Low ESR Ultrathin Supercapacitors for Handheld and Other Small Electronic Devices

Yoshihiko Ariizumi, Franciscus Pratiktohadi, and
Sagar N. Venkateswaran,
OptiXtal, Inc., 1901 S 54th St, Philadelphia, PA 19143
www.optixtal.com

ABSTRACT

OptiXtal, Inc. produces ultrathin, small supercapacitors that allow engineers and designers the freedom to access additional power without increasing battery size and the expensive package redesign it may entail. Our supercapacitors are flexible and conformable to fit the available space.

We show four small supercapacitors (all are smaller than 9mm x 11mm x 1 mm) and characterize them in terms of charge/discharge cycling, self-discharge voltage, leakage current, capacitance and ESR. Our results show that these supercapacitors have relatively high capacitance, low ESR, low leakage current, and good self-discharge characteristics. We believe that, with minor modifications, our small supercapacitors can find use for burst power in many applications including medical devices, computer memory support systems, and small sensor devices.

INTRODUCTION

The current popularity and proliferation of handheld devices have been made possible by increasingly smaller components including energy storage devices. According to the Moore’s law the number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years. The trend has continued for more than half a century and is not expected to stop until 2015 or later [1]. We are witnessing that other components are similarly following this law. However, capacitors, especially supercapacitors, have remained comparatively bulky and inflexible, having thus lagged in this trend. In this paper we will show that supercapacitors are also joining this trend of miniaturization.

Along with miniaturization, there is an increasing use of energy saving and harvesting techniques to power these devices, which has led to an evolution in low power electronics. Mobile devices are apparently not an exception. Previously GSM (Global System for Mobile Communication) required more than 1W [2] and currently there are emerging standards that require only up to 0.2 W and 0.25W per mobile device for LPGSM (Low Power GSM) and DECT (Digital Enhanced Cordless Telecommunications) respectively [3]. Safety, health issues [4][5], local networks in sensitive areas such as hospitals [6][7], interference issues during machine to machine talk [8][9][10]; all can be mitigated by going to a low power regime.

In this paper we suggest that supercapacitors, which were once disadvantageous in higher power applications [2], may be now a viable option for the low power, particularly burst applications that go with these newer standards [11].

We propose that under certain conditions, mini supercapacitors may supplement or replace the pulse capacitors that are commonly used in handheld devices. There are several advantages to using our mini supercapacitors. For one, they do not contain any rare earth or other metals that are currently subject to supply constraints as evidenced by recent reports in the media. This makes supercapacitors relatively inexpensive. A second and more important reason is the failure mode of the component. As opposed to the violent and in many cases explosive failure mode of the pulse capacitors, a supercapacitor upon overcharging fails in a benign manner. Additionally, supercapacitors can have as high as thousands of times more capacitance and thus have high current capability.

DISCUSSION

Characteristics of the Smallest Mini Supercapacitors

In this section the major characteristics of the mini supercapacitors are discussed. Figure 1 shows the unique shapes and sizes of supercapacitors that we have custom-built to market demand. We have also conducted flexibility studies on some of them [14]. As devices get smaller and more and more components get squeezed into a given volume, components will be required to be form factor compatible to optimize packing. Our aim in this figure is to illustrate our ability to custom build supercapacitors to fit them into available space requirements of a package. In this paper we will focus on the family of mini supercapacitors labeled number 9, 10, 11 and 12. You can note that these sizes are smaller than the dime that is shown on the figure for comparison purposes.

Fig. 1

Table 1 shows the dimensions, weight and maximum voltage that the mini supercapacitors are designed for. The table below points out that our supercapacitors are ultrathin (e.g., less than 0.9mm). Other makers' supercapacitors are much thicker and inflexible [13]. The closest comparable in the market are the ones produced by CapXX, which have the thickness of 1.1 mm, more than twice of our thinnest supercapacitor, and occupies 8 times the space occupied by our mini supercapacitors [3].

