Application Note

Open-Wire Detection in BMS Systems

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ABSTRACT

Open-wire faults in BMS voltage-sense, battery-terminal, and current-sense paths can cause incorrect measurements and reduce protection reliability in electric-vehicle and energy-storage systems. This application note, targeting BMS hardware and system-safety designers, uses TI BQ76952, BQ78706 and BQ79731 devices as examples to explain cell-input open-wire behavior and practical diagnostics. It describes AFE internal current-source discharge methods for cell-sense inputs, VBAT/VCn comparison for battery-terminal detection, and GPIO-based or redundant-ADC methods for current-shunt sense paths. These methods help detect disconnected harnesses before residual capacitor voltage or missing current information leads to unsafe system decisions, improving BMS diagnostic coverage, functional safety and system reliability.

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1 Introduction

Fault diagnostics are one of the most important topics in BMS functional safety and are required to help ensure reliable system operation. A BMS usually contains many wiring harnesses; if a sensing harness becomes disconnected or open, the system can be seriously affected. This application note uses devices such as the BQ76952 and BQ79731 as examples to discuss reliable open-wire detection at the CELL-sense inputs and proposes several methods to address open-wire detection challenges at the battery terminals and current-sense path.

2 CELL Open-Wire Detection Flow

CELL open-wire detection is one of the key diagnostic requirements for a battery-monitoring analog front end (AFE). Most TI battery monitor AFEs, such as BQ76952, BQ79718, and BQ78706, integrate this function. When a CELL sense wire is open, the external filter capacitor connected to the CELL input can retain the previous voltage for a long period of time. Because the AFE CELL-input pins are typically held in a high-impedance state to minimize quiescent current, this residual voltage may remain on the sensing node and can cause the AFE to report an incorrect CELL-voltage measurement.

In a typical AFE open-wire detection scheme, an internal current source is enabled on the VC_1-to-VC_n CELL-input pins with respect to VSS. When the current source is enabled and an open-wire condition exists in the CELL-voltage sensing path, the residual voltage on the affected sensing node is discharged. The device can then determine whether an open-wire fault has occurred based on the resulting CELL-voltage behavior. The following sections use BQ76952 as an example to describe the detailed open-wire detection sequence.

2.1 VC_1-VC_{n-1} Open-Wire Detection

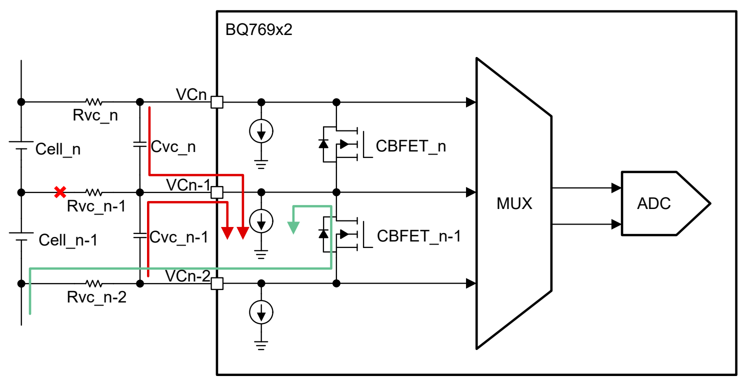

Figure 2-1. Discharge Path During VC_1–VC_{15} Open-Wire Detection

As shown in Figure 2-1 , cell voltage sensing will not be affected if there is no open-wire condition. If a cell input pin is floating due to an open-wire condition, this current source will discharge the capacitance, causing the voltage at the pin to slowly drop. As the voltage of the capacitor drains, the open-wired cell's voltage decreases at the device's inputs, this eventually triggers a ***Cell Undervoltage*** protection fault (CUV).

The drop of voltage in the capacitor of the open-wire cell input, also causes the adjacent cell above it to proportionally increase in voltage as the open-wired cell's capacitance is drained, which eventually leads to a ***Cell Overvoltage*** protection fault (COV).

The voltage changes due to the OW condition may trigger Permanent Fail (PF) protections by the device. The cell voltage on the OW input pins continuously dropping low enough to trigger a ***Safety Undervoltage PF*** , or a ***Safety Overvoltage PF*** on the cell above it.

When OW source completely drains OW cell, causing adjacent top cell input to now measure twice the original cell voltage with respect to the input pins. It is important that the undervoltage and overvoltage protections and PFs be enabled with appropriate threshold settings for the open wire condition to be detected and the desired reaction initiated.

