# Applications at a Glance

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**Authors:** Yuval Hernik
**Tel:** +972-54-3000191
**E-mail:** Yuval.Hernik@vishaypg.com

# 10 Case Studies Show How Precision Current Sense Vishay Foil Resistors Improve the Flexibility, Longevity, and Safety of Li-ion Batteries

Lithium-ion (Li-ion) batteries are well established in portable consumer electronics and now also gaining popularity in military and advanced civilian avionics, as well as space applications. In all these systems they provide higher capacity for the same size and weight than older battery chemistries; in other words, they have a much higher energy density. As their scope of applications has expanded from consumer products to satellites, land vehicles, airplanes, alternative energy, smart grids, civilian avionics, and energy grid storage, ever more stringent requirements have been placed on these batteries, especially in terms of cell safety and lifetime.

Several years ago Vishay Foil Resistors (VFR) decided to focus on developing resistive devices that would complement the growing use of lithium-ion batteries. The contribution of VFR was mainly to provide high-precision current sense Bulk Metal® Foil resistors to allow a quick and accurate evaluation of the battery life and safety. Current sensing circuits provide the data battery control circuits need to operate properly, and Bulk Metal® Foil resistors are among their fundamental building blocks. In this application, a controlling circuit monitors current flowing through a current sense resistor as a voltage drop across the resistor and directs parameter changes to ensure that optimum circuit performance is maintained.

End products may use either external discrete resistors or resistors integrated with the controller IC, but for prototype development it is always recommended to use discrete precision resistors. Figure 1 shows a common input current sense resistor configuration with the voltage measured across the discrete Bulk Metal® Foil current sense resistor in order to measure the exact current flowing into the converter unit. Sometimes you can increase power efficiency by putting the high precision current sense resistor on the input side, rather than the output side of the sensing circuit. In either case, selection of the proper current sense resistors is vital for the stability, extended battery life, and optimum performance of portable and battery operated equipment.

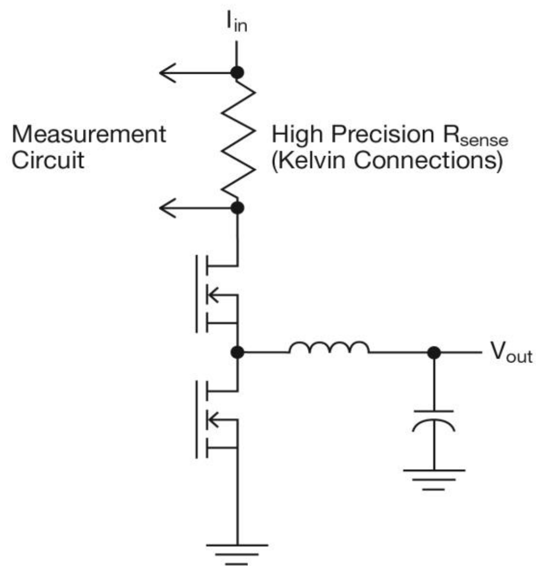



*Figure 1 Common Input Precision Current Sense Resistor Style.*

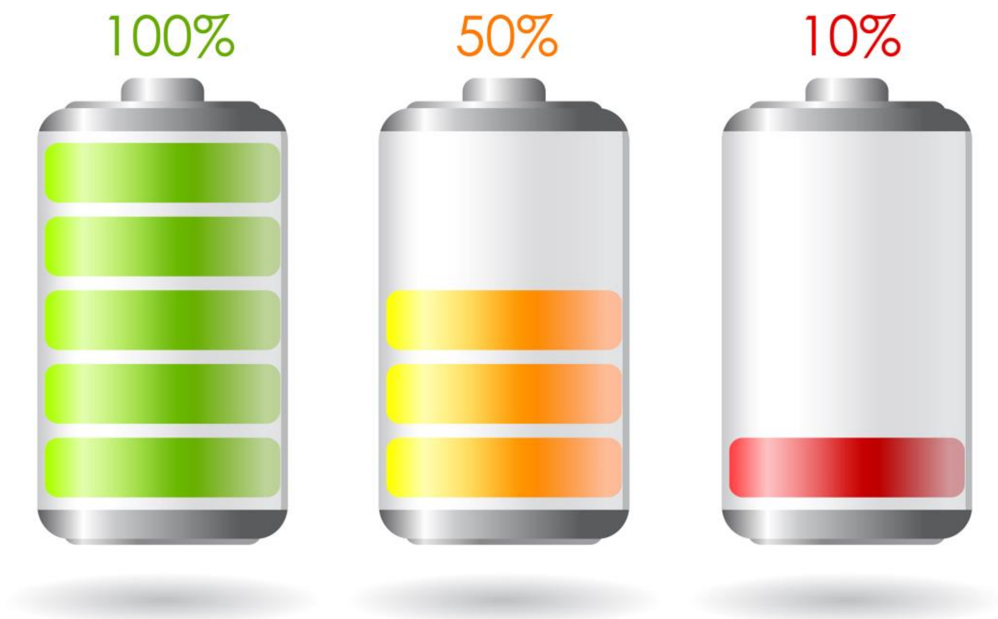
Power supplies, battery chargers, and DC/DC converters are all among the analog applications that use sensing circuits. The charging process goes through several critical phases to ensure the battery is charged to its maximum capacity while at the same time following certain safety rules to avoid explosion or fire.