Label	Dimension	Weight	Vmax
Mini #9	9 mm x 11 mm x 0.8 mm	0.08 g	2.7V
Mini #10	7 mm x 9 mm x 0.8 mm	0.07g	2.7V
Mini #11	9 mm x 11 mm x 0.7 mm	0.07g	2.7V
Mini #12	9 mm x 10 mm x 0.5 mm	0.07g	2.7V

Table 1

Fig. 2 shows applied voltage as a function of time for mini supercapacitor (#9) shown in Fig. 1. The initial formation began with the charge at the constant current of 2mA up to 2.7V. After a rest of 15 seconds, the mini supercapacitor was discharged at 2mA to 1.35V and then subject to three additional charge discharge cycles between 2.5V and 1.25V at 15mA, when Capacitance and ESR were measured. The initial voltage curve and repeatable cycling curve exhibits the behavior expected of a supercapacitor. The tested mini supercapacitors had a capacitance of as high as 250 mF and an ESR of as low as 3Ω.

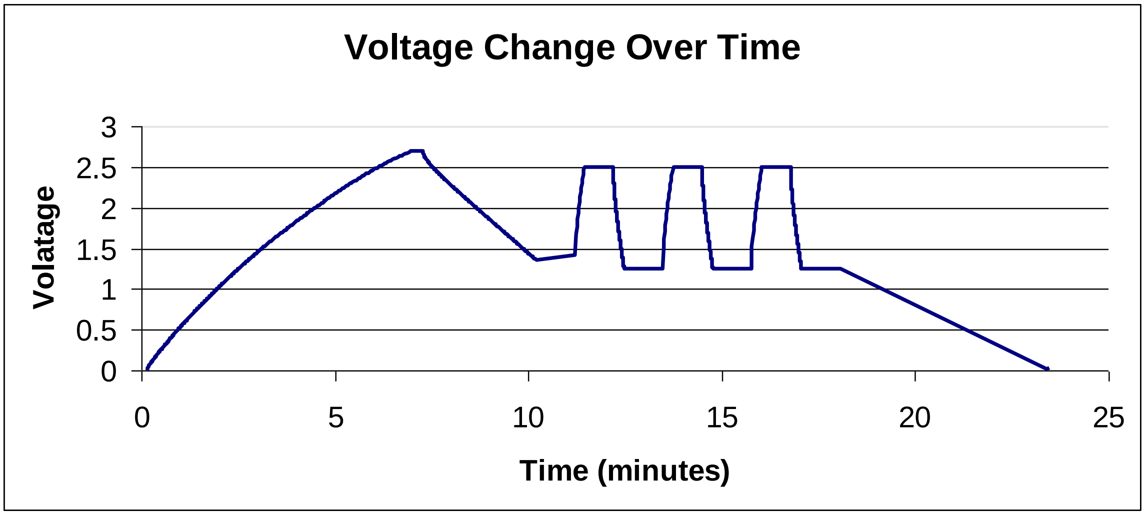

Fig.2 Formation and 3 charge-discharge cycles Mini (#9) Supercapacitor

The mini supercapacitors were subjected to 10,000 cycles of accelerated testing. The supercaps were charged at 15mA to 2.5V, clamped at this voltage for about 5 seconds and then discharged at 15mA to 1.25V. After a voltage clamp at this voltage for 10 seconds, it was again charged to 2.5V at 15 mA. This cycle was repeated for 5,000 cycles and at the end of each cycle ESR and C was measured. We found that after 5000 cycles capacitance decreased from 210mF to 190 mF (a decrease of about 10%), while the ESR increased from 8.5 Ω to 12.3 Ω, an increase of about 44%. If the supercapacitor continued to decline in this manner and at this rate, we can expect that the capacitance will decline to the 80% level (our cut-off limit for useful cycle life) only after much more than 10,000 cycles. We have to keep in mind that this lifetime is achieved at a relatively high current (15mA), and continuous charge-discharge to 2.5 V-1.25 V. In a more realistic scenario, where the supercap will be used in burst power mode, (for example in a GSM with a pulse width at half maximum (PWHM) of 577 µs, with a duty cycle of 12.5%), much larger lifetimes will be achievable.

