TAP TIMES

Test, Assembly & Packaging TIMES

Volume 9, Number 3
March 2018

Ultracapacitors: The super component for power management?

Editor's Note: This original article represents our continuing coverage of emerging technologies. While our main focus remains IC assembly, packaging and test, emerging technologies present an area that often touches on processes and techniques employed in semiconductor manufacturing.

Ultra capacitors, also called supercapacitors (SC) or electric double-layer (EDLC) capacitors, are passive devices which can be used for energy storage and offers high power density (KW/Kg), fast recharging, a wide operating temperature range and long life.

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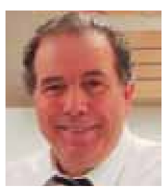


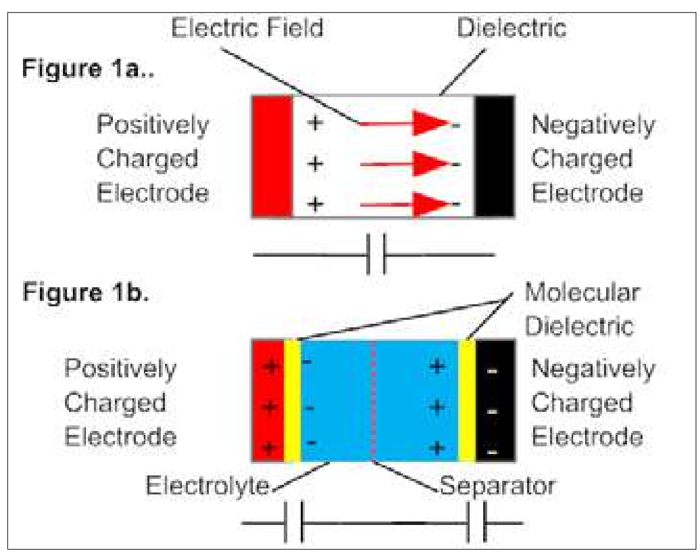
SCs store energy in an electric field unlike batteries. Without the limitation of battery chemical reactions, SCs can be charged and discharged hundreds of thousands of times.

As shown in Figure 1a, for conventional capacitors the two electrodes are separated by a solid dielectric.

When voltage is applied, electrons move from one electrode to the other. The capacitance can be derived from the equation shown at top right. ***Next page***

Photo courtesy Steve Roux, escomponents.com

C=ε*A /d
Where ε= the relative dielectric constant
A= area of the electrodes
d = the thickness or separation of the dielectric plates



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In SCs the carbon electrodes are separated by a liquid electrolyte. This electrolyte has positive and negative ions dissolved in an either a water-soluble- or non-water solution.

Non-porous separator
An electrically non-conductive porous separator allows ions to move between electrodes when voltage is applied. This prevents the electrodes from shorting to each other as shown in Figure 1b (page 3).

One of the key attributes of SCs is the electrical double layer effect at each SC electrode . [1]

Extremely thin monolayer of solvent
The layer of solvent acts as a dielectric between the double layers of charge to create a large capacitor due to the extremely thin monolayer of solvent at each electrode.

This dimension (d) is a molecular size on the order of 0.5 nanometers. Additionally, as shown in Figure 1c, the porous structure of the carbon electrodes increases the surface area (A) by over 100,000; and significantly increases the capacitance from the capacitance formula.

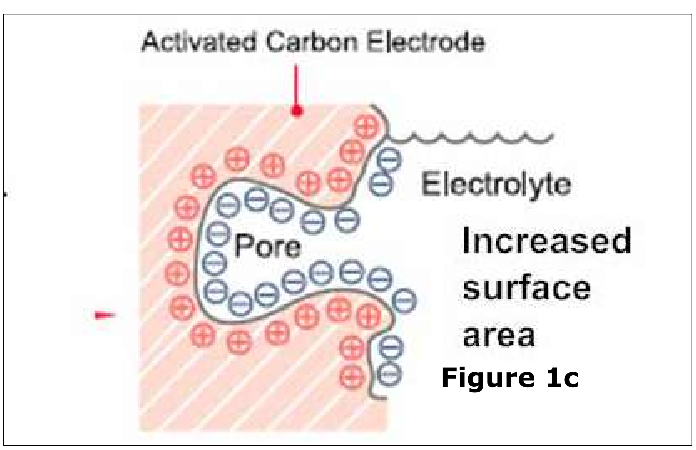

Figure 1c

Thus, super capacitors can be made on the order of thousands of farads (F) where conventional capacitors are measured in microfarads (µf = 10-6F).

Low breakdown voltage rating
While the thin dielectric result increases the capacitance, it does cause lower breakdown ratings compared to traditional capacitors.

Typical breakdown voltage rating for an SC is a nominal ~2.5-2.7 volts. (Some manufacturers may package two SCs in series to increase the breakdown voltage) This is significantly lower than the 25 – 1,000 volts for typical multilayer ceramic capacitors.

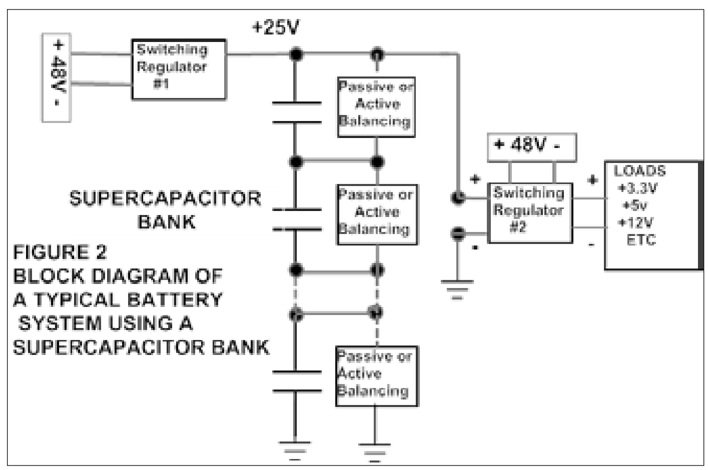

FIGURE 2 BLOCK DIAGRAM OF A TYPICAL BATTERY SYSTEM USING A SUPERCAPACITOR BANK

Stacking remedy
The remedy is to stack the SCs as shown in Figure 2 above.

