Whitepaper
AN1005

Simple Measurement of Supercapacitor Parameters

Background

CAP-XX supercapacitors have very low leakage current and Equivalent Series Resistance (ESR). This application white paper describes the process of measuring capacitance, ESR and leakage current without the use of highly specialised equipment.

Simple Measurement of Supercapacitor Parameters

Outline

CAP-XX prismatic supercapacitors have high capacitance ranging from 0.1 to 2.4 Farads and an ESR (Equivalent Series Resistance) from 15 mΩ to 330 mΩ. The ESR for these supercapacitors must be measured using 4-wire measurement systems such as an LCR bridge. However, these instruments often attempt to measure capacitance & ESR using small AC signals at high frequencies. Supercapacitors are DC components whose capacitance rolls off at frequencies above several Hz, making them unsuitable for measurement by some LCR bridges. Further, LCR bridges are expensive specialized pieces of equipment and so are not always available.

Along with ESR and Capacitance, the other important parameter is Leakage Current. CAP-XX supercapacitors, when charged, continue to absorb current in the order of 0.1-10 μA. This current exists due to the chemical nature of the supercapacitors. Leakage current is important in applications where this energy drain is significant, such as when the supercapacitor:

- Is coupled with a small energy harvester which produces very low current;
- Or is across a battery and is a continuous drain on the battery's charge;
- Or in an application that requires low self-discharge.

Leakage current for a supercapacitor is a complex function of voltage, time, temperature and the change in temperature. This application note presents a simple way to measure ESR, capacitance and leakage current using electronic equipment commonly available in most labs: a low current power supply, a digital storage oscilloscope (DSO) and a multimeter.

ESR And C Measurement

The CAP-XX Solution

The diagram below shows the setup used in this application note for measuring ESR and C for Cap-XX supercapacitors.

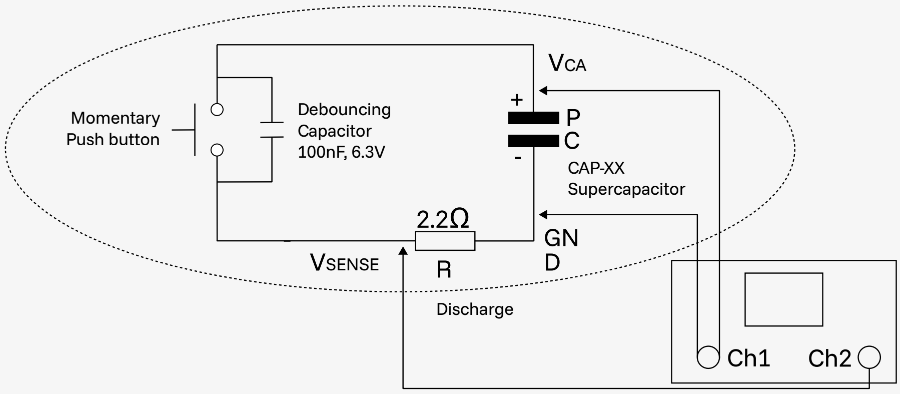

Fig 1: Measurement Setup for C & ESR

A picture of the items circled in Fig 1 above is shown below in Fig 2. This illustrates how simple the setup is. The distance between the resistor (R) and supercapacitor's negative terminal (V-) should be as short as possible and the connection should use thick wire to keep the impedance low. Attach the scope ground to the supercapacitor V- terminal and the scope V_{CAP} probe to the supercapacitor V+ terminal. Attach the scope V_{SENSE} probe as close as possible to R.

