Multilayer Ceramic Capacitors in Automotive

Modern EV's, HEV's and PHEV's are sparking a revolution in the capacitor technology used in the control electronics. Higher temperatures inside the control circuits mean that conventional plastic film capacitors are no longer suitable for all applications and ceramic MLCC's are now being increasingly used, with the added benefits that MLCC's are generally surface mount direct to boards, yielding greater efficiency of assembly and allowing shorter circuit tracks with lower inductance. In many cases this last point allows lower capacitance values to be used, meaning that smaller components or less components can be used.

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According to Figure 1, MLCCs are being used extensively in modern cars. In considering the basic requirements for MLC chips, first we must consider the necessity for all components to meet the demanding requirements of AEC-Q200, the "Stress Test Qualification for Passive Components" laid down by Automotive Electronics Council (AEC) Component Technical Committee. These subject components to a set of rigorous tests to determine the basic reliability in application. Generally, the most severe tests for MLCCs relate to the mechanical stresses induced by the board bend and thermal cycling requirements, designed to ensure a component is capable of withstanding poor processing and handling, as well as the mechanical stresses experienced in application. Poor mechanical design and material selection can result in a component suffering from a mechanical crack which may result in a short circuit at a later date (see Figure 2).

Avoiding cracks due to mechanical stress

Knowles Syfer brand were the first MLCC manufacturer to develop a flexible termination system for their surface mount capacitors - FlexiCap™. This technology