Note

The BQ769x2 does not have a dedicated OW bit to indicate that an open-wire condition has occurred. However, one can infer this state based on the COV/CUV protections and cell voltages.

2.2 VC_n Open-Wire Detection

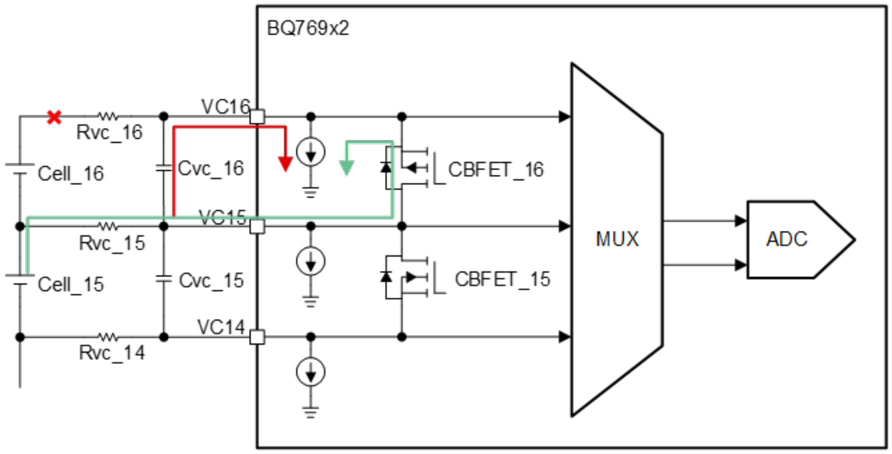

Figure 2-2. Discharge Path During VC_{16} Open-Wire Detection

When the $CELL_{16}$ input pin is floating due to an open-wire condition, the internal current source discharges C_{VC_16} with a slew rate. The voltage on C_{VC_16} continues to decrease until the body diode of the internal CELL-balancing FET becomes forward biased. Eventually, the voltage difference between VC_{16}~VC_{15} is close to 0 V. The BQ device can report a CUV event for CELL 16. In this condition, VSTACK becomes equal to the sum of 15 CELL voltages, while VBAT remains equal to the sum of all 16 CELL voltages.

2.3 VC_0 Open-Wire Detection

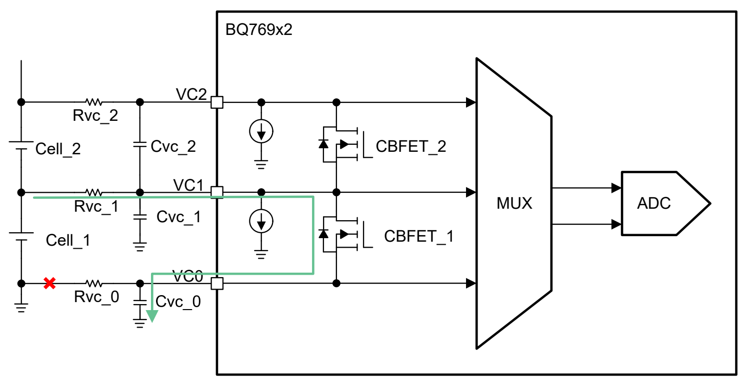

Figure 2-3. Discharge Path During VC_0 Open-Wire Detection

When the $CELL_1$ input pin is floating due to an open-wire condition, VC_1 remains approximately equal to the $CELL_1$ voltage because VC_1 and VC_0 have independent common-mode capacitors. The voltage on C_{VC_0} is pulled up close to the $CELL_1$ voltage by the leakage current through the body diode of $CBFET_{\_1}$. Eventually, the voltage between VC_1 and VC_0 becomes close to 0V, while the voltage between VC_2 and VC_1 remains consistent with the $CELL_2$ voltage. In this condition, the BQ device can report a CUV event for $CELL_1$.

To distinguish a true CUV event from an open-wire event, compare the VBAT measurement with $VC_{\_sum}$, which is the sum of the individual CELL-voltage measurements.

3 Shunt Open-Wire Detection

If an open-wire condition occurs in the shunt current-sense path, the AFE can no longer determine the actual load current. This condition can potentially result in a severe overcurrent or overload event. This section describes two approaches for detecting this fault: a shunt current-sense open-wire diagnostic circuit and redundant current measurement.

