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Value Enhancements Push Capacitor Technology Forward

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Economic evolution dictates that companies which offer the best, highest-valued products to its customers will thrive. For capacitor manufacturers, this translates into helping their customers build products with the best performance per unit price. Whether this means helping a customer reduce component count, lower impedance per board space, implement a custom capacitor for heat sink mounting, or select the lowest cost capacitor per ripple ampere, capacitor manufacturers are rising to the challenge of providing ever-increasing value.

What has always been of value to the capacitor user is low impedance per volume and per dollar. Twenty years ago this usually meant high capacitance, since power supplies were linear and frequencies were low. Electrolytics were used extensively; however they were wet, poorly sealed and tended to have limited life due to dry-out and even leakage. The main terminal types were axial leaded, radial leaded, screw-terminal and twist-lock.

Present-Day Capacitor Technology

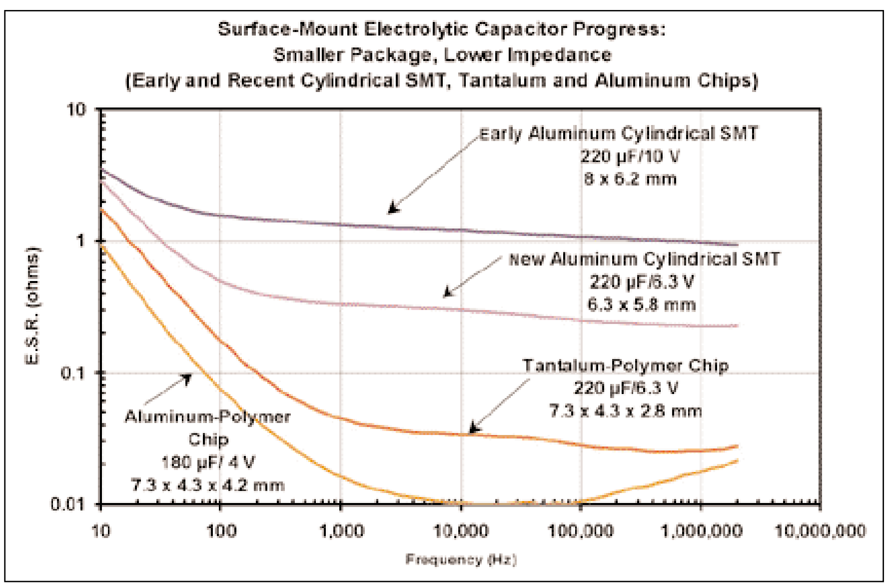
Although there are still many applications that require high capacitance density such as battery stiffening capacitors for car audio, hold-up capacitors, linear power supplies and defibrillators, low impedance today means low effective series resistance (ESR) and effective series inductance (ESL). In general, lower ESR means new materials technology, and lower ESL implies smaller size.

In the past 15 years, electronics topology and assembly have radically changed in several major ways. For the most part, power supplies have changed from linear to switchmode, assembly has migrated from through-hole to surface mount technology (SMT) and personal computers and cordless/cellular phones have grown from novelty to necessity. All of these new technologies have driven capacitor development. Investments in electrolytic foil etch technology that began 30 years ago paid off in the 1980s, when capacitance densities tripled. Simultaneously, electrolyte and seal technology produced capacitors with 1/3 the ESR and 30 times the life. Film capacitor metallization technology improved in the 1990s to offer energy densities above 1 kV that are competitive with electrolytics. Multilayer ceramic capacitors (MLCCs) have overcome reliability problems to offer the lowest possible ESR in the 1 µF to 20 µF range per volume.

SMT capacitor demand has radically changed the way most capacitors are made. Although a major change was not required for ceramic and mica capacitors, producing electrolytic and film capacitors in SMT chip form presented great challenges. For electrolytics, the biggest challenge was migrating from a conventional, ionically conducting wet electrolyte to a dry, electronically conducting polymer while meeting the self-healing characteristics. This achievement has paid off with much lower ESR and extended frequency response.

