Flat supercapacitors evolve to meet needs.

Some devices require high-current power pulses that only double-layer capacitors can support.

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Applications in electronics are constantly growing in diversity. In recent years, there has been a growing demand for very compact, battery-powered portable devices. Fueling that growth has been a steady improvement in the capabilities and cost effectiveness of rechargeable lithium batteries. Even with the advancements in battery technology, the developments have limits and improvements have slowed.

Many battery-powered devices have power needs that vary greatly as their mode of operation changes. Some need high-current power pulses that may be difficult or impossible for batteries to supply without increasing the risk of performance failures, reduced operational life, or even premature battery failures. The problem is that batteries have high internal resistances (ESR) that are too large to continue to consistently deliver high-power pulses. Devices that would require high-power pulses include:

- GPS tracking systems
- Bluetooth communications devices
- LED safety flashers
- Bar-code equipment
- Remote-control systems
- Automatic meter readers (AMRs)
- RFID equipment
- Medical equipment
- Alarm and security systems
- Portable music players and other audio amplifiers

For some, there is a need to transmit data for only a few milliseconds each minute. The pulse currents during transmission range from 1 mA up to 3 A. While batteries are high-energy devices, they have difficulties delivering such short high-pulse currents without the battery becoming damaged, especially at low temperatures.

It is well known that adding supercapacitors in parallel with the source battery can help supply power during these pulses. As supercapacitors have become more cost effective, they have found an increasing use in this role.

Supercapacitor applications

Placing a supercapacitor, with its huge storage capabilities, in parallel with a battery can easily supply almost any required pulse currents. After delivering the pulse current, the supercapacitor is quickly recharged by the battery between the pulse cycles. This reduces the stress on the battery, extending the overall life of the battery by a factor of three or more, compared to not having the supercapacitor in the circuit. *Figure 1* illustrates this principle.

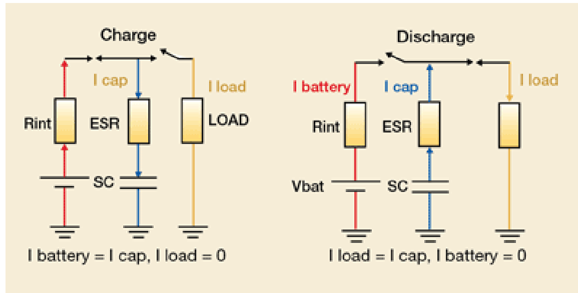


Fig. 1. Battery-powered pulse circuit.

Supercapacitors, also called EDLCs (electrochemical double layer capacitors) or ultracapacitors, are electrochemical devices that have high capacitance and high energy density compared to other common capacitors, such as tantalum and aluminum electrolytic types. Compared to lithium batteries, supercapacitors have up to 10 times the power density.

Being high-energy devices, batteries have an advantage over supercapacitors. They can deliver more energy over a longer period of time in a more efficient package than supercapacitors. Supercapacitors on the other hand are high-power devices able to deliver a large amount of energy in a very short time.

Supercapacitors have been commercially available since 1978. At first, these were low-voltage devices that had high ESR and were primarily designed for backup applications. Since then, they have gone through considerable technical and manufacturing changes, to the point that there are several types commercially available. While terminology may vary, most supercapacitors fit into one of these application categories: (1) Backup, (2) High energy, or (3) Pulse.

All supercapacitors are basically constructed from two carbon-based electrodes (mostly activated carbonhaving very high surface area), an electrolyte (aqueous or organic) and a separator that allows the transfer of ions, while providing insulation between the electrodes.

While basic appearances may be similar, supercapacitors store energy in a different way than electrolytic capacitors. As voltage is applied to a supercapacitor, ions in the electrolyte solution diffuse across the separator into the pores of the electrode of opposite charge.

Charge accumulates at the interface between the electrodes and the electrolyte; forming two charged layers (double layer) with a separation distance of just a few angstroms (0.1 nm). This is the distance between the electrode surfaces to the center of the ion layer. Since the capacitance value is proportional to the surface area and is the reciprocal of the distance between the two layers, high capacitance values can be achieved in a very small space.