This configuration, however, causes a problem: Due to variations in each SC capacitance value, leakage current, and Equivalent Series Resistance (ESR) an uneven distribution of voltage over the stack can be developed which may exceed the breakdown voltage rating of one of the SCs in the stack.

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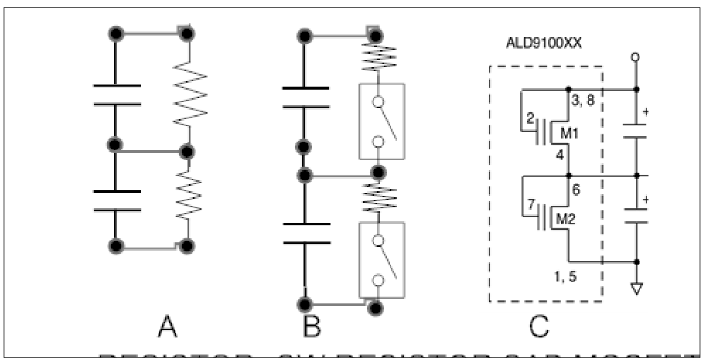
Over voltage may cause reduced SC operating life or eventual catastrophic failure.

Added complications
This situation becomes more complicated if we consider aging, temperature variation, operating temperature range, leakage current variation with charging voltage, charging current and temperature.

Similar to battery cell balancing, typically there are two techniques for SC cell voltage balancing: passive and active balancing.



As shown in Figure 3a, above, a resistor bypasses each SC. This is a passive technique where the resistor is chosen by the ratio of the SC voltage/SC leakage current.

Temperature variance
The problem is that the leakage current varies with temperature and aging and the resistor dissipates power.

Another passive technique, which is more efficient, is to sense the voltage across each SC and then switch in a fixed resistor when the SC voltage goes beyond an operating voltage threshold shown in Figure 3b.

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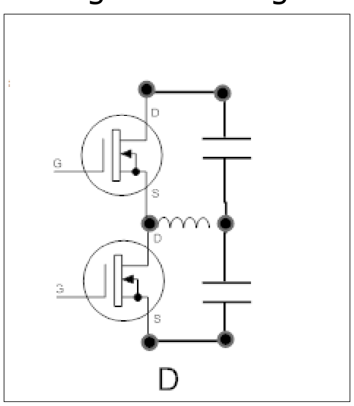
Usually the control chip is a microprocessor with additional MOSFETs to switch resistors or a specific Super Capacitor Manager IC such as the Texas Instruments bq33100, which is a fully integrated, single-chip, solution.

Cell balancing
Figure 3c show a circuit design for SC cell balancing using a Super Capacitor auto balancing Linear Systems (SAB) MOSFETt circuit.

Balancing with SAB MOSFETs is automatic when connected across the SC, one MOSFET will turn itself on automatically to balance, and the other one will turn itself off automatically to balance the stack.

Figure 4, below, shows another type of voltage balancing circuit, which employs buck-boost structures. These circuits instantly equalize the SC cell voltages. An example of an IC which provides this function is the Linear Technology LTM8064s to charge and actively balance supercapacitors.



Summary
Compared to batteries, SCs feature higher peak currents and hundreds of thousands of recharging and discharging cycles.

"The supercapacitor is often misunderstood; It is not a battery replacement to store long-term energy. [1]

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"If, for example, the charge and discharge times are very long, use a battery; if shorter, then the supercapacitor becomes economical.

Ideal for a quick charge
Supercapacitors are ideal when a quick charge is needed to fill a short-term power requirement; batteries are chosen to provide long-term energy.

Combining the two into a hybrid battery satisfies both needs and reduces battery stress, which results in a longer service life." [2]

Many new IOT wireless applications are opening up with the potential of new materials such as graphene and ***Next page***

Typical Applications

-Automotive subsystems
-Burst/boost power delivery for cold-starting diesel or gas engines
-Energy storage recovery
-Hybrid vehicles
-Railroad braking
-Industrial motor braking
-UPS and telecom system power stabilization
-Wireless sensor networks
-Wind turbine pitch control

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carbon nanotubes (CNT) and new electrolytes to manufacture SCs.

Power management star?

Will Ultracapacitors become the Super Component for Power Management? Some of the new applications shown are ideal to take advantage of the attributes of SC and move the technology to the next level.

Notes:

1. Conway, Brian E., *Electrochemical Capacitors, Their nature, Function and Applications, Chemistry Dept., University of Ottawa, Canada.*

2. Roux, Steve, *Ultracapacitors 101, "Frequently Asked Questions, https://www.escomponenets.com/ultracapacitors-LS-mtron*

Mr. Terlizzi is vice president at GM Systems LLC, a management and technology consulting firm. For over 30 years, he has designed and developed power mangement systems, single board computers, microelectronic device, thick and thin film hybrids and other products for military, aerospace and consumer markets.

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In addition, he is also a member of the program committee for the CMSE conference and exhibit, hosted by T.J. Green Associates LLC.