Choosing Current Sense Resistors for Li-Ion Batteries

By Bryan Yarborough

INTRO TO LI-ION

Li-Ion is a rechargeable electro-chemical energy system that is being used as a power source for a wide range of mobile applications, from the smallest wireless speaker buds to electric vehicles to extremely large MWh grid energy storage systems. Its high energy density, efficiency, cycle life, and reduced costs make it a very attractive method for energy storage, but it is a relatively new electrochemistry when compared to other rechargeable battery technologies.

CHARGING AND DISCHARGING LI-ION

Charging is accomplished in three different phases where the lithium-ion moves from the cathode material to the anode. If the battery is deeply discharged, such that the cell voltage is 2.5 V, then the charger will start out with a “trickle” charge mode, which is a low current charge rate that allows the cell voltage to rise slowly for a short period of time and then move to a “constant current” mode once the cell voltage reaches a specific voltage. The final mode is a “constant voltage” charge that allows the current to taper to a low rate before ending. The charge ends once the cell voltage and final charging current have reached the limits to prevent overcharging, which could lead to cell degradation or catastrophic failure. At this point, the capacity is 100 % and charging is terminated because the chemistry is degraded if it is left with a “float” charge, which is where the voltage is held at the maximum cell voltage indefinitely.

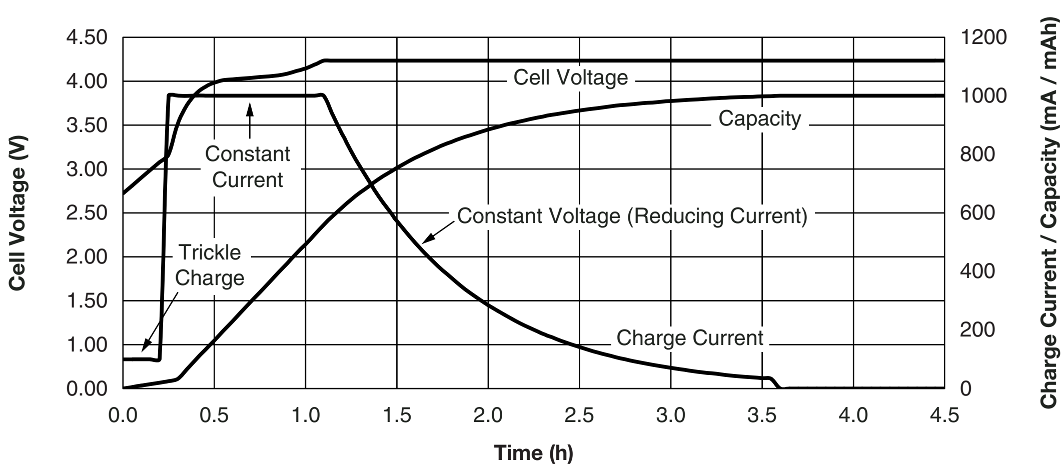

Fig. 1 - Li-Ion Charge Profile

Cell or battery capacity is determined by a cell that is fully charged to the maximum voltage and taper current and then discharged to the cut-off voltage at a specific rate, typically C/2 or C/5. A C/2 discharge rate for a 1 Ah battery would be 0.5 A for two hours until the cut-off voltage. Open circuit cell voltage is related to the remaining capacity, but it can't be easily determined during discharge because the temperature and discharge rate affect the cell voltage. If the battery's state of charge is unreliable, then a user can never be certain regarding the remaining time for operation, creating “range anxiety,” where the battery unexpectedly reaches cut-off voltage while in use. The remaining capacity, or state of charge, can be reliably determined by counting the charge entering and leaving the battery, known as coulometric or charge integration.

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STATE OF CHARGE - ASIC VS. EXTERNAL SENSE RESISTOR

Coulometric, or charge integration, can be accomplished in a variety of ways, but two of the more common methods are through the use of an application-specific integrated circuit (ASIC), or by using a resistor. The ASIC approach can save board space by using a single IC with an internal sense resistor for charge integration. This solution can be quite accurate, but it has a defined current limit and can be damaged by surge events that come from closure of a mechanical switch, battery insertion, or even short circuit. Additional circuitry may be required to handle these surge events such as a Schottky clamp diode, but these can have excessive leakage current at high temperatures that lead to a coulometric counting error. Additionally, if the objective was to reduce board space and / or cost, then the necessary additional circuitry for fault tolerance could match or exceed the original intended benefit.

