Polymer Film Capacitors Provide Needed Performance

Rick A. Price
Paktron Capacitors
1205 McConville Road
Lynchburg, VA 24502
Phone: 434-239-6941 Fax: 434-239-4730 Web site: http://www.panconcorp.com

Abstract – Mechanical flexibility, immunity to aging and stable operating characteristics are the hallmarks of polymer film capacitors used in power applications.

There is probably not a single electronic design engineer who has not come up with a new circuit design only to have it fail during bench testing because it appeared that either there was a design error or a faulty component had been used. In the majority of cases it is neither; with the failure occurring because of a key component's unacceptable parasitic losses due to its reaction to temperature, voltage and/or frequency variations. There is nothing more frustrating than spending the time troubleshooting a "defective" circuit only to find the cause being a 4.7µF capacitor that has an actual effective working value of only 0.33µF.

Electrical and mechanical stability of components in power train applications has always been a major issue. The drive to lower cost and produce smaller sized components has generally removed some of the safety margin in the designs or caused increased parasitic losses. In what seems like the ultimate validation of the superior performance characteristics of polymer film capacitors, various capacitor type (tantalum, aluminum electrolytic and ceramic) manufacturers have now begun adding polymer elements to their products in order to enhance electrical and mechanical performance. Rather than using these polymer "hybrids", those requiring the highest performance, most stable capacitors commercially available should choose polymer film capacitors for their critical applications.

Critical electronic systems used in markets such as Military, Flight or Telecommunications require the use of components with inherent reliability. No matter how much circuit redundancy or accelerated screening testing is done there always exists a golden nexus that can produce a single point of failure (SPoF) requiring circuit designers to spend a great deal of time trying to minimize the probability of the