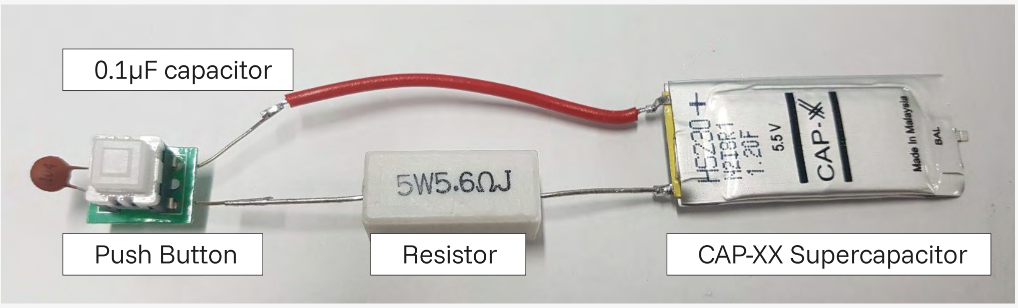

Fig 2: Picture of Supercapacitor Measurement Setup

Note that dual cell CAP-XX supercapacitors have a 3rd terminal, labelled "BAL", which is at the midpoint of the 2 supercapacitor cells and used for cell balancing. For this exercise, where it has been assumed that the supercapacitor is only on charge for a few minutes while these measurements are carried out, we have ignored the balance terminal and left it not connected and not shown it in Fig 1. If you are going to leave the supercapacitor at voltage for an extended time, then place a pair of 2.7KΩ resistors, one across each cell (from –ve to BAL, and from BAL to +ve). This will keep the supercapacitor cells in voltage balance but have an insignificant effect on your results.

Items required are:

- Digital Storage Oscilloscope (DSO) (min. requirements: 2 channels., 20 MHz BW limited, pulse trigger)
- 2 × Voltage probes for the DSO
- DC Power supply (required output voltage: 5.5V max)
- 2 × alligator clip leads
- 5.6 Ω resister (>5W; desirable tolerance of 0.1%)
- Momentary action push button (with minimal switch bounce)
- 0.1μF capacitor (to debounce the push button action)
- CAP-XX supercapacitor to be measured

Note that the resistor should be measured with a calibrated meter before doing the ESR and C measurements. From the setup above, the wire-wound resistor was measured to be 5.54Ω.

The capacitance measurement technique is based on the fact that one time constant, (τ = R*C) is the time required to discharge the capacitor voltage down to 36.8% of its initial voltage. Hence, for a supercapacitor charged to 5V, the voltage should drop to 1.84V and a for a single cell supercapacitor charged to 2.5V, to 0.92V after one time constant of discharge. Since the resistor value is known, then C = time to discharge to 36.8% of initial voltage/R. The ESR drop is measured as the voltage drop from immediately before time 0 (when the switch is depressed) to a few μsec later when the voltage and current have settled (~3μsec later from Fig 4) divided by the current step measured just after the switch is closed. The current step = V_{SENSE}/R.

Capacitance Measurement

1. Assemble the circuit as shown in figure 1.

2. Set channel 1 (V_{CAP}) on the DSO to 1 V/div and DC coupled.
   To get exact values, use calibrated voltage probes.

3. Set channel 2 (V_{SENSE}) on the DSO to 1 V/div and DC coupled.
   To get exact values, use calibrated voltage probes.

4. Set the time base to 1 sec/div.

5. Enable 20 MHz bandwidth limit on all channels and set trigger on channel 2 at around 1.5V.

6. Charge the supercapacitor to its rated voltage using the DC power supply and then disconnect.

7. Press the push button until the capacitor voltage has dropped below 0.5V.

   Refer to the waveform in Fig 3 for the steps 8–11

8. For measuring capacitance, initial voltage, $V_{INIT} = V_{RATED} - \Delta V_{ESR}$.
   Use the cursor on the oscilloscope to determine this value. In Fig 3, this is 4.98V.

9. After one time constant, the capacitor voltage would be, $V(\tau) = V_{INIT} \times 0.368$ Volts.
   In the example of Fig 3, this = 4.98V x 0.368 = 1.83V.

10. Using the cursors, find the time (τ) at which the capacitor voltage = $V(\tau)$.
    In the example of Fig 3 this = 6.72 secs.

