Technical Note
Hybrid Capacitors in Consumer Applications

by VinaTech Marketing Team

We often take electronic gadgets for granted until we need them and the batteries are dead or flat, having to wait over an hour for recharging or desperately searching for two matching AAA batteries so we can get going again. With the advent of Hybrid capacitors these situations can now be avoided, keeping consumers happy and preventing millions of batteries ending up in landfill.

Hybrid capacitors are a type of supercapacitor that has higher operating voltage and energy density, making it appear to be a hybrid between batteries and supercapacitors. Table 1 below shows a comparison between the relative performance of Lithium-Ion batteries, NiCad batteries, Electric double layer capacitors (EDLC) and Hybrid capacitors. With relatively high energy density, long operating life, fast recharge, and low leakage current making Hybrid capacitors an excellent choice to replace batteries in consumer electronics.

Table 1. Comparison of different technologies

Characteristics	Li-Ion Battery	NiCd Battery	EDLC	VEL Hybrid Capacitor
Cell Voltage Range	2.8V - 4.2V	1.2V - 1.3V	0V – 3V	2.5V - 3.8V
Operating Life	2 - 5 years	>10 years	>20 years	>10 years
Energy Density (Wh/l)	250 – 693	50 – 150	1 - 6	10 - 90
Operating Temperature	-15 - +45C	-20 - +45C	-40 - +85C	-25 - +85C
Self Discharge	2-3%/month	15-20%/month	75%/month	2-3%/month
Charging	Slow - few hours	Long - many hours	Rapid - seconds	Fast - minutes
Failure Mode	Unpredictable Rapid drop in voltage	Unpredictable Rapid drop in voltage	Predictable Drop in capacitance	Predictable Drop in capacitance
Safety	Environmental Hazard	Environmental Hazard	Friendly	Friendly
Mandatory Recycling	Yes	Yes	No	No

Examples of Hybrid capacitor solutions include:

TV Remote Control

One of the most frustrating battery failures must be in the TV remote, the batteries last a long time but always fail at the worst moment. There being nothing worse than the frantic search for replacement batteries as your favourite show is about to start.

Two standard AAA Alkaline batteries typically last 3-5 years in this application with average load current in the range 30 – 50 microamps. Replacing these with a solar cell and rechargeable Hybrid capacitors allows for a solution that will last well over 10 years. If we look at a solution that is about the same diameter as the 8.3mm AAA batteries and that can provide approximately 1 month of operation without recharge, the required capacitance is given by:

$C = (i \times dt)/dv$

Where C = capacitance in Farads, i = current, dt = discharge time in seconds and dV = change in voltage.
In this case:

i = 45 microamps
dt = 31 days = 2678400s
dv = nominal charge voltage minus minimum allowable voltage = 3.8 – 2.5 = 1.3V

Hence:

C = (45E-6 x 2678400)/1.3
= 92F

To keep to the 8mm diameter requirement this capacitance is achieved by using two 50F cells connected in parallel, like the VINATech VEL08253R8506G (50F, 3.8V) that comes in 8mm diameter by 25mm length.

To allow almost instant use, even after long term storage, a USB charging facility can also be added. Using USB, 5V, 1.5A, charging this solution can be fully recharged in a little over 1 minute.

Solar Wireless Keyboard

Solar powered wireless keyboards typically come with built in rechargeable batteries that allow for up to 4 days usage without recharge, in most cases these are replaceable but not always. The disadvantages of this approach being:

- Slow charging, with faster charging using bright sun light shortening the battery life.
- Extensive use in low light increases battery depth of discharge, which shortens the battery life.
- Battery failure is unpredictable and replacements aren't always readily available, which is inconvenient for the user and an adds expense.
- Depending on use profile battery replacement can be required as often as every 12 months.

Using a single 100F, 3.8V Hybrid capacitor provides over 2 hours of zero-light usage based on 50mW consumption. With the following advantages:

- Can accept high charge current without damage, allowing rapid bright light recharge
- Has long cycle life of >20k cycles full depth of discharge
- Can operate for 10-15 years without replacement
- Ready to use even after long periods in storage, <1% per year self-discharge
- Can be disposed of in the same way as other electronic components
- Provides a reliable long term, environmentally friendly, solution

As with the TV remote rapid recharging, in ~1 minute, via a USB port is also an option.

Wireless Mouse

Standard wireless mice are normally supplied with two AA Alkaline batteries that can last up to a year (depending on usage), while solar powered versions typically have a rechargeable AAA battery fitted. Based on a typical use profile power consumption is approximately 1mW, so for a 30F, 3.8V hybrid capacitor, such as the VINATech VEL08203R8306G, the mouse could operate for a duration given by:

$dt = (C \times dv) / i$

as hybrid capacitors have a minimum allowable voltage of 2.5V the average current will be:

$i = 1mw / ((3.8V + 2.5V)/2) = 317.5$ microamps

so

$dt = (30F \times (3.8V – 2.5V)) / 0.3175mA$
$= 122834s = 34$ hours

In this case solar charging can be intermittent with the users' hand covering the panel while the mouse is in use. So, this can be supplemented or replaced by wireless charging via the mouse mat, ensuring uninterrupted operation even during continuous mouse usage.

Smart Doorbell

Smart doorbells are becoming an increasing popular security device offering peace of mind with simple installation and ease of use. Powered by two 18650 size 3.6V 3000mAh Li-Ion batteries the normal period between charges is 6-12 months. But forget to charge them before going on your family holiday and you may find the video and voice functions let you down when you need them the most.

