

# Evolution of Supercapacitors

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Supercapacitor technology has really come of age. In less than 10 years, these high charge electrochemical devices have evolved in two directions from the large, low voltage cylindrical devices originally designed for DC applications such as voltage hold-up for clocks in microwave ovens & VCRs. At one end of the scale, vastly larger high voltage/ high Farad arrays for hybrid vehicles are now available, and in the other direction a new series of small, low profile prismatic pulse supercaps have been established.



The new generation of pulse supercapacitors are characterized by very low ESR enabling them to supply peak current on demand while trickle charging from primary Li-Ion or standard AA or AAA batteries. Their low-profile design enables deployment on small CCAs (PCBs) where they are ideally suited to increasingly power hungry applications such as wireless cards and high density data transfer in portable devices. In these applications, peak energies are required that would need double the current available from the primary battery to allow fast transmission of data, or digital signal processing of the Mbs of data in digital SLR / video applications, where flash / strobe functions vie with signal processing of burst-rate exposures and writing of multiple files per second.

Supercapacitors, as implied by their name, are capable of storing huge amounts of charge.

Standard capacitors do this by having a dielectric material between the capacitor plates that can be polarized on the application of an electric field. As the internal dipoles align within the dielectric, an electric field is established as measured by the voltage at the plates. The more charge the plates can hold, the higher the capacitance, and the energy stored (in Joules) is equal to  $\frac{1}{2}(C \times V^2)$ , where C = capacitance (in farads) and V = the plate voltage.

Supercapacitors achieve the same result, but by bulk separation and movement of charges, rather than dielectric dipole alignment. The mechanism for moving opposite charges to different sides of a separator is electrochemical in nature and very similar to battery technology. How long the energy will be stored in either standard or supercapacitors will depend on the internal leakage current (as dipoles relax or charges re-combine). How fast the stored energy can be released will depend on the internal resistance of the device.

Standard capacitor technologies are investing in materials development to improve dielectric constant, dielectric leakage, internal resistance and voltage capability. Likewise with supercapacitors; the original products available were based on high resistance electrochemical systems, giving 'battery-like' storage and discharge

characteristics, but new material developments have enabled the development of low ESR devices ideal for pulse applications.

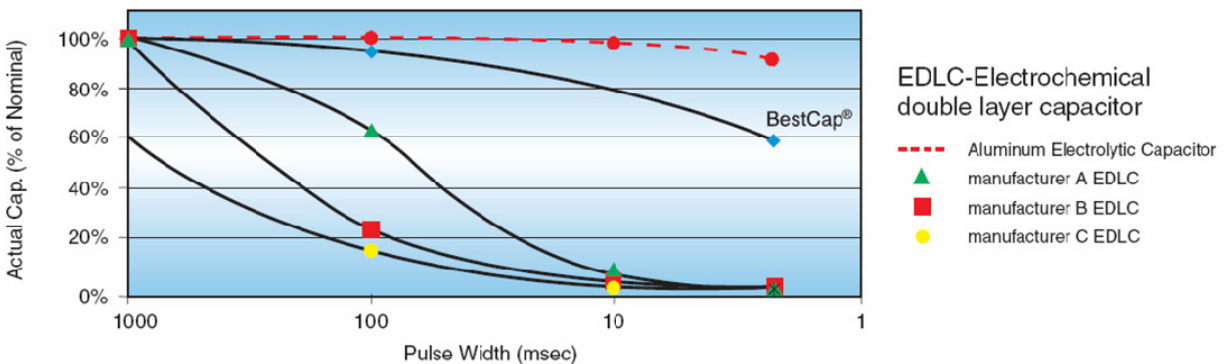
When we calculate the energy stored from dipole alignment in a standard capacitor, we are looking at a purely DC function. But most applications require the capacitor to pass a signal, which means having the plates linked by an AC voltage. The question then becomes how well can the dipole oscillations keep up with the incoming signal frequency to pass it on with no distortion? This is what differentiates standard capacitor types and suits them to different applications. For example, tantalum can will respond well in the 100kHz to 1MHz range, with bulk capacitance values to 2200uF at 6v, with ESR < 50mOms. Because the capacitance retention is high (~90%) at 100kHz they are ideal for a wide range filtering of SMPS devices. Ceramic type II material is also suited to this range, with lower bulk capacitance, but lower ESR (~100uF / 5mOhms). Meanwhile, Class I dielectrics will have far higher operating frequencies for RF applications, with single layer devices approaching 10GHz response for optical systems.