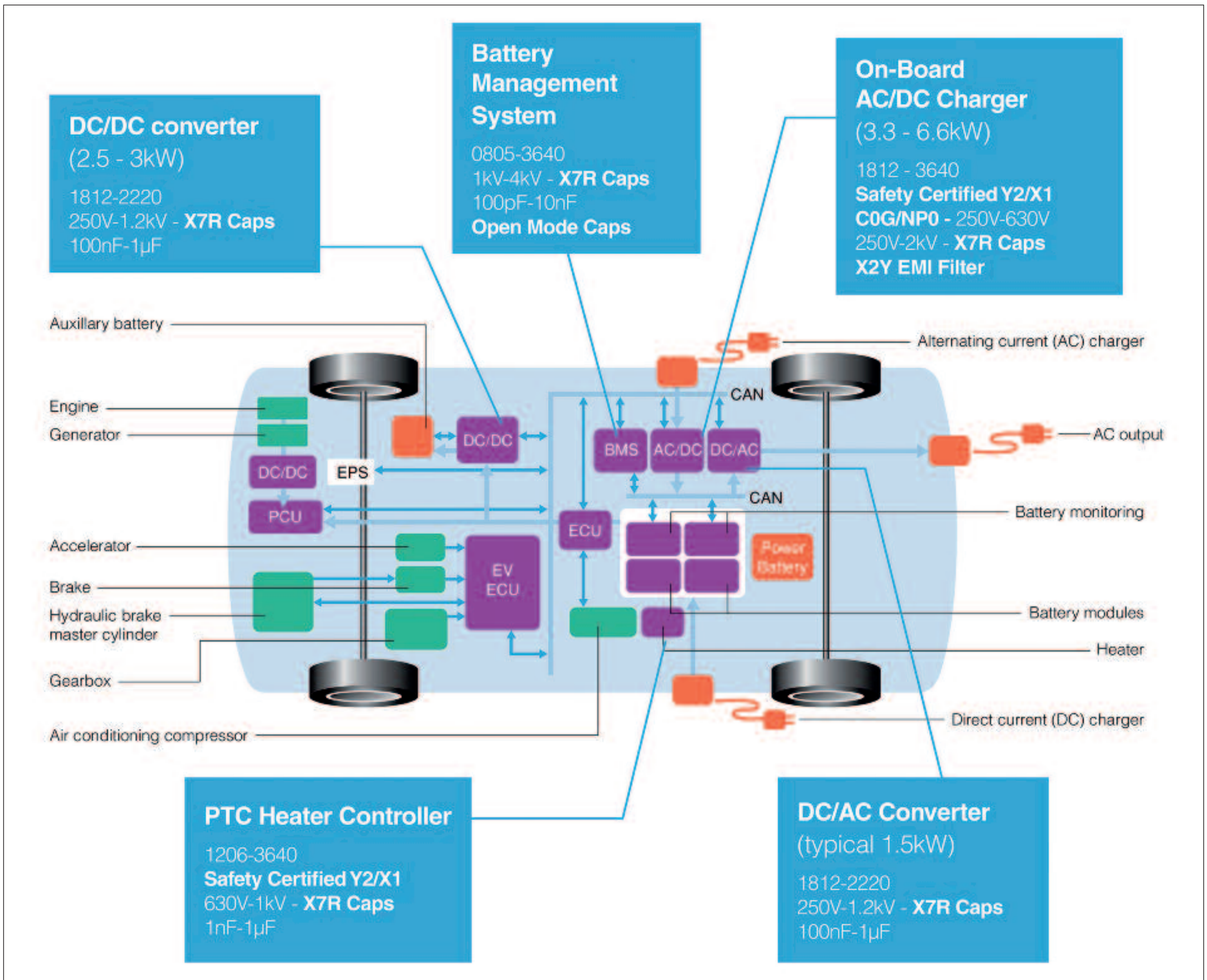

Figure 1: Some examples of locations where MLCCs are now being used in (electric) automotive applications

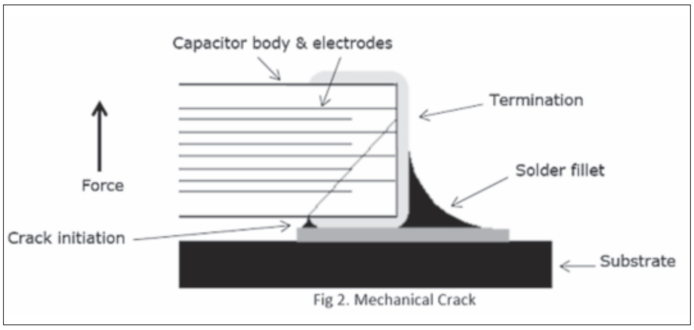

Figure 2: Mechanical crack mechanism

makes it possible for large case size MLCC's, up to 3640, to be approved to the AEC-Q200 requirements by isolating the ceramic from the mechanical stresses. This termination is essential to ensure type II (X7R, X5R & X8R) dielectrics meet the requirements of the AEC-Q200 specification, although it is also available on selected type I (C0G / NP0) dielectric ranges.

Alongside the termination, it is possible to design special internal electrode configurations to reduce the likelihood of catastrophic electrical failure in the case a crack does occur. Open-mode MLCC's (Figure 3) have the internal electrode patterns pulled back from the opposing end of the chip, meaning if a crack is induced, it is much less likely to propagate through an area of active overlap and cause an electrical short circuit. Tandem-mode designs (Figure 4) use a sequential electrode design, placing two capacitors in series within a single MLCC. Each capacitor is designed to withstand the full rated voltage of the component, so in the case of a failure in one, the capacitor the other end can withstand the full rating and the component continues to work, albeit at a reduced capacitance value. These recent developments have made the reliability of surface mount MLCCs exemplary, which in turn has seen an increase in their use throughout a car's electronics.

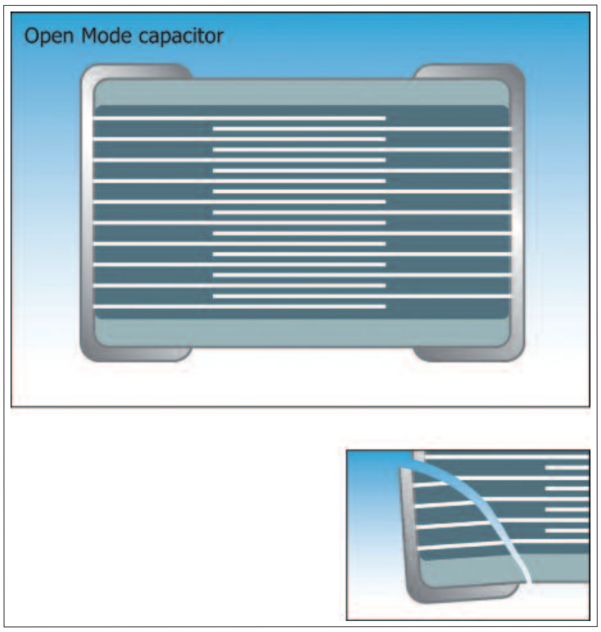

Figure 3: Open-mode MLCC's have the internal electrode patterns pulled back from the opposing end of the chip