Li-ion battery chargers are in fact complex and challenging circuits. They require accurate current and voltage settings and monitoring as well as a constant current and constant voltage. If these accuracy requirements are not met, the charger will fail to completely charge the battery and reduce battery life, or otherwise permanently reduce battery performance.

The Li-ion battery needs to be charged and monitored by precision current sense resistors at a known current level until it reaches its final voltage. At this point, the charger circuitry should switch over to constant voltage mode, and provide the current necessary to hold the battery at this final voltage. Thus, the charger must be capable of providing stable control loops for maintaining either current or voltage at a constant value, depending on the state of the battery.

When we work with Li-ion batteries for high grade projects, especially those where lives are at stake or battery packs are being used in remote locations, there is little room for mistakes. The main design challenge in Li-ion charge circuits is to find the optimal point between overcharging, which could result in battery failure, and undercharging by more than a certain percentage, which results in reduced capacity. Bulk Metal® Foil resistors achieve the necessary accuracy in the charge-control circuitry. In addition to the high-precision current sense resistors, the controller also has a precision voltage reference and a low-offset high-gain feedback precision amplifier. The combined errors of all these active and passive components should be less than a total error budget of ±1%.

As mentioned above, continuous accurate and stable monitoring of input and output current requires a low but very precise resistance value with low temperature sensitivity for reliable feedback to the charger IC. The need for safety was re-emphasized in the latest near-catastrophic incidents that involved the charging of Li-ion batteries. This motivated designers of sensitive applications, especially in the avionics industry, to search for more precise and reliable commercial off-the shelf (COTS) resistors with which to accurately monitor the battery voltage while connected to the charger. Bulk Metal® Foil current sense resistors with Kelvin connections, low TCR, and low thermal EMF, such as the VCS1625Z (Z-Foil), VCS1610Z (Z-Foil), and the CSM Series, provide the accuracy and stability required for the complete charging cycles of lithium-ion batteries.




Under certain uncontrolled conditions such as extreme current charging or discharging, Li-ion cells can be dangerous and may explode or overheat if provisions are not made for their proper use. One of the main concerns with excessive discharge is the possibility that the cells inside the battery might short-circuit, a permanent, irreversible event. Overcharging can also be critical because it can destroy each cell by overheating, resulting in additional catastrophic events.

A Li-ion battery can be fabricated by connecting two or more cells in series. In most of the high-grade applications, the battery may be charged and discharged for hundreds and thousands of cycles. As this occurs, it may have a different impact on each of the cells. The cells may become mismatched. If this phenomenon is not corrected with precision analog circuitry, one or more cells may become undercharged or overcharged, either of which can lead to failure of the batteries and the overall system in which they are being used. Designers need to keep this in mind when considering the overall long-term costs of a system, and the consequences of attempting to save on up-front assembly costs.

**Bulk Metal® Foil Main Features:**

- Temperature coefficient of resistance (TCR) for Z-Foil technology:
  ±0.05 ppm/° C typical (0°C to +60°C, +25°C ref.)
  ±0.2 ppm/°C typical (-55°C to +125°C, +25°C ref.)
- Power coefficient of resistance for Z-Foil technology (Power TCR)
  "ΔR due to self-heating": ±5 ppm at rated power
- Load life stability: to ±0.005% (50 ppm) at +70°C, 10,000 hours at rated power
- Resistance tolerance: to ±0.001% (10 ppm)
- Electrostatic discharge (ESD) at least to 25 kV
- Thermal stabilization time <1 sec (within 10 ppm of steady state value)
- Thermal EMF: 0.05 µV/°C
- Not restricted to standard values; specific "as required" values can be supplied at no extra cost or delivery (e.g., 1K2345 vs. 1K)

**Characteristics of Different Types of Resistors for Lithium-Ion Battery Circuits**

| Technology | Temperature Coefficient of Resistance (TCR) –55°C to +125°C, +25°C ref. | Initial Tolerance | End of Life Tolerance | Load Life Stability at +70°C, Rated Power 2000 Hours and 10,000 Hours | ESD (V) | Thermal Stabilization | Noise (dB) |
|---|---|---|---|---|---|---|---|
| **Bulk Metal® Foil** | **±0.2 ppm/°C** | **From 0.001%** | **<0.05%** | **0.005% (50 ppm) 0.01% (100 ppm)** | **25,000** | **<1 second** | **–42** |
| High-Precision Thin Film | ±5 ppm/°C | From 0.05% | <0.4% | 0.05% (500 ppm) 0.15% (1500 ppm) | 2500 | >few minutes | –20 |
| Precision Thick Film | ±50 ppm/°C | From 0.5% | <5% | 0.5% (5000 ppm) 2% (20,000 ppm) | 2000 | >few minutes | +20 |
| Wirewound | ±3 ppm/°C | From 0.005% | <0.5% | 0.05% (500 ppm) 0.15% (1500 ppm) | 25,000 | >few minutes | –35 |

