

bq29330 External Short-Circuit Protection

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Battery Management

ABSTRACT

In Li-ion battery pack design, short-circuit protection should be given sufficient emphasis to ensure that even if an external pack short does occur it is benign. Properly designed battery fuel gauge solutions using the bq29330 analog front-end protector (AFE) and bq20z90, bq20z70, bq20z95, or bq20z75 fuel gauge ICs not only safeguards the battery, but also ensures a full recovery of functionality from such an event.

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1 Introduction

The scope of external short circuit may cover the following situations.

1. The presence of an accidental short across the Pack+ and Pack– terminals of the battery pack.
2. A battery pack is inserted into the system. When the protection MOSFETs are turned on, at system-present detection, the system’s large input capacitor is charged by the battery. The inrush current causes a brief, high rate of discharge that exceeds the short-circuit protection threshold.
3. An overload that exceeds the short-circuit protection threshold.
4. A DC battery charger is connected to the pack with its polarity mistakenly reversed.

The design of the battery pack electronics is such that even if an external pack short does occur it is benign – the pack may be temporarily or permanently disabled, but would not start a fire. Some users require that the pack fully recover from such an event when the short is removed. This application report details how the short-circuit protection works in bq29330 Li-ion battery protector and how to address some of the troubling issues involved.

2 Operation of Short-Circuit Protection

A typical battery pack designed with bq29330 fuel gauges contains up to four-series Li-ion cells and the battery management unit (BMU). The BMU is comprised of an AFE, the bq29330 that controls a pair of back-to-back connected MOSFETs, a small microprocessor—the fuel gauge IC, and optionally, a secondary voltage protector IC. Protection of the short circuit is implemented by the AFE hardware rather than the gauge software, primarily because the firmware cannot handle this type of failure fast enough, which can cause harsh consequences if the current is not cut off quickly. The current-sensing comparator in the AFE is much faster for this type of protection.

The MOSFETs used with the bq20z70/z75/z90/z95 fuel gauges and the bq29330 AFE are of N-channel type. [Figure 1](#) shows a portion of the gas gauge application circuit that includes the bq29330 AFE, the N-channel protection FETs, the cells, and the sense resistor R_s . Because of the use of N-FETs at the most positive battery connection side, charge pumps are required to generate a voltage above the battery stack voltage in order to turn on the N-FETs. In normal operation, the FETs are all closed. When Pack+ is shorted to Pack–, a great amount of current is flowing in a loop formed by the cell stack, the charge and discharge FETs, Pack± terminals, and R_s . When the negative voltage appearing at the SRP pin of the AFE exceeds the programmed level, short-circuit protection is activated. A short-circuit delay timer (programmable from 0 μ s to 915 μ s) starts ticking, the DSG charge pump is halted, and the DSG pin is in high impedance. When the timer times out, the chip logic commands the discharge FET to switch off by shutting down the charge pumps and discharge the FET drive outputs through SWDL. Once the current is cut off, the discharge FET remains off until the fuel gauge commands the AFE to turn on the discharge FET again.