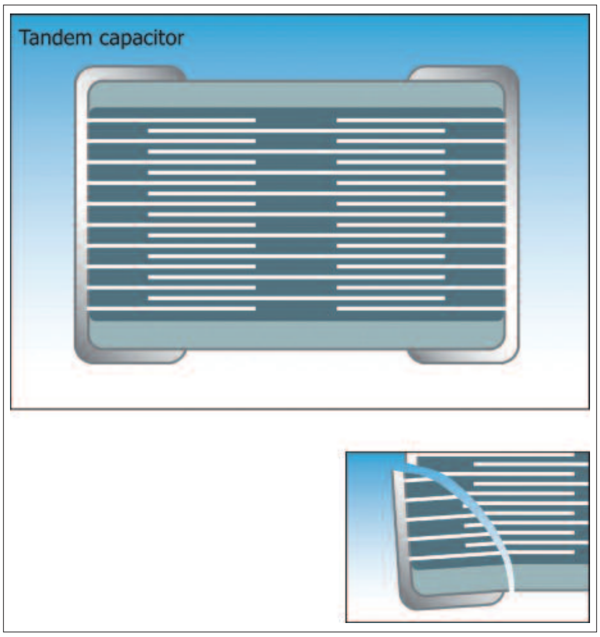

Figure 4: Tandem-mode designs use a sequential electrode design, placing 2 capacitors in series within a single MLCC

One noticeable trend of late has been the increasing ambient temperature of the electronic systems on board. Airflow, required for cooling, is more closely controlled as aerodynamic drag is more of a concern; miniaturization drives enclosures even smaller; the complexity of on-board systems has reached levels that could not have been imagined and, with the advent of battery and power train control systems, components are being asked to handle higher power ratings.

MLCCs with X8R classification (rated -55°C to +150°C) were developed many years ago specifically for automotive applications, but have always had poor volumetric efficiency compared to other dielectrics. Recent new dielectric systems are now addressing this and recent developments have seen significant improvements in the available ranges. This factor is actually a side effect of the new dielectrics being developed for environmental reasons, which have also seen the first 100 % lead free X8R capacitors reach the market.

Coming soon

Looking to the future, temperatures will continue to rise as passive components are moved closer to the power electronics, reducing the circuit tracks and therefore the effective inductance but also allowing lower capacitance values to be specified. Here, the automotive industry can look to developments in the oil exploration down-hole industry, which has seen 200°C MLCCs arrive on the market. For the first time, these are available with low-cost plated, nickel barrier, termination systems allowing the full requirements of aged solderability and dissolution of termination specifications to be met. These systems meet the full requirements of the AEC-Q200 specification on C0G type I dielectrics. Future developments will see available temperature ranges increase further, with 250°C rated parts already on the horizon.

Electric vehicles require higher voltages

Early on we stated that there was a revolution in the capacitor technology used in the control electronics being driven by modern EVs, HEVs and PHEVs. Of course, MLCCs have been used in automotive applications for years, but the big change that is being seen is the voltage rating and size of

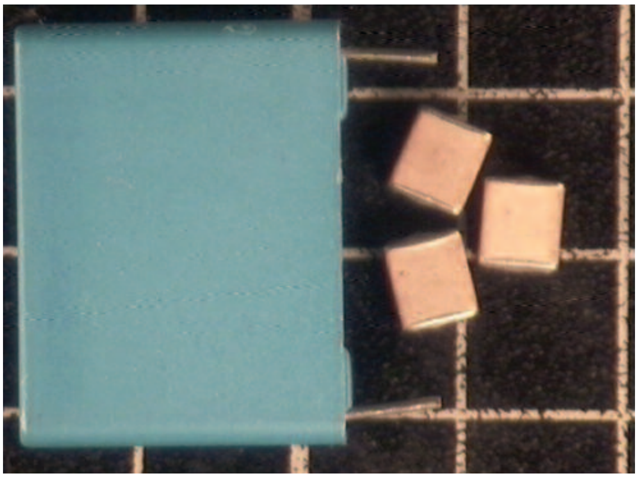

Figure 5: Examples of 400 V DC 1 µF Polypropylen film and 630 V 1 µF MLCC capacitors (right)

components now being used. Not so long ago, there was a rule of thumb that you didn't place an MLCC bigger than 1210 (0.12" x 0.10") directly onto a board due to the risks to reliability. The developments mentioned above have smashed this ceiling and it is now not unusual to see capacitor as large as 0.5" square and up to 0.3" thick placed directly onto substrates.

The size increase is being driven by the need for higher voltages, higher capacitance values and higher AC ripple currents (i.e. power dissipation). With reference to Figure 1, it can be seen that typical MLCC voltage in EV is 250 V DC to 2 kV DC, but 4 kV DC and higher is required in some cases, particularly to meet impulse or surge requirements. Typical capacitance in this application is 100 nF to 4.7 µF. The reason for these high values is the manner in which MLCCs are now being used to replace film capacitors in filtering circuits with high DC bias voltage and high ripple current requirements. Ceramic will never eradicate film capacitors from automotive applications as plastic film offers much higher capacitance ranges, but where possible an MLCC can offer a much smaller component size and weight for the equivalent plastic film (Figure 5).