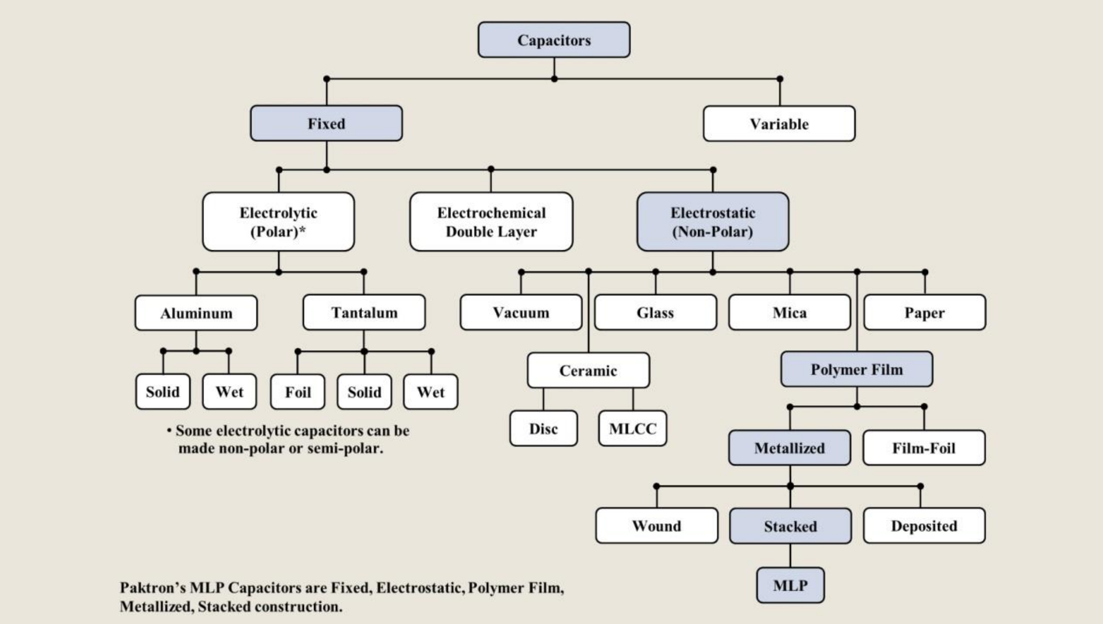

Fig. 1 Capacitor Family Tree

occurrence of such failures. One approach that has proven to be successful for over six decades is the use of polymer film capacitors. These capacitors have been in commercial use since the 1950's. Due to their low mass, outstanding performance capabilities and unmatched inherent reliability, polymer film capacitors have long ago been established as the choice in high performance, mission critical applications. Instead of using capacitors that simply get by, critical applications require units with an established track record of both durability and reliability. Industries such as Telecom learned decades ago that while the other capacitor technologies have their viable uses, in pivotal applications only polymer film capacitors have the inherent performance, stability and reliability needed. The Telecom industry's commitment to using polymer film capacitors is such that all the major Telecom companies once produced their own; until the commercial market was finally able to produce the quality and volume levels that Telecom required. Telecom was not alone, with other industries such as aerospace, the military and automotive having also produced their own polymer film capacitor products to meet their special needs.

While polymer film capacitors have been around commercially for almost 70 years they are not a stagnant technology, but rather have evolved with the market needs to be smaller, more reliable and ever higher performing. Polymer film capacitors have gone from a simple wound film-foil construction to using metallized plates to stacked construction and finally to its latest iteration of MLP (multilayer polymer) construction (see Figure 1). Polymer film capacitors are available in axial and radial lead configurations as well as special surface mountable constructions to meet various assembly needs. While there are numerous custom polymer film capacitors available, the polymer film market is not a cottage industry (i.e. producing job shop quantities of very highly specialized capacitors), but rather is a high volume, highly automated behemoth supplying billions of capacitors to every conceivable market. Polymer film capacitors can be found in markets ranging from the automotive industry to zero-current switching power converters. While the target applications have changed in each of these markets over the years, by changing application focus to match polymer film's unique capabilities market growth has been sustained.

Ceramic Capacitor Cracking

For many years there has been a long-standing debate about the use of multilayer ceramic (MLCC) vs. polymer film capacitors (wound, stacked or MLP). As circuit designs have shrunk in physical size, multilayer ceramic capacitors have been winning the design-in race with available case sizes down to 0201 (0.008" x 0.005"). Unfortunately, while ceramic capacitors do an outstanding job in small sizes and at low voltages, in applications where the case size and applied voltages are increased, inherent problems quickly arise. Multilayer ceramic capacitors made from large slips (large dielectric plates), tend to crack (see Figure 2) due to circuit board flexure and mismatched CTE's (**C**oefficient of **T**hermal **E**xpansion a.k.a. TEC) while MLP polymer capacitors have CTE's almost identical to FR-4 PC boards. While the MLCC crack alone is not catastrophic to the capacitor, it becomes a nexus, allowing moisture and other ionic contaminants to enter the capacitor. At some point the crack will become a conductive parallel path that ultimately results in a low resistance path or short circuit failure (see Figure 3). To prevent these problems, using empirical observations, many industries have simply

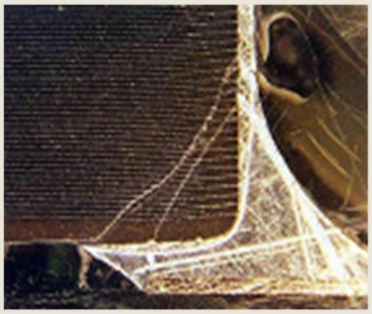

Fig. 2 Ceramic Capacitor "Cracking"

Material	CTE (ppm/°C)
Ceramic Capacitor	9.5-11.5
Alumina	≈7
Copper	17.6
Copper Clad Invar	6-7
Filled Epoxy Resin	18-25
FR-4 PC Board	≈18
Nickel or Steel	≈15
Polyimide/Class PCB	≈12
Polyimide/Kevlar PCB	≈7
Tantalum	6.5
Tin Lead Alloys	≈27
MLP Polymer Film Capacitor	≈17

CTE – **C**oefficient of **T**hermal **E**xpansion a.k.a. TEC

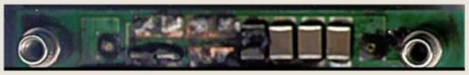

Fig. 3 Ceramic Capacitor Short Circuit Failure

decreed that they will use no multilayer ceramic capacitors with greater than an 1812 case size or voltage ratings higher than 50-100vdc. In other words, in low voltage signal processing, multilayer ceramic capacitors are usually the capacitor of choice while in power handling applications of 42 volts and higher, polymer film capacitors provide the best performance and reliability.