11. Equate this time to the product of $R_{DISCHARGE}$ (5.54Ω) and Capacitance and find the capacitance, $\tau = R \times C$;

$$\text{Thus, } C = \frac{\tau}{R} \text{ Farads} = \frac{6.72}{5.54} = 1.21 \text{ Farads.}$$

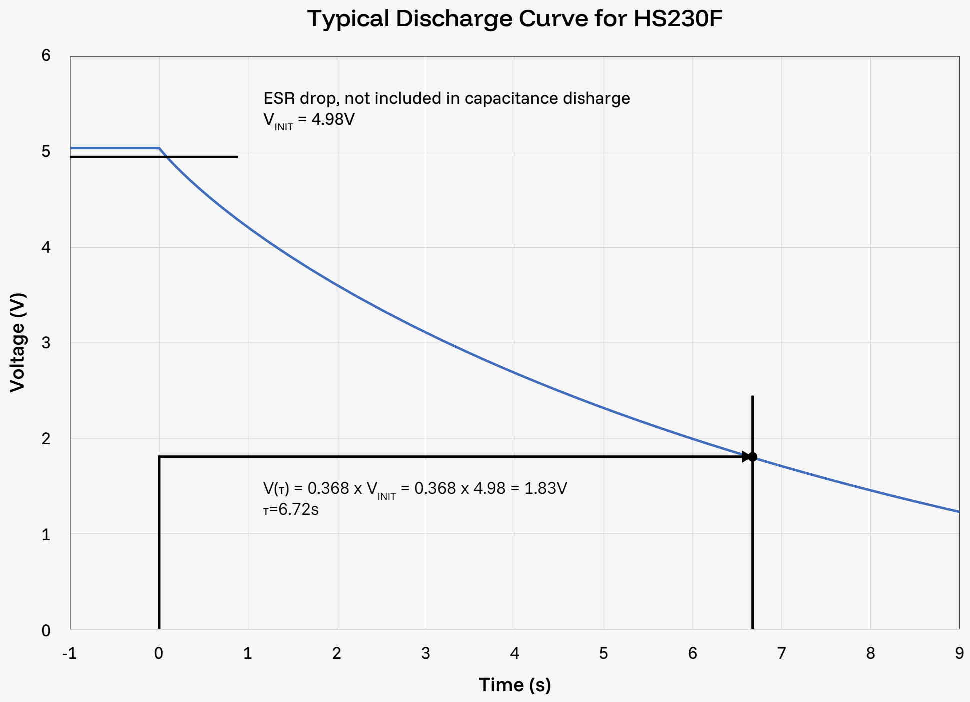

Fig 3: Discharge for Capacitance Measurement

ESR Measurement

1. **Assemble the circuit as shown in figure 1.**

2. **Set channel 1 (V_{CAP}) on the DSO to 20mV/div and AC coupled.**
   (Measure V_{CAP} using a calibrated voltage probe to get the exact value.)

3. **Set channel 2 (V_{SENSE}) on the DSO to 1V/div and DC coupled.**
   (Measure V_{SENSE} using a calibrated voltage probe to get the exact value.)

4. **Set the time base to 10µsec/div.**

5. Enable 20 MHz bandwidth limit on all channels and set trigger on channel 2 at around 1.5V.

6. Charge the supercapacitor to its rated voltage using the DC power supply and then disconnect it.

   Note: Supercapacitor ESR will depend on the "state of charge", or how long the supercapacitor has been left on charge. ESR will increase slightly (by approx 10%), when the supercapacitor is at full state of charge, i.e. left on voltage for 48hrs. CAP-XX production measurement of ESR is done at full state of charge. If an accurate reading of ESR at full state of charge is required, then at step 6, leave the supercapacitor connected to the DC supply at its rated voltage for 48h hours before disconnecting it. Otherwise, leave the PSU connected until the supercapacitor draws < 1mA. Disconnect both +ve and ground terminals of the PSU.

7. Press and hold the push button momentarily.

   Refer to the waveforms in Fig 4 for steps 8–10

8. Using the cursors, find the voltage just before 0µs and when the voltage & current step have settled (~10µs in this example) on channel 1 = V_{CAP}.

