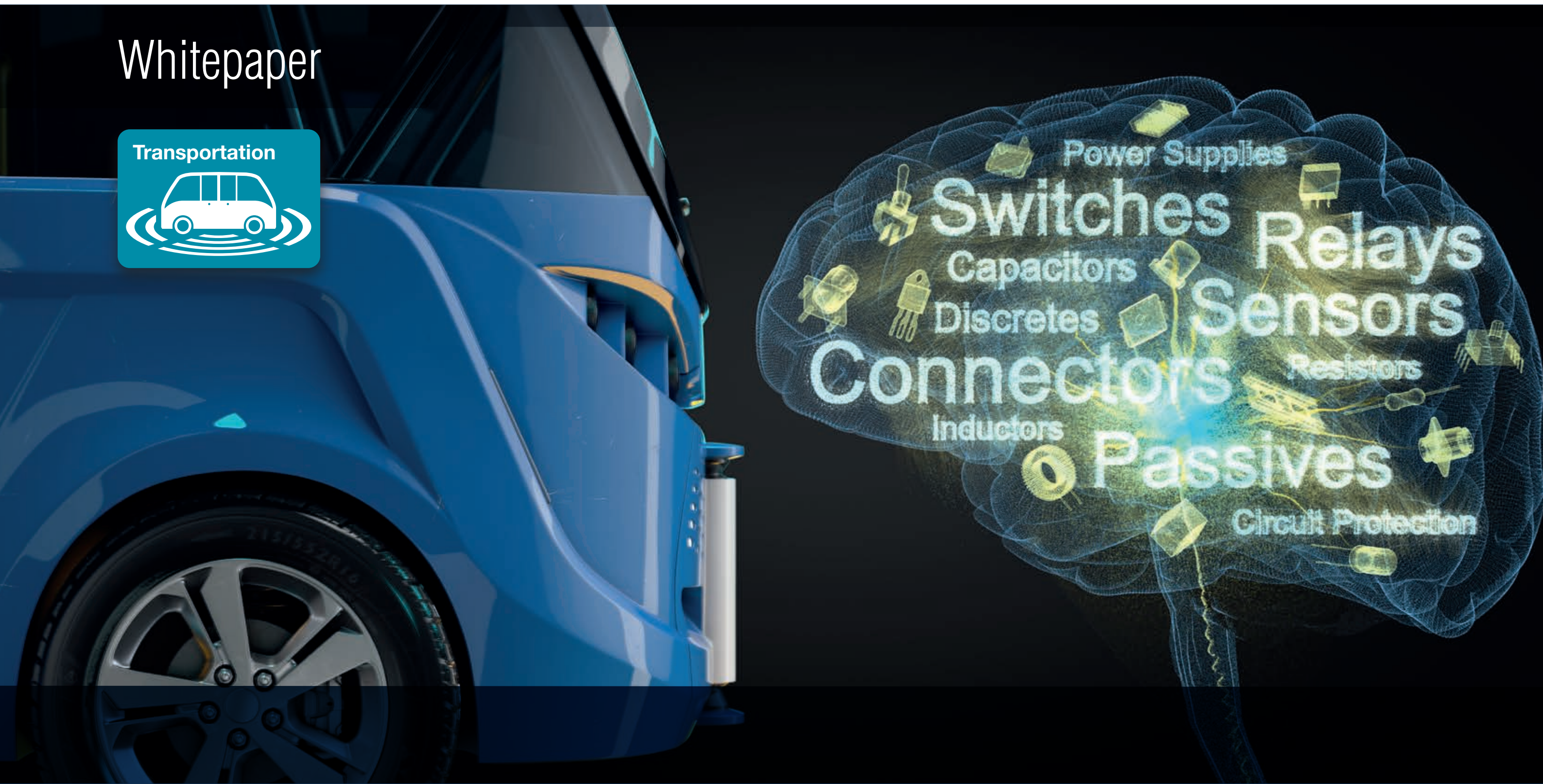
Whitepaper



Supercapacitors as a long-life solution in battery powered applications

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The Specialist in Electronic Component Distribution

Supercapacitors have long been used for supplying a peak power demand in many consumer electronics devices such as a flash function on a smartphone to deliver large amounts of current quickly and reliably.

New materials and structures have expanded their use beyond small coin-cell sized devices into larger supercapacitor cells and modules with a wider supply voltage range. This has seen the benefits of supercapacitors integrated into a broader range of applications as part of the power supply. They can deliver the peak-power demand of a wide range of battery powered applications, and, in the process prolong the life of the battery, and by not having to specify a larger battery, save both physical space and cost.