Similarly, supercapacitor technologies are evolving to enable a wider range of applications. All have benefited from nano-particle technology (development of high surface area carbon layers), but one of the most exciting developments in recent years has been the introduction of “proton polymer” technology for the separator system. This technology has the following benefits:

- High DC capacitance in the 50mF – 1F range
- High Capacitance retention at millisecond pulse intervals
- A wide range of voltage ratings from 3.6v – 15v (and beyond).
- Low ESR (20mOhms – 300mOhms)
- Low Leakage current (2uA – 5uA range)
- Long Cycle Life : Deep charge-discharge tests of up to 10 million cycles (or 8 months of non-stop testing) do not show any significant effect on these capacitors

The packaging of pulse supercapacitors is also evolving, with the emphasis on small footprint and low-profile. For example, AVX's BestCap® Series was originally introduced more than eight years ago with a standard 28mm x 17mm outline and a larger 48mm x 30mm version. These had height profiles ranging from 2.0mm to 6.mm. Now, an even smaller outline is available (20mm x 15mm) with an even smaller version in development (15mm x 12mm). The construction is extremely robust, having a precision steel outer body and the internal element epoxy sealed in place. The internal element is built with environmentally friendly, solvent-free, aqueous materials with multiple cells making a homogenous matrix. Because of the solid casing and homogenous internal element, parts can withstand in excess of 1000g shock / acceleration while the internal element has an operating temperature range from -40C to +75C.

Figure 2. Actual Capacitance vs. Pulse Width



A supercapacitor's electrical characteristics as shown above, combined with low profile format, ideally suit them for digital wireless applications. One major consumer application is the wireless card, either in PCMCIA or USB configurations where supercapacitors provide the necessary pulse energy to support the current-on-demand required for GPRS and EDGE transmissions while being trickle charged from a notebook or PDA Li-Ion battery. Because they can support these pulses over a wider operating range than primary batteries (and extend battery life by 200%-300%), they can improve efficiencies in many devices and there are a number of heavy-duty wireless card applications that benefit from this, one being remote optical scanners. An important factor in wireless transmission is the effective capacitance at the transmission pulse rate. Many supercapacitors with high DC capacitance suffer from limited effective capacitance retention as transmission pulse rates and/or duty cycles increase. The proton polymer system used by some supercapacitors provide a high effective capacitance, meaning that high duty cycles (eg GPRS-8 to GPRS-10) can be supported with a lower DC capacitance rating – which in turn requires a lower trickle charging energy budget for the device – a very important factor in turn-on time for some hand-held devices. The range of rated voltages (from 3.6 to 5.5v) for these applications means that a pulse supercapacitor can be used across the GSM chip (3.5v), across the Li-Ion battery (4.5v) or at the DC-DC o/p (5.5v). The 5.5v deployment allows for holdup of additional circuitry, or elimination of other sub-circuitry (LDO etc.).

Other energy demanding applications include high-end digital cameras; these have a high-energy budget due to all the ancillary systems (zoom, focus and processor support during caching of large data files during multiple burst operation), but also require instantaneous power to fire the flash when required, without draining the other applications.

As portable devices, these can be used in quite hostile environments wherever data-logging, inventory control or package monitoring is required, which often includes wide temperature range and shock or vibration. In cases where the device can be dropped while in operation, the prime concern is not just the survivability of the instrument, but whether any data drop-out will occur. In battery-only operated devices, the resultant "battery-chatter" can mean loss of critical data; by having a supercapacitor hard soldered in place, then there is no discontinuity in operation as a result of severe shock.

This level of robustness and electrical characteristics mean that they can support many “industrial grade” battery assisted applications where pulse power current on demand is required, from wireless transmission to electromechanical applications. These include remote installation and wireless control of automated valves, automatic metering systems, remote RFID readers and remote security systems. In many of these systems, the primary cell may not be a battery, as it could also be a solar cell.

Another emerging application is battery-less operation. While supercapacitors operate as a secondary device in most systems, if only a trickle charge is required, then sometimes a primary (or solar) cell is not needed; there are a number of ways that movement or vibration can be used to generate energy, from piezo to inductive devices. Energy harvesting systems are now available that can be deployed on any mechanically vibrating system and can provide voltage output to a storage device. In these applications, proton polymer has another advantage – higher voltage ratings from 7v to 15v are available as discrete devices and there is no need for the balancing resistors as when using other types of supercapacitors in series configuration.

As discussed earlier, the energy stored in a capacitor is equal to  $\frac{1}{2}(C \times V^2)$ , as this is a function of the square of the voltage, in any system designed to store energy, doing so at higher voltage results in much greater efficiency. The capacitor in these systems has a dual function: 1) to store the harvested energy and also use it to provide current for any remote device that is being supported; 2) In the case of wireless devices, the high capacitance retention with duty cycle is another way the proton polymer technology adds to the efficiency of the system.

Pulse supercapacitors have come a long way since their introduction less than ten years ago – from consumer applications to remote industrial systems, the next ten years should prove them to become as ubiquitous as “dielectric” types.