**Product Group:** Vishay Foil Resistors

**Precision Bulk Metal® Z-Foil Current Sense Resistors in the Analysis and Improvement of Lithium-Ion Battery Efficiency and Lifetimes**

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The use of Bulk Metal® Z-Foil current sense resistors has led to a dramatic reduction in noise levels and, therefore, to a dramatic increase in the accuracy of high- and ultra-high-precision chargers that are used to test and improve lithium-ion battery efficiencies and lifetimes.

**Industry/Application Area:** Automotive, aerospace, and all other industries using Li-on batteries

**Product Used:**

- Model Z201 (ultra-high-precision Bulk Metal Z-Foil, through hole, radial leaded)
- Model VHA512 (ultra-high-precision Bulk Metal Z-Foil, hermetically sealed, axial leaded, current sense)
- Model CSNG (ultra-high-precision Bulk Metal Z-Foil, new generation high-power current sense design)

## The Challenge

Li-ion cells can fail due to parasitic reactions between the charged electrode materials and the electrolyte that slowly consume electrode and/or electrolyte materials. Due to these parasitic reactions, the amount of charge stored in the battery during the recharge (the charge capacity) is typically slightly greater than that delivered during the discharge, and this Coulombic Efficiency (the ratio of the discharge capacity to the charge capacity) leads to gradual loss of cell capacity, over time and cycles, and ultimately leads to cell failure. High-precision coulometry, developed by the Dahn Research Group, is used to precisely measure a cell's charge and discharge currents and, thereby, makes possible the analysis of these parasitic reactions and the development of more efficient, longer lasting electrode and/or electrolyte materials. But the fraction of this charge/discharge current that comes from these parasitic reactions is very small and very hard to detect, and, even if accurately measurable, it would typically take months or years to detect such effects using standard battery test equipment. But with the ability to establish a highly stable current and then measure this current to a very high precision level, very small current fluctuations can be accounted for and the current flow from these parasitic reactions can be detected with only a few charge/discharge cycles - which, in turn, allows researchers to determine, after only a few weeks of testing, whether new or alternative electrode materials and/or electrolyte additives will have a positive impact on lithium-ion battery lifetime, even for batteries that need to last from 5 to 30+ years.

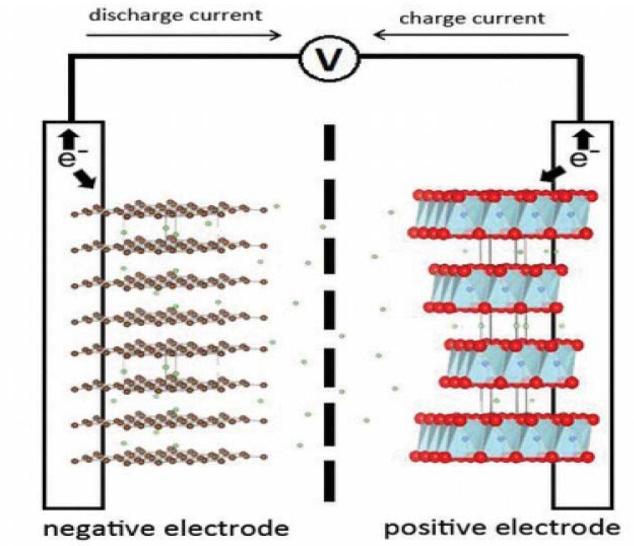


*Figure 1: Schematic diagram showing the generalized operation of a Li-ion cell*

**The Solution**

Using resistors featuring the latest Bulk Metal Z-Foil technology from Vishay Precision Group (VPG) applied in a current sense design, the Dahn Research Group has developed the Dalhousie Ultra High Precision Charger (UHPC) multi-channel cell charging system, which allows for precise, thermally stable measurement, comparison, and control of Li-ion cell charging and discharging currents. Bulk Metal Z-Foil resistors were chosen particularly for their tight tolerances (0.005%), low noise (0.01 µV per 1 V of applied potential), and low temperature coefficient (0.2 ppm/°C typical).

Please see Figure 2 on page 41 in the paper from Toby Mishkin Bond (2012, Improving Precision and Accuracy in Coulombic Efficiency Measurements of Lithium Ion Batteries) for a 'schematic diagram of the UHPC showing how current measurement is implemented'.

