1 Basics

Basically, an UltraCap is an electrochemical double layer capacitor consisting of two electrodes, which are immersed into an electrolyte (Fig.1). When the electrodes are being electrically charged, the ions of the electrolyte move under the influence of the electric field towards the electrodes of opposite charge. In the charged state, a fraction of the anions and cations are located adjacent to the electrode such that they balance the excess charge in the activated carbon. Thus, across the phase boundary between carbon and electrolyte there are two layers of excess charge of opposed polarity. This is called an electrochemical double layer. The high energy content of UltraCaps in comparison to aluminum electrolytic capacitors originates in the activated carbon electrode material, which has an extremely high specific surface area of about 2000 m2/g and the extremely short distance between the opposite charges of the capacitors, which is of the order of a few nanometers (2 ... 5 nm). Since the dielectric is extremely thin – it only consists of the phase boundary between electrode and electrolyte – capacitance of a few thousand Farads can be realized in devices as small as a soda can. UltraCaps rely on an electrostatic effect, purely physical and highly reversible. Charge and discharge performs upon movement of ions within the electrolyte. The more or less randomly distributed ions move under the influence of the electric field toward the electrodes of opposite charge. Consequently, there are some fundamental property differences between UltraCap and battery technologies, which result in long shelf life, extended useful life, high cycle life and a maintenance-free product. At present the tendency to enhance the energy and power output means increasing the nominal cell voltage of the device. It is desirable to work with voltages as high as possible. Currently the nominal cell voltage has increased to 2.5 VDC, while the research goal already targets higher voltage. Obtaining the higher voltages required by the application is possible by connecting capacitors in series with power modules.

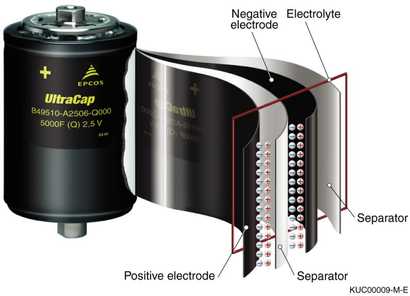


Figure 1
UltraCap layer structure

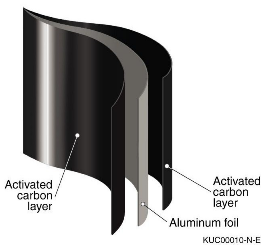


Figure 2
Electrode structure

2 Material selection and construction

The best way to realize high capacitance is to use activated carbon as the electrode material (Fig. 3). The reasons are high surface area, chemical inertness, electrical conductivity and relatively low cost. Powder technology can be wound into round shaped capacitors, leading to faster process flow techniques. In carbon powder technology, the carbon powder is backed onto the current collectors. It is common practice to soak the separator (paper, polymer membranes or glass fibers) in a highly conductive organic electrolyte to establish ion movement during charge and discharge cycles. The effective existing terminal voltage will be limited by the dissociation voltage, so that electrical loads can move from electrodes to the direct attached ions on them. The use of an aqueous electrolyte limits the rated voltage to about 1 V. Once this voltage is exceeded, electrolysis of the electrolyte and thus the evolution of gas occur. Electrolytes based on organic solvents are currently used by EPCOS with rated voltages of 2.5 V. Organic electrolytes are preferred for achieving higher voltages than 2.5 V, feasibly in the future. All other materials are chosen such that they are compatible with the electrolyte and electrochemically inert at the applied voltages. Aluminum is a typical choice for current collector and case material. The components are contained in a metal case (round) that only has a minimum area of plastic seals in order to electrically insulate the terminals properly. This reduces the diffusion of electrolyte through the seal, which would lead to drying of the capacitor and an increase of the ESR value.

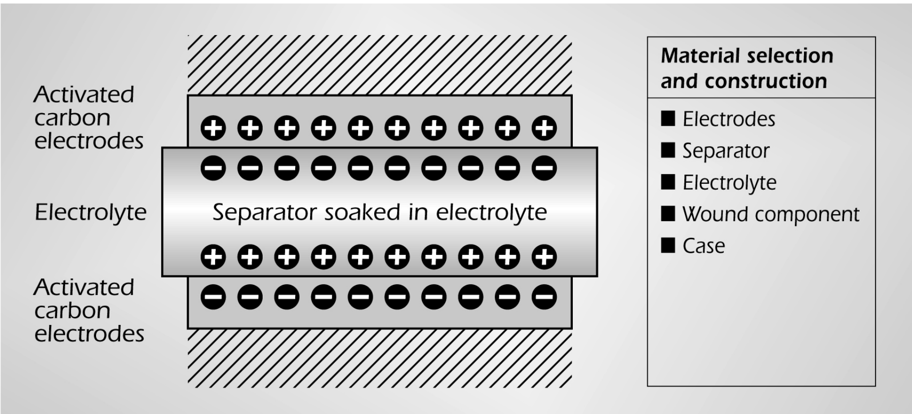


Figure 3
Schematic of an electrochemical double layer capacitor (charged condition)

3 Comparison between UltraCaps and batteries

The electric energy in batteries is stored indirectly in chemical compounds and released on the basis of Faraday's oxidation and reduction processes of electrochemically active materials. The chemical reactions on the electrodes have a major influence on the aging of batteries. In a capacitor, the electric energy is stored direct as a positive or negative charge on the plates, without any reaction on the electrode surfaces. The aging of capacitors is not directly affected by the reverse charging process, and they can be charged and discharged frequently without noticeable changes in their characteristics. What is more, double layer capacitors achieve more than ten times the power density of lead-acid batteries. UltraCaps and batteries also differ in that batteries are able to store a lot of energy slowly and UltraCaps less energy but fast (a matter of seconds). When high power output is to be produced, this is a considerable load on a battery (high internal resistance) but not on an UltraCap (small internal resistance), meaning a negative influence on the service life of a battery.

