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CAP-XX White Paper

Leakage Current, Pre-charging & Leakage Current at shallow discharge

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1. Leakage Current:

Super capacitors are subject to leakage current and the amount of this leakage current varies subject to various brands/suppliers, though CAP-XX super capacitors have the lowest leakage current compared to similar size/type super capacitors. Leakage current is also proportional to Capacitance. For CAP-XX supercapacitors, the rule of thumb is ~1µA/F.

The initial leakage current on all organic electrolyte super capacitors is quite high when they are tested or mounted onto a PCB straight from its transport packaging. In CAP-XX's case, the initial leakage current is about 10-20 times its long term value which is reached after 100-120 hours when the super capacitor is on normal charge at room temperature.

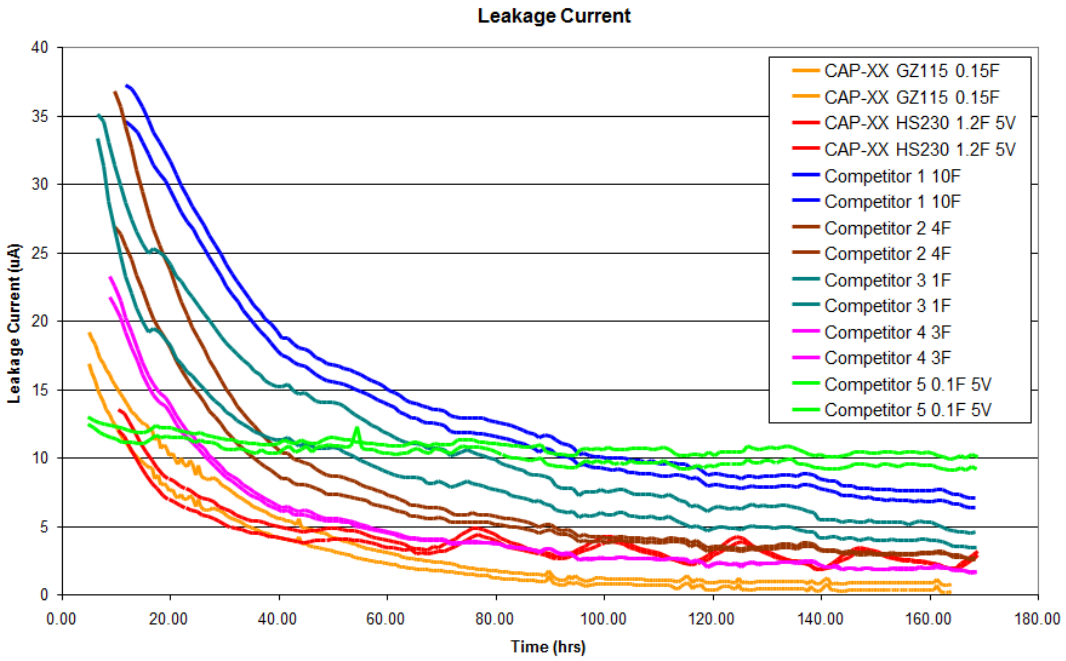

Figure 1: Leakage Current: CAP-XX vs Competition

From Figure 1 , it is important to note here, that CAP-XX super capacitors reach a lower leakage current than any competing super capacitors in less than 20 hours and the long term leakage current is at least 1/3 lower than any competing brands. Competitor 5 is an aqueous electrolyte supercapacitor. It reaches its equilibrium level leakage current almost immediately, but this level is ~20 x higher than the comparable CAP-XX GZ115.

In order to reduce leakage current on super capacitors faster, one has to hold a super capacitor on charge and high temperature. In case of a CAP-XX super capacitor, the long term leakage

current is reached within approx. 50 hours if it is held at 4.5V and 70°C and subsequently cooled down to room temperature.

2. Pre-Charging a Super Capacitor:

The corollary of having higher initial leakage current is that the part may take longer to charge than theory predicts if it is charged at very low current, in the order of 10's of µA, as might be supplied by an energy harvesting source. Figure 2 shows this for supercapacitors being charged at 20µA. The curves shows the actual voltage vs time for 2 cells of each supercapacitor type being charged while the straight line in the same colour shows the predicted voltage from the equation V = I x time/C. In order to reduce the time it takes to initially charge a super capacitor at very low current, it is possible to pre-charge this super capacitor with a high current for a short period of time.

