Application Note

Using Integrated Designs to Optimize High-Voltage Measurement

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ABSTRACT

As the electric vehicle market trends towards batteries with higher voltages and lower volumes, optimizing the design of high voltage measurement circuits must be considered. Current discrete designs take up large areas, have significant lifetime/temperature drift in precision, and suffer from lower accuracy as a result of exposed node contamination/parasitic leakage. However, using an integrated design for high voltage measurement helps remedy these problems, improving on safety, size, and reliability.

This application note highlights the differences between discrete and integrated designs for high voltage measurement in battery management systems and discusses how the TPS4141-Q1 and RES60A-Q1 can be used in such applications.

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1 Introduction

The growing electric vehicle (EV) market and trends towards higher voltage, smaller battery packs with increased power density, necessitates a safer, more reliable, design for High Voltage (HV) measurement. The increasing number of HV measurement sockets in modern Battery Management Systems (BMS) warrants the need for an alternative to current discrete designs because of the large size, reliability problems associated with exposed nodes, and high part count. Compared to existing discrete resistor divider designs for HV measurement, TI's cutting-edge integrated HV divider technology results in a smaller design with a precise resistor ratio and longer lifetime, all while achieving cost parity. Additionally, modern BMS requirements for improved quality and control are addressed with a smaller part count, eliminating complicated Bill of Materials (BOMs) and saving time during development, especially between EV platforms. The TPS4141-Q1 or RES60A-Q1 are fit to deliver all the advantages of an integrated design compared to legacy discrete designs in the areas of **Scalability, Safety, and Reliability.**

2 HV Measurement

HV measurement is used to measure high-voltages at numerous places in a BMS as shown in Figure 2-1. This is not exhaustive, as HV measurements are needed at various points to safeguard essential components of the BMS.

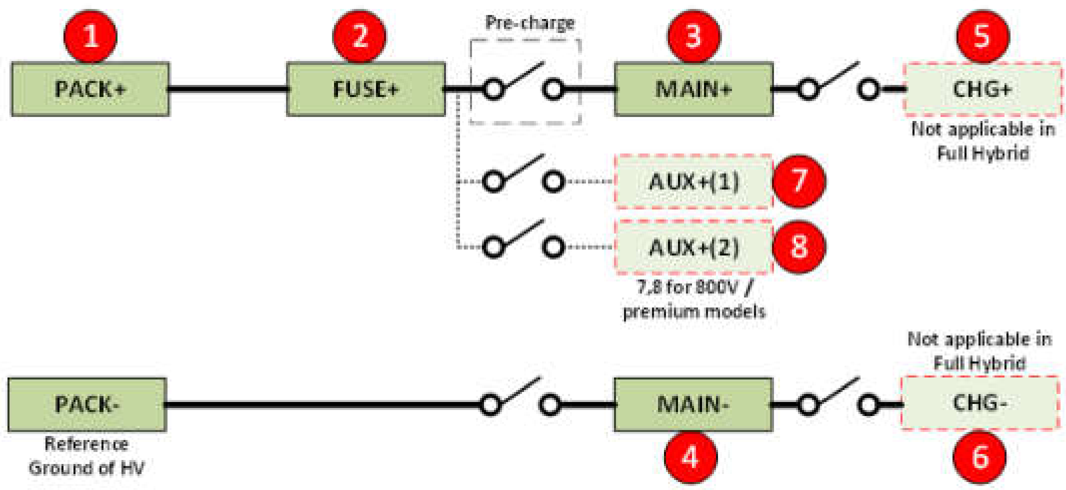

Figure 2-1. High Voltage Measurement Points in a BMS

To accurately perform HV measurements, an analog-to-digital converter (ADC) is necessary to sample and communicate the resulting voltage to the rest of the system. However, the input to an ADC must usually not exceed 5V. To achieve this, resistor dividers are commonly used to reduce the high-voltage signal into a proportionally lower voltage. The range of this low-voltage signal is determined by the ratio of the resistor values and the high-voltage input ranges to be supported. Once the low-voltage signal is acquired and the resistor ratio is known, this is easy to calculate the high-voltage input.

2.1 Safety

HV measurements must be accurate to make sure battery levels and associated voltages across HV links are correctly known, since these values inform the charging and discharging cycles. Incorrect cycles reduce the lifetime of the battery, and therefore the range of the EV. In the event of dangerous voltage levels, the measurements become critical to safety. This is especially important considering the trending of EV battery packs towards higher voltages.