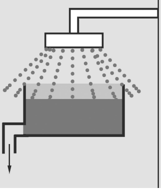
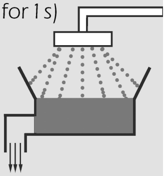
	Battery Lead-acid 12 V/44 Ah	**UltraCap** 3600 F/2.5 V
Provided energy	Only part of provided energy can be stored	Total provided energy can be stored
Energy density	40 Wh/kg	4 Wh/kg
Power density	300 W/kg 	5 kW/kg (pulse for 1 s) 

Figure 4
Comparison of battery and UltraCap properties

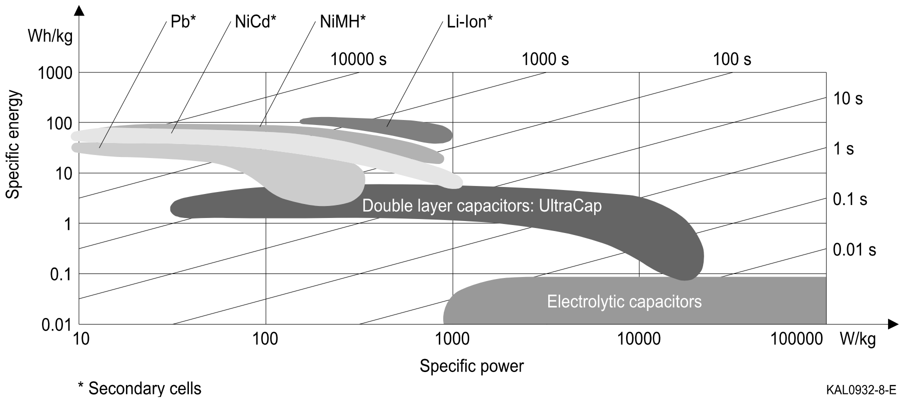


Figure 5
Comparison of storage technologies

4 Charging and discharging

UltraCaps are very tolerant regarding the methods as long as the charging voltage does not exceed the rated voltage. In practice the charging current is limited by the current output of the power supply (charging source). UltraCaps possess a very low internal resistance, so the charging current will not exceed the limit mentioned in the UltraCap data sheet. UltraCaps rely on an electrostatic effect, which is purely physical and highly reversible. Charge and discharge occurs upon movement of ions within the electrolyte. This mode of energy storage is in contrast to all battery technologies, since they are based on the formation and dissolution of chemical compounds on the battery electrodes (Faraday reactions). In comparison it is not necessary to reach a certain state of charge (output voltage) in order to use an UltraCap. The battery output voltage does not indicate the actual charging condition and is not easy to control (flat voltage level between fully charged and discharged). The UltraCap characteristics show a simple relationship between voltage level and charging condition (Fig. 6).

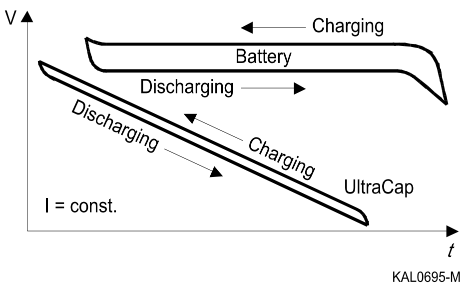


Figure 6
Comparison of battery and UltraCap charging and discharging curves

Expected life depending on output voltage (cell voltage) and ambient temperature (operating temperature)

As the attached graph (Fig. 6) shows, the higher the rated cell voltage, the shorter the expected life of a double layer capacitor like UltraCap. A cell voltage of higher than 3 V causes increasing decomposition of electrodes resulting in overpressure (gassing) released through the rupture joint (exhausted via an air filter) of the capacitor. For limited periods the UltraCaps can be operated at higher voltages, as their expected life depends on operating conditions such as voltage and temperature (Fig. 7). However under no circumstances should the maximum operating temperature of +70 °C and surge voltage of 2.8 V be exceeded.

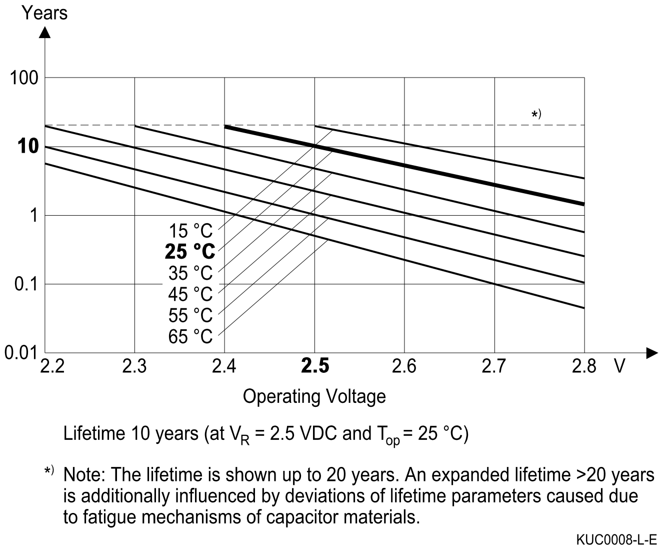


Figure 7
Lifetime

5 Soldering

Excessive time or temperature during soldering will affect capacitor's characteristics and cause damage to the insulation sleeve. Capacitors should be dipped in solder less than 10 seconds. Contact of the sleeve with soldering iron must be avoided.