Using electrostatic technologies in supercapacitors rather than the electrochemical technology of battery cells provides another level of control and reliability for all kinds of power sub-systems, overcoming the limited lifetime of batteries, particularly in industrial and transportation applications.

This whitepaper looks at the basics of supercapacitors, and those that are available for a range of higher-power industrial examples such as powering the startup-surge demand of electric vehicles.

Capacitor technology

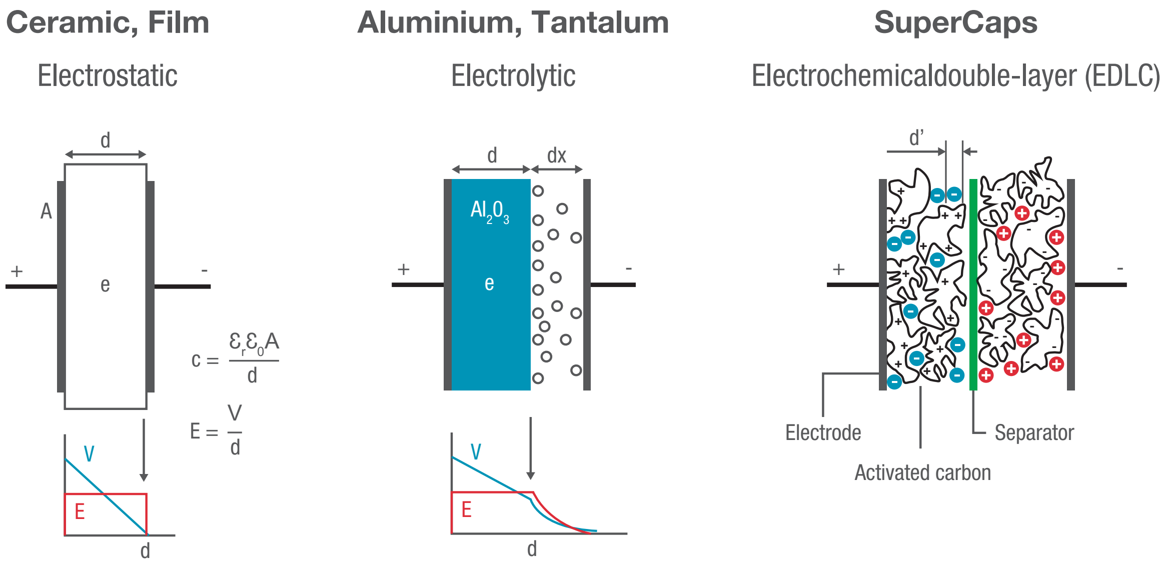
Supercapacitor values range from several millifarads to 1,000s of Farads. They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable batteries.

The hybrid electrochemical pseudocapacitance type devices are largely based on activated carbon that amplifies the surface area, A, of the electrode, d, that is defined by the diameter of the salt ion in the electrolyte between the electrodes. The voltage is a function of the ionic breakdown of the salt ion, and so is a function of temperature and voltage. See Figure 1.

The most common type is the Electrostatic double-layer capacitors (EDLCs), which use carbon electrodes (in the form of graphene or 3D structures) with much higher electrostatic double-layer capacitance than electrochemical pseudocapacitance. The separation of charge is of the order of 0.3 to 0.8 nm, much smaller than in a conventional capacitor.

Hybrid capacitors, such as the lithium-ion capacitor, use electrodes with both techniques, combining electrostatic capacitance and electrochemical.

Figure 1: Different capacitor technologies – Source (AVX)



