Experimenting with Super Capacitors

By Forrest M. Mims III

Japan's NEC Electron announced the development of the super capacitor in 1980. This is a new kind of capacitor with considerably more capacitance than conventional capacitors. The farad, the basic unit of capacitance, is so large that conventional capacitors are usually specified in terms of millionths or even trillionths of a farad. Super capacitors have capacitances of up to a farad or more.

NEC's claim to have developed a super capacitor was met with surprise and perhaps a little skepticism. Shortly after its 1980 announcement, NEC flew some of its U.S. staff to Japan for a thorough briefing on the new super capacitors. Details provided by NEC's researchers revealed that the new "supercaps" have 3,000 times the efficiency of a conventional aluminum electrolytic capacitor of the same size. This makes possible a 1-farad capacitor that is less than half the size of a C-size flashlight cell.

While they are commonly used as backup power sources for CMOS RAM, super capacitors have many other uses. They can provide brief periods of backup power for solar-powered equipment. They can power LEDs and LED flasher circuits. They can also be used in simple timer circuits, and they can even serve as short-duration power sources for small lamps and motors.

Later, we'll examine some of these applications for super capacitors in more detail. First, however, let's find out more about how these remarkable components work and how they are made.

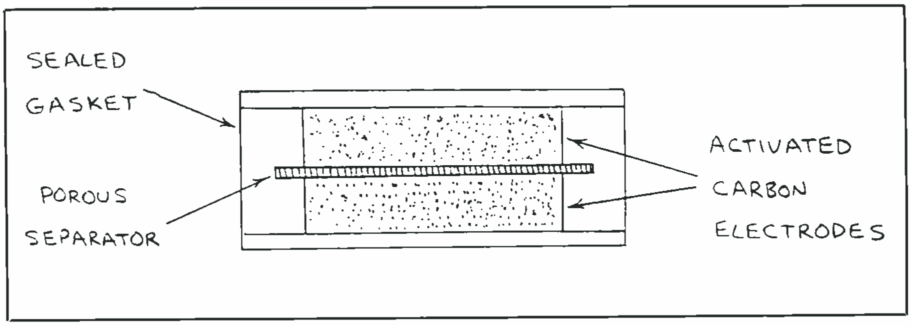

Fig. 1. Internal construction details of a super capacitor.

How They Work

A capacitor is simply two conductors separated by an insulator known as a dielectric. The capacitance of a capacitor is determined primarily by the surface area of the conductors, the distance separating them and the dielectric constant of the insulator between them. The dielectric constant is the ratio of the capacitance of a capacitor with a particular dielectric to that of the same capacitor with air for a dielectric.

You can make a capacitor that has a value of a few picofarads by twisting together two short lengths of insulated wire. For larger values, you can make a "sandwich" of aluminum foil and plastic film.

Prior to the development of super capacitors, electrolytic capacitors provided the highest capacitance of all capacitor varieties. The dielectric of an electrolytic capacitor is formed by depositing a very thin oxide film on an aluminum or tantalum plate. The surface area of the plate is greatly increased by an etching process that leaves a rough, pitted surface. Since the dielectric insulates in only one direction, the terminals of the electrolytic capacitor are polarized.

Super capacitors are not polarized and are projected to have exceptionally long lifetimes. They consist of two conducting surfaces separated by a liquid electrolyte such as sulfuric acid. The key to obtaining exceptionally high capacitance is to use activated charcoal for the conductors. Activated charcoal is a highly porous substance that has an enormous surface area. The total surface area of a few grams of the material is close to an acre!

A super capacitor is made by mixing powdered activated charcoal with an electrolyte such as sulfuric acid to form a thick paste. The capacitance of the paste can range from 200 to 400 farads per gram! Disks of the material are sandwiched on each side of a porous separator to form a capacitor as illustrated in Fig. 1. The porous separator allows charges to move through the electrolyte while separating the plates.

