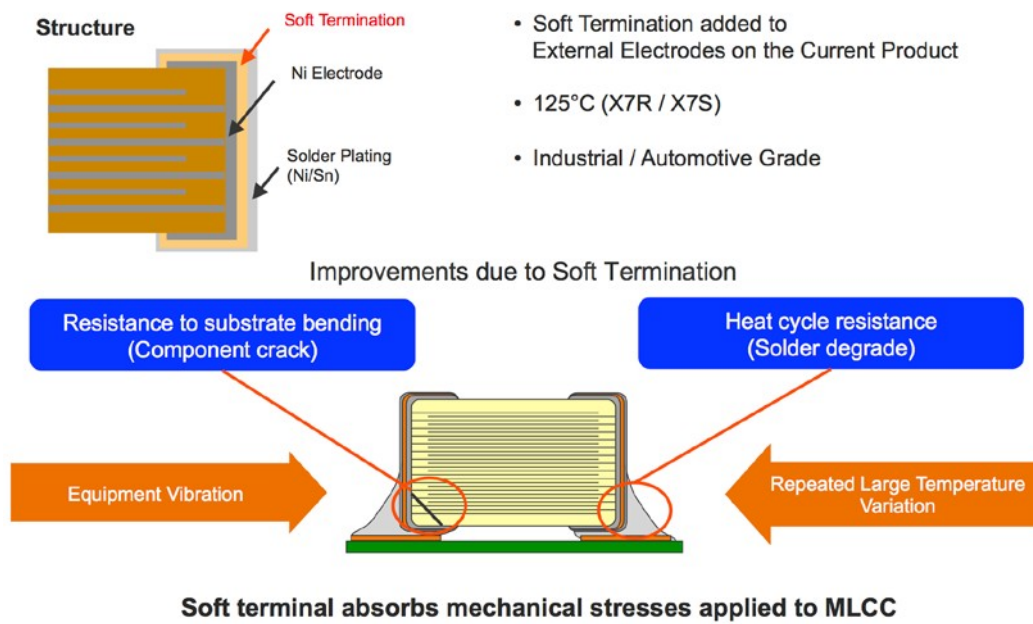


Figure 12. Soft Termination Features

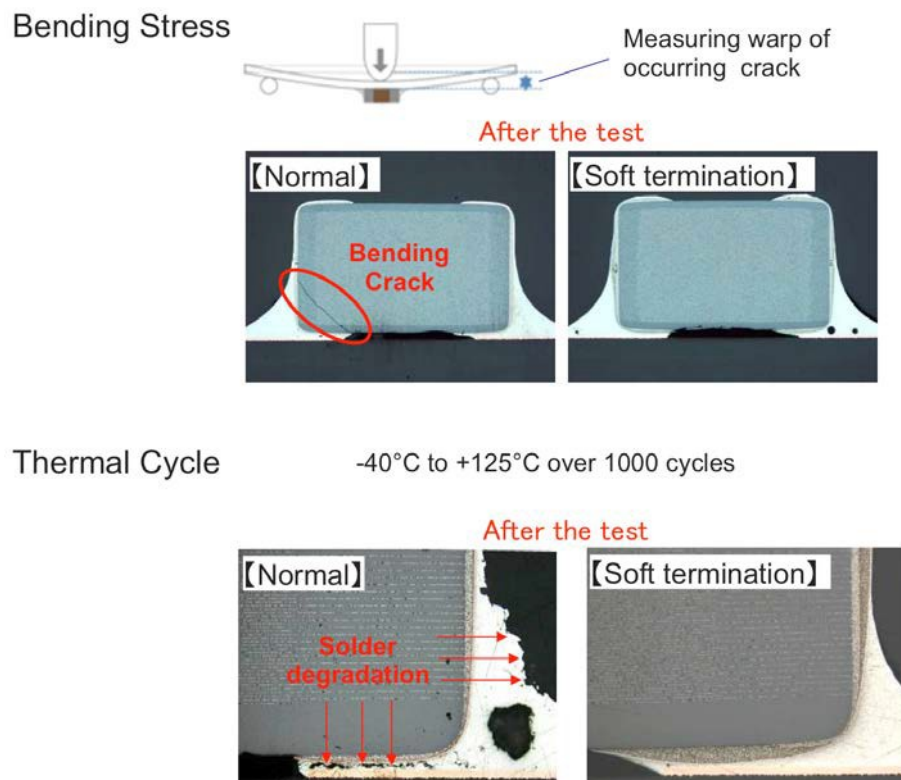


Figure 13. Protection Against Mechanical Stresses

Frame-Type MLCC

A frame-type MLCC can also be used in high-stress applications to reduce failure rates and improve product reliability. The frame lead mechanically isolates the MLCC from the PCB, absorbing external stresses and resulting in more robust performance. They are a good solution for applications that experience both board bending (PCB distortion) and audible ringing caused by MLCC vibration.

Audible ringing can occur when an AC voltage is applied to an MLCC. The piezoelectric properties of the ceramic cause the MLCC to expand and contract, which can cause the circuit board to vibrate. If the changing voltage causes the board to vibrate at a frequency under 20 kHz, a sound can be produced that is audible to human ears. The frame lead is effective at dampening such oscillations. The frame lead also absorbs other stresses due to board flexion and temperature changes. See Figure 14.