2.2 Reliability

HV measurement must continue to be accurate, even after multiple charge/discharge cycles over the lifetime of the vehicle and usage profiles. Reliability of the design directly impacts the lifetime of the battery, making vulnerability to error crucial. The design must be sufficiently resistant to extraneous stresses like temperature, humidity, and contamination.

2.3 Scalability/Size

As EVs trend towards smaller, lighter systems to support larger ranges, system components must scale down. PCB area and weight are relevant considerations. Sub-circuits – including HV measurement designs – are expected to follow suit. A smaller footprint not only addresses this concern, but also saves cost via board space reduction, adds flexibility to PCB design, and encourages the use of more measurement units.

2.4 The Problem with Discrete Designs

Current BMS HV monitoring designs use discrete implementations of the voltage divider circuit – resistors, switches, and op amps are individually soldered onto the PCB. However, these designs have a handful of issues.

Due to creepage and clearance requirements, these resistor chains can become quite long to put a sufficient physical distance between the high-voltage node and low-voltage node. This takes up more space on the board. Since the resistors are not all of the same type, they have different tolerances and can demonstrate significant temperature/lifetime drift, lowering ratio precision. In addition, exposed nodes of the discrete components provide a potential source of leakage or parasitic capacitance or inductance that can reduce the accuracy of the overall measurement. Vulnerability of the nodes to contamination can also harm precision or shorten the lifespan of the parts. The price associated with discrete designs must account for the cost of resistors, switches, and op amps (voltage buffers) as well as cost of board space and assembly expenses. This compounds with each HV measurement unit, increasing overall cost and BOM complexity.

2.5 Integrated Designs

Integrating a HV measurement design – putting the voltage divider, switch, and buffer in a single package – resolves pitfalls of the discrete design.

An integrated design reduces the footprint significantly since creepage and clearance requirements are met without the need for multiple, spaced out resistors. This provides more flexibility on the PCB, reduces costs associated with space, and accommodates scaling trends. Removing the need for multiple discrete components also simplifies the BOM and makes this easier to add more HV measurement units to a system.

Placing all components in a single package also removes exposed nodes associated with the discrete design. This practically eliminates contamination and the effects on accuracy as a concern. The potential for leakage and inductive or capacitive parasitics minimized and the components are protected from external conditions such as humidity.

Some external factors, like temperature, can be less impactful to the precision of the measurement since gradients concentrated over a smaller area can demonstrate less variation from resistor to resistor. Precise resistor *ratios* are more important to voltage divider accuracy than precise resistor *values*, so such effects are negligible compared to the discrete design.

2.6 TPS4141-Q1

One example of an integrated design for HV measurement is the TPS4141-Q1, shown in Figure 2-2, which is capable of voltage sensing up to ± 1200V and includes resistors, a switch, and a programmable gain amplifier (PGA) all in a single package.