A double layer of charged particles accumulates at the boundary between the electrolyte and the carbon. For this reason, super capacitors are often known as "double-layered capacitors."

Sulfuric acid will decompose into hydrogen and oxygen with an electrical charge in excess of 1.2 volts. Therefore, a single super capacitor element has a maximum working voltage of only 1.2 volts. Capacitors with higher working voltages are made by stacking capacitor elements to form a series array. For example, a 5-volt capacitor is made by stacking up to six capacitors. NEC currently makes 5- and 10-volt super capacitors.

Recall now that the total capacitance of capacitors connected in series is less than the individual capacitance of each capacitor. The total capacitance of two capacitors in series is the product of the two capacitors divided by their sum. The total capacitance of three or more capacitors in series is the reciprocal of the sum of the reciprocals of the capacitance of each capacitor, or $C_{total} = 1/[(1/C1) + (1/C2) + (1/C) + \ldots (1/Cn)]$. This means that each capacitor in a 1-farad series stack if four super capacitors has a capacitance of 4 farads.

Figure 2 illustrates what was inside an NEC double-layer capacitor that I disassembled for this report. Opening the device certainly was *not* easy! In fact, I came away from the experience as impressed by the device's sturdy construction as by its enormous capacitance.

First, I peeled away the capacitor's touch plastic coating. Then, I used a wire cutter to clip away the collar around the edge of the can in which the capacitor was housed. The rim of the can is rolled inward under pressure to form a tight bond between the can and upper terminal. High pressure is required to provide a good electrical connection between the terminals and the relatively high resistance of the conductive plastic that lines each end of the capacitor stack.

After clipping away the collar, I was able to remove the upper terminal and the plastic cylinder that surrounded the capacitor stack. The stack, however, was cemented to the bottom of the aluminum can, presumably with electrically conductive adhesive. To remove it, I had to cut most of the can away and pry the stack from within the metal with a small screwdriver.

Though the super capacitor I disassembled was rated at 5.5 volts, it contained only four individual capacitors. This gives a maximum working potential per capacitor of 1.375 volts, which is higher than the 1.2-volt peak permitted for capacitors with a sulfuric-acid electrolyte. Therefore, it's possible that an electrolyte that has a higher disassociation voltage was used in the capacitor I disassembled.

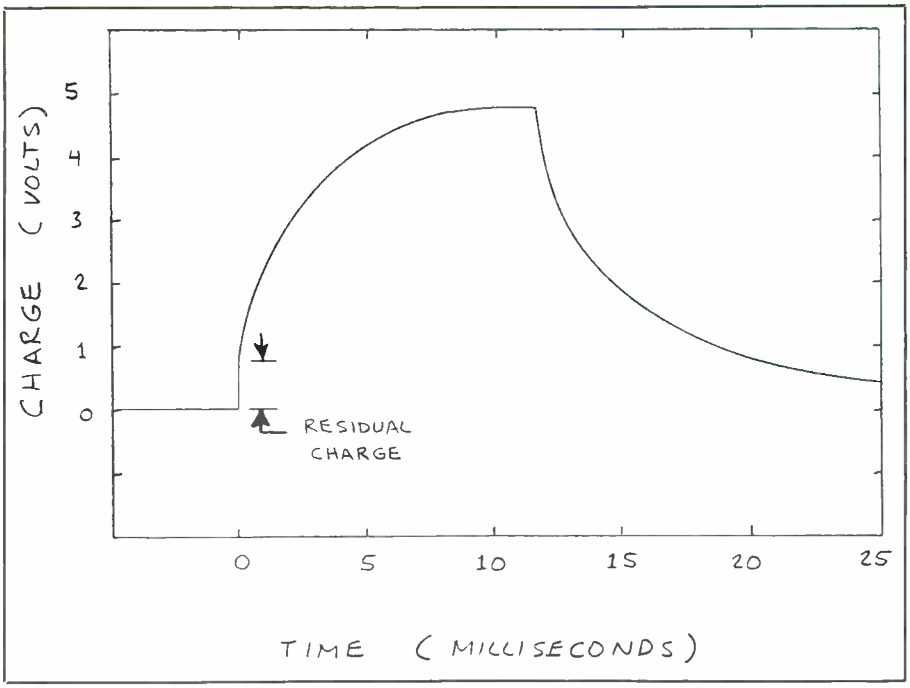

Fig. 3. The charge/discharge cycle of a 0.1-farad super capacitor.