9. Using the cursors, also find the voltage on channel 2 = V_{SENSE} (across the $R_{DISCHARGE}$).

10. To calculate ESR:

$$\Delta V_{ESR} = V_{CAP@0\mu s} - V_{CAP@10\mu s}$$
$$= 0.037\text{V (From Fig 4)}$$

$$\text{Current} = \frac{\text{Voltage across } R_{DISCHARGE}}{R_{DISCHARGE}}$$

$$= \frac{4.88}{5.54} = 0.88\text{A}$$

$$\text{Hence} \quad ESR = \frac{\Delta V_{ESR}}{\text{Current}}$$

$$= \frac{0.037\text{V}}{0.88\text{A}}$$

$$= 42\text{m}\Omega$$

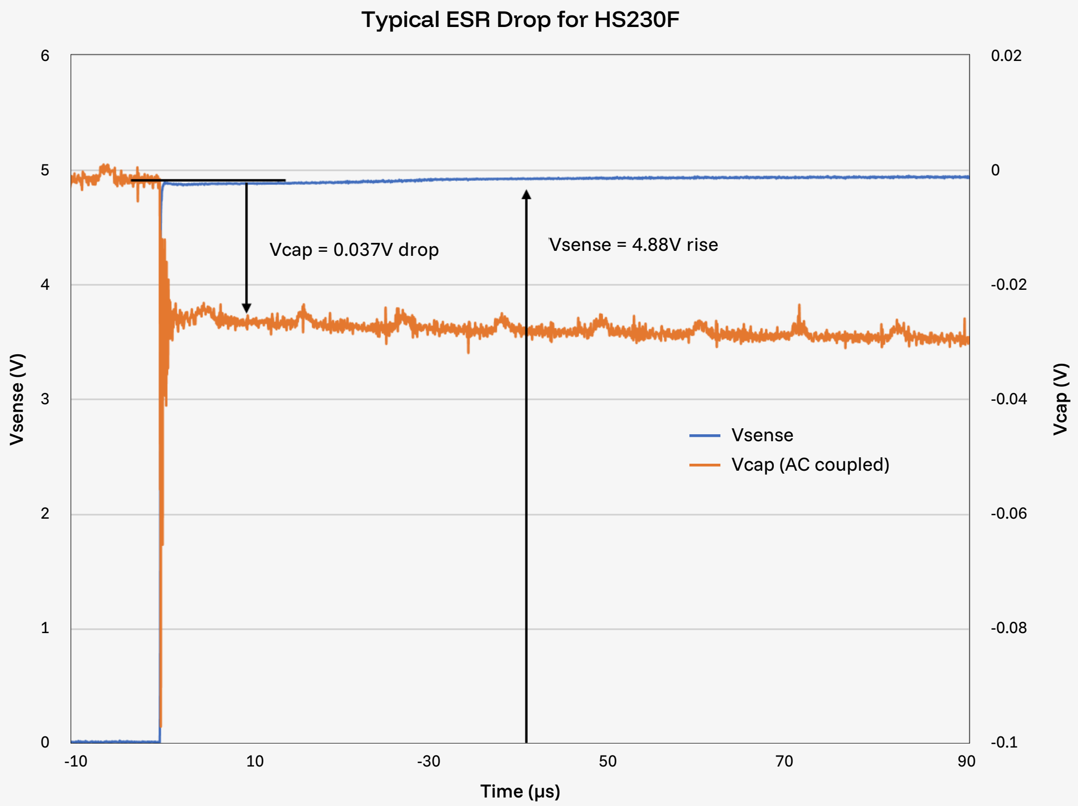

Fig 4: Waveforms for ESR Measurement

RATED ESR	RATED C	MEASURED ESR	MEASURED C
45mΩ	1.2F	42mΩ	1.21F

Table 1: Result Summary for HS230F

Leakage Current Measurement

The CAP-XX Solution

The diagram below shows the setup used in this application note for measuring leakage current.

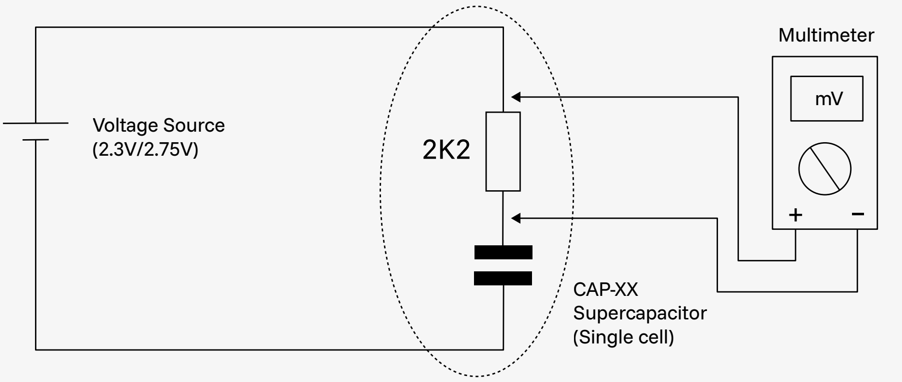

Fig 5: Measurement setup for leakage current

A picture of the items circled in Fig 5 is shown below in Fig 6.