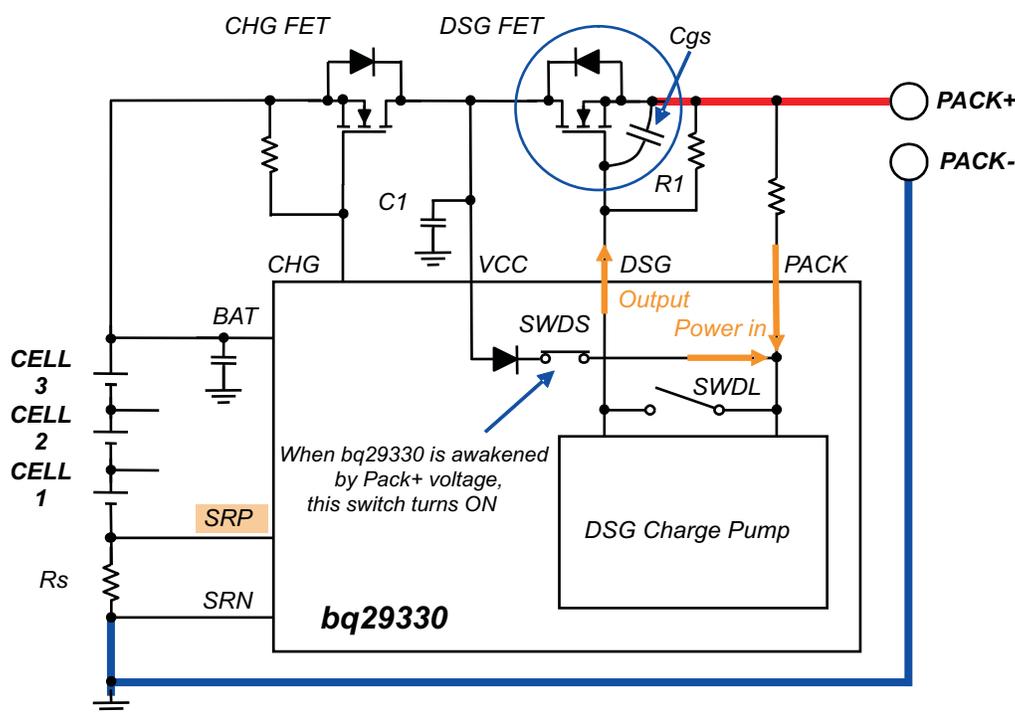


Figure 1. Principle of Protecting DSG FET During Short Circuits

2.1 Possible Pitfalls and the Workaround

2.1.1 Excessive Negative Voltage at the AFE SRP Input

During discharge (a short circuit is regarded as a discharge at a very high-current level), the voltage at the AFE's SRP pin is negative because SRN is the ground ([Figure 1](#)). The negative voltage at SRP pin is a function of the number of paralleled cells, the value of the sense resistor, and the value of the short-circuit

resistance between Pack+ and Pack-. Just like every IC pin, there is a parasitic, normally reverse-biased diode between the substrate (anode) and the AFE SRP pin (cathode). A parasitic current, known as substrate current, occurs when this diode becomes forward-biased. When the negative voltage at SRP exceeds -0.5 V during a short circuit, the resulting unwanted substrate current can disrupt the normal operation of the AFE.

In order to protect the AFE from excessive negative voltage at the SRP pin during short circuits, an appropriate sense resistor must be chosen. From a battery fuel-gauging accuracy point of view, the sense resistor should be chosen to have a maximum allowable value because accurate fuel gauging requires precision measurement of the battery current with a large dynamic range. Not only should the fuel gauge be capable of measuring normal application discharge current (a few amperes) with accuracy, but also small standby current of the system, which could be a few milliamperes. Too small a sense resistor value would equivalently amplify the offset error at such low currents. On the other hand, for the sake of limiting the negative voltage at the SRP pin, the smallest possible sense resistor values should be used. The following sense resistor values are recommended for notebook Li-ion battery applications: For 1-parallel (1p) design, a maximum recommended R_s is $20\text{ m}\Omega$; and for 2p-cell (two cells in parallel) design, a maximum value of $10\text{ m}\Omega$ is recommended. For 3p-cell or higher, a maximum of $5\text{ m}\Omega$ is recommended in order to limit negative voltage at the SRP pin. [Table 1](#) summarizes these recommendations.

Table 1. Recommended Sense Resistor Setting

No. of Parallel Cells	1-p	2-p	3-p and Higher
R_{sense}	10~20 $\text{m}\Omega$	5~10 $\text{m}\Omega$	5 $\text{m}\Omega$

In some applications with 3-p and even higher power, even $5\text{ m}\Omega$ is still too large for the AFE to function properly in a short-circuit situation. However, reducing the value of R_s further degrades gas-gauging accuracy. What can be done to achieve a balance between fuel-gauging accuracy and short-circuit protection? A few options follow:

1. Use a Schottky diode to limit the maximum voltage drop across AFE's SRP and SRN, so that the parasitic diode is not forward-biased even when the pack terminals are shorted.

