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The Evolution of Low ESR Double Layer Capacitors

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The concept of using the double layer capacitor (DLC) for storing charge between an electrode and electrolyte was first introduced in 1845. However, the first products utilizing this technology were not developed until 130 years later. During the late 1970s, capacitors with values in the Farad (F) range, with working voltages of 2.3 to 2.7 V were introduced for commercial applications in Japan. Today, these devices are routinely used for DC back-up applications in the micro-amp range, with high ESR values of 10 to 100 Ohms.

For pulse power applications, it was necessary to develop DLCs with low ESR capabilities. Some manufacturers have introduced these new families of DLCs, also referred to as "supercapacitors", with voltage ratings of 3.5 to 5.5 volts and low ESR values in the range of 30 to 200 mOhms, with some technologies now achieving 12 V ratings. These capacitors are specifically designed for pulse power applications because they maintain low ESR values and retain high capacitance values at high frequency (pulse widths of 0.5 to 5 ms).

Due to their low profile (1.9 to 6.5 mm), long cycle life and low leakage currents, these supercapacitors are well suited for digital wireless applications. In addition, the devices are finding acceptance as replacement for aluminum electrolytics where size and profile are critical. These devices also enable the replacement of lithium ion by alkaline cells, as primary in many electronic applications where the cost is of paramount importance, extending battery life by 200 to 300 percent.

This innovative aqueous based technology for pulse supercapacitors utilizes proton-conducting membranes, resulting in lower ESR and higher capacitance values in a package size for devices with voltage ratings of 3.5 to 12 volts.

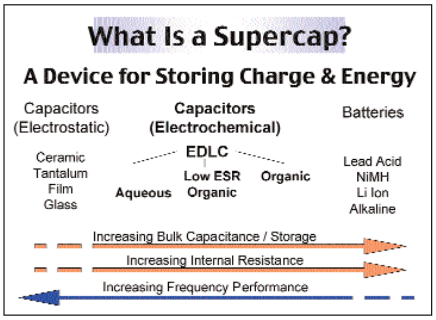

Figure 1.

Supercapacitors in Perspective

Historically, the prime technology driver for batteries and capacitors was the emergence of the telegraph and telephone. Since then, capacitor technology has evolved in both directions, covering the spectrum from picoFarads to DC Farad equivalent while batteries are driving to longer life (mAHr ratings) and lower internal resistance for improved frequency response. Supercapacitors occupy the middle ground, based on electrochemical processes analogous to batteries but with charge delivery characteristics more akin to electrostatic capacitors. As this species evolves, they are extending to higher bulk storage on the low frequency side to low ESR / fast energy delivery on the high frequency side, as shown in Figure 1.

Introducing Proton Polymer

Common drivers for mobile electronics technology are smaller size, increased functionality and lower cost. Electrostatic capacitors are meeting the challenge with increased surface area substrates (from micron-sized tantalum powder to multiple ceramic stacks), and higher dielectric constant materials (X5R and niobium pentoxide).

For electrochemical capacitors, there are parallel developments with higher surface area substrates (finely divided carbon membrane) and more effective charge carriers. These include high charge density organic molecules for DC backup types and highly mobile ionic transport in the proton polymer pulse delivery types.

Aqueous Based Technology and Proton Polymer Characteristics

Capacitors are built with environmentally friendly, aqueous materials with multiple cells. Each cell is between two current collectors and consists of two carbon electrodes, separated by the proton conducting solid polymer separator. The separator is specially designed with a polymer-based composition that results in very low leakage current and low ESR, essential for high current pulse applications.

The number of cells is adjusted to provide a range of voltage ratings from 3 to 12 volts, limited only by the height of the device. This flexibility in a stack of cells in the same package offers advantages over other technologies where each cell has to be separately enclosed.

This proton polymer system provides a high level of capacitance retention at increasing frequency for short pulse width applications. Figure 2 shows that the retention is similar to a bank of aluminum electrolytic capacitors.