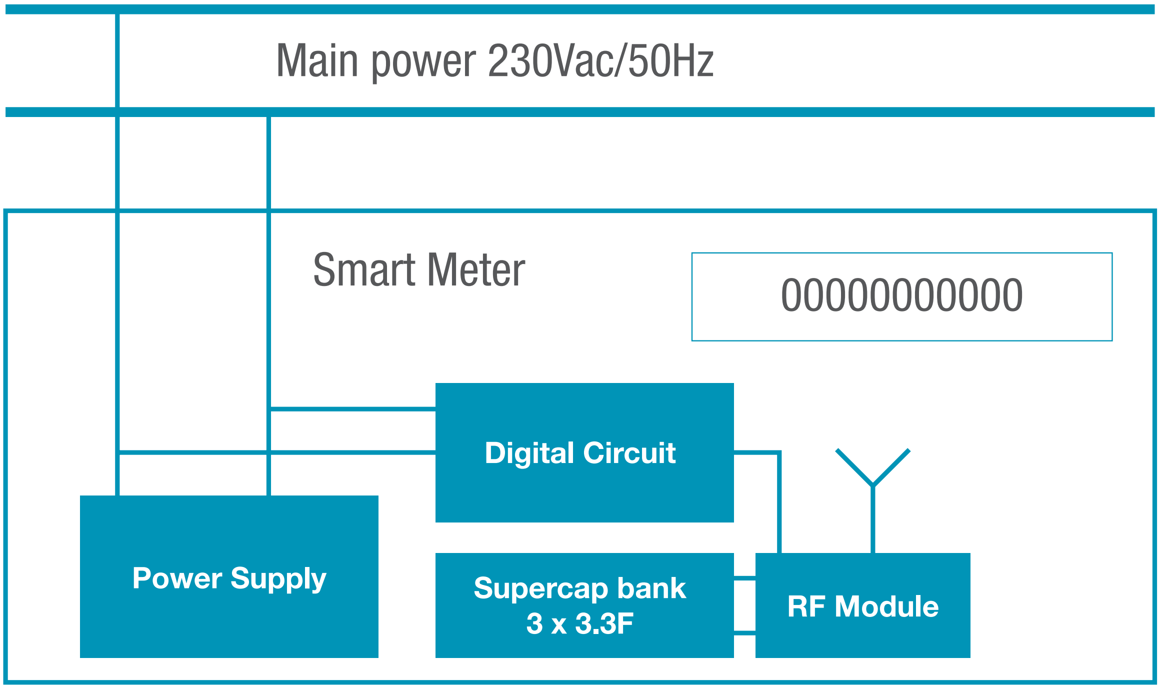
Supercapacitor applications

Supercapacitors can be used in a wide range of applications, from pulse power for wireless transceivers, to power hold-up sub-systems to provide a 'dying gasp' to allow memory systems to shut down reliably in the event of a power failure. They can also be used in energy harvesting systems to give power controllers the boost they need to start operating in the Internet of Things and even as a complete replacement for a battery.

As a result, the market for these devices is expected to grow from $700m in 2016 to over $2bn by 2019, a dramatic increase over a short period of time.

This growth is driven by the wide range of applications. Data storage systems such as solid state disks need high currents for a short time to shut down safely, and in case of interruption of the 230Vac main power, a smartmeter needs to provide a 'dying gasp' message. This is done via an RF module using the energy stored in a supercapacitor bank. See Figure 2.

Figure 2: Using a supercapacitor to allow a smart meter to send a 'dying gasp' message in the event of a power failure (Source Eaton)



A 3phase static uninterruptible power supply (UPS) recently installed in a print factory in Estonia uses a 600F supercapacitor board to provide up to 60kW for a maximum of 20 seconds in order to allow a data system to shut down safely in the event of a power failure, but it can also be used to compensate for voltage sags and micro interruptions in facilities that can create data errors.

Supercapacitors can also be used to capture energy from vehicles. Regenerative braking systems take the energy from brakes in electric cars or forklift trucks and convert it to electricity. Storing it directly in a battery creates problems of charging and battery lifetime, so a supercapacitor is used instead. As it uses electrostatic forces, it has a dramatically longer lifetime and the captured energy can be easily stored and then used by the electric subsystem in the vehicle, for example to power the stop-start operation.

Hybrid double-decker busses used by London Transport are using AECQ automotive qualified supercapacitor modules to store and release mild hybrid drive-train regenerated energy and contribute to the hybrid drive's efficiency in a 48V powertrain. Parallel connections ensure the required capacity for the drive cycles.

Supercapacitors are even replacing batteries entirely in some specific applications. Busses on dense urban routes in Switzerland, where the bus stops every few minutes, are using those stops to recharge the supercapacitor banks quickly while taking on more passengers, delivering enough charge quickly to get the bus to the next stop. This can reduce the weight of the bus and the cost of replacing the batteries, which is significant.

Supercapacitor vs battery

An electrochemical battery using lithium, manganese or nickel, or even lead-acid, can store energy for a substantial amount of time but needs careful charging over time and has a relatively limited number of cycles. For example 500 for a lithium ion battery - see Figures 3 & 4. In contrast, the supercapacitor charges simply like a capacitor and supports millions of cycles, delivering large amounts of power in a short time that would make a battery catch fire by over discharging. The challenge is the output voltage and the time it retains the charge, which can be measured in minutes rather than months.