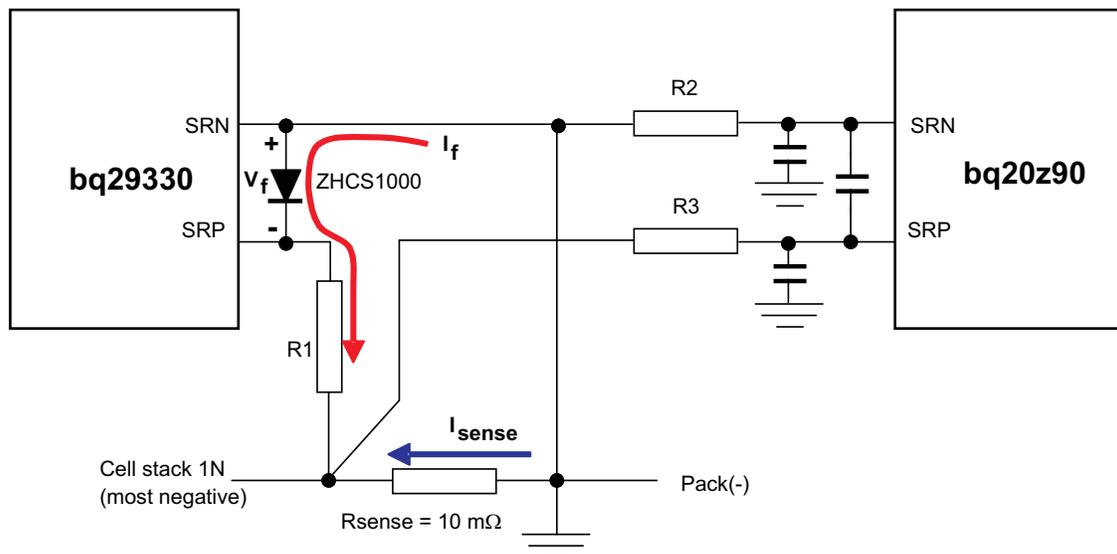


Figure 2. Use Schottky Diode and Resistor to Limit Negative Voltage at SRP

For example, if R_1 ([Figure 2](#)) is chosen to be $1\ \Omega$, and the Schottky diode is chosen to be ZHCS1000, and the desired short-circuit trip current is 60 A across a $10\text{-m}\Omega$ sense resistor, then a load curve can be drawn in overlay with the $I_f - V_f$ curve of the diode ([Figure 3](#)). The load curve is described by the equation:

$$V_f = R_{\text{sense}} \times I_{\text{sense}} - I_f \times R_1$$

Where V_f is the forward voltage drop of the diode, and I_f is the current passing through the diode when it is forward-biased.

The intersection of the load curve with the diode curve is the operating point when the short circuit occurs, at which point the Schottky diode is forward-biased. It is obvious that temperature has a strong effect on the voltage that appears at the SRP pin (SRN is connected to ground). At the desired short-circuit triggering point of 60 A, voltage drop across the sense resistor is 0.6 V, and the voltage drop of the diode is 0.32 V, 0.23 V, and 0.14 V at -55°C , 25°C , and 125°C , respectively. Because only one register value can be configured for the bq29330's short circuit in discharge (SCD) threshold, the lowest value, 0.14 V, must be chosen (point A). This leads to a conservative design because at room temperature, for example, once current goes above 18 A, the diode is forward-biased and triggers the short-circuit protection. Furthermore, setting the lower level overload protection has to go through the same exercise. So, the conclusion is that the highly nonlinear I_f - V_f behavior of the Schottky diode does not offer a practical solution.