Not all supercapacitors are suitable for all applications. For example, the larger pseudo and prismatic supercapacitors cannot be used in pulse applications because these capacitors have:

- Capacitance values too high (>1 F)
- Rated voltage too low
- Internal ESRs to large
- Electrolyte not environmentally friendly (ACN)
- Physical dimensions form factor not correct
- High cost

Flat-style supercapacitors

The form factor of typical supercapacitors precludes their use in pocket-sized instruments. To overcome this shortfall, several capacitor manufacturers have developed flat-style supercapacitors, designed specifically for battery support applications.

Most are rectangular or square in shape, are quite thin, encapsulated in an aluminum foil packet or rigid metal shell and can be surface mounted or stood on end as any other radial-leaded device would be. While each relies on some similarities in the physics of how they function, and each typically delivers up to 1-F capacity, production methods, chemistry and package construction can vary. This in turn affects cost and the suitability for different applications. One of the newest approaches is a patented automated manufacturing process, developed by Cellergy and applied in Illinois Capacitor DFC Series supercapacitors. This process is the first to be based on conventional printing techniques, thereby overcoming the high-cost factor often associated with supercapacitors. As in the case of the other flat devices, this process has been developed specifically for the production of supercapacitors for pulse/battery support applications.

A key component of the process is a proprietary, printable aqueous electrode paste using activated carbon. This is printed with an electrode matrix structure on an electronically conductive film. The electrodes are then encapsulated with a porous ionic conducting separator, and another electrode matrix is then printed on the separator. This process is repeated as often as required, enabling customization of the product to the specifications of the end user. This customization (see *Fig. 2*) can allow the device to be made in almost any shape or size, for maximum use of available space.

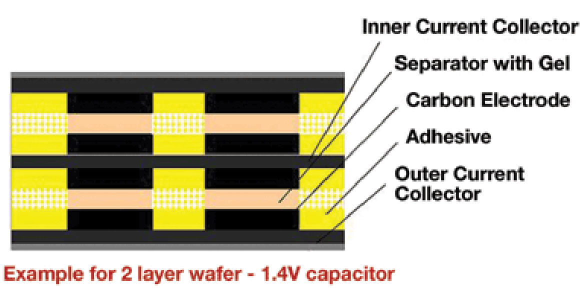


Fig. 2. Example of customized wafer of 1.4-V capacitor.

In addition to greater cost effectiveness and flexibility of form, this technique allows Illinois Capacitor DFC supercaps to offer:

- Lower ESR values
- Higher-rated voltages
- Low leakage currents in a shorter amount of time — 12-hour specification versus 72-hour specification for organic electrolyte type of supercapacitors
- Sturdy encasement in a metal shell, with epoxy end-fills (versus aluminum foil packet)
- Nonpolarized
- Better temperature stability at low temperature
- Long life — 500,000 pulses
- Environmentally friendly (aqueous electrolyte vs. ACN inorganic electrolyte capacitors)

The landscape of this capacitor market segment is growing rapidly because of the need for compact portable power. Developments are continuing with supercapacitors to overcome some of the factors currently limiting their use. Increases in the operating voltages and maximum operating temperature are goals of capacitor designers, as well as making the electrolytes, particularly for organic ones, more environmentally friendly.

Battery support

The biggest challenge for designers of battery-powered circuits is to limit the voltage drop in their designs. Obviously when the voltage drop in the circuit is too large, the device will not function properly. Too large a voltage change will cause the internal passivation layer of the lithium battery to breakdown, leading to higher leakage currents and result in shortened battery life. In the case of low ambient temperatures, the internal resistance of the battery would increase dramatically, further shortening battery life.

By connecting supercapacitors in parallel with the battery, the supercapacitors reduce the voltage drop that would occur in the battery, which in turn dramatically increasing its life. *Figure 3* illustrates this effect.