3.1 Open-Wire Detection Solution of Shunt

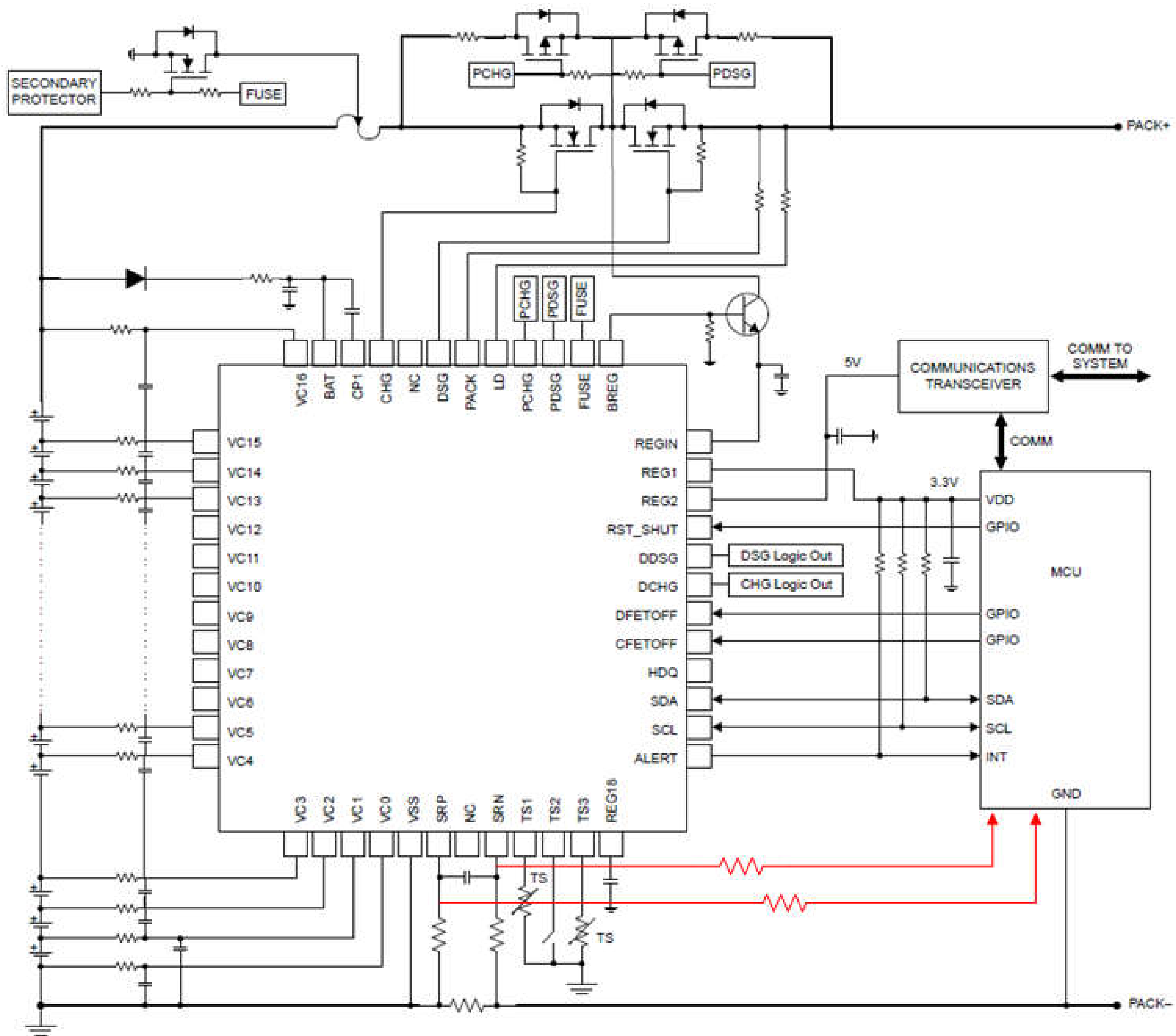

Figure 3-1. Open-Wire Detection Solution of Shunt

As shown in Figure 3-1, this article proposes a low-cost diagnostic circuit by adding a resistor divider between the series filter resistors and the MCU GPIO pins. During normal operation, the MCU pins remain in a high-impedance state (Hi-Z), so the circuit does not introduce additional static power consumption.