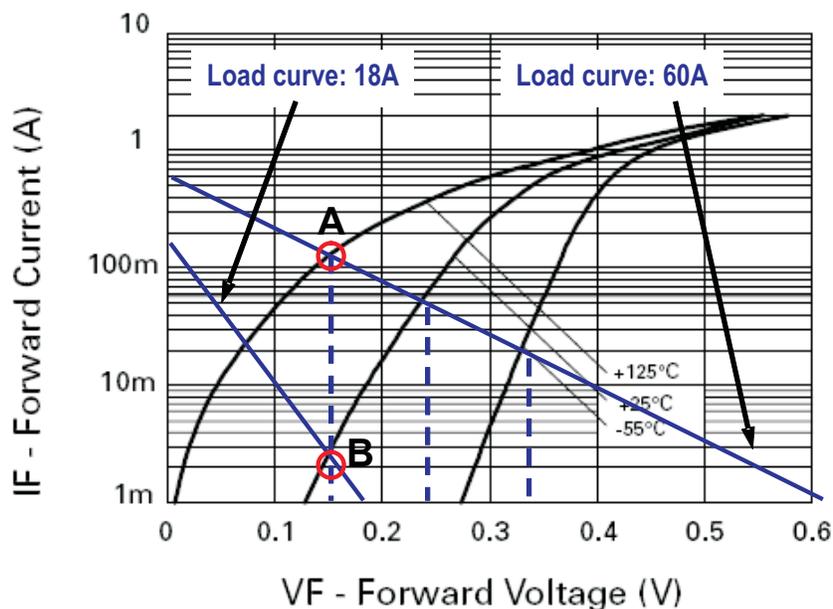


Figure 3. Load Curve When $R_1 = 1\ \Omega$ and Short-Circuit Current Is 60 A

2. Use a resistor divider between AFE's SRP and SRN pins

A better solution to limit the negative voltage at SRP pin is to use a resistor divider to create a voltage that is proportional to the actual voltage drop across the sense resistor. The SRP and SRN pin of the bq29330 can be modeled as two current sources as indicated in Figure 4. Because of the out-flowing current, the resistor divider R_1 and R_2 should not be excessively large to ensure linearity. The advantage of this solution is that temperature effects can be effectively canceled because both R_1 and R_2 should have similar temperature coefficients so that the divider ratio remains fixed.

