Technical Article

How integrated resistor dividers improve EV battery system performance

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In modern electric vehicles (EVs) and hybrid electric vehicles (HEVs), the battery management system (BMS) serves as the brain of the battery pack, responsible for ensuring battery performance, safety and longevity. The BMS monitors parameters such as state of charge, which provides insight into the remaining energy available, and state of health, which assesses the overall condition and aging of the battery cells. These metrics help maintain efficient energy usage and delay premature battery degradation.

In order to meet regulations around battery efficiency and environmental sustainability, automakers must maintain high levels of battery health throughout a vehicle's life. For example, the California Air Resources Board introduced standards mandating that EVs maintain at least 80% of their electric range for 10 years or 150,000 miles by model year 2030. This is a culmination of lesser requirements set to take effect as early as model year 2026, with stipulations to continue tightening the regulation following model year 2031. Similar standards have already taken effect around the world, necessitating more advanced and integrated solutions within the BMS to improve sensing accuracy. In this article, I'll show how integrated high-voltage resistor dividers can offer a more precise and space-efficient approach to voltage attenuation compared to discrete resistor chains, enabling the BMS to better balance the battery pack and improve its lifetime.

Figure 1 illustrates the battery cells and battery management system inside of an EV.

Figure 1. ≥400V EV batteries are attenuated by resistor dividers to interface with the rest of the BMS

Application basics

The typical EV battery voltage is ≥400V, with the industry trending toward higher voltages of 1kV or more. Higher voltage batteries help reduce the maximum current requirements and maximize efficiency. Measuring this voltage and communicating it to relevant vehicle systems requires signal conversion with an analog-to-digital converter (ADC), which is typically powered by a voltage around 5V. ADCs cannot accept an input signal greater than that voltage.

Protecting the ADC and other low-voltage components from the relatively large voltage of the battery requires a device such as an isolated amplifier to maintain a barrier between the high- and low-voltage domains. Despite being a bridge between two voltage domains, isolated amplifiers can only accept a voltage range similar to the ADC, necessitating attenuation of the battery voltage before reaching the isolated amplifier. A resistor divider is commonly used for this purpose, reducing the high-voltage signal into a lower-voltage full-scale range.

Figure 2 is a circuit diagram for DC bus measurement designed using long strings of resistors in order attenuate the battery voltage to an acceptable level.

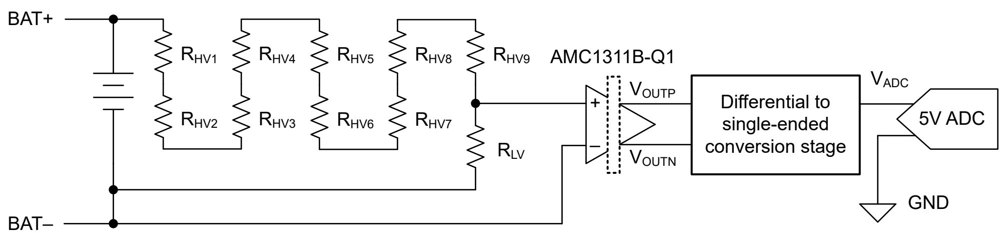

Figure 2. Circuit for battery voltage measurement using a discrete resistor ladder

Disadvantages of discrete resistor chains

When dealing with voltages greater than 400V, you must consider creepage and clearance distances in order to prevent electrical arcing and ensure safe insulation. Although a traditional resistor divider requires only two resistors, it is for creepage and clearance that high-voltage attenuation often features long chains of resistors to increase the physical distance between a high- and low-voltage node. Per IEC 60115-8, the maximum sustained voltage drop across each resistor is limited; typically, 200V for each 1206-case-size surface-mount resistor and 150V for each 0805-case-size resistor.

This design method does include some drawbacks. Even with precision resistors, variations in the inherent tolerance of each discrete resistor can lead to significant discrepancies in the voltage division ratio, resulting in inaccurate voltage measurements. Discrete resistors are also susceptible to changes in resistance from temperature variations and aging. The solder points on either end of such resistors are also exposed, potentially resulting in additional leakage and parasitic capacitance or inductance unless you incorporate a conformal coating or other protection, which increases solution costs.