**The User Explains**

Since CE is defined as the ratio of discharge and charge capacities, the absolute accuracy of current source output is not particularly important, provided the charge and discharge currents are properly matched. The Dalhousie HPC was developed for this purpose and designed to significantly outperform commercially available chargers, allowing calibration between these currents to within 0.01%. The current sources used are very good, but it is necessary to measure the long-term drift and oscillations in the supplied current (over 3-4 weeks), as it is important for calculating the total charge sourced/sunk. In addition, both positive and negative currents (charge/discharge) are run and the current sources may have small offsets between charge and discharge currents. For these reasons, it is critical that the current calculated from the voltage drop is correct, even if there are small temperature fluctuations in the system.

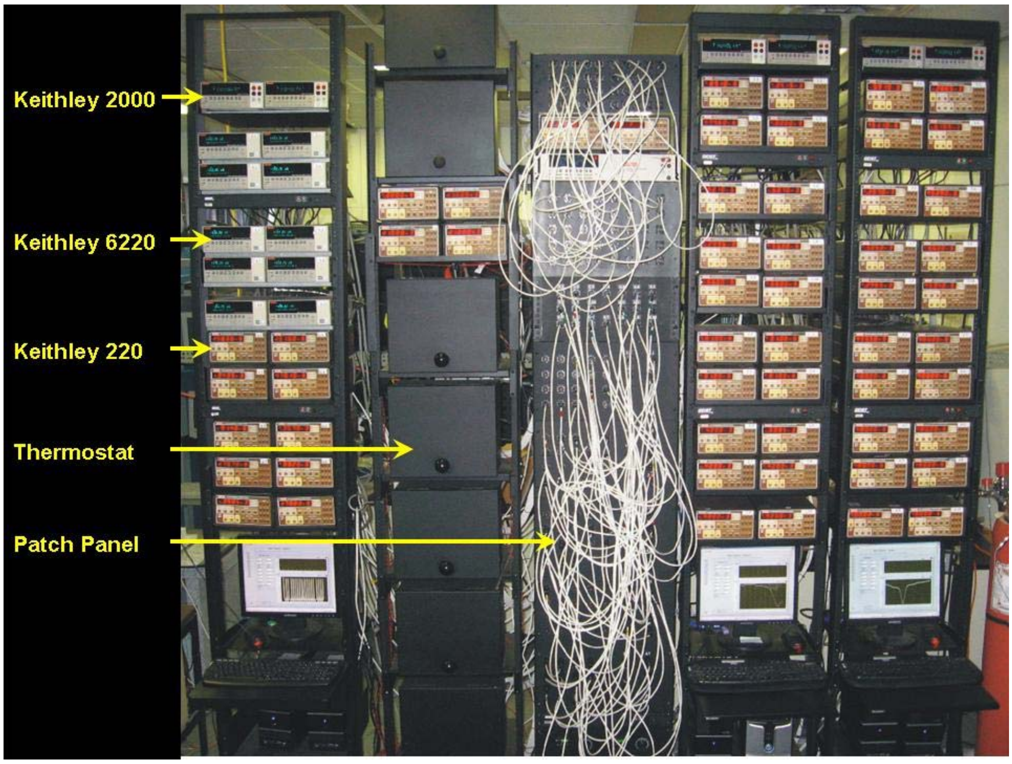


*Figure 2: The Dalhousie HPC*

In 2011, the Dahn Research Group undertook to improve even further the performance of the Dalhousie HPC, by increasing the data sample rate and enabling the measurement of current – all with the purpose of increasing charger precision and improving the ability to resolve increasingly minute differences in CE between different cell chemistries. Using various models of Bulk Metal Z-Foil resistors, including prototypes and samples manufactured and provided by Texas Components Corporation (Houston, Texas, USA) and Vishay Precision Group (Holon, Israel), further tests and research were performed to identify key parameters and opportunities for improving HPC performance. The following parameters were all found to improve the precision of the HPC device, leading to the development of the Dalhousie UHPC:

- In-situ measurement of current output that is used to calculate capacity
- Temperature control of current sources and DMMs
- Voltage stabilization of power supplied to current sources and DMMs
- Increased sample rate (for measuring both cell voltage and current)