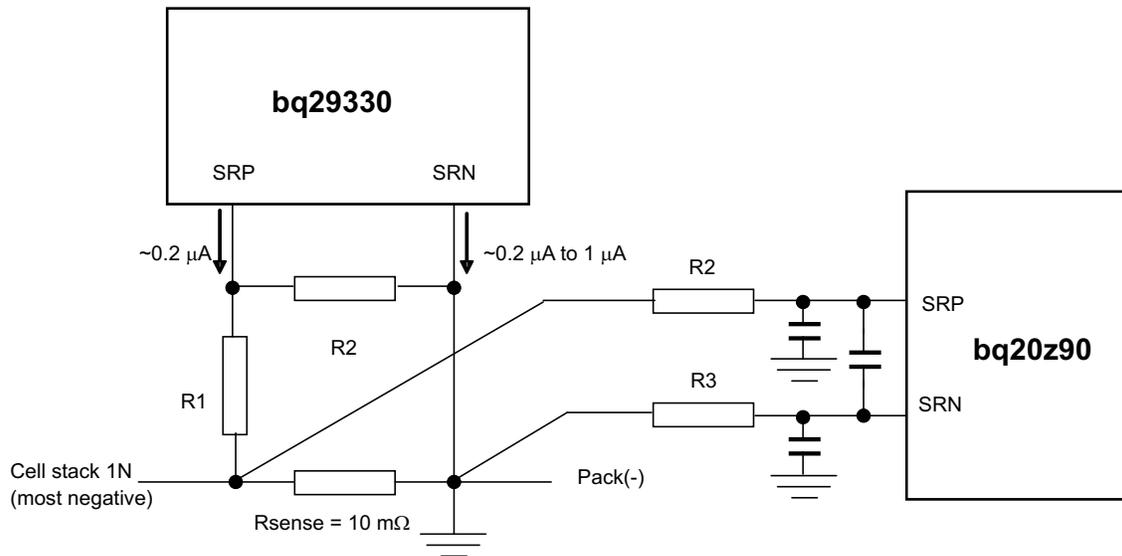


Figure 4. Resistor Divider Protects SRP From Excessive Negative Voltage

Figure 5 provides some measurements showing the voltage divider ratio of 1/3, 1/2, and 2/3. Obviously, the small bias currents from the SRP and SRN pins have negligible effects in linearity for the resistor values in the range of a few kilohms. The resistor-divider method can be used to effectively limit the voltage at the SRP pin. An additional advantage of this method is that the internal current threshold of the AFE, such as OLV, and SCC and SCD, can be chosen conveniently based on the ratio of the resistor divider.

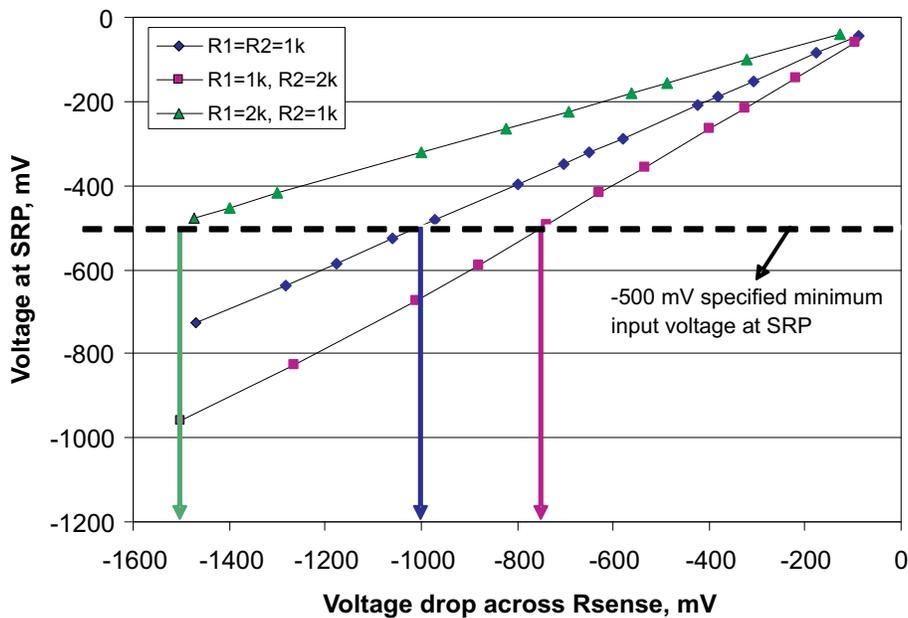


Figure 5. Resistor Divider Down-Scales the Negative Voltage Appearing at SRP Pin

2.1.2 Negative Voltage at AFE VCC Pin

For a 3p- and above applications, the high surge energy associated with the short-circuit event is sometimes coupled into the circuit due to the resonance between the trace inductance and loop capacitance, and drives the voltage at VCC pin below ground, which also leads to substrate current problem. It is recommended to insert an additional signal diode D1 to work with C1, as shown in Figure 6, in order to stabilize the voltage on the VCC pin.