We have also determined the maximum current that can be carried by the mini supercapacitor (the supercapacitor equivalent for the so-called C-rate in a battery). The supercapacitor was subjected to different charge-discharge rates, and we choose the maximum current allowed as one that takes 1 second to discharge from Vmax to ½ Vmax. The following graph (Fig. 3) shows the discharge curve at a constant discharge current of 30 mA. The initial large drop is the instantaneous drop attributed to ESR. After the initial drop, the voltage gradually decreases to 1.25 V and takes about 3.2 seconds. The graph proves that our mini supercapacitor can easily handle 30mA. To get a discharge time of 1 second, we estimate that the discharge current can be increased about 3 times close to 100 mA. In a pulse mode, this capacitor may handle pulse currents well in excess of 100 mA.

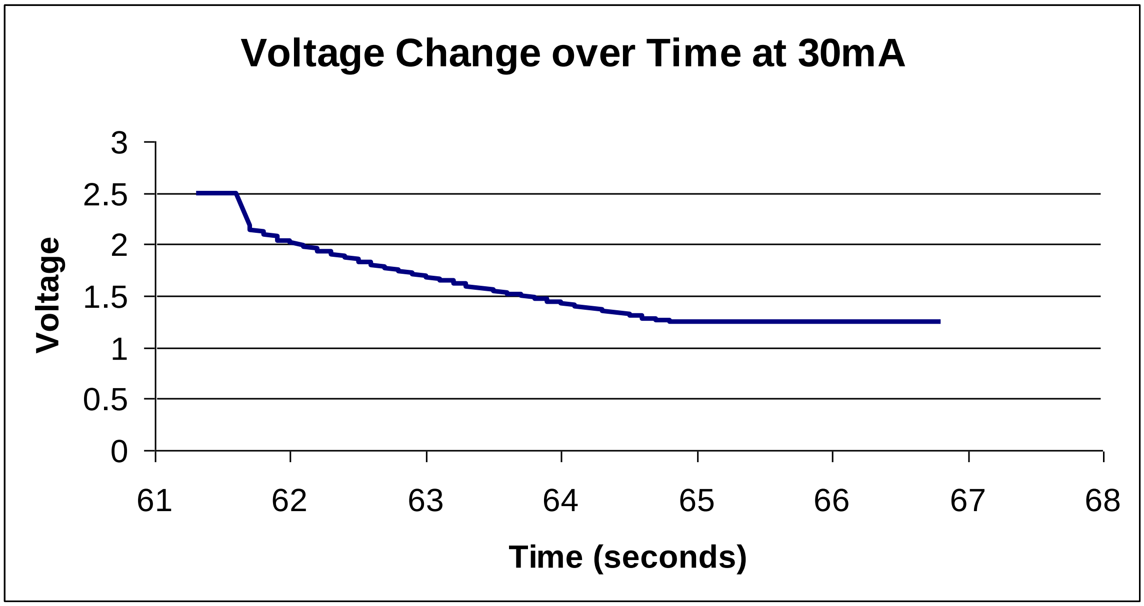

Fig. 3 Voltage change over time at a constant discharge current of 30 mA

Leakage current is another important characteristic of our supercapacitor. It determines the amount of current that must be trickled in from a battery and/or energy harvesting source to top up the supercapacitor while in a "sleep" mode. A low leakage current is invaluable in prolonging battery life and in the application of use of energy harvesting transducers. Leakage current was measured by charging the supercapacitor to 2.7V, clamping it at this voltage, and then measuring the amount of current required to maintain it at 2.7V after 72 hours. Fig. 4 shows a small slice of the time data. Please note that we are only showing the data to the first 35 minutes, as we believe this will be sufficient to simulate usage in a pulse GSM type environment.

We see that during the clamp condition at 2.7V, the sustaining current quickly dropped to micro ampere range and is approaching 50µA in 30 minutes. This means that to maintain the supercap at 2.7V, an energy harvester or battery would have to provide 50 µA x 2.7V, or 135 µW, an amount that is low enough to not impact battery life in a significant way. We also note that after 72 hours the leakage current for this mini supercapacitor became 1.5µA.