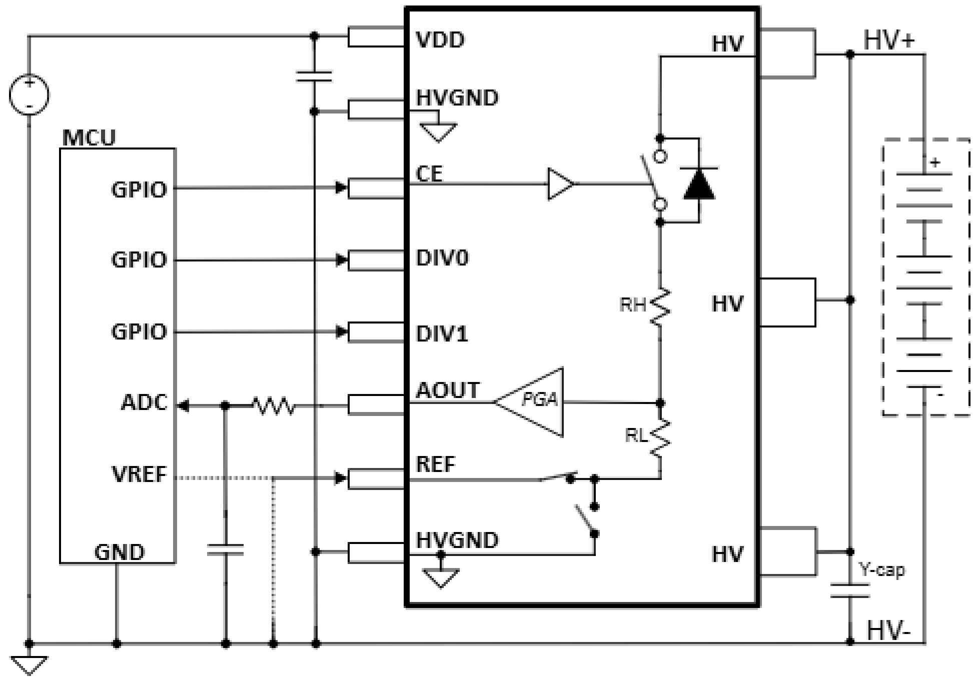

Figure 2-2. TPS4141-Q1 Simplified Application Schematic

The TPS4141-Q1 has 30MΩ of total resistance from the precision matched divider. The resistors meet creepage and clearance requirements within the package and take up less area than discrete counterparts.

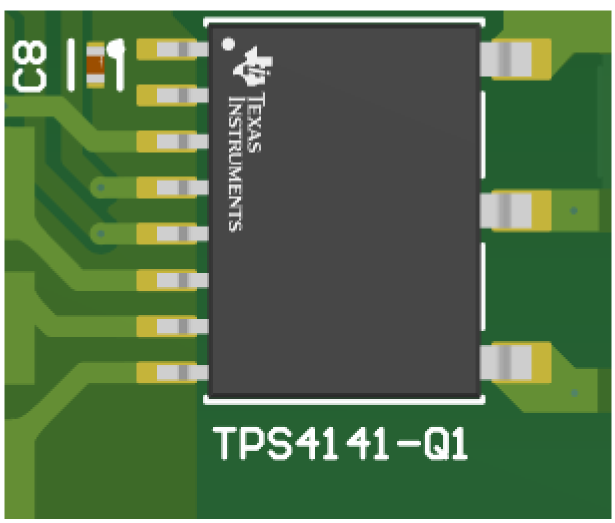

Figure 2-3. Size Comparison of Discrete Designs

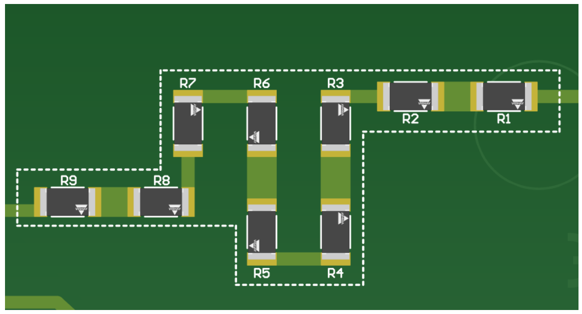

Figure 2-4. Size Comparison Of Discrete Integrated Designs

Figure 2-3 and Figure 2-4 illustrates the reduction in board space, showing a discrete design using resistor ladders on the left and the TPS4141-Q1 on the right. The TPS4141-Q1 takes up 180mm^2, demonstrating a >60% decrease in area compared to the 488mm^2 taken up in the discrete design (even excluding switches or buffers). This offers more flexibility in the design and accommodates scaling trends in the EV market.

The resistor ratio is precisely designed for high accuracy – all the resistors are made of the same material and are deposited at the same time. This contributes to excellent ratio matching and practically non-existent temperature/lifetime drift. Integration into a single, small package further protects the ratio precision by providing shielding from contamination and spatially-distributed environmental factors like humidity and temperature. Additionally, high impedance nodes are not exposed as the nodes are in the discrete design, so leakage and parasitics are not of great concern.

A switch in series with the resistor network is also present within the package. Not only does this offer more robust control, the FET reduces leakage current when measurements are not being performed, enabling lower power consumption. Just as well, this adds a layer of protection in the case of fault conditions. This is increasingly important as EV batteries trend towards higher voltages for faster charging.

