SUPERCAPS

When is a capacitor more than just a capacitor? When its capacitance is so big that the charge it stores can run a circuit for a significant period of time . . .

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THE SUPERCAP IS HERE. All 1 000 000 µF of it (that's right, one Farad!). Negate your Nicads. Levitate your lithiums. The world of the future belongs to a cap no bigger than a fifty cent piece.

According to NEC, who has announced its release in Australia, the FZ and FA series capacitors will be available in 0.022 F, and 1 F versions. Sizes vary slightly over the ranges but the F2 series 1 F is 28.5 mm across by 25 mm high. And that is just about as big as they come.

The first thing that comes to mind is that a capacitor like this would make a magnificent power backup source. Just how good can be seen from Figure 1, which shows the time taken to loose 10% of the initial charge. As one would expect it depends on the current drawn, but the figures are staggering nevertheless. For instance the FA series 1 F capacitor will supply 10 mA for 50 seconds, or 100 mA for 5 seconds.

Used in conjunction with CMOS technology, where current drain is measured in microamps, the figures are even more impressive. The FZ version 1 F supercap will supply 60 µA for a whole day, while maintaining a voltage above 40% of the original (see Figure 2).

NEC has claimed that a supercap will maintain a 1k byte CMOS RAM for more than 30 days and a µPD7507C microcomputer for more than a day. If it is desired to improve these figures there is nothing to stop a designer connecting supercaps in series or parallel to increase the working voltage or the total capacitance (and thus the backup time, see Figure 3).

As one might expect, the supercap is not the result of ordinary capacitor technology. You don't generate figures like those above by winding up strips of aluminium in plastic tape.

The supercap is an 'electric double layer' capacitor. An electric double layer is the name given to the area around the interface of two dissimilar materials, where charged particles exist. In the supercap there are two materials: an activated carbon and a slightly damp solution of sulphuric acid in an electrolyte. When a charge is applied across the junction, charged particles congregate at the interface. In our case the carbon hosts the positive ions, the electrolyte the negative ones (see Figures 4 and 5).

The charge is actually contained in the ions. NEC claims that the capacitance obtained in this way is between 20 and 40 µF/cm². Notice that the capacitance depends on the actual physical area of the interface. If you want large capacitance, you need large areas. At first sight this might seem to mean that large capacitance must lead inevitably to large capacitors, but this need not be necessarily so.

The activated carbon used in the supercaps is specially processed to achieve very high porosity, so that the interface surface area is greatly increased. The same principle is used in air cleaners, where it is necessary to bring a very large surface area into contact with the air. In fact, it is possible to achieve a surface area of 10 000 000 cm² with every gram of carbon.

Some simple multiplication will show ▶

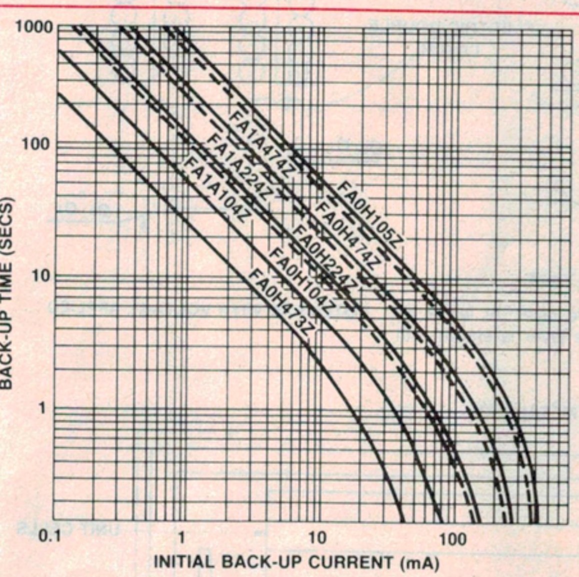


Figure 1: Time versus current as voltage decays from 5 V to 4.5 V.