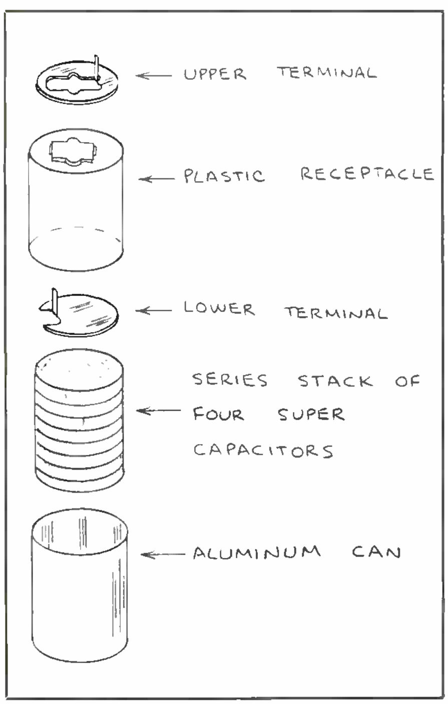

Fig. 2. Internal construction details of a NEC super capacitor.

Super Capacitors Versus Storage Batteries

The first time you experiment with a super capacitor, you may be tempted to think of it as a rechargeable battery. I did. But a super capacitor is *not* a battery. The shape of its charge/discharge curve is identical to that of any other capacitor.

Figure 3 is an oscillogram of a complete charge/discharge cycle of a 0.1-Farad double-layer capacitor. To make this oscillogram, I first connected an oscilloscope to the capacitor's terminals. The sweep speed was set to 2 seconds per division. Next, I placed a sheet of tracing paper over the scope's screen. I then triggered the sweep and connected a 5-volt supply to the capacitor through a 68-ohm series resistor. As the moving dot traversed the screen, I traced its course with a pencil.

Incidentally, note the portion of the charging curve labeled "residual charge" in Fig. 3. This is an allowance for the nearly 1 volt of change that remained on the capacitor even after I shorted together the two terminals of the device for a few minutes.

To capture the discharge cycle, I allowed the moving dot to move across the screen until it reached the peak of the charge cycle traced on the paper. I then connected a 68-ohm resistor across the capacitor's terminals and traced the descending path of the moving dot.

Now that we agree that a super capacitor is not a battery, let's look at some advantages of super capacitors over batteries. As a backup power source, double-layered capacitors can compete with storage batteries only when the current drain is very low. Nevertheless, they do have some important advantages over conventional storage batteries.

Since internal impedance is relatively high, the terminals of a double-layer capacitor can be safely shorted together. The capacitor will discharge under this condition, but at much too slow a rate to

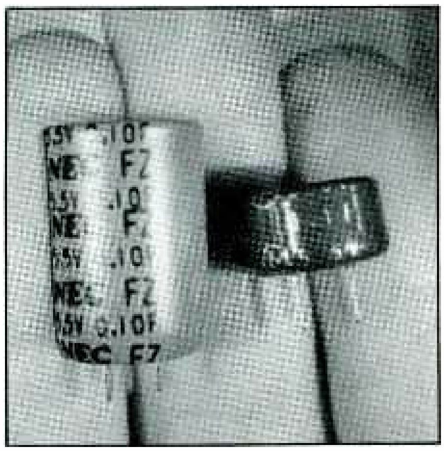

Fig. 4. Double-layer capacitors made by NEC (left) and Murata. Both capacitors have a rated capacitance of 0.1 farad.

cause heat build-up. Try this with a nickel-cadmium storage cell, lithium cell an most other electrochemical supplies, and you will quickly find yourself with an extremely hot power source. Some chemical power cells will even explode when their terminals are shorted together. Some batteries have an internal thermal fuse that automatically disconnects a battery when its temperature rises to an unsafe point.

