Guide on supercapacitor leakage current behavior in EH applications

Introduction

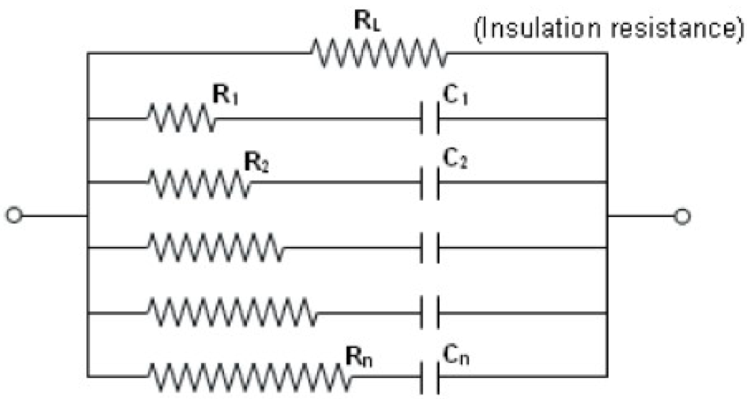
In majority of energy harvesting applications, the energy harvesting source cannot supply the application directly. This is a result as typical modern application in embedded systems are designed to operate in short high intensity pulses while the energy harvesting sources are typically providing low power over longer periods of time. Therefore, it is necessary to store the collected energy, so the application can use the energy in a short burst.

The energy is typically stored in either batteries or supercapacitors. There are many benefits of using supercapacitors, such as high number of charge/discharge cycles, high pulse current delivery, extended temperature operating range compared to batteries, no under voltage issues and can be stored completely empty for long periods of time. All of these characteristics make them ideal for energy harvesting applications. However, supercapacitors have two main drawbacks. First is relatively small energy density compared to batteries and the second is large leakage currents.

This guide is aimed at determining what level of leakage current can be expected out of a super capacitor and help design energy harvesting applications to utilize full potential of supercapacitors.

Structure of a supercapacitor

A supercapacitor is a series of large number of parallel capacitors with a series resistance. This structure is shown in the figure below.



Electrical model of a supercapacitor.

It should be noted that the resistance values increase and the capacitance value decreases as we move to the further elements in the chain.

Due to this type of structure when a supercapacitor is being charged different internal capacitors will charge at a different rate. Once the majority of the capacitors are charged and the charging current drops to few mA it would seem as if the capacitor if fully charged however there are typically elements in this parallel network that are still not completely charged. This is the primary reason why manufacturers consider the supercapacitor charged only once it has been charging for several days.

The existence of the internal network is also a reason why the leakage current seems high at the beginning after the source is disconnected. It seems like the charge is being used but it is actually being redistributed. After approximately 72h the leakage current reaches the stable value.

In the following section we will address how the leakage current is impacting operation of supercapacitors in an energy harvesting application.

Supercapacitor in Energy harvesting scenario

In order to evaluate the behavior of supercapacitors in a scenario where they are being charged slowly and intermittently, as the energy form the solar cell is available, we have setup a set of experiments where the supercapacitors are charged using a pair of AM1417 or AM1454 amorphous silicon solar cells from Panasonic.

The test was conducted by placing the supercapacitors and solar cells on the window over a course of several days. The solar cells are connected to the capacitors using BAT54 diodes that have small forward voltage drop and reverse current in the range of 400nA which a good approximation of a dormant or low power operating sensor node.

We have run two tests over a course of several days with different sized capacitors and monitored the discharge of the capacitors during periods of low light intensity. Note that the measurements had been done during winter months hence the low average light level.

List of capacitors tested:

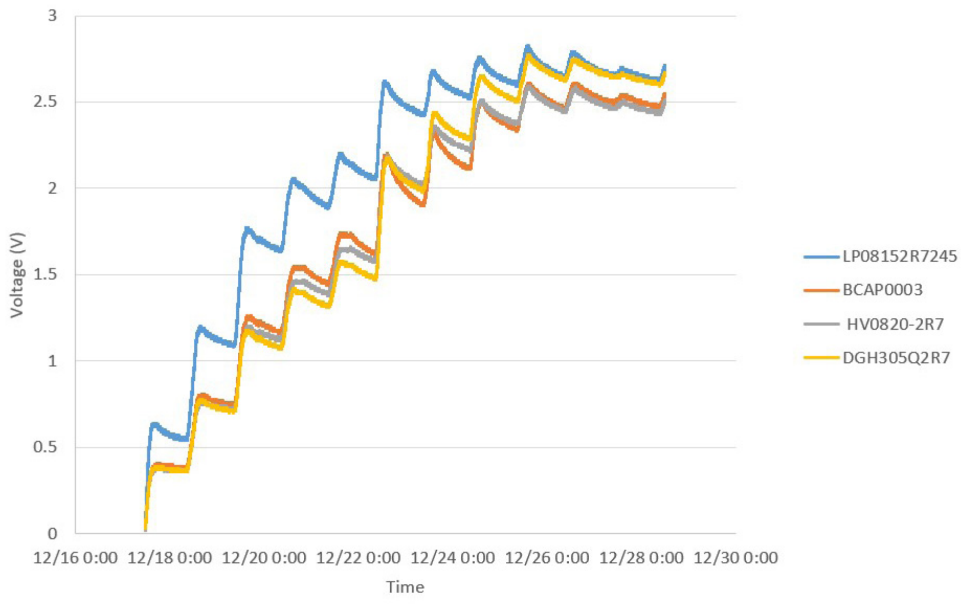
- SCCR16E205SRB: 2F, 3V by AVX
- CPX3225A725D: 7.5mF, 2.6V by Seiko
- GZ109: 120mF, 2.3V by CAP-XX
- SCCR20E335: 3.3F, 3V by AVX
- LP08152R7245: 2.4F, 2.7V by Taiyo Yuden
- DGH305Q2R7: 3F, 2.7V by Illinois Capacitor
- HV0820-2R7: 3F 2.7V by EATON
- BCAP0003: 2.7V, 3F by Maxwell