The external current sense resistor provides the designer with a greater range of options than being locked in with the limits of an ASIC, allowing them to specify the characteristics and technology of the resistor that is most suited to their performance and cost requirements. The importance of resistor characteristics is probably apparent to most designers, who are very familiar with choosing the size / power rating, resistance value, and tolerance necessary.

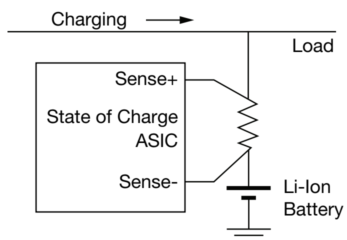
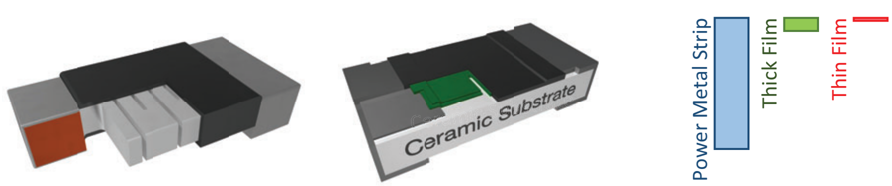


Fig. 2

However, the technology aspect of a sense resistor can be the most overlooked attribute, such as whether to use a thick film or Power Metal Strip® sense resistor. A thick film device can offer a low cost option, but the Power Metal Strip technology is going to offer the lowest TCR for resistance value, lowest resistance values, and most robust, pulse-tolerant performance that will withstand transient conditions.

POWER METAL STRIP RESISTOR TECHNOLOGY BENEFITS

Power Metal Strip technology is very different from thick film or thin film technologies because it is an all-metal welded construction that is thick enough to be self-supporting - there is no substrate. Both thin film and thick film resistor technologies require a ceramic substrate for support. Note the construction differences in the WSL and thick film cutaway illustrations below, as well as the chart that provides a relative comparison of the cross-section thicknesses of the resistor technologies.



WSL Cutaway **Thick Film Cutaway** **Cross-Section comparison**

Fig. 3

In fast electrical transients such as battery plug-in or mechanical switch closures, the pulse capability of the resistor is limited to the amount of heat energy that causes a temperature rise in the resistor element. The more massive resistor element of the Power Metal Strip device will have less temperature rise for the same pulse energy, which translates to superior pulse withstanding capability.

Unlike other manufacturers of metal element current sense resistors, Vishay laser trims the WSL to resistance value and tolerance, which enables a wide range of design options. This flexibility allows designers to specify the resistance value and tolerance that their circuits require, instead of designing their circuits to the resistance values available. Also, because it is laser trimmed, a unique value such as 21 mΩ is not a custom part, and is available with standard lead times and readily available to sample.

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The graphic below helps to illustrate how resistor parameters relate to overall performance, with the most desirable outcome having both accuracy and precision. Most designers instantly recognize that resistor tolerance specifies the accuracy and precision, but they may overlook the impact of the temperature coefficient of resistance (TCR) or power coefficient of resistance (PCR). Both TCR and PCR are temperature-related effects, where TCR is due to the ambient temperature and PCR is a result of the temperature rise or self-heating caused by the operating power.

If the designer specifies a 0.5 % tolerance, then they may expect that they have chosen Illustration 1 below. However, without considering the impact of TCR / PCR, the current measurement may have a performance similar to Illustration 2, where the measurements are tightly clustered but the influences of temperature have created an offset.