Figure 3: A comparison of supercapacitor and battery technologies

Direct Comparison

SuperCaps	
Pros	**Cons**
Long cycle Life	Low specific energy
High load currents	Slightly higher self-discharge
Fast charging times	High cost per Wh
Specific Energy	100 - 200
Good temperature performance	
Batteries	
Pros	**Cons**
High energy density	Limited life cycle
Better leakage current	Long charging times
	Very temperature sensitive

This means that the high power, high current capability of supercapacitors is increasingly used alongside batteries to provide instantaneous power. Interestingly, the safe, fast charging properties supercapacitors are even replacing batteries entirely.

For example, a supercapacitor-powered automatic guided vehicle or warehouse shuttle completing a defined mission normally in 100-200 seconds can be followed by a 10s recharge before starting again. This is a cost efficient solution compared to batteries and can be used in cold environments such as refrigerated warehouses where batteries become sluggish.

Figure 4: The different electrical characteristics of supercapacitors and batteries

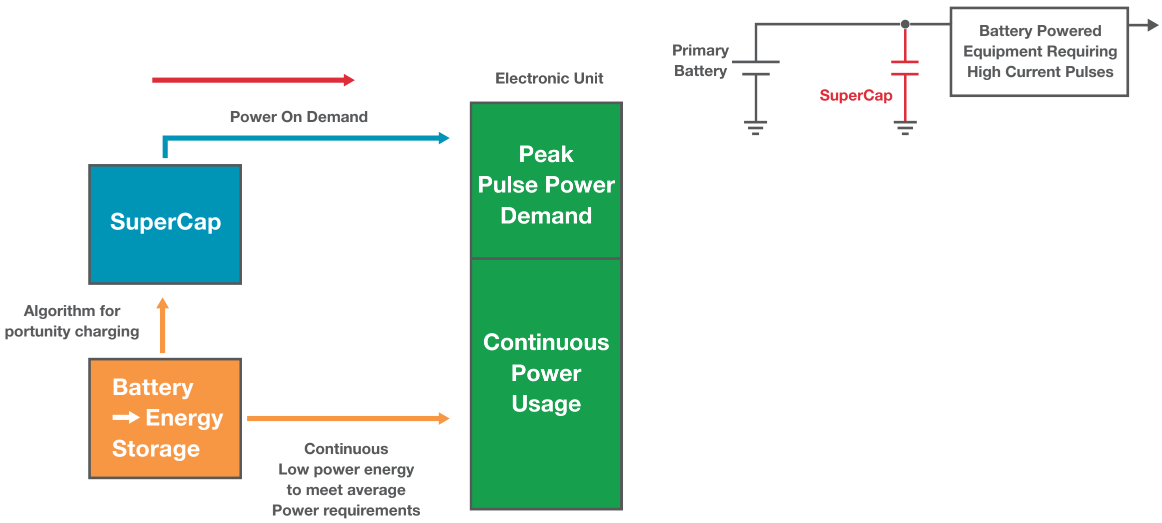
Characteristic Comparison

Characteristic	SuperCap	Li-ion Battery
Charge Time	1 - 10 secs	1 - 60 mins
Cycle Life	1 million	500+
Cell Voltage	2.1V - 3.3V	3.6V - 4.2V
Specific Energy	5	100 - 200
Specific Power	~10,000	1,000 - 3,000
Cost per Wh	> $10	$0.50 - $1
Service Life in Automobile	10+ years	5 - 10 years
Charge Temperature	-55°C to +90°C	0°C to +45°C
Discharge Temperature	-55°C to +90°C	-20°C to +60°C

However supercapacitors have voltage limits. While the electrostatic capacitor can be made to withstand high voltages, the supercapacitor is confined to 2.5–2.7V. Voltages of 2.8V and higher are possible, but with a reduced lifetime. To get higher voltages, supercapacitors are connected in series but this reduces the total capacitance and increases the internal resistance, or Equivalent Series Resistance (ESR). Like batteries, putting three or more supercapacitors together in a string needs voltage balancing to prevent any cell from going into over-voltage.

The discharge curve is another key difference. While a battery provides a steady voltage until discharged, the voltage of the supercapacitor decreases linearly. This means the supercapacitor has to be carefully chosen to ensure that it provides the required voltage for the right amount of time to provide the power needed. This means the two technologies are often used together.

Figure 5: Combining batteries and supercapacitors (Source Eaton)



Selecting the right supercapacitor

A key factor in selecting the right supercapacitor is identifying the operating temperature range and the operating voltage of the application. The key equations are shown in Figure 6:

$$I = C\frac{\Delta v}{\Delta t}$$

$$\Delta Vtotal = I*ESR + I*\Delta t/C$$

$$E = \frac{1}{2}CV^2$$

where Vo is the nominal operating voltage, ΔV is the Cut-off voltage, I is the peak current and Δt is the duration of the energy pulse required.