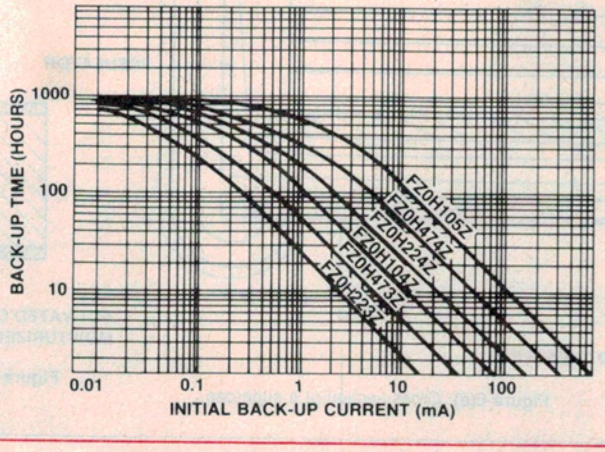
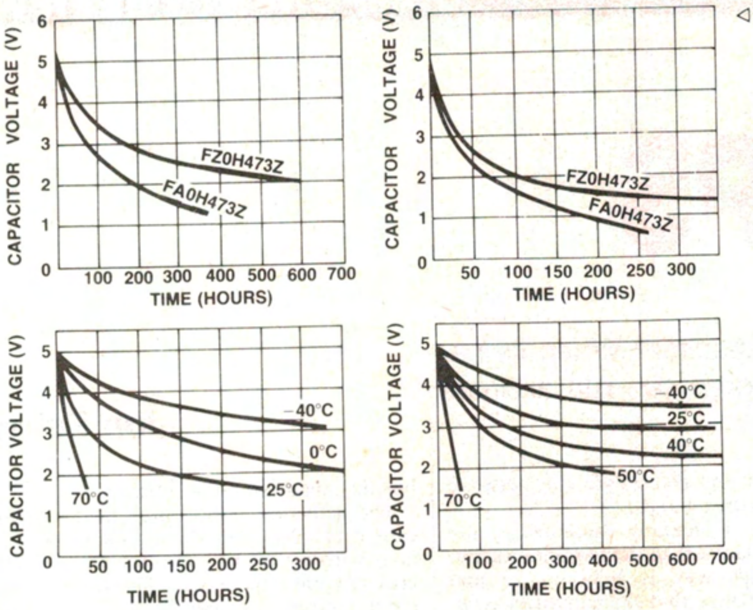


Figure 2: Time versus current for a voltage drop from 5 V to 2 V.



◁ **Figure 3:** The discharge characteristics of the FZOH372Z supercap with a variety of loads.

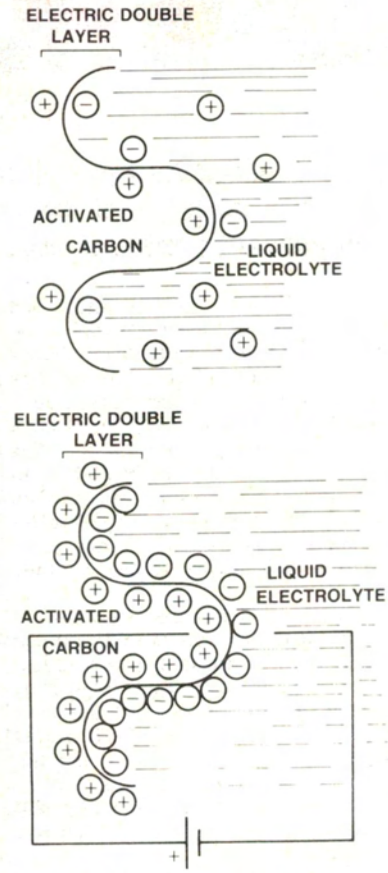


Figure 4: A schematic representation of the interface between the carbon and electrolyte in a supercap. At left, no charge is applied, and the ions are spread throughout the material. At right, a potential exists across the interface and the ions cluster as shown.

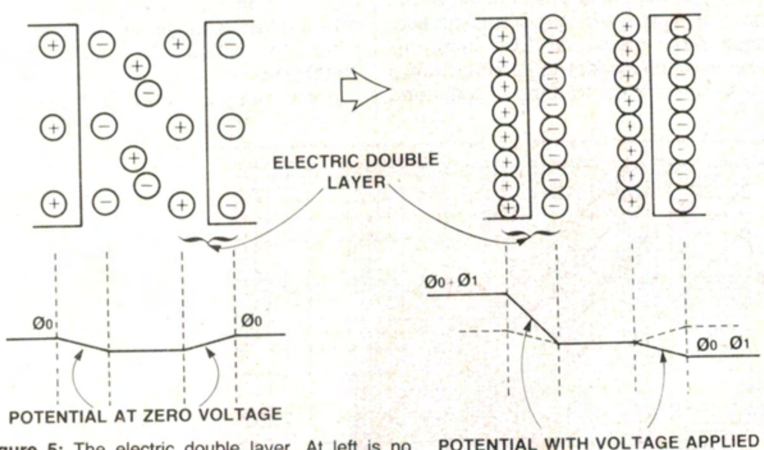


Figure 5: The electric double layer. At left is no potential, at right, the double layer is shown with potential applied.