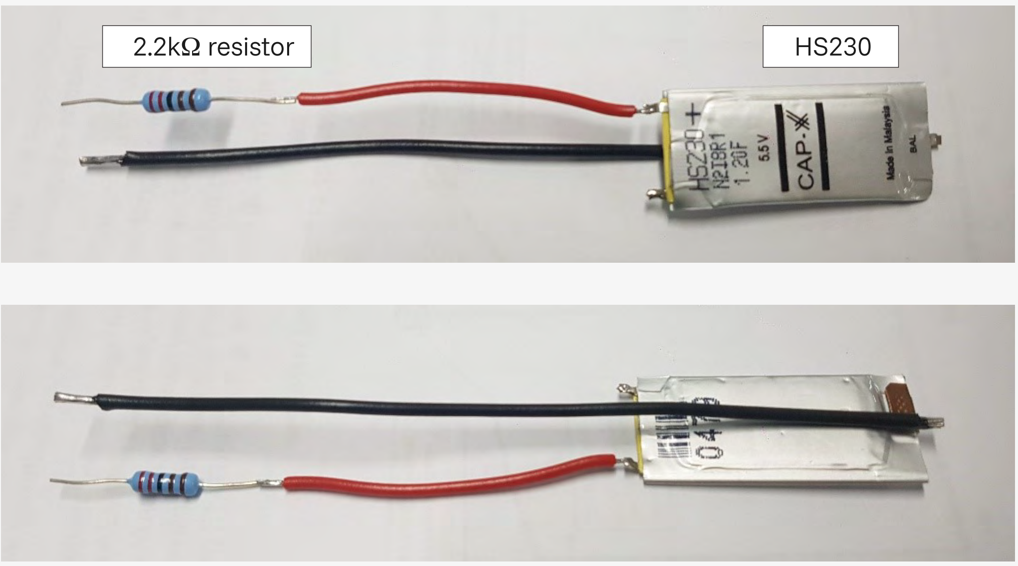

Fig 6: Picture of Leakage Measurement Setup for HS230F

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Items required are:

- 2K2 resistor (1% tolerance or better);
- Insulated wired for capacitor terminals;
- Power supply (with no low frequency noise and output voltage > 2.3V);
- Multimeter (accurate to 0.1mV);
- 2 × alligator clip leads;

Issues to be considered:

- Measurements should be done at room temperature with temperature fluctuation < ±1°C.
- Leakage measurement must be done for a single cell only.
- Power supply should have no ripples or low frequency noise over time or temperature.
- The supercapacitors must not be physically disturbed during the test.

Leakage Measurement

1. **Assemble the circuit as shown in figure 5.**

   Note: to measure the leakage current of the top cell, connect the PSU V+ terminal to the supercapacitor + terminal, and connect PSU V- (or Gnd) terminal to the supercapacitor Bal terminal. This is the connection shown in Fig 6.

2. **To measure the leakage current of the bottom cell, connect the PSU V+ terminal to the supercapacitor Bal terminal, and connect the PSU V- (or Gnd) terminal to the supercapacitor V– terminal.**

3. Pre-charge the supercapacitors directly from the power supply (2.5V for G series / 2.75V for H series) for 15 minutes, i.e power supply is directly across the supercapacitor terminals, with the 2K2 resistor not in circuit. The PSU should be current limited (set to ~2A), or if there is no current limit, be able to manage the inrush current which can be up to 20A initially for a few msecs), or alternatively use a 1Ω current limit resistor between the PSU V+ terminal and the supercapacitor + terminal (for top cell) or supercapacitor BAL terminal (for bottom cell).

4. Disconnect the supercapacitor directly from the power supply and reconnect with the 2K2 resistor in series between the supercapacitor and the PSU, as shown in Fig 6.