Developments continue to drive the size of MLCC's ever smaller, and new dielectric systems are now obtaining impressive volumetric efficiency. The 0.22" x 0.20" x 0.18" 630 V DC rated 1 µF X7R MLCC is a typical example that is now in use in EV battery management systems. This capacitance / voltage combination is only possible due to Knowles patented StackiCapTM technology which allows increased component thickness without the electrostrictive failure mode that plagues thicker MLCC's.

In PHEV's and PEV's, it is also important that the appropriate safety rated class X & Y capacitors are used on the circuits directly connected to the mains and elsewhere were an electric shock situation could possibly occur. MLCCs are capable of safety approvals up to class Y2 and all Knowles safety ranges are also AEC-Q200 certified.

Of course it is important that the capacitor characteristics and performance under real life operating conditions are known and to this extent Knowles are investing heavily in research and development and working closely with a number of automotive electronics suppliers to assist with applications advice.

Finally, we can look forward to some new dielectric developments that are specifically aimed at the future requirements of automotive power electronics. An example of one such development is shown in Figure 6 - this particular dielectric development is currently being developed under the European Union's FP7 Clean Sky Joint Technology Initiative with project partners NPL and Euro support. These materials are at the R&D stage and promise to offer more stability under voltage stress, less dielectric losses and significantly reduced self-heating of the component under high RMS ripple current. These new dielectrics are already undergoing BETA trials in automotive applications in case sizes as large as 0.4" x 0.4" x 0.2", typical voltage and capacitance ratings of 600 V at 1.7µF.

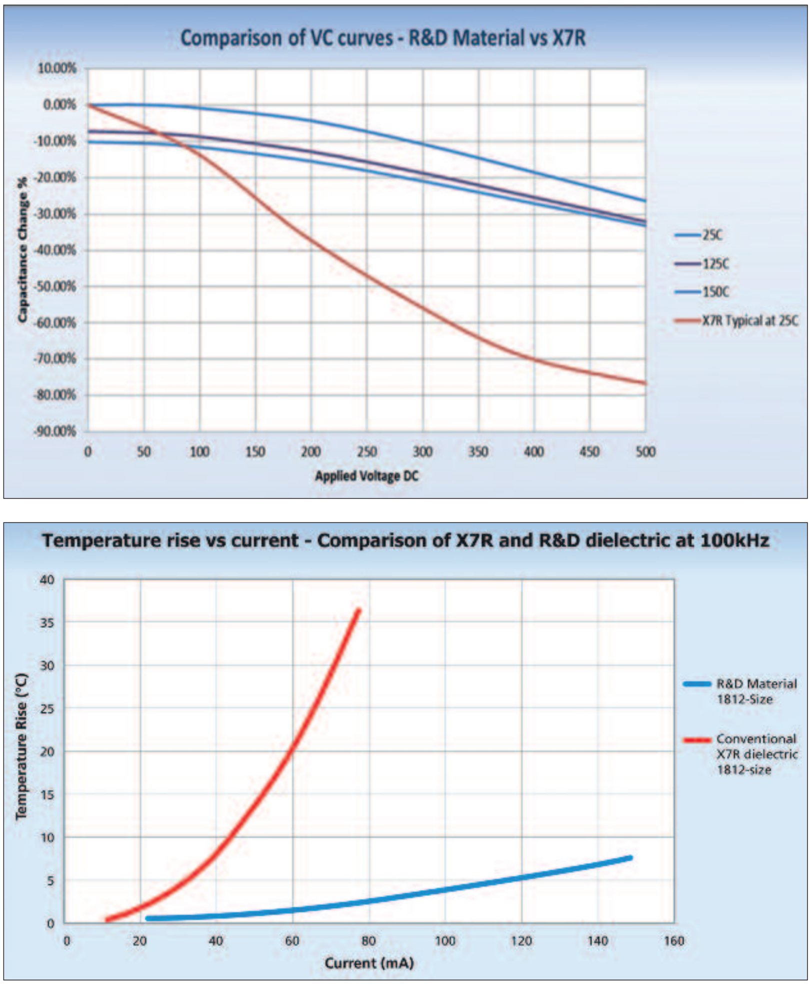

Figure 6: Dielectric development being developed under the European Union's FP7 Clean Sky Joint Technology Initiative, comparison of VC curves (top) and temperature rise versus current (above)

Conclusion

MLCC's are experiencing a boom in automotive applications as their use expands into EV related power electronic applications. Larger case sizes and higher voltages are promoting replacement of film capacitors with the advantages of lower inductance, smaller case size and higher temperature ratings. New dielectric developments over the next 12 months will push MLCC's into further applications with their lower loss and more stable characteristics.