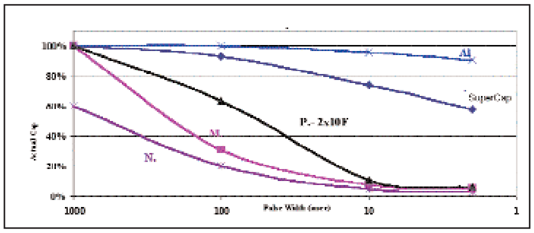

Figure 2.

Depending on rating, these parts have typical ESRs ranging from 4 to 200 mOhm, but the impedance characteristics are also significant, unlike electrostatic capacitors, the impedance curve remains flat down to frequencies <100 Hz. Given these characteristics, together with low leakage current and a wide range of rated voltages, this technology is suited to a multitude of pulse applications.

Pulse Application Considerations

Pulse holdup applications are defined as a system where an energy storage device (battery of fuel cell) supplies a low power continuous load, and also charges the reservoir (capacitor) which is capable of short term, high power delivery on demand for peak load requirements. While many technologies can be used as the reservoir, as peak duty cycles increase (eg. GPRS-8 to GPRS-10) the applications suit the combined high capacitance/ low ESR of pulse supercapacitors. In fact, the application may have a mixed-load requirement, where a smaller bank of tantalums and a pulse supercapacitor can be used.

Such pulse applications are everywhere, including combinations of electrical and electro-mechanical support, from digital cameras (ensuring capture is maintained while zoom and focus motors operate) to remote valve controls (automated faucet to wireless remote valve activation).

The key to pulse supercapacitors is that they bring more battery options to the above applications. With pulse support, standard non-rechargeable alkalines can be used in place of Li-Ion rechargeable types, which is useful for commodity electronics operated away from convenient recharge facilities.

A common example to consider is a GSM/GPRS hand-held device. It requires a current of approximately 2 A for the pulse duration, but due to battery and circuit impedance, the input voltage to the transmitter will drop during the pulse. The transmitter can operate only above a certain input voltage, therefore;

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to maximize the usage time before charging or replacing the battery, the voltage drop due to transmission needs to be minimized. The solution is to connect a supercapacitor close to the transmitter. This will provide pulse holdup characteristics and substantially lower voltage drop for pulse duration of up to 100 msec as shown in Figure 3.

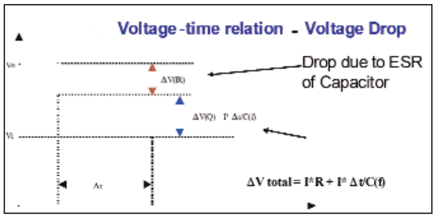

Figure 3.

Apart from providing a technical solution, the proton polymer system has additional advantages, including:

- Wide range of voltages available can be used across the GSM chip (3.5 V), across the battery (4.5 V) or at the DC-DC o/p (5.5 V).
- Lower DC cap for a given pulse capacitance means that the charging circuit can be simplified.
- Low profile (down to 1.8 mm) prismatic form enables part to fit inside PCMCIA card.
- Wider temperature range gives substantially lower voltage drop at cold temperatures (-20ºC).

Pulse Supercapacitor Arrays

Proton polymer technology is based on an aqueous system, where cells have extremely repeatable voltage capability. This enables a wide range of voltage ratings to be manufactured, from < 2 V (to support low voltage power supplies) to 12 V ratings. The voltage repeatability means that these are well suited to serialization, either as discrete capacitors in serialized banks or in volumetrically efficient modules (4 by 90 mF/12 V in series gives a 22 mF/48 V system, with < 400 mOhms ESR). No balancing resistors are needed for discrete parts and are optional with larger serial banks.

References:

1. John Miller, "Capacitor-Battery Power Sources: Designing for Optimal Performance", Proceedings of Fifth International Seminar on Double Layer Capacitors, Boca Raton, Florida, December 4-6, 1995.

2. John Miller, "Battery-Capacitor Power Source for Digital Communication Simulations Using Advanced Electrochemical Capacitors" Electrochemical Capacitors, Edited by F. M. Delnick and M. Tomkiewicz, pp 246- 254, The Electrochemical Society Proceeding Series, Pennington, NJ 1996.

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