Another important advantage is that double-layer capacitors can be charged and recharged indefinitely. And they don't exhibit the undesired "memory" effect that is common to Ni-Cd cells.

Still another advantage is that double-layer capacitors can be operated over a wider temperature range than batteries. For example, NEC's capacitors can be operated over a range of from −25 degrees C to +70 degrees C. They can be stored over a range from −40 degrees C to +85 degrees C.

Finally, double-layer capacitors can be soldered into a circuit and be forgotten. Lithium, Ni-Cd and other backup batteries may eventually need to be replaced as their charges become depleted or their ability to be recharged has declined.

Super Capacitor Sources

You can obtain double-layer capacitors from electronics parts suppliers and mail-order companies. For example, Mouser Electronics (P.O. Box 699, Mansfield, TX 76063) catalog lists more than a dozen NEC "supercaps" in both 5- and 10-volt ratings. The values of these capacitors ranges from 0.022 to 1 farad. Digi-Key Corp. (P.O. Box 677, Thief River Falls, MN 56701) lists a family of Panasonic (registered trademark) double-layer capacitors, including a 3.3-farad device. Both cylindrical and cubic package shapes are available.

MuRata (2200 Lake Park Dr., Smyrna, GE 30080) makes a line of super capacitors called ACE-CAP™. These range in value from 0.018 to 0.1 farad. The 0.1-farad ACE-CAP is apparently identical to Radio Shack's Cat. No. 272-1440 unit.

I've experimented with super capacitors made by NEC and MuRata. As Fig. 4 reveals, the most striking difference between capacitors made by the two companies is their physical size. NEC's 0.1-farad capacitor measures 0.55 inch wide and 0.80 inch high. MuRata's 0.1-farad ACE-CAP is considerably smaller, measuring only 0.5 inch wide and 0.30 inch high. These are nearly the same dimensions for Panasonic's 0.1-farad capacitor.

If you don't have any double-layer capacitors on hand, the fastest way to begin experimenting with the circuits that follow is to use Radio Shack's 0.1-farad unit. You can achieve higher operating voltages by connecting capacitors in series with each other, and you can obtain higher capacitance by connecting capacitors in parallel with each other.

Some Applications

Now that you know what super capacitors are, how they're made and from where they can be obtained, let's look at some applications for these devices.

• *Battery-Backup Applications.* The most common application for double-layer capacitors is to provide backup power for CMOS RAMs, microprocessors and other circuits. Depending on the capacitor used and the CMOS circuit's current consumption, backup times can range from as little as a second to as much as a month or more.