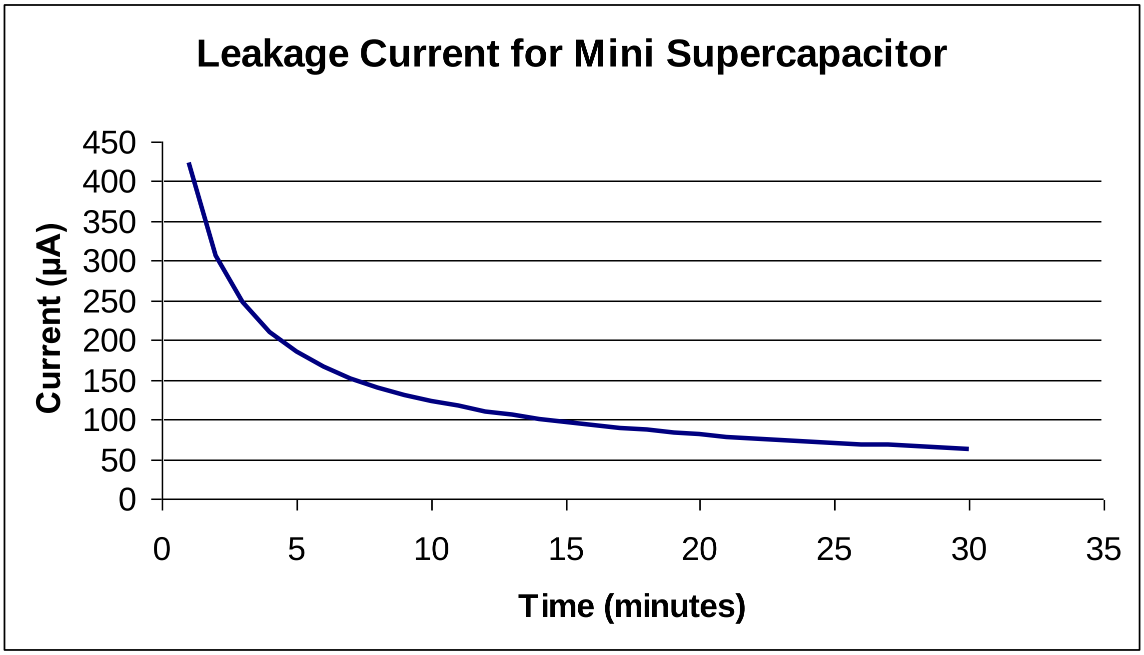

Fig. 4 Initial drop of Leakage Current

Our next set of data for the mini supercapacitor (Figure 5) pertains to self discharge voltage. This data measures the ability of the supercapacitor to maintain its voltage when not in use, in an "open circuit" condition. The open circuit voltage of the supercapacitor is measured over many days and the voltage decay over time is reported. Again, we are only reporting the first 72 hours of data since we feel that this would be more than sufficient for the pulse GSM type application we are envisaging this supercapacitor would be used for. Figure 5 shows that the voltage drops from 2.7 V to about 1.8V in three days.