For film capacitors, the technology migrated from arbor-wound discrete sections to bulk cast and stacked sheets that are sliced and diced. Both of these technologies required a lot of effort to meet wave solder and reflow profiles. Mica chips, such as Cornell-Dubilier's MC Series, are available to 1,000 V DC, usable to several gigahertz and are available to 1,500 pF. Ceramics chips, such as the Kemet 2225, are available to 22 µF. The older tantalum-MnO_2 chip SMT film devices are available to 1,000 µF and reportedly can offer typical ESR below 100 mΩ. Some tantalum-polymer chips, such as the Kemet KO Series, are available to over 220 µF and offer ESRs as low as 7 mΩ by shunning the convention semiconductive MnO_2 in favor of much more conductive organic polymers. Cylindrical surface mount "V-chip" capacitors, such as Cornell-Dubilier's type AFK, are available to 6,800 µF and offer low ESR in the tens of milliohms. Surface mount aluminum-polymer chips are becoming very popular as they are now available to 390 µF and offer ESR as low as 5 mΩ. Figure 1 shows the improvements offered in the various surface mount capacitors as the construction has changed over the past decade.

Figure 1. Materials innovation over the past decade has yielded capacitor chips with smaller size and one hundred times lower ESR.



What Does the Future Have In Store?

From the rate at which capacitor advances are being made, it is patently wrong to call capacitors a "mature technology." Between today and the end of this year, the state-of-the-art in SMT Aluminum electrolytic capacitor ESR will drop from 5 mΩ to 3 mΩ. Niobium capacitors now under development will approach the capacitance density of tantalum at lower cost, and with a raw material that is not subject to large market price fluctuations and material scarcity.

Within one year, wet aluminum electrolytics rated 600 V DC that are in the development lab will become commercially available. In addition, energy densities for aluminum electrolytic etched foil above 200 V are approaching 50 percent of the theoretical maximum. However at low voltages, the etch structure has only been optimized for the low conductivity wet electrolytes, and less than 10 percent of the theoretical capacitance is achieved due to ESR and frequency response considerations. The coming decades will see low-voltage aluminum foil (or perhaps even sintered aluminum powder slugs) ready to take advantage of conductive polymer's two orders of magnitude higher conductivity.

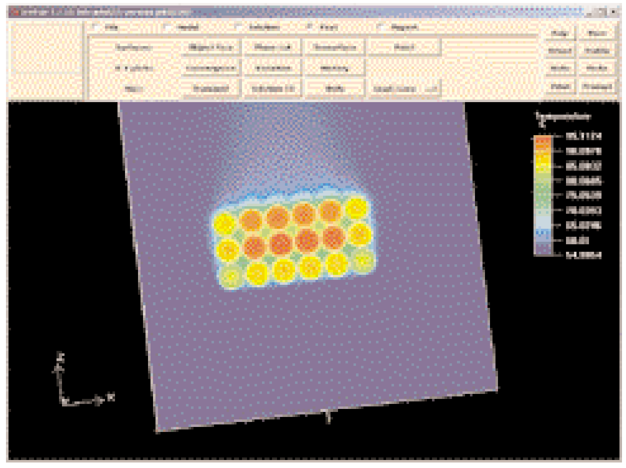


Figure 2. Computational fluid dynamics model of a bank of 18 snap-mount capacitors under conditions of natural convection and radiation heat-transfer modes.

Dry film capacitors will replace oil-impregnated wet films in motor-run applications. Chemical double-layer capacitors will offer lower and lower ESR. All SMT capacitors will meet the requirements of the lead-free solder initiative and its higher solder temperatures.

Conclusion

The successful capacitor manufacturer will differentiate by offering its customers the best set of user-friendly design tools. Capacitor manufacturers already offer many services such as tools that predict capacitance, ESR, ESL, and impedance versus frequency and temperature, and leakage current versus voltage and temperature. Spice capacitor models are often available at the component manufacturers' Web site, as are online tools for predicting capacitor life. Thermal modeling tools are available from some capacitor manufacturers, such as finite-element (FEA) modelers and even computational fluid dynamic (CFD) modelers for predicting the temperature distributions of individual capacitors and banks of capacitors in any imaginable configuration (Figure 2). In the coming years, capacitor manufacturers will provide the tools for their customers to design and evaluate their own custom capacitors.

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