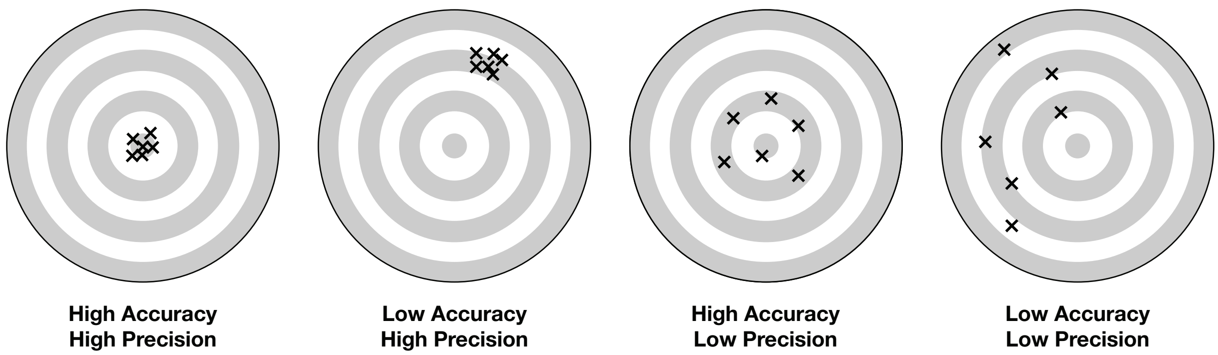

Fig. 4

There are multiple technologies available to choose from: thick film, thin film, and metal element. The graph displays a comparison of TCR vs resistance values. The thick film curve represents a range for the typical TCR values of thick film products. The Power Metal Strip curve displays a constant and low TCR value over the same comparable resistance value range. The TCR for Power Metal Strip resistors will increase, but only occurs at much lower resistance values compared to thick film. Additionally, the Kelvin or four-terminal configuration (WSK2512) of the Power Metal Strip series improves the TCR performance by reducing the influences of the welded copper terminal.

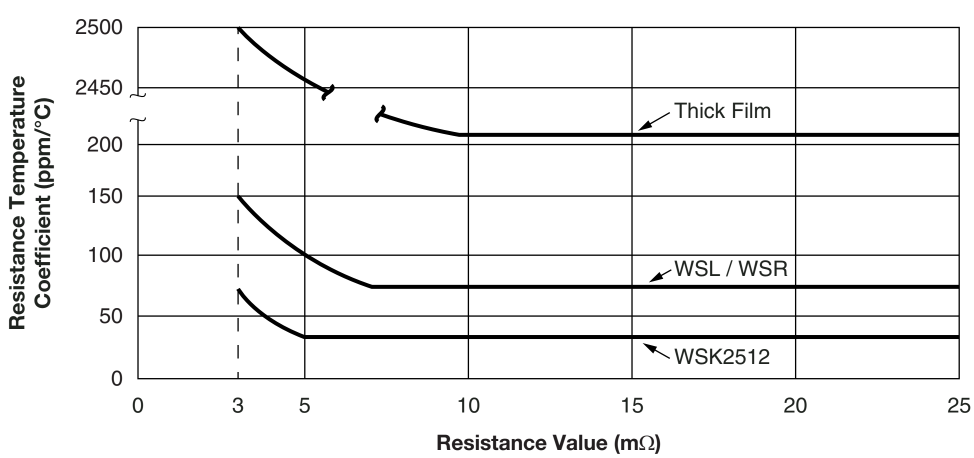

Fig. 5

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WHY CHOOSE VISHAY DALE POWER METAL STRIP CURRENT SENSE RESISTORS FOR LI-ION BATTERIES?

Vishay Dale is the global leader in designing and manufacturing the broadest range of metal element current sense resistor products that provide the greatest design flexibility and proven performance for high reliability applications. When your battery must deliver a long lifetime of energy - safely and efficiently in demanding environments - then Vishay Dale is the preferred choice as the recognized industry leader for accuracy, precision, and stability in current sense resistors.

Key advantages of Power Metal Strip technology include:

- Low resistance values (down to 0.000050 Ω)
- Low TCR (down to 35 ppm)
- Tight tolerance (down to 0.1 %)
- Stability (down to 0.25 % at 2000 h)

Configurations:

- Kelvin / 4 terminal
- Long side termination
- SMD sizes from 0603 up to 5931
- Large format shunts with integrated electronics

We offer **full spectrum support** for your design:

- 3D models, SPICE models
- Fast sampling
- Automotive-qualified products
- Qualification / reliability data packages
- Automotive PPAP documentation (AEC-Q200)
- Resistor characteristic data (TCR, inductance, temperature rise, pulse capability, etc.)
- Custom testing and screening
- Design support tools: pulse calculators, TCR, Ohms Law, etc.

RESOURCES

www.batteryuniversity.com/learn/article/charging_lithium_ion_batteries

ADDITIONAL RESOURCES

- Product Overview “Power Metal Strip Resistors”: www.vishay.com/doc?49581
- Technical Note “Components and Methods for Current Measurement”: www.vishay.com/doc?30304
- Infographic “WSL Series - Current Sense Resistors”: www.vishay.com/doc?48152

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