To prevent this problem the Li-Ion batteries can be replaced by two, solar charged, 1200F, 3.8V Hybrid capacitors, like the VINATech VEL18653R8128G, in the same 18 x 65mm size as the batteries. Assuming an average load current of 1mA means that this solution can maintain power to the doorbell, without any charging, for:

$dt = (C \times dv) / i$
$= (2400F \times (3.8V – 2.5V)) / 1mA$

$dt = 3120000s = 36$ days

As with the battery powered doorbell this solution could also have USB charging allowing for rapid recharging in less than 30 minutes.

Electric Toothbrush

Electric toothbrushes come in a wide variety of types, from the low-cost, low-quality versions that use disposable AA batteries to the high end, high performances products that are typically powered by one or two rechargeable Ni-MH batteries.

Rechargeable toothbrush solutions are available with anywhere from 2 to 15 days of operation between charges, with recharge times in the 3 – 12 hour range. Looking at Hybrid capacitor alternatives, based on the following operating conditions:

Nominal charge voltage – 3.8V
Minimum allowable voltage – 2.5V
Operating power – 10W
Required operating time – 2 minutes twice a day for 3 days = 12 minutes = 720s

Giving a required capacitance:

Required Energy = 10W x 720s = 7200 Joules

Energy (E) = $0.5 \times C \times V^2$

And as such:

$C = E / (0.5 \times V^2) = 7200 / 0.5 \times (3.8^2 – 2.5^2)$
$= 1758F$

Using two 1200F, 3.8V Hybrid capacitors, like the VINATech VEL18653R8128G, will provide the following operating time:

$dt = (C \times dv) / i$

$i = 10W / ((3.8V + 2.5V)/2) = 3.17A$

$dt = (2400F \times (3.8V – 2.5V)) / 3.17A$
$= 984s = 16$ minutes

Recharging using a standard 1W toothbrush wireless charger would take ~30 minutes after 2 minutes of use. But as Hybrid capacitors can be safely recharged at a much higher current, via a shaver socket for example, a full recharge can be achieved in less than 3 minutes (assuming 45W charging).

Power Tools

For the DIY enthusiast, odd job, or trades men the electric screwdriver and drill are essential tools of the trade, making the job quicker and easier. Available as either individual items or

combined in to one convenient tool electric drills and screwdrivers are typically powered by 12V-22V Lithium-Ion batteries that provide run times from as little as 5 minutes up to 1 hour.

Screwdrivers and combined devices tend to require 100 – 250W while drills can operate at up to 500W, with recharge times ranging from 1 – 5 hours. Taking a basic 100W screwdriver, that has a requirement to perform 100 operations per charge, as an example:

If each screw takes 3 seconds to fit then the run time needs to be at least 5 minutes, so the required energy is:

Energy (E) = 100W x 300s = 30,000 Joules

Energy (E) = $0.5 \times C \times V^2$

And as such:

$C = E / (0.5 \times V^2) = 30{,}000 / 0.5 \times (3.8^2 - 2.5^2)$
$= 7326F, 3.8V rated$

or

$C = E / (0.5 \times V^2) = 30{,}000 / 0.5 \times (11.4^2 - 7.5^2)$
$= 814F, 11.4V rated$

This can be achieved by using three 3500F, 3.8V Hybrid capacitors, such as the VINATech VEL35603R8358G, connected in either series or parallel. This would give almost 7 minutes of operation when new and over 4.5 minutes at end of life, which equates to over 90 operations.

While this meets the same level of performance as a basic battery powered screwdriver recharge times of only 1-2 minutes are possible using the Hybrid capacitor solution, compared with over an hour when using batteries. As a result, trades people, who generally have high usage, can still use this option despite its relatively short run time as the downtime for charging is so short.

Food Processors

The term food processor refers to the wide range of tools available for use in the preparation of food and drinks, like mixers, blenders, juicers, grinders, slicers & choppers. Many of these items are available as a cordless, battery powered, product with similar use profiles and runtimes as the power tools described above.

Battery powered mixers, handheld and portable blenders typically operate at 30 – 100W with operating time between charges ranging from as little as 5 minutes up to half and hour. Replacing the battery in a 50W product with a single 3500F, 3.8V Hybrid capacitor, like the VINATech VEL35603R8358G, the following operating time can be achieved:

$dt = (C \times dv) / i$

$i = 50W / ((3.8V + 2.5V)/2) = 15.9A$

$dt = (3500F \times (3.8V – 2.5V)) / 15.9A$
$= 286s = 4.8$ minutes

Which is similar performance to some battery powered devices but with the capability to recharge in 1-2 minutes instead of 1-2 hours.

Another example would be electric salt & pepper mills, they typically us four AA batteries that last 9-12 months which gives an average current of 1.5mA. Using two 1200F, 3.8V Hybrid capacitors, that have approximately the same volume as four AA batteries would give a time between charges of:

$dt = (2400F \times (3.8V – 2.5V)) / 1.5mA$
$= 2080000s = 24$ days

This could be supplemented by solar cells to minimise user charging, although full recharge can be achieved in <5 minutes with a 50W charger. As well as eliminating the need to replace the batteries every year this solution also overcomes an issue with battery powered grinding mills being top heavy and easy to knock over.

Conclusions

Taking advantage of improvements in low light solar charging and the capability to rapidly recharge Hybrid capacitors allows for the replacement of batteries in many household devices. This removes the inconvenience caused by battery failures and long charge times, while also minimises any potential downtime and proving a reliable power source for the whole life of the product.

From an environmental perspective the production of Hybrid capacitors produces a smaller carbon footprint that that of batteries and they can be disposed of safely along with the other components of the product. There use can also massively reduce the number of batteries being produced and subsequently going for recycling or in to landfill. Making Hybrid capacitors good for the environment as well as the user.