We were primarily interested in higher capacity supercapacitors that could store sufficient energy for powering a few microwatts load over a course of an entire night when the solar cells wouldn't be able to provide power.

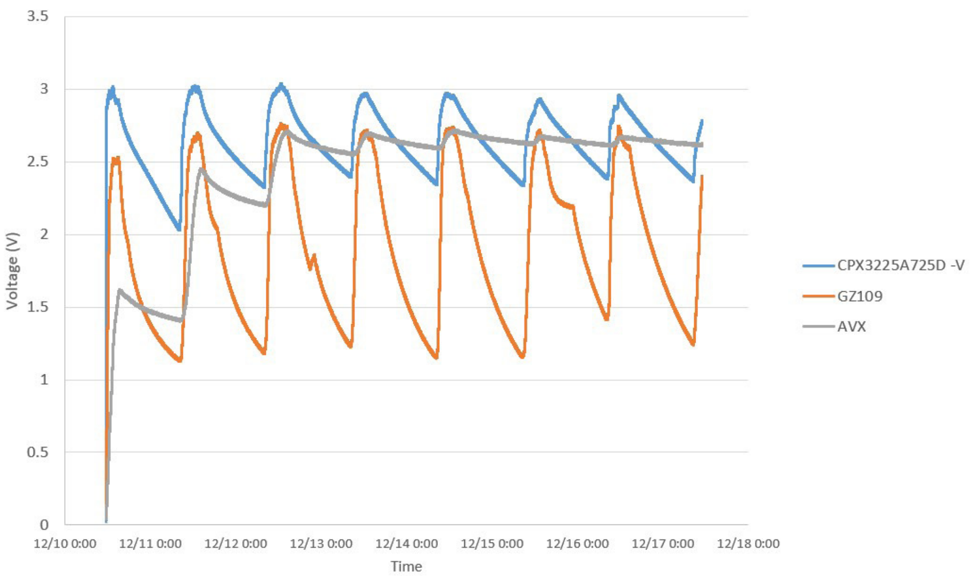
Leakage current test

After measuring the leakage current all of the capacitors were within limits as specified by the manufacturer. The surprise was the SCCR16E205SRB unit that states the max DCR at 10μA however the average leakage was measured at around 2μA. All 3F capacitors have exhibited the discharge current of about 5-6μA. This is a substantial amount of leakage current as it can be compared to the current consumption of a Bluetooth low energy wireless sensor node that is transmitting once every second temperature measurements.

The following graphs represent the voltage on the capacitors over a period of several days of charging:



The charging of 3F capacitors using direct coupling to solar cells.



Charing of 7.5mF, 120mF and 2F units using direct coupling to solar cells.

From the graphs depicting direct charging several important conclusions can be derived. First the stable leakage current is achieved relatively fast after the solar cells would stop providing power on its output. Due to low current charging the time required for the charge to be equally distributed among internal capacitances is small.

Second, if the rise of the voltage is large, on a sunny day for example, the time required for the capacitors to redistribute the charge increases. This can be seen in the graph on the days where the charging slope is steep there is a steep slope shortly after the charging stops, followed by a milder slope as the leakage current value is reached.

Third, the leakage current doesn't grow linearly with the increase of the capacitance. In the case of supercapacitors with the capacitance in the range <1F, the leakage current even of few microamperes will discharge a significant portion of the capacitor between charges. This can be seen in the example of GZ109 capacitor that would self-discharge from 2.6V to 1.2V over night.

In the case of few mF capacitors, like the CPX3225, that are specifically designed for ultra-low leakage, the among of energy lost is significantly smaller as the leakage currents are in the rage of 10nA. In our test the major loss from the capacitor was going through the reverse polarized Schottky diode BAT54 and still the voltage at the end of the night was typically 2.3V.

Conclusions

The leakage current of a supercapacitor has to be taken into account when sizing the capacitors as the leakage current can be as large the power budget of the application that is being powered. In case of ultra-low power systems ultra-low leakage capacitors should be selected however these are coming with small capacitances in the range of 10 mF. In the case of applications that have current consumption in the range of few µA it will be necessary to choose capacitors that are over 2F to store sufficient energy in the capacitor to both cover the leakage current and provide the necessary power to the application.

Want to know more?

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