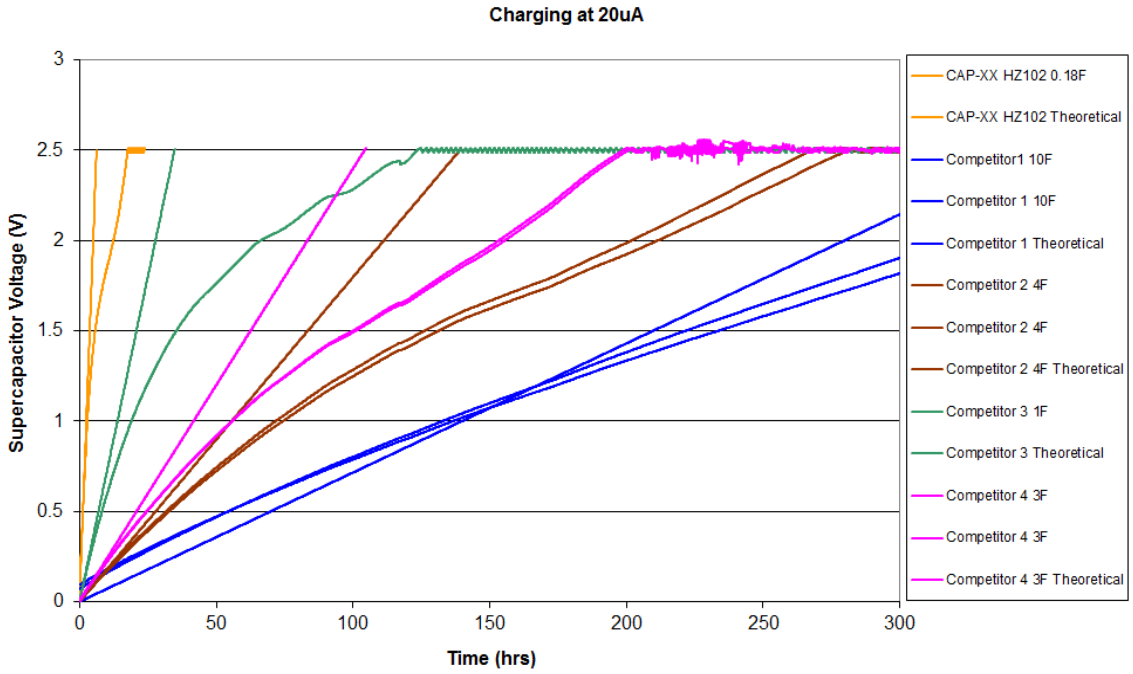

Figure 2: Theoretical vs Actual Charging Time: CAP-XX & Competitors

In practice, even a 1 minute pre-charge reduces the charge time by half. This pre-charge can be applied after soldering the super capacitor onto the PCB and the voltage may be applied direct to the super capacitor terminals.

Figure 3 below shows how it is possible to significantly shorten this time to charge by pre-charging the super capacitor at a higher current of approx. 10mA.