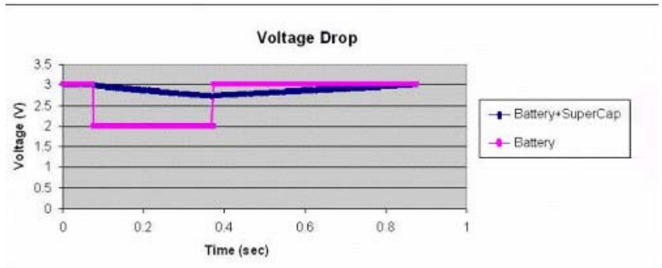
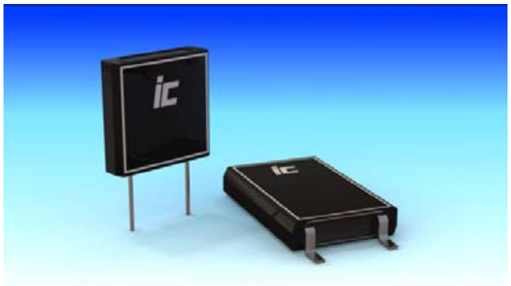


Fig. 3. Voltage drop of battery alone vs. battery plus supercapacitor.

> ***"Compared to lithium batteries, supercapacitors have up to 10 times the power density."***



Illinois Capacitor DFC Series Supercapacitors

Examples of how a supercapacitor reduces the battery voltage drop:

Example 1. Active RFID/Battery operated passive RFID

Advantage: Supercapacitor extends RFID tag battery lifetime!

Typical pulse details: Regular RFID pulse transmission is 30 mA, expected pulse width is 50 ms, and typical period is 1 min.

Requirements: Maximum allowed voltage drop is 1 V.

Solution without supercapacitor:

Voltage drop calculation:

I = Peak pulse current = 0.03 A

Typical lithium battery internal resistance (BIR) = 50 Ω

Δt = Pulse width (50 msec)

The total voltage drop is given by: [VDROP = I*BIR]

VDROP = 0.03 A * 50 Ω = 1.5 V
(larger than the max. 1 V required)

VOUT = 3.6 V – 1.5 V = 2.1 V

Solution with supercapacitor:

Voltage drop calculation:

ESR = Supercapacitor internal resistance: (ESR= 360 mΩ)

C = supercapacitor capacitance, (C = 20 mF)

The total voltage drop is given by:
[VDROP = I*ESR + Δt*I/C]

VDROP = 0.03 A * 0.36 Ω + 0.05 s * 0.03 A/0.02 F =
~ 0.1V << 1 V

VOUT = 3.6 V – 0.1 V = 3.5 V

Example 2. AMR – automatic meter reader

Advantage: Supercapacitor extend AMR's battery lifetime to 10 to 15 years!

Typical pulse details: Regular AMR signal is 30 mA, expected pulse width is 300 ms, and typical period is 1 min (enough time to charge supercapacitor).

Requirements: Maximum allowed voltage drop 300 mV.

Solution with supercapacitor:

Voltage drop calculation:

I = Peak pulse current (0.03 A)

ESR = Supercapacitor internal resistance: (ESR= 180 mΩ)

Δt = Pulse width (300 ms)

C = Supercapacitor capacitance, (C = 40 mF)

The total voltage drop is given by:
[VDROP = I * ESR + Δt * I/C]

VDROP = 0.03 A * 0.18 Ω + 0.3 s * 0.03 A/0.04 F =
0.23 V < 0.3 V

VOUT = 3.6 V – 0.23 V = 3.37 V

Conclusion

As demonstrated in the examples cited, supercapacitors can increase circuit performance and prolong the life of batteries. This can add value to the end-product and ultimately reduce the costs to the customer by reducing the amount of batteries needed and the frequency of the replacement of the batteries.

The low-profile form factor of flat supercapacitors now makes it possible to add supercapacitor battery support to compact portable devices and other circuitry where available space is limited. The chemistry behind the newest pulse or battery-support supercapacitors, being more environmentally friendly, will find increasing acceptance in portable power devices where environmental concerns of high importance.

In addition, because they have a long life and extend the operating life of the batteries they support, they contribute greatly to the environmental friendliness of the end-product, while reducing maintenance costs. With these strong benefits, flat supercapacitors should be considered whenever a battery-powered portable device meets the profile we've described.

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