Electrical Specifications

The HW109 is a single cell supercapacitor. The HW209 is a dual cell supercapacitor with two HW109 cells in series, so HW209 capacitance = Capacitance of HW109/2 and HW209 ESR = 2 x HW109 ESR.

Table 1: Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Conditions</th>
<th>Min</th>
<th>Typical</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Voltage</td>
<td>Vpeak</td>
<td>HW109</td>
<td>0</td>
<td>2.9</td>
<td>5.8</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HW209</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature¹</td>
<td>Tmax</td>
<td></td>
<td>-40</td>
<td></td>
<td>+85</td>
<td>°C</td>
</tr>
</tbody>
</table>

Table 2: Electrical Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Conditions</th>
<th>Min</th>
<th>Typical</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Voltage</td>
<td>Vn</td>
<td>HW109</td>
<td>0</td>
<td>2.75</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HW209</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitance</td>
<td>C</td>
<td>HW109 DC, 23°C</td>
<td>240</td>
<td>300</td>
<td>360</td>
<td>mF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HW209</td>
<td>120</td>
<td>150</td>
<td>180</td>
<td>mF</td>
</tr>
<tr>
<td>ESR</td>
<td>ESR</td>
<td>HW109 DC, 23°C</td>
<td>50</td>
<td>60</td>
<td>120</td>
<td>mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HW209</td>
<td>100</td>
<td></td>
<td></td>
<td>mΩ</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>I_L</td>
<td>2.75V, 23°C 120hrs</td>
<td>1</td>
<td>2</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>RMS Current</td>
<td>I_RMS</td>
<td>23°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Current²</td>
<td>I_P</td>
<td>23°C</td>
<td></td>
<td>4</td>
<td></td>
<td>A</td>
</tr>
</tbody>
</table>

¹Max continuous operating temp = +70°C but can withstand excursions to +85°C.

²Non-repetitive current, single pulse to discharge fully charged supercapacitor.

Table 3: Thickness

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>No adhesive tape on underside of the supercapacitor</th>
<th></th>
<th>Adhesive tape on underside, release tape removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW109F</td>
<td>1.0mm</td>
<td>HW109G 1.1mm</td>
<td>HW209F</td>
<td>2.1mm</td>
</tr>
</tbody>
</table>

This datasheet should be read in conjunction with the CAP-XX Supercapacitor Product Guide which contains information common to our product lines.
Definition of Terms

In its simplest form, the Equivalent Series Resistance (ESR) of a capacitor is the real part of the complex impedance. In the time domain, it can be found by applying a step discharge current to a charged cell as in Fig. 1. In this figure, the supercapacitor is pre-charged and then discharged with a current pulse, I = 1A for duration 0.01 sec.

The ESR is found by dividing the instantaneous voltage step (∆V) by I. In this example = (5.491V - 5.403V)/1A = 117mΩ.

The instantaneous capacitance (C_i) can be found by taking the inverse of the derivative of the voltage, and multiplying it by I.

The effective capacitance for a pulse of duration ∆t_n, C_e(∆t_n) is found by dividing the total charge removed from the capacitor (∆Q_n) by the voltage lost by the capacitor (∆V_n). For constant current C_e(∆t_n) = I x ∆t_n/∆V_n. C_e increases as the pulse width increases and tends to the DC capacitance value as the pulse width becomes very long (~10 secs). After 2msec, Fig 1 shows the voltage drop V_{2ms} = (5.40 V – 5.35V) = 50mV. Therefore C_e(2ms) = 1A x 2ms/50mV = 40mF. After 10ms, the voltage drop = 5.40 V – 5.265V = 135mV. Therefore C_e(10ms) = 1 A x 10ms/135mV = 74mF. The DC capacitance of an HW209 = 0.15 F. Note that ∆V, or IR drop, is not included because very little charge is removed from the capacitor during this time. C_e shows the time response of the capacitor and it is useful for predicting circuit behaviour in pulsed applications.

Fig 1: Effective capacitance, instantaneous capacitance and ESR for an HW209
Measurement of DC Capacitance

Fig 2: Measurement of DC Capacitance for an HW209

Fig 2 shows the measurement of DC capacitance by drawing a constant 100mA current from a fully charged supercapacitor and measuring the time taken to discharge from 1.5V to 0.5V for a single cell, or from 3V to 1V for a dual cell supercapacitor. In this case, \( C = \frac{0.1A \times 3.32s}{2V} = 166\text{mF}, \) which is well within the 150mF +/- 20% tolerance for an HW209 cell.