In order to try to emulate the inherent mechanical flexibility of polymer film capacitors, various ceramic capacitors are now adding an additional termination layer of conductive polymer to provide a cushioning effect during soldering and board flexing (see Figure 4). According to manufacturer's specifications, adding this layer allows for a board flexure of up to 5.0mm before ceramic capacitor cracking begins.

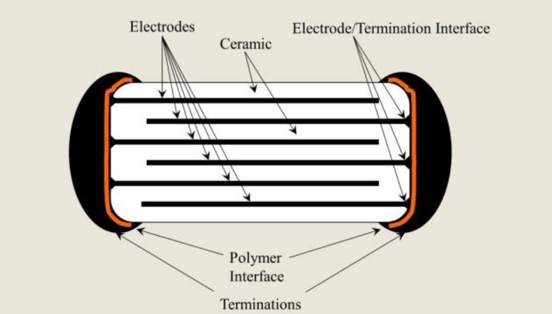

Fig. 4 New MLCC Flexible Terminations

Flexure or printed wiring board (PWB) bending is a significant source of stress that can lead to component failure. Ceramic capacitors are inherently brittle and can exhibit catastrophic failure if cracked during PWB bending if the crack propagates across opposing electrodes and there is sufficient energy present in the power supply. MLP capacitors are made with polymer films, which are not brittle under normal conditions and are more forgiving when physically stressed. The most common test procedures for this type of robustness follow EIAJ specification RC3402 where a capacitor is reflow soldered to pads on a test PWB. The assembly is mounted component face down, supported on the PWB ends and bending stress is applied to the backside of the assembly with a ram directly behind the component under test. The basic setup is shown in Figure 5. Capacitance shift is used to detect failure under test conditions but this may not detect cracking of ceramic capacitors. The standard also uses a 1.0mm deflection as an acceptance level for no failures. A test PWB with 1.0mm of deflection is also shown in Fig. 5. A maximum deflection of only 1.0mm is difficult to achieve at every step of PWB

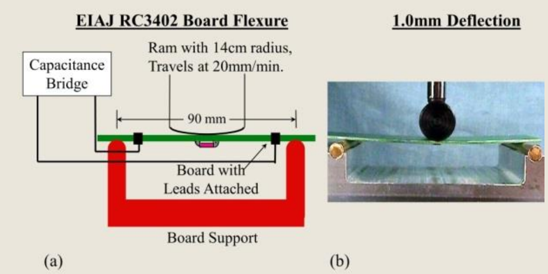

Fig. 5 **Board Flexure**

assembly and final product manufacturing to eliminate flexure cracking of ceramic capacitors. Flexure testing has found that while all non-flexible termination 1812 ceramic chip capacitors tested in this particular test set failed between 3.0 and 4.0mm of deflection, MLP chip capacitors flexed at 7.0mm and subjected to 500 hours of accelerated life testing showed no failures or degradation. Throughout the testing, it was evident that MLP capacitors did not exhibit failure or degradation when tested at or beyond deflection values that cracked ceramic capacitors of similar size and values.

While the new flexible termination MLCC capacitors are guaranteed to withstand up to 5.0mm of deflection it comes at the cost of adding an additional non-metallic interface in the power stream of the capacitor. Anyone familiar with the use of conductive epoxies has first-hand knowledge of the potential pitfalls of adding series impediments to current flow, especially in high power applications.

While the use of flexible terminations on MLCC capacitors may help with preventing cracking due to board flexure, these capacitors are still subject to cracking due to internal differential stresses caused by both thermal and piezoelectric influences..