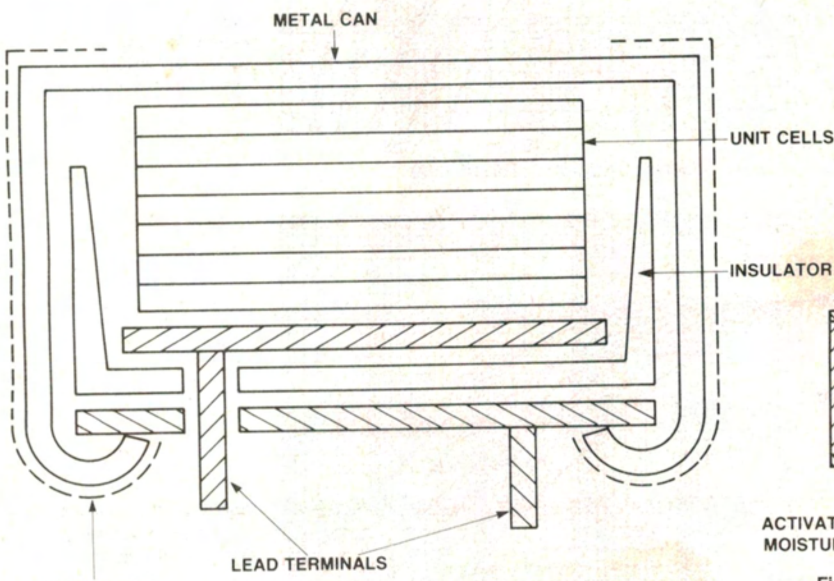


Figure 6(a): Cross section of a supercap.

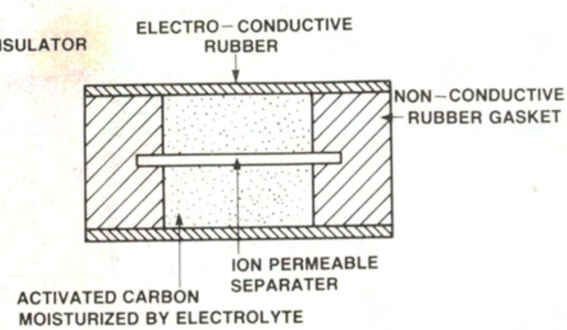


Figure 6(b): A single unit cell of a supercap. Maximum voltage is about 1.2 Volts.

you that this means one gram of activated carbon used in this mode will produce between 200 and 400 Farads worth of capacitance.

In practice, a supercap is constructed rather like a battery, with a number of cells. Each cell has a breakdown voltage of about 1.2 V and the total breakdown voltage of the capacitor is determined by the number of cells connected in series that go to make up the whole unit. Most of the supercaps are rated at 5 V, although a few are rated at 10 V.

Each cell is constructed (see Figure 6) of two layers of activated carbon separated by an ion-permeable separator. The cell is contained in a non-conductive rubber gasket with electroconductive rubber ends (for connection to other cells). The whole unit is vulcanised together to hermetically seal in the contents. To create a working capacitor, a number of these units are stacked on top of each other and placed in a metal can. Contact with the outside world is via two leads that contact with either end of the stack.

The result is a device with many of the desirable features of large capacitors and batteries, without most of their disadvantages. Like a capacitor, the supercap can be charged and discharged as often and as fast as required without any ill-effects. Unlike batteries, there is no need for a special charging circuit and no 'discharge memory' effect.

Unlike both batteries and other large capacitors, the supercap has a life expectancy as long as most of the components it will be associated with. It does not 'dry out' the way other large capacitors do, firstly because each cell is sealed, and secondly because the moisture content of the electrolyte is very small to start with. Unlike a Nicad, its life expectancy is quite independent of the number of charge cycles it has undergone.

Another advantage is that if it does fail, a supercap will usually fail with its leads open circuit rather than short circuit the way most conventional capacitors do. If it is subject to excessive voltage and/or heat, the electrolyte may start gassing (i.e. vapourising). Under these conditions there may be a loss of contact between the electrolyte and the conducting rubber, resulting in an open circuit.

As one would expect there are a number of disadvantages one can point at when looking at supercaps. For a start, they are not suitable in smoothing operations. They have a relatively high internal resistance, and as a result will develop too much ac ripple voltage across them in most smoothing applications.