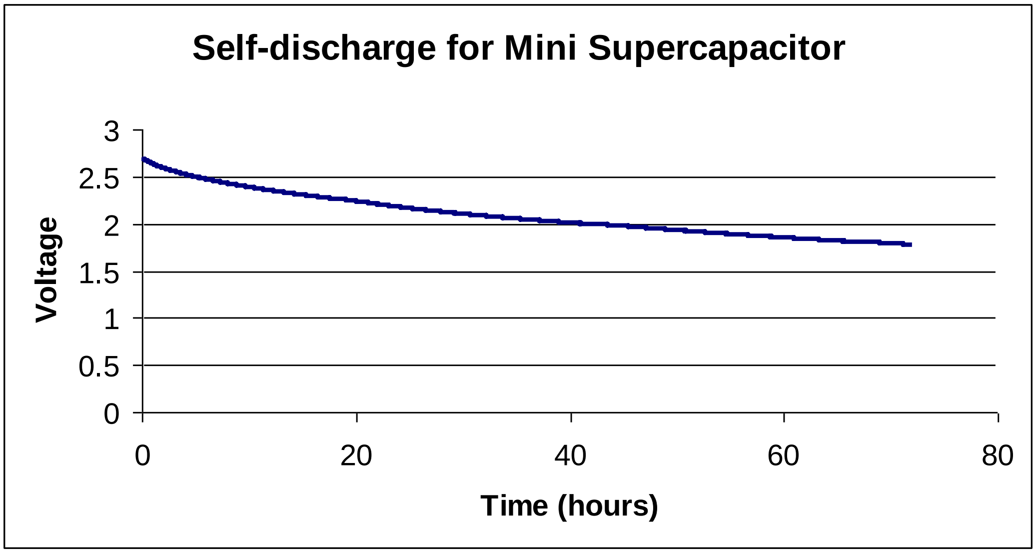

Fig. 5 Open Circuit Voltage of the mini supercapacitor measured as a function of time

The Use of Mini Supercapacitors for burst power applications

In a report published 5 years ago, Pothier and Gormally [2] compared the performance of Ta capacitors and supercapacitors to provide burst power for a GSM transmitter. They considered a scheme where the input power from a PCMCIA source at 3.3V and 1A (max), was supplemented by the capacitor. The voltage drop across the capacitor was calculated using the equation ($V = IR + I (t/C)$), where I is the current, t is the pulse width, and R is the ESR. They found that the high ESR of the supercapacitors created an unacceptably large voltage drop leading to insufficient power to run the GSM transmitter. The Ta capacitor was, they concluded in their example, the correct capacitor to use.

In this paper, our aim is to find conditions where the above equation might be favorable to mini supercapacitors. Before we begin this exercise we note that both Ta pulse capacitors and supercapacitors have both strengths and weakness. For about the same footprint, Ta capacitors have much lower capacitances and lower ESR, while supercapacitors have both much higher capacitances (almost 1000 times larger), and ESR (almost 1000 times larger). This means that for mini supercapacitors, the second term in the equation **I (t/C)**, is negligibly small and can be dropped. So the voltage drop across the supercapacitor is mostly IxR, and we can see that for applications requiring currents of 200 mA or smaller, the voltage drop across a 3 Ω supercapacitor is limited to 0.6V or less. Under these low current conditions and limited voltage drops, many schemes can be devised using input voltages less than 3.7V, and currents at a milliampere level to provide 0.2W to 0.3 W, a power that is sufficient to implement LPGSM, DECT, or a similar protocol [3]. These schemes may also include energy harvesting.

We note that in some cases, mini supercapacitor can also be added in parallel to an existing Ta pulse capacitor. This will have the added benefit of increasing the capacitance and decreasing the ESR of the combined unit.

Recently, there have been reports in print and other media regarding supply constraints to rare earth and other metals. In particular, this condition may constrain their supply and cause upward pressure on prices for common pulse capacitors, an important component in handheld devices. Under certain circumstances small size and form-factor enabled supercapacitors might be a good substitute. Additionally, our supercapacitor can provide at least hundreds times larger capacitance than a comparable common pulse capacitor, at a relatively lower price and with a benign failure mode. Overcharging a supercapacitor leads to an increased ESR and then failure. There is no risk of fire or damage to other components due to short circuiting. Common pulse capacitors on the other hand require strict safety handling. Inadvertently switching polarity on the pulse capacitor can cause fire and explosion.

CONCLUSION

We have shown that OptiXtal can make 200 mF, 2.7V mini supercapacitors with ESR of 3 Ohms. The supercapacitor has dimension of 9mm x 11 mm and is ultrathin with a thickness of 0.8 mm. It has a low leakage current that is favorable for trickle charging from a primary battery and/or an energy harvester. The mini supercapacitor has the ability to handle up to 100 mA current and possibly 200 mA in pulse currents. These factors suggest to us that they can be used as part of a secondary circuit to run low power RFPA for many applications including machine-machine talk etc. This will have the added benefit of running newer applications without increasing battery size, and without impacting battery life. The low power used by the PA also implies that they will have fewer issues with interference, and safety etc.

RERERENCES & NOTES

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