

Methods for measuring capacitance, inflow current, internal resistance and ESR

Capacitance measurement

Supercapacitors exhibit considerable “dielectric absorption” charge storage. As such, some traditional methods of measuring capacitance may not yield accurate results when measuring supercapacitors. A method for measuring capacitance in supercapacitors is outlined below. This method is recommended over others such as determining the 63 percent voltage point and using the time in a RC time constant calculation.

The following test circuit can be set up with a common laboratory power supply set to the specified current and voltage limits. The charging waveform, shown in Figure 1, is best recorded with a digital oscilloscope. The cursor function can be conveniently used to directly read the time points between the 1.5 volt and 2.5 volt crossing. The basic equation for the average current in a capacitor is:

$$I = C \left(\frac{\Delta V}{\Delta t} \right), \text{ solving for } C: C = I \left(\frac{\Delta t}{\Delta V} \right)$$

For $I = 1$ ampere and $\Delta V = 1$ volt, therefore $C = \Delta t$.

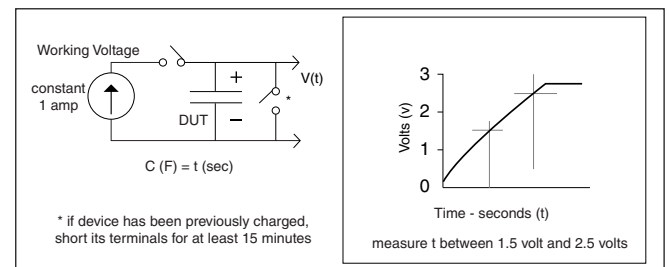


Figure 1. Supercapacitor charging circuit and waveform

Capacitance in this example is numerically equal to the time in seconds for the capacitor to charge from 1.5 V to 2.5 V. Because dielectric absorption is pronounced, the device under test should be well discharged before beginning the test to ensure consistent results. If the device has previously been charged, then its terminals should be shorted for at least 15 minutes before beginning the test.

Inflow current measurement

Since supercapacitors exhibit pronounced dielectric absorption, the measurement of actual leakage current, or self-discharge current, is made difficult. When a supercapacitor is charged to its working voltage, the inflow current exhibits large, slowly decaying values for long times. The inflow current is the sum of dielectric absorption current flow and actual leakage current. Dielectric absorption current flow represents charge going into storage, but deeply buried in terms of possessing a very long time constant. The inflow current as a function of time is essentially logarithmic, as shown in Figure 2.

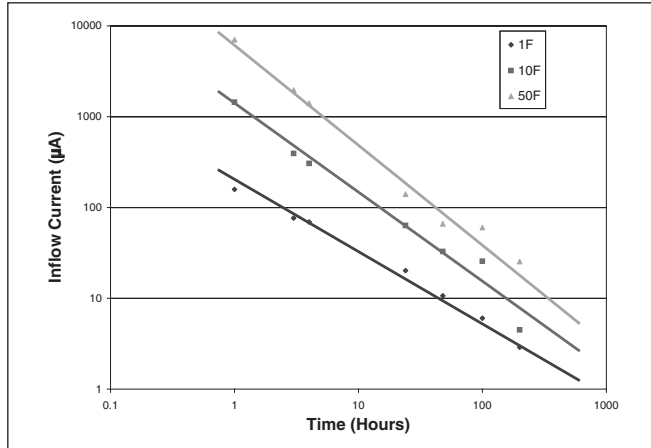


Figure 2. Inflow current vs. time

These typical curves are measured with the test circuit shown in Figure 3. The parts were short circuited for 2 days prior to beginning the test. Therefore, stored dielectric absorption charge was essentially non-existent.

True leakage currents, where dielectric absorption goes to zero, take over 100 hours to reach as shown in Figure 2. These leakage currents are on the order of only a few microamperes. To continue to measure inflow current beyond this point, one needs to use instrumentation capable of accurately measuring microvolts and/or a larger resistor value can be used in the circuit in Figure 3.

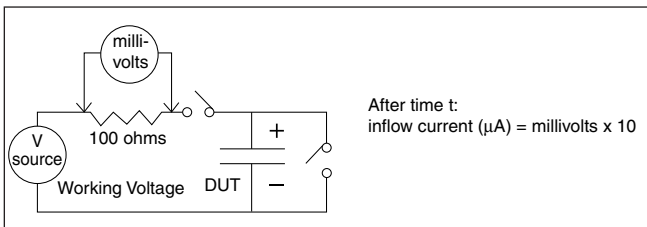


Figure 3. Inflow current test circuit

Internal resistance and ESR (equivalent series resistance) measurement

For product specification purposes ESR or AC impedance is measured using a commercial LCR bridge at 1 kHz. This produces a rather precise, reproducible value. Another method is used to measure what is called the internal resistance or DC impedance and can be performed with the same instrumentation used to measure capacitance (described above). This method produces a value for internal resistance which is not nearly as precise and reproducible as the ESR measurement. However, internal resistance is more directly related to device behavior in many pulse power applications.

Shown in Figure 4 is the oscilloscope trace obtained using the capacitance test circuit and method. An enlargement of the beginning of the trace is shown in Figure 5. The instantaneous voltage step which occurs the moment the 1 ampere charging current is applied is used to calculate internal resistance. The internal resistance or DC impedance is equal to the step voltage divided by 1 ampere. For devices which exhibit lower internal resistance than this example, a higher constant current is required.

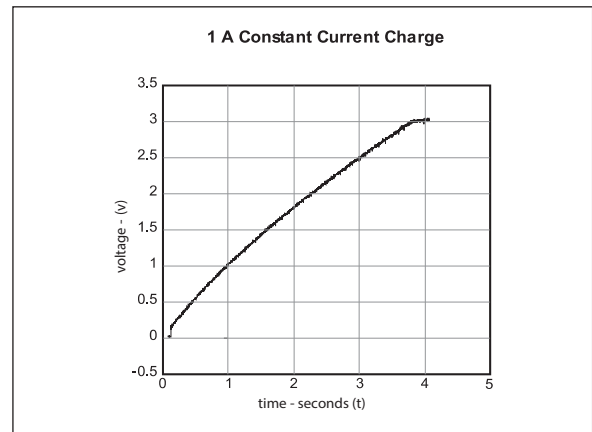


Figure 4. Resistance measuring waveform using voltage

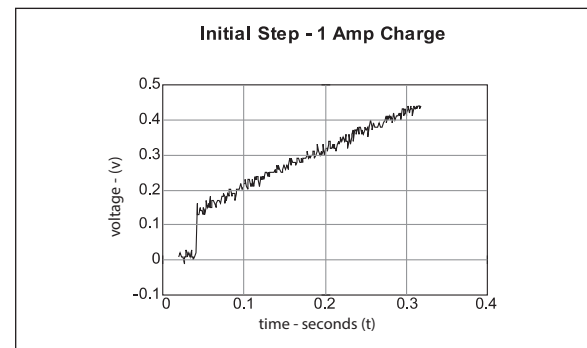


Figure 5. Initial voltage step of resistance measuring waveform using voltage

In this example:

$$\text{Internal resistance} = \frac{\text{initial voltage step}}{\text{constant current}} = \frac{0.15 \text{ V}}{1 \text{ A}} = 0.15 \text{ Ohms}$$

Studies have shown that the internal resistance or DC impedance value is usually between 1.1 and 1.5 times the measured ESR or AC impedance value.

Eaton
Electronics Division
1000 Eaton Boulevard
Cleveland, OH 44122
United States
www.eaton.com/electronics

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