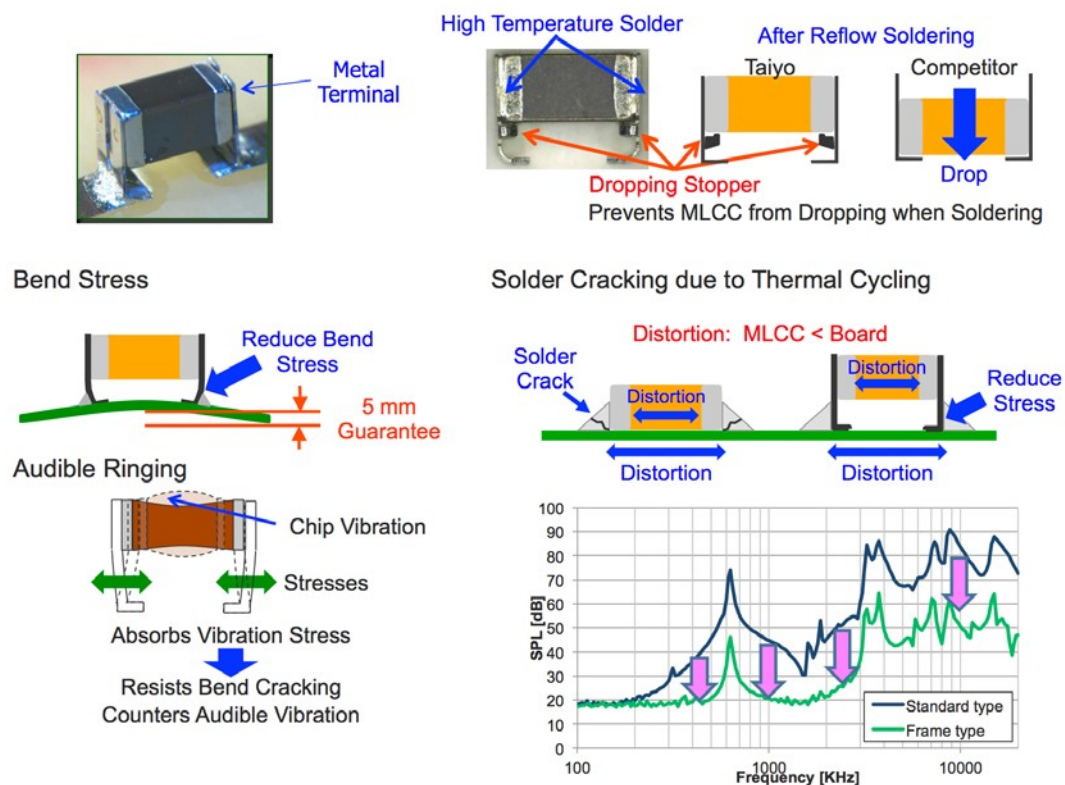


Figure 14. Frame-Type MLCC Features

TAIYO YUDEN continues to develop new technologies, such as further refining ceramic powder, to expand the use of MLCCs into more application spaces. These are shown in Figure 15 and include:

1. Continuing to miniaturize MLCCs, enabling the use of smaller circuitboards.
2. Development of MLCCs that support large capacitance with high reliability, enabling the replacement of polymer capacitors in high-capacitance applications.
3. Increasing the MLCC voltage rating to improve the safety of applications requiring surge voltage protection.
4. Develop atypical MLCC sizes supporting high voltage and high capacitance so that film capacitors can be replaced.
5. Improve reliability in applications with high mechanical stress by adding soft-termination and frame-lead technology to each MLCC offering.

The TAIYO YUDEN development roadmap for MLCCs is aligned with the application needs of the industrial / automotive market.

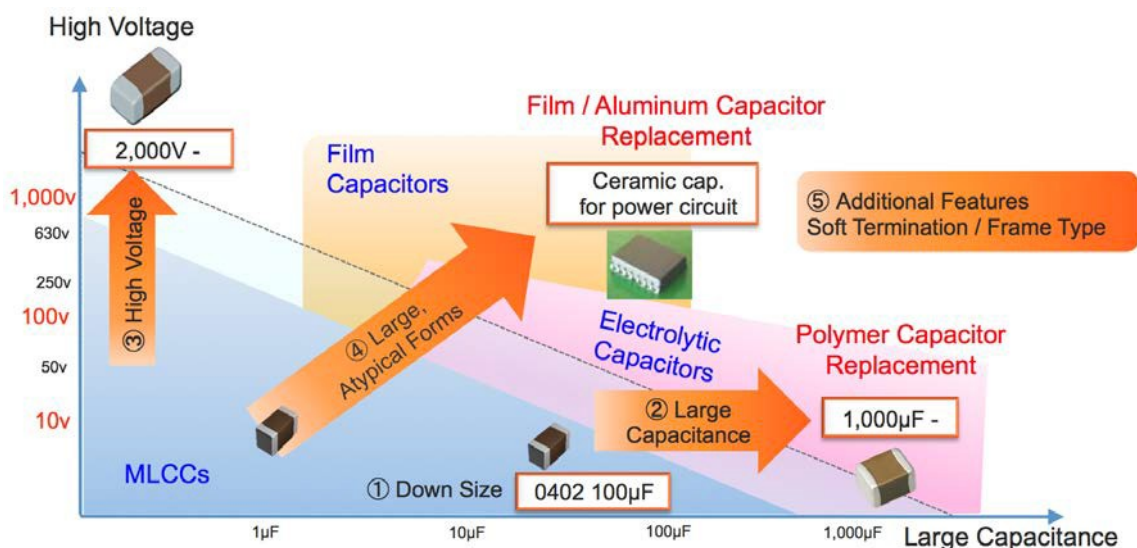


Figure 15. Future MLCC Technology Development