Aging

Electrolytic capacitors (aluminum electrolytic, tantalum, etc.) like batteries have their functionality based on a chemical reaction. Because of entropy, time will eventually slow, stop or reverse that reaction and the capacitors will become non-functioning. Electrostatic capacitors (ceramic, polymer film, etc.) do not function due to chemical reactions, but ceramic capacitors contain certain base elements and dopants that can radically affect their longevity. The most commonly used ceramic capacitors are based on a barium-titanate dielectric that exhibits "aging" which produces decreases in capacitance values over decade-hours of time. Basically the dielectric "relaxes" or transforms to a lower dielectric constant material thereby reducing the capacitance value of the MLCC capacitor. Decade-hours are industry time periods of 1-10, 10-100, 100-1000 hours etc. For example, an X7R ceramic capacitor loses between 6.0-7.5% of its capacitance value in its initial 1000 hours while a Z5U capacitor can lose almost 20% (see Figure 6). Ceramic capacitor manufacturers carefully guard band their capacitance value testing to compensate for the capacitance loss so that by the time the capacitors are first used by the capacitor user they are initially within tolerance. Unfortunately, capacitor aging occurs both on the shelf and while in-use, meaning that in applications that require the capacitance remaining within a specific range, in-plant testing by the capacitor user can produce acceptable results, while end user testing at a later time could produce unacceptable results. Ceramic capacitors can also be de-aged by subjecting the capacitors to temperatures above the dielectric's Curie point (>120°C) after which the aging process starts anew. This de-aging characteristic could prove to have interesting repercussions in applications using high temperature, no-lead solder assembly operations. For example, initial capacitance readings on the MLCC capacitors could be well within the acceptable range, but after being subjected to high soldering temperatures the capacitance values could be outside of a workable tolerance range causing equipment malfunction. After a thousand or so hours the capacitors may age back to acceptable values.

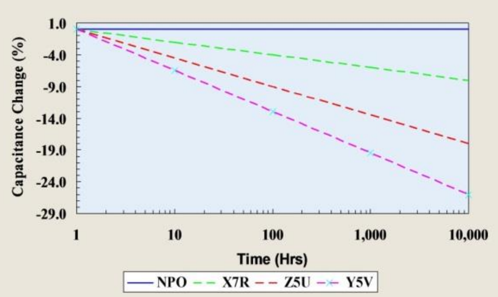

Fig. 6 Ceramic Capacitor Aging

Voltage Sensitivity

Multilayer ceramic capacitors also exhibit increasing capacitance instability with increasing applied voltage (see Figure 7). An applied voltage of 100vdc can result in capacitance losses of up to 40% while an applied voltage of 400vdc produces losses of up to 80%.

Figure 8 shows how the dissipation factor of MLCC capacitors increases with increasing applied AC voltage.

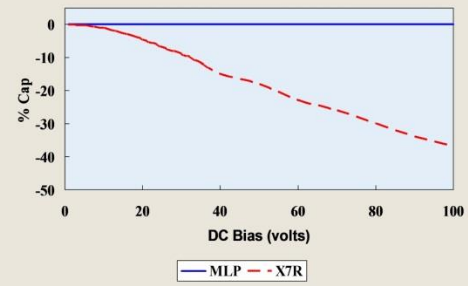

Fig. 7 % Capacitance Change vs. DC Bias

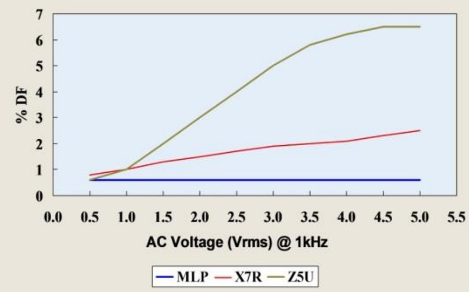

Fig. 8 %Dissipation Factor vs. Vrms

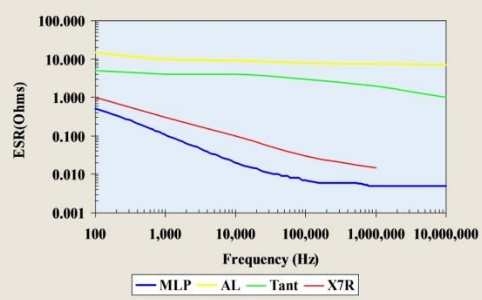

Fig. 9 ESR vs. Frequency

ESR

One of the most important attributes of a capacitor used in power circuits is its Equivalent Series Resistance (ESR). ESR determines the I^2R heating losses for the capacitor, which in turn establishes the efficiency, pulse handling and indirectly the reliability of the circuit. Figures 9 shows comparisons of the ESR of various dielectric systems and how they vary with frequency.