Measurement of ESR

Fig 3: Measurement of ESR for an HW209

Fig 3 shows DC measurement of ESR by applying a step load current to the supercapacitor and measuring the resulting voltage drop. CAP-XX waits for a delay of 50µs after the step current is applied to ensure the voltage and current have settled. In this case the ESR is measured as 100mV/1A = 100mΩ.
Effective Capacitance

Fig 4: Effective Capacitance

Fig 4 shows the effective capacitance for the HW109, HW209 @ 23°C. This shows that for a 1msec PW, you will measure 20.4% of DC capacitance or 61.2mF for an HW109 or 30.6mF for an HW209. At 10msecs you will measure 50% of the DC capacitance, and at 100msecs you will measure 79% of DC capacitance. Ceffective is a time domain representation of the supercapacitor’s frequency response. If, for example, you were calculating the voltage drop if the supercapacitor was supporting 1A for 10msecs, then you would use the $C_{eff}(10\text{msecs}) = 50\%$ of DC capacitance = 75mF for an HW209, so $V_{drop} = 1\text{A} \times \text{ESR} + 1\text{A} \times \text{duration/C} = 1\text{A} \times 100\text{mΩ} + 1\text{A} \times 10\text{ms} / 75\text{mF} = 233\text{mV}$. The next section on pulse response shows how the effective capacitance is sufficient for even short pulse widths.

Pulse Response

Fig 5 shows that the HW209 supercapacitor does an excellent job supporting a GPRS class 10 pulse train, drawing 1.8A for 1.1ms at 25% duty cycle. The source is current limited to 0.6A and the supercapacitor provides the 1.2A difference to achieve the peak current. At first glance the freq response of Fig 8 indicates the supercapacitor would not support a 1ms pulse, but the Ceff of 30mF coupled with the low ESR supports this pulse train with only ~165mV droop in the supply rail.

Fig 5: HW209 Pulse Response
DC Capacitance variation with temperature

![Graph of DC Capacitance variation with temperature]

**Fig 6: Capacitance change with temperature**

Fig 6 shows that DC capacitance is approximately constant with temperature.

ESR variation with temperature

![Graph of ESR variation with temperature]

**Fig 7: ESR change with temperature**

Fig 7 shows that ESR at -40°C is ~2.6 x ESR at room temp, and that ESR at 80°C is ~0.8 x ESR at room temperature.
**Frequency Response**

Fig 8: Frequency Response of Impedance (biased at 2.7V with a 50mV test signal)

Fig 9: Frequency Response of ESR, Capacitance & Inductance

Fig 8 shows the supercapacitor behaves as an ideal capacitor until approx 7 Hz when the magnitude no longer rolls off proportionally to 1/freq and the phase crosses -45°. Performance of supercapacitors with frequency is complex and the best predictor of performance is Fig 4 showing effective capacitance as a function of pulsewidth.
Leakage Current

Fig 10 shows the leakage current for HW109 at room temperature. The leakage current decays over time, and the equilibrium value leakage current will be reached after ~120hrs at room temperature. The typical equilibrium leakage current is 1µA at room temperature. At 70°C leakage current will be ~10µA.

Charge Current

The corollary to the slow decay in leakage currents shown in Fig 10 is that charging a supercapacitor at very low currents takes longer than theory predicts. At higher charge currents, the charge rate is as theory predicts. For example, it should take 0.3F x 2.4V / 0.00002A = 10hrs to charge a 0.3 F supercapacitor to 2.4V at 20µA, but Fig 11 shows it took 27hrs. At 200µA charging occurs at a rate close to the theoretical rate.
Continuous current flow into/out of the supercapacitor will cause self-heating, which limits the maximum continuous current the supercapacitor can handle. This is measured by a current square wave with 50% duty cycle, charging the supercapacitor to rated voltage at a constant current, then discharging the supercapacitor to half rated voltage at the same constant current value. For a square wave with 50% duty cycle, the RMS current is the same as the current amplitude. Fig 12 shows the increase in temperature as a function of RMS current. From this, the maximum RMS current in an application can be calculated, for example, if the ambient temperature is 40°C, and the maximum desired temperature for the supercapacitor is 70°C, then the maximum RMS current should be limited to 3.3A, which causes a 30°C temperature increase.

**CAP-XX Supercapacitors Product Guide**

Refer to the package drawings in the *CAP-XX Supercapacitors Product Guide* for detailed information of the product’s dimensions, PCB landing placements, active areas and electrical connections, as well for information on endurance and shelf life, transportation and storage, assembly and soldering, safety and RoHS/REACH certification.