In a long chain of discrete resistors these effects can compound, further degrading voltage-sensing accuracy over time; causing state-of-charge and state-of-health estimation errors leading to suboptimal battery-management decisions such as incorrect charging and discharging cycles; and ultimately shortening battery life and weakening the EV’s range.

Advantages of integration

The wide-body SOIC package of the RES60A-Q1 integrated resistor divider is specifically designed to meet the creepage and clearance standards defined by the International Electrotechnical Commission 61010 standard, handling voltages up to 1.7kV.

This device provides significant advantages in terms of performance and reliability. Specified maximum limits for initial ratio and over-time tolerance help ensure that the voltage-division ratio remains accurate, despite the effects of aging or environmental changes such as temperature shifts. This reliability is important for applications where consistent performance is a priority.

The integrated circuit-packaged design eliminates the need for lengthy chains of discrete resistors, reducing the required printed circuit board footprint. This consolidation not only simplifies circuit layout but reduces assembly costs. Fewer exposed nodes reduce the likelihood of errors from leakage or parasitics, eliminating the need for conformal coating and also potentially reducing costs.

Figure 3 is a circuit diagram for DC bus measurement in which the RES60A-Q1, RES11A-Q1 and AMC1311B-Q1 provide a way to measure the voltage that crosses the isolation barrier and achieve a full-scale range error <1%.

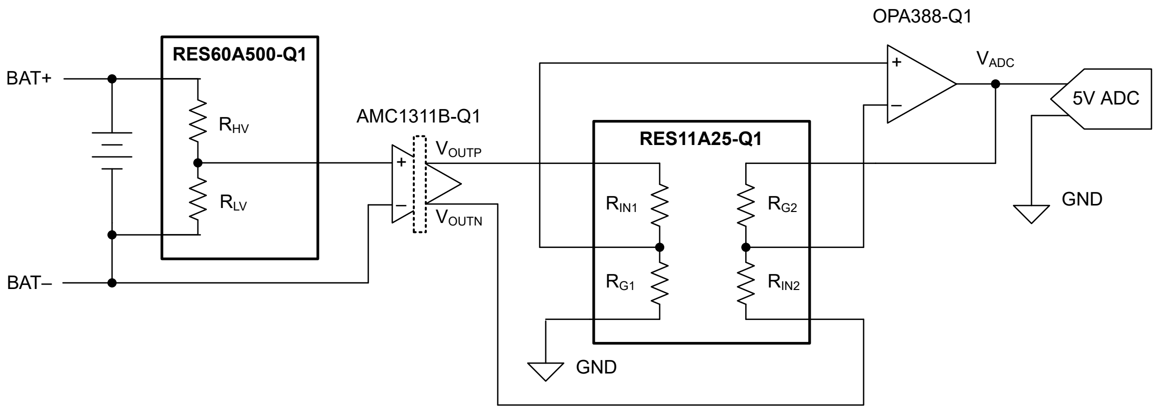

Figure 3. Circuit for battery voltage measurement featuring the RES60A-Q1, RES11A-Q1 and AMC1311B-Q1

Differential- to signal-ended conversion

Isolated amplifiers such as TI's AMC1311B-Q1 with differential outputs are popular because differential outputs are ideal for carrying signals across longer distances, and designers will often place their low-voltage components away from high-voltage sources for safety reasons. Feeding this signal into a single-ended ADC requires differential to single-ended conversion through the addition of an integrated difference amplifier or four discrete resistors configured around an amplifier (see Figure 3).

For the same reasons that a discrete resistor divider can introduce error during attenuation, individual resistors can also introduce ratio drift in a discrete difference amplifier implementation. Combining an integrated resistor such as the RES11A-Q1 with a high-precision amplifier such as the OPA388-Q1 can produce a difference amplifier with a high common-mode rejection ratio, which can help reduce noise and other errors.

Conclusion

Transitioning from discrete resistor chains to a solution such as the RES60A-Q1 offers numerous advantages when designing high-voltage attenuation circuits for a BMS. When coupled with complementary components such as the RES11A-Q1 for differential signal conversion, these integrated devices can help EVs maintain battery health over extended periods.

Additional resources

- See the RES60A-Q1 data sheet.
- Read the application note, "Optimizing CMRR in Differential Amplifier Circuits With Precision Matched Resistor Divider Pairs."
- Order the evaluation module (RES60EVM) on TI.com and get started today.

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