The equivalent series resistance (ESR) and leakage current (LC) in the design are key considerations. The ESR can double over the lifetime of the supercapacitor, and the nominal capacitance can drop by 30%, so that combination requires more careful sizing of the device or devices for the design.

Understanding the application is also essential. Energy harvesting as very different current requirements from pulse power or power hold-up, so specifying the right device needs a good understanding of the design. What will the peak current requirement be, and how long will it be required. Power hold up will need a longer current retention time that pulse power, for example.

Lifetime

The lifetime of a supercapacitor is a function of voltage and temperature. From internal testing and "rule of thumb," the life time doubles for every 10°C lower operating temperature, and again doubles for every 0.1-0.2V lower operating voltage, so the system specification relates directly to the reliability.

Form factor

Supercapacitors come in a wide range of form factors, from cylindrical devices that look like capacitors to rectangular blocks, prismatic cells or even pouch cells. The BestCap range from AVX is a low ESR pulse SuperCapacitor in a low profile design based on the non-hazardous proton activated polymer system This has a capacitance range of 4.7mF to 1F across 2.0V to 20V and an ESR of 25mΩ to 600mΩ. The operating temperature range: -20°C to +70°C (selected values offer -40°C to +75°C).

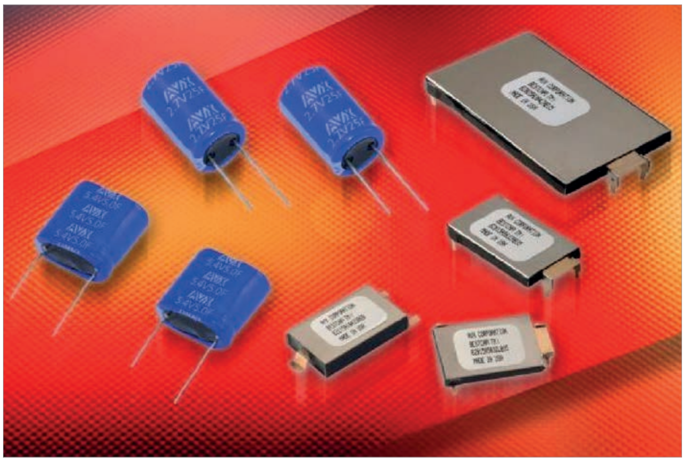
Cylindrical supercapacitors provide a capacitance range of 1F to 3,000F with an operating temperature range of -40°C to +85°C at voltages from 2.7V at 65°C, derating to 2.3V at 85°C (3.0V Series up to 65°C). These can provide a high pulse power capability.

SCM Series-connected (2 or 3 cells) standard SuperCapacitor modules feature very high capacitance, low ESR, and low leakage current with a capacitance range of 0.33F up to 15F. With the series connection these can provide a voltage range of 5.0V to 9.0V and are available in balanced or unbalanced versions.

The operating temperature range is -40°C to +85°C and these are available with Epoxy filled plastic packaging for a longer lifetime in humid environments.

Prizmacap prismatic electrolyte supercapacitors range from 25x21mm to 155x85mm in size but crucially have a low profile design down to 0.5mm thickness and range from 1F to 500F with a voltage range of 2.1V at 70°C derating to 1.1V at 90°C, and operate down to -55°C. A key feature of these supercapacitors is a leakage current down to 10µA.

Figure 6: The range of supercapacitor form factors from AVX (Source AVX)



With many devices aimed at 2.7V operation, improvements in technology by Eaton have meant that 3.0V supercapacitors are becoming increasingly popular. These are drop in replacements but the relatively small change in operating voltage delivers twice the expected operating life at same working voltage and can handle higher power than the 2.7V version. The smaller size also supports high cell count designs, with 10 to 20% fewer cells needed for the same operating voltage.

Conclusion

There are many differences between supercapacitors and batteries, and the supercapacitor technology is often misunderstood. The fast charging and pulsed current delivery make the devices suitable for a wide range of power applications, from holding up a storage system to ensure a reliable shutdown while providing a cleaner voltage, to powering busses or automated vehicles in factories. Supercapacitors can run in the cold environments where many batteries cannot, and can even replace batteries entirely in certain applications.

However, the linear discharge means that these devices have to be carefully sized for a design to ensure that they can deliver the current that is actually required over the right time, which can be challenging.

Innovation in the design of the electrodes mean that the energy density is always increasing, providing more power in smaller form factors for a wider range of applications and increasing in voltage to improve the system performance even further.

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