Table 2-1. Divider Ratio Settings

VREF	DIV<1:0>	Divider Ratio
0V	00	160
	01	320
	10	640
	11	1000

The integrated programmable-gain amplifier (PGA) supports four divider ratios to match the full-scale input voltage of the analog-to-digital converter. The divider ratios can be set and changed dynamically using DIV0 and DIV1 inputs. This saves development time as each HV measurement circuit in the BMS does not need to be designed from scratch, but rather can be changed spontaneously. This also enhances flexibility of the design, allowing this to interface with a host of analog-to-digital converters without sacrificing resolution. Such simplicity and versatility make this easier to develop BMS across EV platforms.

The TPS4141-Q1 also supports bi-directional voltage measurement by supplying an external precision voltage to REF. This allows the product to measure both positive and negative voltages with respect to HVGND. In combination with the dynamically adjustable divider ratio, the TPS4141-Q1 optimizes the AOUT output swing over the full voltage range present on HV, improving accuracy.

Integration of the resistors, switch, and PGA — in conjunction with control offered by the DIV0, DIV1, and REF pins — maximizes performance in the smallest area possible. Compared to the discrete design, saving cost on components, assembly, and board space. Discrete designs can also have extra costs associated with safety measures to counter issues non-experienced by the integrated design, like the coating of exposed nodes.

2.7 RES60A-Q1

If a system does not require the added safety of a switch and does not greatly benefit from the PGA, another integrated option is the RES60A-Q1.

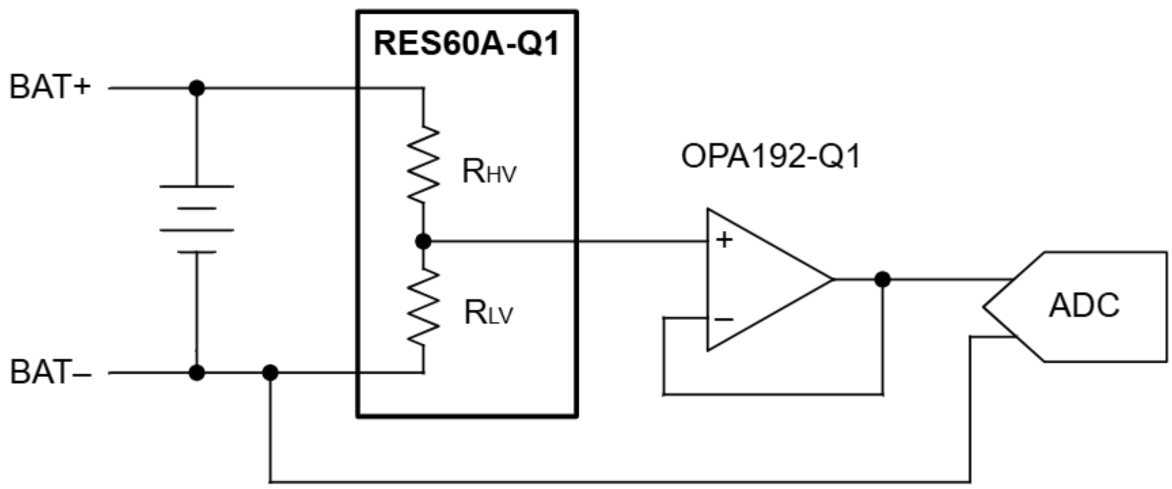

Figure 2-5. RES60A-Q1 Typical Schematic

The RES60A-Q1, shown in Figure 4, consists of high-precision matched resistors for HV measurement. The device has an input resistance of 12.5MΩ and is capable of sustained sensing of 1400VDC. Much like the TPS4141-Q1, this also saves on space, has excellent ratio matching with minimal temperature/lifetime drift, and is more resilient to contamination when compared with a discrete design.

The RES60A-Q1 is a safe, reliable, and scalable design if no other components (switches, PGAs) are required.

3 Summary

The growing EV market and trends towards higher voltage, lower volume batteries necessitate a safer, more reliable, and scalable design for HV measurement. Current discrete designs fall short of a design because of the size, problems associated with exposed nodes, and more involved BOMs. Integrating the voltage divider results in a smaller design with a more precise resistor ratio and longer lifetime. Depending on whether the system requires extra protection and control, either the TPS4141-Q1 or RES60A-Q1 are fit to deliver all the advantages of an integrated design.

4 References

1. Texas Instruments, *How integrated resistor dividers improve EV battery system performance*, technical article

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