**Case Studies**

#1

The PRND hermetically sealed foil resistor network was designed into the new lithium-ion battery cell monitoring system for the International Space Station power system upgrade. The Bulk Metal Foil network contains 13 resistors with different values which precisely monitor each cell's voltage and current during charging/discharging .The device's tight ratio matching and long term stability are critical to maximizing the battery's capacity and life.
Datasheet: http://www.vishaypg.com/ppg?63228

#2

For a space mission, battery charging needed to be controlled much more precisely to ensure that the lithium-ion cells would last as long as 15 years. The design engineer chose to use the VCS1625ZP (Z-Foil Technology) for a control circuit that monitors current flowing through a sense resistor as a voltage drop across the resistor and directs parameter changes to ensure that optimum circuit performance is maintained.

Datasheet: http://www.vishaypg.com/ppg?63155


#3

The design engineer needed a switched power supply to increase or decrease the battery supply voltage. A switching regulator circuit was used, a method that can either increase or decrease the supply voltage. The IC controller requires the use of a Bulk Metal Foil current sense resistor such as the CSM3637.

Datasheet: http://www.vishaypg.com/ppg?63089

#4

The VCS331Z (Z-Foil) power current sense Bulk Metal Foil resistors are used for battery performance evaluation tester for an alternative energy in Germany.

Datasheet: http://www.vishaypg.com/ppg?63240

#5

Since the charging process for Li-ion batteries can take a few hours, testing a Li-ion battery charger using its normal load is time-consuming and inconvenient. New generation current sense resistors and the VCS1610Z miniature current sense resistors with Z-Foil technology are used in a control circuit for simulating the behavior of a Li-ion battery, thus providing a more convenient method for testing Li-ion battery chargers than using real batteries.

Datasheets:
http://www.vishaypg.com/ppg?63226
http://www.vishaypg.com/ppg?63240


#6

New current sense Bulk Metal Foil resistors have been used for current monitoring during the final "charge and discharge" test process after manufacturing of Li-ion batteries for automotive, PC, and smartphone applications. The charge current is sensed via the voltage developed across an external precision sense resistor. The sense resistor must be placed between the supply voltage ($V_{IN}$) and the source of the external pass transistor. The current sense resistor handles a fast charge current of 1 A to 20 A or higher, typically.

Datasheets:
PSB series for 20 A – 200 A (automotive) www.vishaypg.com/ppg?63227
RB series for 1 A – 10 A class (PC, smartphone) http://www.vishaypg.com/ppg?63238

#7

In a step-down DC/DC converter circuit using an IC, the Bulk Metal Foil current sense resistor develops a small voltage across it, which is related to the current flowing through it. In this case, the current sense resistor is useful for regulating the current supplied to the device. The engineer is using a VHP3 style precision resistor.

Datasheet: http://www.vishaypg.com/ppg?63005

#8

The drive behind this project was to develop a battery with more features and less frequent re-charging, using the higher energy density of a lithium-ion battery. This project uses a charger controller IC that regulates the current and voltage with higher resolution. A typical charging current is 500 mA, so a 200 mΩ VCS1625P 1% Bulk Metal Foil resistor is used to provide a 100 mV signal with low power dissipation.

Datasheet: http://www.vishaypg.com/ppg?63155

Movie: Solar Energy: http://www.vishaypg.com/foil-resistors/videos/?video=34

#9

An aircraft designer uses a linear lithium-ion (Li−ion) battery charge controller to provide the required control functions for charging Li−ion batteries precisely and safely. It features the constant current and constant voltage method (CCCV) of charging. The charging current can be measured with the VCS331Z high-precision current sense foil resistor. The charge controller provides a constant current, constant voltage (CCCV) to the lithium-ion batteries used in the aircraft. The external Bulk Metal Foil sense resistor enables controlling both the full charging current and 10% of the full charge current. The voltage is regulated at 1% during the final charge stage. There is virtually zero drain on the battery when the input power is removed.

Datasheet: http://www.vishaypg.com/ppg?63240

#10

An alternative energy-harvesting-based system needs to be able to store energy when the energy cannot be harvested. The design engineer developed a modern and reliable series of rechargeable batteries. The main goal is to develop a battery management circuit enabling the best possible measurement of the “state-of-charge” (SOC) of the battery cells. The characteristics of Li-ion cells complicate SOC measurement, so precise ICs and precision current sense resistors with improved stability and low thermal EMF were selected to extend battery lifetime, with the final design using six such resistors.

Datasheet: http://www.vishaypg.com/ppg?63240

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