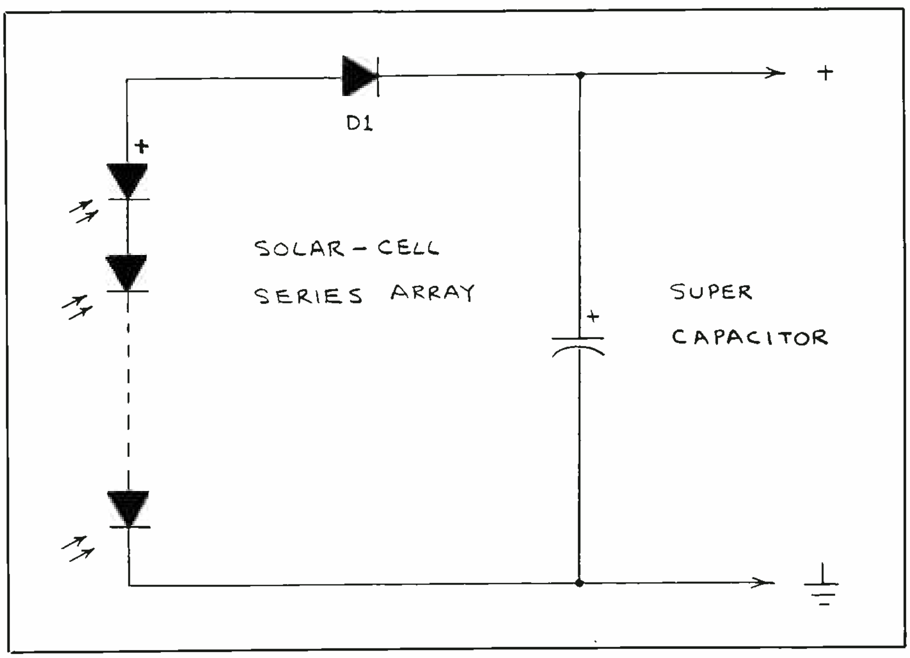

Fig. 5. Charging a super capacitor with a solar-cell array.

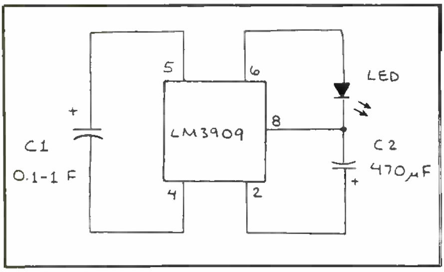

Fig. 6. Super-capacitor-powered LED flasher circuit.

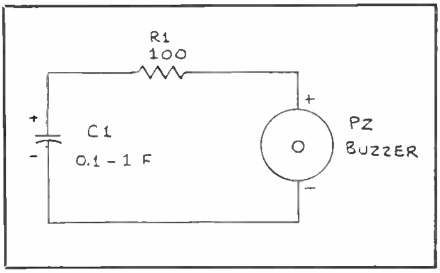

Fig. 7. Using a super capacitor to power a piezoelectric buzzer.

In a typical application, the super capacitor can simply be connected directly across the power-supply pins of the chip to be backed up. The capacitor will be charged to the power supply's potential. When the power supply is disconnected or disabled, the super capacitor then provides backup power.

In many cases, a double-layer capacitor can power an operating CMOS circuit. You can, however, increase backup times by powering only the CMOS RAM portion of a circuit. In any event, you must avoid subjecting the capacitor to more than its rated voltage.

MuRata's 0.1-farad ACE-CAP will typically deliver a linear current of 10 microamperes for 1,000 minutes, 100 microamperes for 100 minutes, and so forth. This capacitor can be fully charged in about an hour. It will self-discharge from 5 to 3.2 volts in 240 hours.

While these specifications are impressive enough on paper, they become even more interesting when you experiment with actual devices. Consider the charging time. While a full charge may require an hour, a double-layer capacitor can be charged reasonably close to full capacity in a minute or so. No charging resistor is necessary.

As for the self-discharge time, I charged a 1-farad NEC double-layer capacitor to 4.5 volts in a minute or so. A week later, the capacitor retained a charge of 3.05 volts.

• *Solar-Cell Charger.* A series of solar cells can easily be used to charge a double-layer capacitor to any point between 0.5 volt (one cell) to 5 volts (10 cells). Figure 5 shows how to insert a protective diode between a solar-cell array and a super capacitor to prevent the latter from discharging through the solar cells when they are not activated by light.