Another problem is that they are very limited in their maximum working voltage. The decomposition of the electrolyte limits the voltage across each cell to about 1.2 V. In theory it is possible to stack as many as one likes in series to create as high a working voltage as required. However there are impediments to developing this idea to the nth degree. As the number of cells increases so does the series resistance, and so does the physical size of the capacitor. For this reason NEC has decided to restrict construction to 5 and 10 V models.

From the point of view of the manufacturer there is a further disadvantage, namely that both solvents and ultrasonic cleaners may have bad effects on the capacitors. Both these cleaning methods are in common use after boards have been through automatic insertion and soldering equipment.

Figure 7 shows the standard method of using a supercap as a power backup. Resistor Rc is a current limiting resistor, and should be defined by the maximum current capacity of the power supply. At the start of charging a supercap will draw 50 mA. (It takes about fifteen minutes to charge to within 0.4 V of the power supply.) The diode is used to decouple the capacitor from the power supply in the event of the latter's failure. The only other consideration that one needs to bear in mind is that for maximum usefulness the supercap should be placed as close as possible to the device it is going to sustain.

Supercaps necessitate a complete rethink of the way designers attack the problem of backup power. They do not provide the total answer, if only because of their limitations on voltage. But for most computer applications, they represent a significant step forward. ●

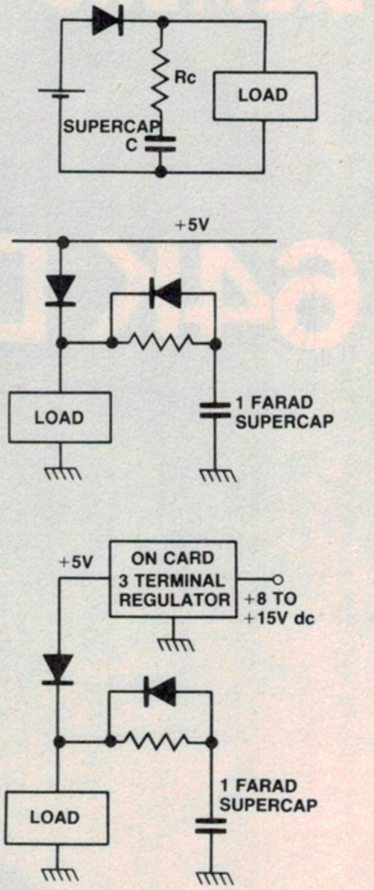
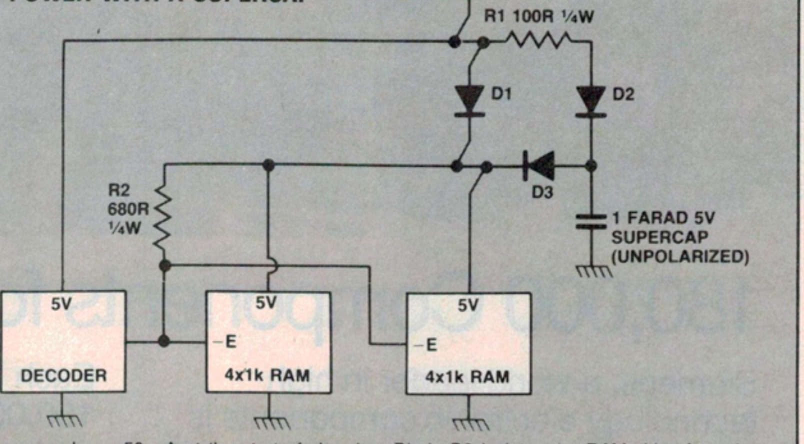


Figure 7: Three possible back up configurations.

BACKUP POWER WITH A SUPERCAP



A 1 F supercap draws 50 mA at the start of charging. Diode D3 isolates the RAM chips from the voltage across the capacitor as it slowly charges. It takes about 15 minutes to charge within 0.4 V of the supply voltage.

The diodes are Schottky types that offer low forward resistance and low reverse-bias leakage current. When power fails, the power supply is isolated from the supercap by diode D2 and from the RAM diode D1. The decoder goes high, ensuring that the RAM will not be selected during power failure (supercap holds the chip-enable line high). Resistor R2 must be small (680 ohms) to hold up the decoder output stage, because the pull-down transistor turns on (briefly) and draws a little current during power shutdown.

All RAM address, data, and control lines (except chip enable) should be held low by 4.7 k resistors during power-off to prevent the input stages of the CMOS RAM devices from drawing high current. A power-detect circuit and appropriate software could be included to ensure that RAM is not being written to when the power fails.