During the diagnostic operation, the MCU drives the GPIO pins high. This pulls the SRN/SRP pins to a level that is high enough to generate a clearly measurable signal for the internal ADC of the AFE. By reading the AFE current measurement, the MCU can determine whether the SRP and SRN pins are shorted together or shorted to VSS. If the filter resistors and the current-sense wires are not open, the current value reported by the AFE should match the expected value calculated from the resistor-divider network. If a filter resistor or current-sense wire becomes open, the voltage applied to the current-sense input is determined mainly by the MCU pull-up voltage, which can directly trigger SCD protection.

Note

When designing this circuit, make sure that the voltage applied to the AFE current-sense input pins, SRP and SRN, does not exceed the absolute maximum ratings of these pins. Otherwise, the MCU pullup voltage may damage the AFE.

3.2 Current-Sense Diagnostics with Redundant ADC

Another higher-cost approach for current-sense diagnostics is to add an independent ADC channel in a separate measurement path. This redundant measurement path helps detect an open-wire condition in the current-sense path or an abnormality in the primary ADC measurement. For example, bidirectional current-sense devices such as INA194 or AMC1350 can be used to implement redundant current measurements. However, this approach increases the overall system cost and introduces additional quiescent current consumption.

In energy storage system (ESS) applications, TI's BQ79731 UMI sensor integrates two independent current-sense ADCs. Open-wire detection can be implemented by using the redundant ADC together with an independent RC input path. This approach simplifies the system design and helps improve power density.