5. Wait for 120–125 hours.

6. Then measure the voltage across the 2k2 resistor and divide it by 2200 to get the leakage current. In order to eliminate the effects of any noise, it is recommended to take the average of 10 measurements.

In tests done at Cap-XX, the following measurements were taken:

Capacitor Type	Capacitor Rating		Time (Hrs)	Voltage Across 2k2 (mV), V_L	Leakage Current (µa) (V_L/2200)
	C (F)	ESR (mΩ)			
HS230F	1.2	45	120	4.6	2.1
HA230F	0.4	130	120	2.9	1.3
GW201F	0.4	55	120	0.7	0.3
GS206F	0.68	35	120	2.4	1.1

Table 2: Result Summary

The graph in Fig 7 shows how leakage current decays over time to an equilibrium value. It can be seen that after around 120 hours, absorption current/charge current is no longer significant compared to leakage current. At this time, a reasonable measurement of leakage current can be made.

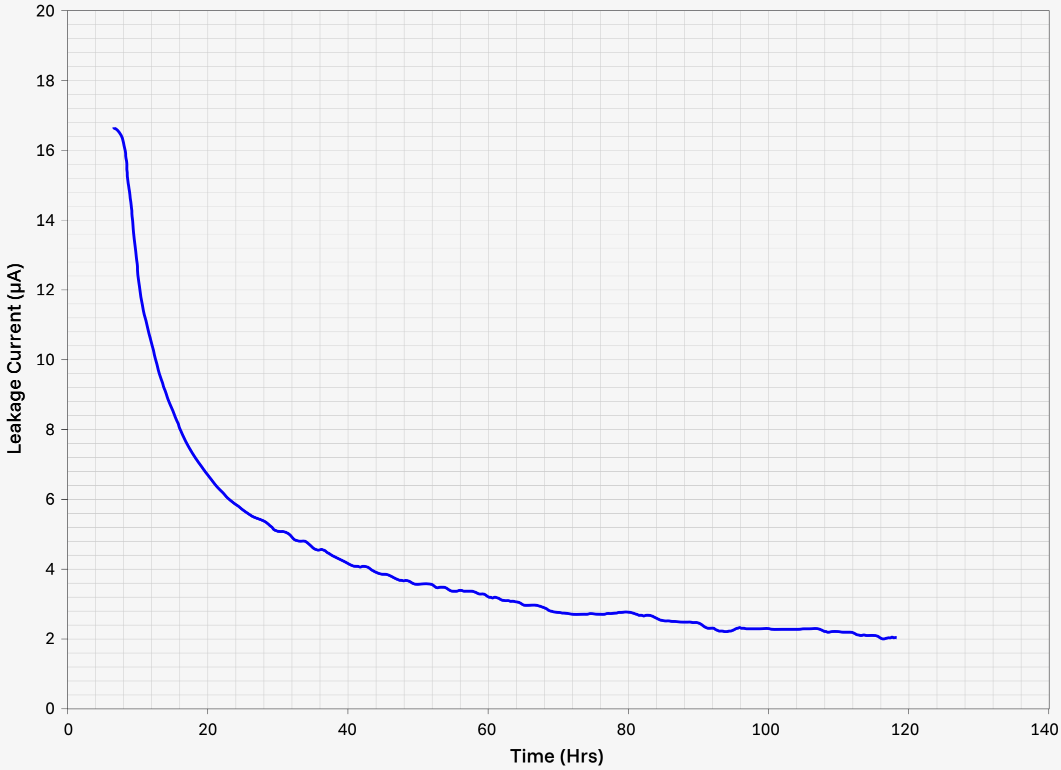

Fig 7: HS230F Leakage Current over time

The benefits of the measurement methods in the whitepaper:

- Cheap
- Reliable
- Components easily available

Further Information

CAP-XX will be pleased to provide further information on the applications described here, and on the use of supercapacitors in any application. Please use the contact details provided on the CAP-XX web site **cap-xx.com.**

This application white paper is available on the CAP-XX web site. On the web site you may also find product bulletins, datasheets, SPICE models, application white papers, application briefs and design-aid calculators.

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