Temperature Sensitivity

Figure 10 shows an example of how the capacitance value of the different capacitor technologies can change with temperature variations. For ceramic capacitors by definition an X7R can change by ±15% over a temperature excursion of -55°C to +125°C while a Z5U can change by +22% to -56% over a temperature excursion of +10°C to +85°C and a Y5V can change by +22% to -82% over a temperature excursion of -30°C to +85°C.

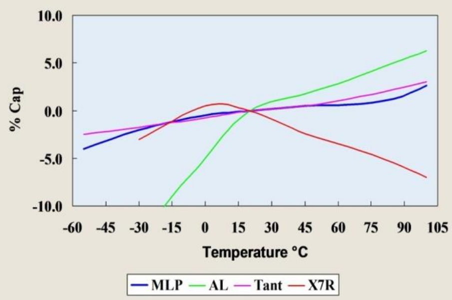

Fig. 10 % Capacitance Change vs. Temperature

In critical applications manufacturers require the use of capacitors with established track records in both durability and reliability. For these applications, only capacitors with the necessary inherent performance, stability and reliability should be used. After almost 70 years of supplying such capacitors, polymer film capacitors have established themselves as the technology for other dielectric system types to try to emulate. Imitation may be the sincerest form of flattery, but in critical applications rather than compromising on "me-too" polymer hybrid capacitor products the choice should be as it has always been – pure polymer film capacitors.

Commodity grade capacitors do an excellent job in commodity/consumer applications, but their use is application specific and they have their limitations. This is not an unknown problem, with the information on their instability published in most capacitor manufacturers' data sheets. Multi-layer ceramic (MLC), aluminum electrolytic and tantalum capacitors were originally intended for use in commodity applications for basic functions such as by-passing (decoupling), coupling, filtering, frequency discrimination, DC blocking and voltage transient suppression, but designers have been trying to extend their use into high performance applications (such as Military, Flight, high-end Telecom, medical, high-end consumer electronics, etc.). In these types of applications performance and stability, as opposed to size and cost, are the critical criteria. Designing with commodity grade capacitors (i.e. MLC, aluminum electrolytic and tantalum capacitors) is applicable for use in commercial based, commodity applications, where all that is required is just having a capacitance be present, but in high performance applications, stability, and the hit that performance takes because of the lack of it, cannot be ignored. In critical applications, where just getting by is not acceptable design criteria, the selection of the proper capacitor technology is paramount to a product's success. A specification listing 2000 hour product life for a component means only 83.3 days of continuous 24/7 run time operation making the extrapolation to 10-20 years life a far reach for most capacitor systems that are subject to electrical degradation with time. Instead of using capacitors that simply get by, critical applications require units with an established track record of both durability and reliability. Because of the need for high reliability and long life, high tech industries learned decades ago that while the commodity grade capacitor technologies have their viable uses, in pivotal applications only metallized polymer film capacitors have the inherent performance, stability and reliability needed.

MLP Polymer Film Capacitors	
Reliability	Designed to provide 20+ years of application life.
Performance	Exceeds other capacitor technologies in electrical performance.
Stability	Exceeds other capacitor technologies in electrical performance stability including no aging or wear-out modes.
Mission Critical	The go-to capacitors for "cannot fail" applications.

Performance Advantages of MLP Capacitors
Electrically Stable Under AC Voltage
Electrically Stable Under DC Voltage
TCE compatible with FR4
Electrically and Physically Stable over Temperature
No "Aging" Mechanism
Resilient Under Thermal Shock
Self-Clearing Thin Electrodes
Stable under Mechanical Stress
Ultra Low ESR
Dissipation Factor < 1.0%
High dv/dt
No Wear out Mode
Non-Piezoelectric
Non-Polar
Surface Mountable
Lead (Pb) Free Interface
Leak Free "Dry" construction
High voltage capability (up to 500vdc)