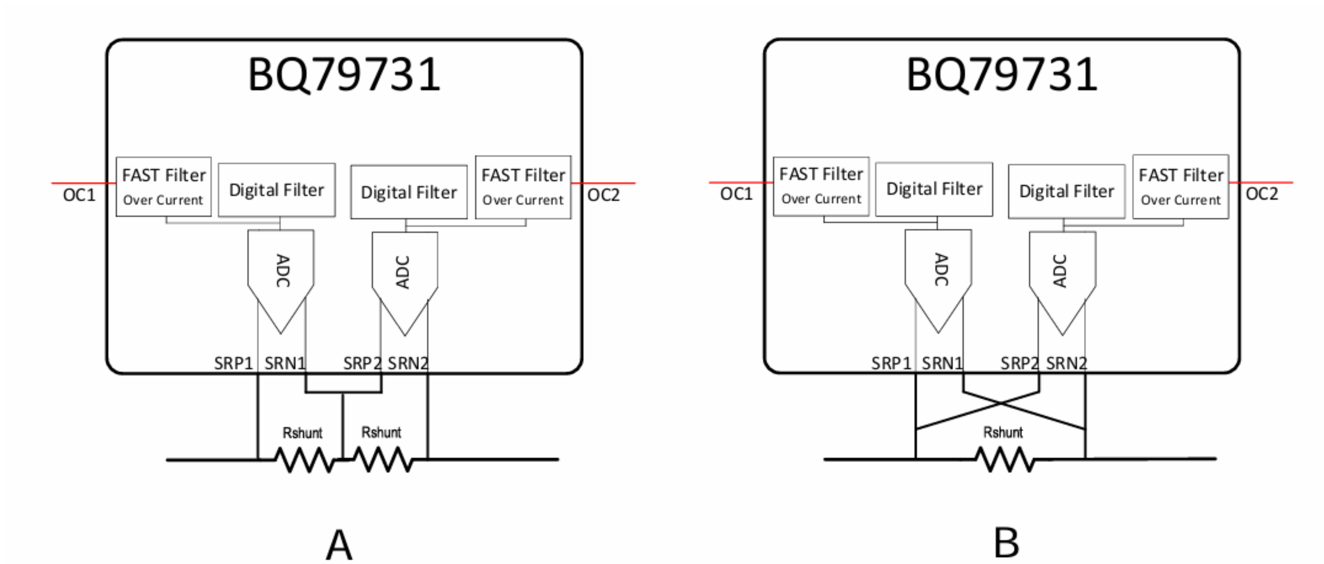

Figure 3-2. Redundant Current-Sense Diagnostics with BQ79731

4 Other Diagnostics: VBAT, VSS

4.1 VBAT Open-Wire Detection

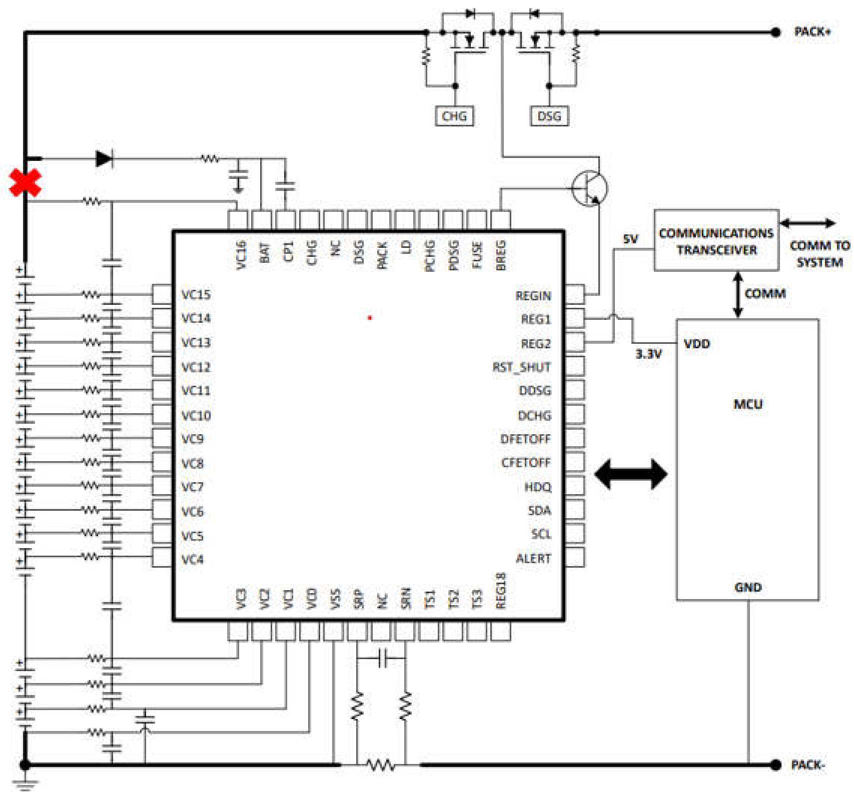

Figure 4-1. VBAT Open-Wire Detection

In the BMS design, the VC_n sensing cable and power cable connections are normally recommended to be routed separately. AFE is powered by power cable via PCB trace. The difference between the VC_n voltage and the VBAT reading can be used to determine whether an open-wire condition has occurred. In BQ76952, a VBAT under voltage condition can force the device into SHUTDOWN mode to protect the system.

4.2 VSS Open-Wire Detection

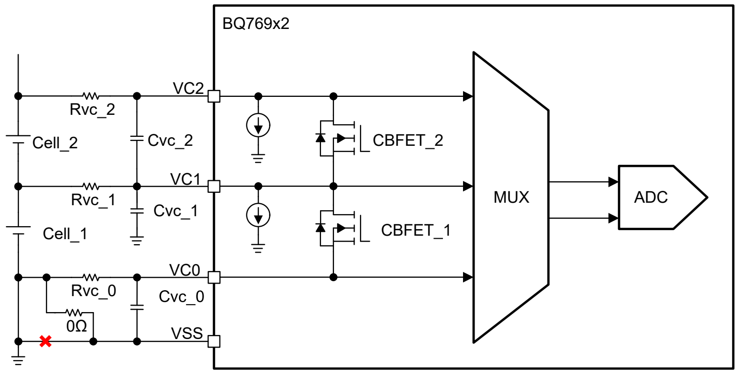

Figure 4-2. VSS Open-Wire Detection

A VSS open-wire condition can be detected by the MCU measuring a pin voltage, such as REG18 or REG1 with division resistor network. When VSS is open wire, the internal VSS of the IC floats up above board GND with a diode drop voltage. The AFE generates REG18 and REG1 relative to the internal VSS, so REG18 and REG1 is higher than normal relative to board GND. So MCU can measure this failure.

5 Summary

This application note summarizes open-wire detection methods for BMS and helps BMS designers understand typical open-wire fault mechanisms and provides practical circuit and diagnostic design guidance to improve system reliability, protection accuracy, and functional-safety robustness in EV, datacenter, and ESS applications.

6 References

1. Texas Instruments, *BQ76952 3-Series to 16-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, and LiFePO4 Battery Packs*, datasheet.
2. Texas Instruments, *BQ76952 Technical Reference Manual*, technical reference manual.
3. *Using Low-Side FETs with the BQ769x2 Battery Monitor Family*, application note.
4. Texas Instruments, *Microcontroller Code Examples for BQ769x2 Battery Monitors*, code examples.
5. Texas Instruments, *[FAQ] BQ76952: Common questions for TI's BQ769x2 Family of Battery Monitors*, FAQs.