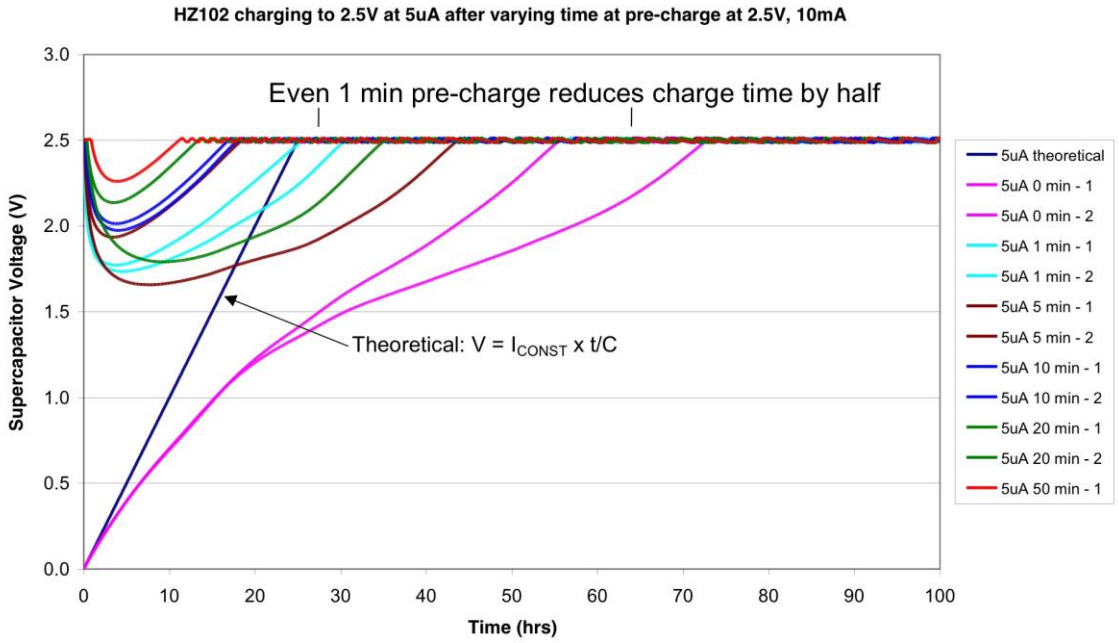

Figure 3 Reduction of charging time due to higher current pre-charge

3. Leakage Current following a shallow discharge of a CAP-XX Super Capacitor:

Leakage current following a shallow discharge is another issue to consider, takes 5 days at room temp to reach equilibrium leakage current only if the super capacitor is fully discharged, i.e. held at short circuit (0V) for many hours. At CAP-XX we do this by placing a clip lead across the terminals to form a short circuit over night before a leakage current test.

In case of a shallow discharge, which is the case for most applications, leakage current decays much more rapidly. In the example below, CAP-XX discharged HW109Fs with and without pre-charge from 2.7V to 2V at 100mA and then re-charged back to 2.7V through a 2.2KΩ resistor acting as a current limit, as might be the case with a low power energy harvester or coin cell. We did this every hour (exactly every 1.08hrs = 3894s and the results are shown in Figures 4 and 5. The max charge current = 0.7V/2.2KΩ = 318uA. The charge current decays exponentially with time constant = 0.32F x 2.2K = 704s. Therefore, after 1.08 hours = 3894s, the supercapacitor will have charged to 2.0V + 0.7V x $(1-e^{-3894/704})$ = 2.6972V so the charge current should be (2.7-2.6972)/2200 = 1.26uA. Any current above this is due to leakage current.

In Figure 4, the blue cells, which have been pre-charged for 48hrs, decay to 4.0µA, which means leakage current = (4.0 – 1.26)µA = 2.74µA. The red cells, which have had no pre-charge decay to 10µA which indicates a leakage current of 8.74µA.

In Figure 5 below, the charge current at 59.65hrs for the blue cells which have been pre-charged is 3.1µA or a leakage current of 1.84µA while the charge current for red cells with no pre-charge is 4.4µA, so the leakage current = 3.14µA. The cells without pre-charge converge to the same leakage current as the cells with pre-charge in 2 – 3 days, which is short compared to the life of the application which may be several years.