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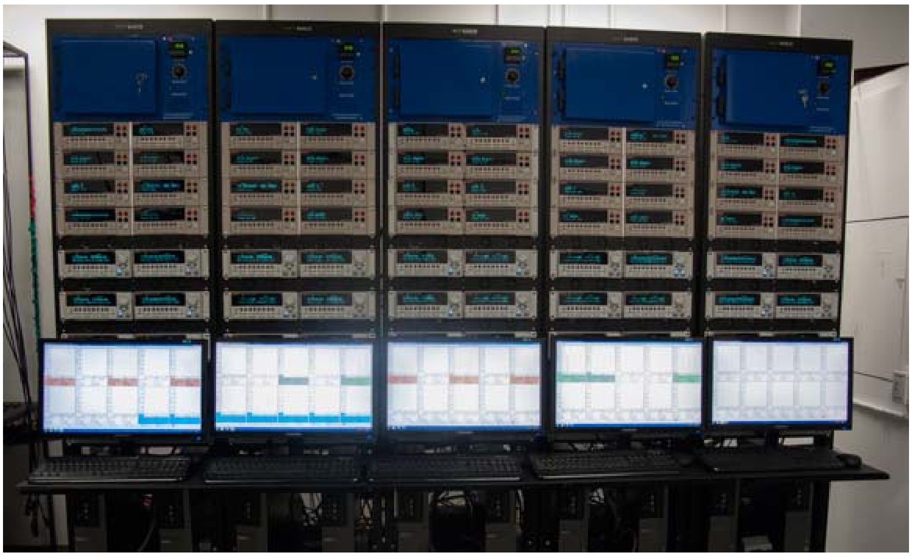

*Figure 3: The Dalhousie UHPC*

Of the four parameters listed above, in-situ accurate measurement of current output was found to be the most important parameter by far in reducing noise. All 60 channels of the existing HPC equipment were upgraded to allow for more reliable measurement of current through the use of Bulk Metal Z-Foil resistors applied in a current sense design. Multiple resistors are used per channel, with the goal of controlling the voltage drop across the current sense resistor to about ~1V, as this is the range where the overall measurement system's TCR is the lowest. Multiple resistor sizes are used in each channel to support cells with a variety of capacities and charging/discharging currents, while still limiting the voltage drop across each resistor. Each channel has a dedicated array of resistors installed in a relay system that can select a suitable resistor based on the current output of a channel without having to manually swap out the resistor. Although these resistor relays are housed in a temperature control box, it is critical that no fluctuation in temperature contribute to changes in the resistance value and, therefore, to the resultant current measurements made thereby. A control factor again facilitated by the use of Bulk Metal Z-Foil resistors. All HPC/UHPC channels now use resistors featuring Bulk Metal Foil technology, and further research is being conducted to improve these even further and to develop commercial versions as well for additional applications. Use of the Bulk Metal Z-Foil technology current sense resistors has led to at least a 5-fold reduction in noise levels in the UHPC systems versus the prior-generation HPC systems.

**“In our HPC and UHPC multi-channel Li-ion cell charging systems, the best solution for improving stability and scaling signals without losing resolution and accuracy is the use of current sense resistors featuring Bulk Metal® Z-Foil technology from Vishay Precision Group."**

**Acknowledgements:**

The **Dahn Research Group at Dalhousie University** is a research lab specializing in the physics and chemistry of materials for energy storage, primarily focusing on the area of Li-ion batteries. The goals of this group are to improve the energy density, increase the safety, decrease the cost, and improve the cycle and calendar lifetime of the batteries. Ongoing projects include analysis of new positive electrode materials, new negative electrode materials, and Li-ion battery safety – such projects being well established with a long history in the group. In particular, studies of the reasons for the failure of Li-ion cells began in 2008, and currently represent the largest focus area for the group.
www.dal.ca/diff/dahn.html

**Texas Components Corporation** has been a part of the electronic component sales and distribution industry in North America since the 1960's and has been producing precision foil resistors since 1980. Today, with over three decades of experience, Texas Components supports a full line of standard foil resistors as well as offering other related designs and derivative products. Texas Components' fully equipped manufacturing and distribution facility is centrally located in the USA and is well staffed with friendly sales representatives and experienced engineers to support specialized designs and applications. Texas Components specializes in the fast delivery of sample and prototype quantities while also supporting full manufacturing volumes and scheduled deliveries. Texas Components also provides extensive post manufacturing operations and other testing services, including discrete parametric screening, set-matching, power conditioning, burn-in, and life-tests.
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