I connected a miniature solar-cell array to a super capacitor. When the cells were placed under a small desk lamp, the capacitor was charged to about 4.5 volts in a few minutes. The capacitor was then

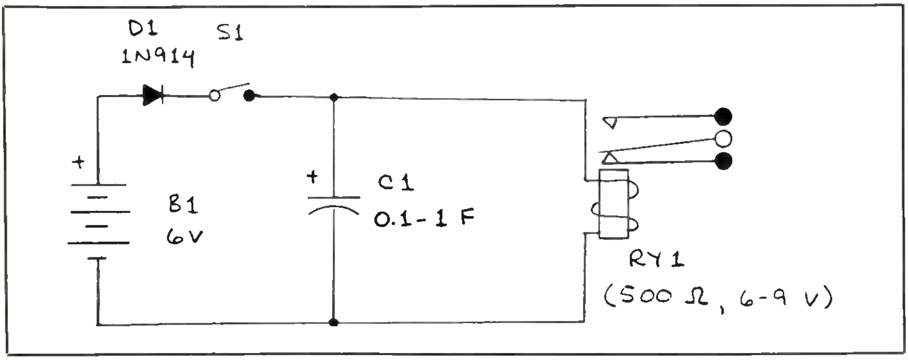

Fig. 8. An ultra-simple super-capacitor timer circuit.

able to drive a super-bright light-emitting diode through a series resistor.

A practical application for a solar-cell-charged super capacitor is as a backup source for brief intervals when the sun is obscured by clouds. A product ideally suited for this application is the solar-powered radio.

• *Capacitor-Powered LED Flasher.* A super capacitor will directly power a LED with a built-in flasher chip. However, this variety of LED draws so much current that the capacitor will be rapidly discharged.

The LM3909 LED flasher chip is much better suited for this application. This chip will reliably operate over a power-supply range of from 1 to 5 volts and consumes little current. The very brief pulses it applies to the LED keep average current consumption very low.

Shown in Fig. 6 is the method used to power a simple LM3909 LED flasher circuit with a double-layer capacitor. When *C2* has a value of 470 microfarads, this circuit will flash about once per second. Upgrading *C1*'s value to 1 farad and charging it to 5 volts will operate the circuit for at least 10 minutes. When the capacitor is discharged, it can quickly be recharged by connecting a 5-volt dc supply across its terminals.

If a 5-volt power supply is not available, you can use a 6-volt battery to recharge the double-layer capacitor. To do so, first insert a silicon diode (1N914 or similar) between the battery and capacitor to drop the battery's potential to a maximum of 5.4 volts. This method works when the capacitor is rated at 5.5 volts. Use two diodes in series if the capacitor is rated at 5 volts.

• *Capacitor-Powered Buzzer.* A piezoelectric buzzer can easily be powered for several minutes or more by a super capacitor to provide a fail-safe alarm that will operate even when power has been interrupted to the buzzer's driving circuitry.

Shown in Fig. 7 is a typical circuit for powering a piezoelectric buzzer with a super capacitor. In this circuit, *R1* is used to increase the discharge time of the capacitor, even though it reduces somewhat the volume level of the sound emitted by the buzzer. You can experiment with different resistances to determine the optimum tradeoff between sound level and discharge time.

• *Super-Capacitor Timer.* For very long timing cycles, I prefer to use a crystal-controlled programmable timer or a computer. This provides a much more precise timing period than when using a capacitor alone as a timing element. However, is you are willing to trade a bit of accuracy for economy and simplicity, you can use super capacitors in the RC circuits of many timers. Based on my preliminary experiments, timing cycles of a week or more can easily be achieved.

You can even use a super capacitor alone as a timer. Figure 8 illustrates one method for doing this. Here, double-layer capacitor *C1* is connected directly across the terminals of a small relay. The relay's contact arm will be pulled in as long as the charge on the capacitor is adequate. When the charge falls below the minimum holding value, the relay will deenergize. A new timing cycle can be begun by closing *S1* for a minute or so. Larger values of capacitance will give longer timing cycles. Longer timing cycles can also be realized by keeping *S1* closed long enough to fully charge *C1*.

Going Further

I've used double-layer super capacitors to power small motors, incandescent lamps and a transistor radio. No doubt you'll think of other applications for super capacitors as you experiment with them in actual circuits. ME