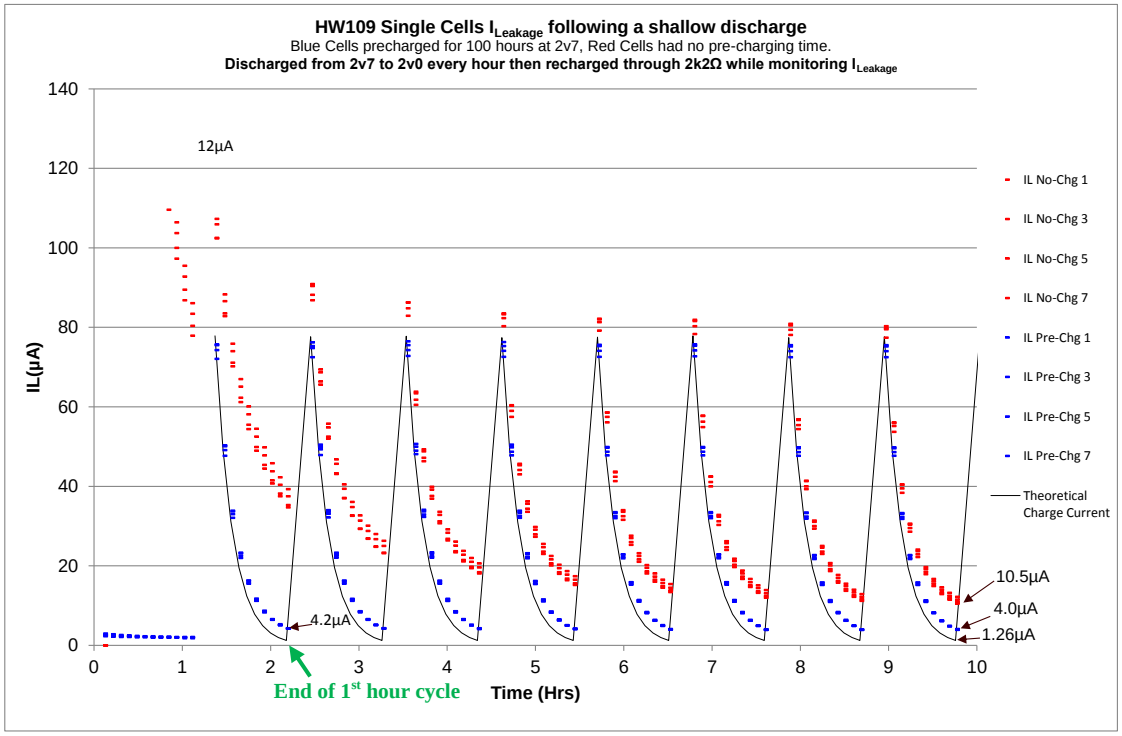

Figure 4: Reduction of charging time due to higher current pre-charge after 8 x 1hour cycles
(Note: Thin black line shows the theoretical charge current)

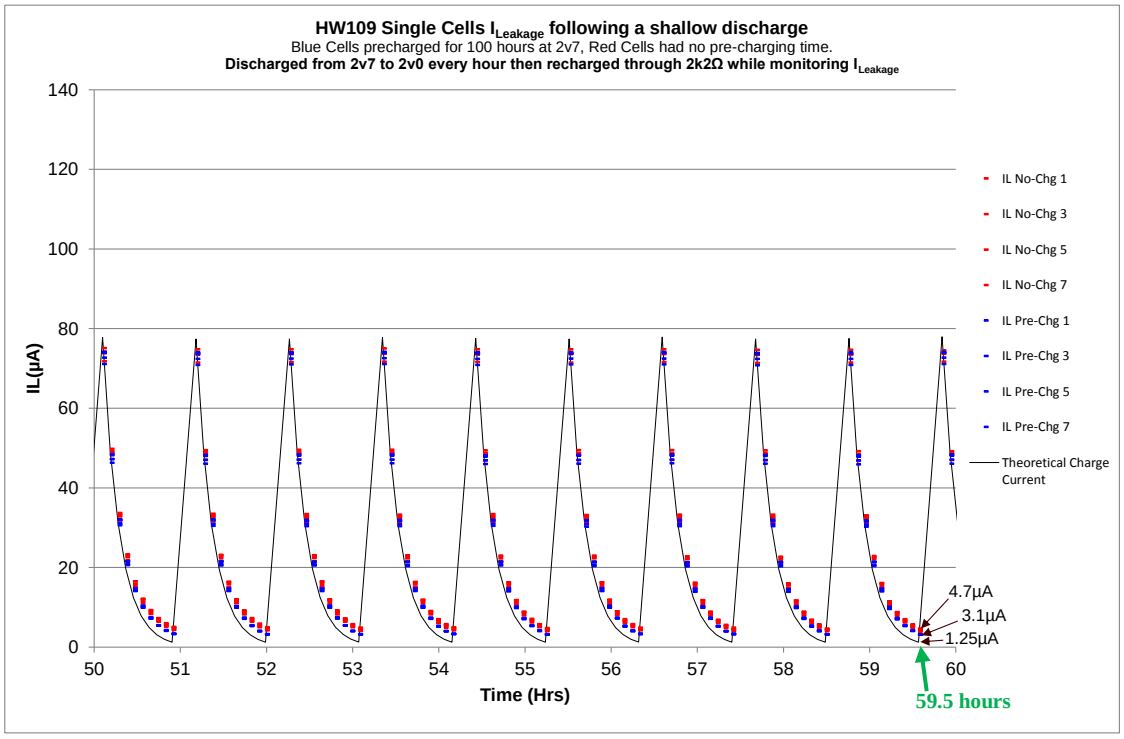

Figure: 5 Reduction of charging time with/without higher pre-charge current (after 59.5 hours)

Figures 4 & 5 show how with a shallow discharge the super capacitor does not return to the very high initial leakage current values of Figure 1 and even after 1hour it decays back to low levels of a few µA.