2.1.3 Discharge FET Gate Overstress for High-Power Packs

There is a side-effect with D1. When the Pack terminals are shorted, in the worst case the event may be accompanied with a number of contact bounces. As a result, voltage waveform at the Pack+ and at the drain of the discharge FET can experience multiple peaks and valleys; and D1 and C1 form a peak detector, driving the voltage at bq29330's VCC pin higher than the battery voltage (Figure 6). During the brief short-circuit delay time (discharge FET is on during this time), with the source of the FET at near ground level, the charge pump internal diodes may be forward-biased, and the gate-to-source voltage may exceed the maximum rated limit (typically ± 20 V) during the short-circuit delay time. To alleviate this effect, a Zener diode ZD1 (12 V~16 V) must be added to protect the gate from overvoltage stress when D1 is present.

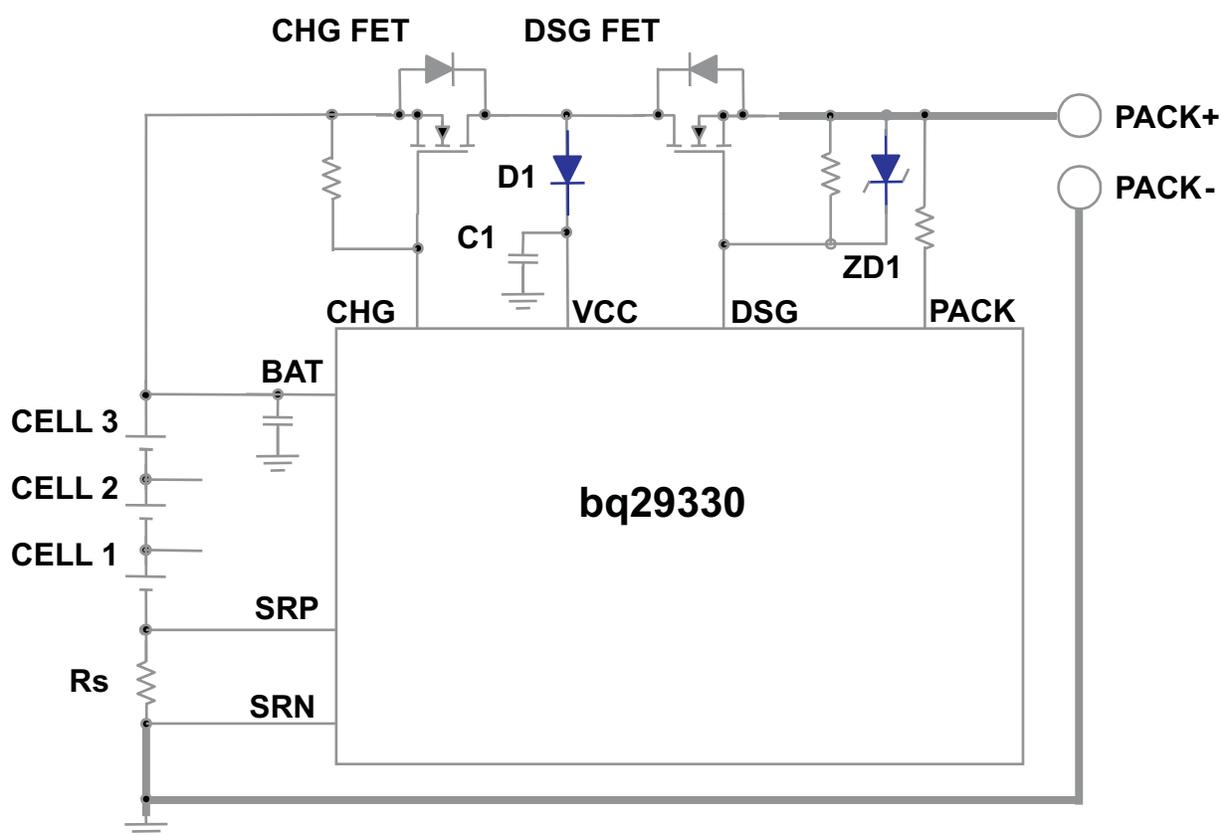


Figure 6. Recommended Circuit for High Power Packs (3-p and above)

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