Application Note

Insulation Resistance Detection for HEV Applications

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ABSTRACT

The BQ79731-Q1 provides voltage and current monitoring for high-voltage automotive applications. These functionalities, in combination with the GPIO inputs, can be used to implement a scheme for insulation resistance detection. Various factors must be designed for this function including bypass capacitors, a resistor ladder, and timing schemes. With this circuitry, the host MCU can then use the voltage measurements to perform estimation calculations. If necessary, the host MCU can then use this information to take necessary safety precautions.

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1 Introduction

Insulation resistance is a measure of how insulated the battery pack is from chassis ground. In ICE (internal combustion engine) vehicles, the negative terminal of the 12V battery is typically connected to the chassis for grounding. In HEVs (hybrid/electric vehicles) this is not possible for the high-voltage battery packs. The battery pack must be properly isolated from the chassis to ensure the consumer safety and to protect the integrity of the electronics throughout the vehicle.

In HEVs the battery pack is floating relative to chassis ground so two measures of insulation resistance are typically useful, one for describing how insulated the negative terminal is from chassis ground and one for the insulation of the positive terminal from chassis ground.

For an automotive system, the insulation resistance should be in a range from hundreds of kiloohms to megaohms. If the insulation resistance drops below this range this can indicate a problem with the insulation which can be downright dangerous.

The insulation resistance can change due to environmental factors such as temperature and humidity (Martindale). It can also change due to mechanical stress such as the stress induced during the manufacturing process (Su). Mechanical stress can also be caused with changes in the car's condition such as expected wear and tear or sudden impact.

Perhaps the most important factor that affects the insulation resistance is the battery pack voltage. Generally, as the voltage increases the insulation resistance decreases (Su).

2 Insulation resistance detection in a system

In an HEV system, the BQ79731-Q1 is intended to be a pack monitor to measure various voltages and currents of the battery pack, as depicted in the system diagram below.

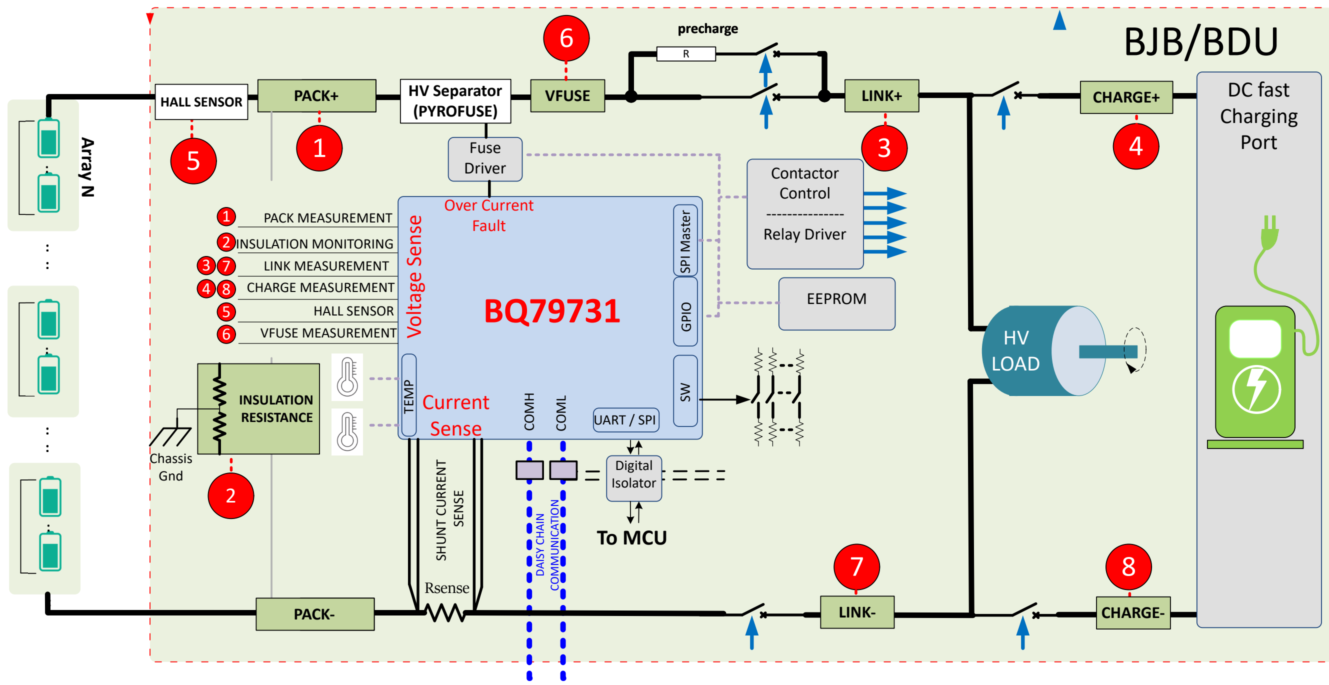

Figure 2-1. BQ79731-Q1 System Diagram

The BQ79731-Q1 does not calculate the insulation resistance. A circuit to detect the insulation resistance can be designed using the integrated voltage and current sensing capabilities of the BQ79731-Q1. Then the host MCU should take these voltage measurements to calculate the approximate insulation resistances. The MCU must also be programmed to take appropriate action should the insulation resistance drop too low in order to protect the consumer and the integrity of the automotive electronics. The proposed circuit to detect the insulation resistance is pictured below:

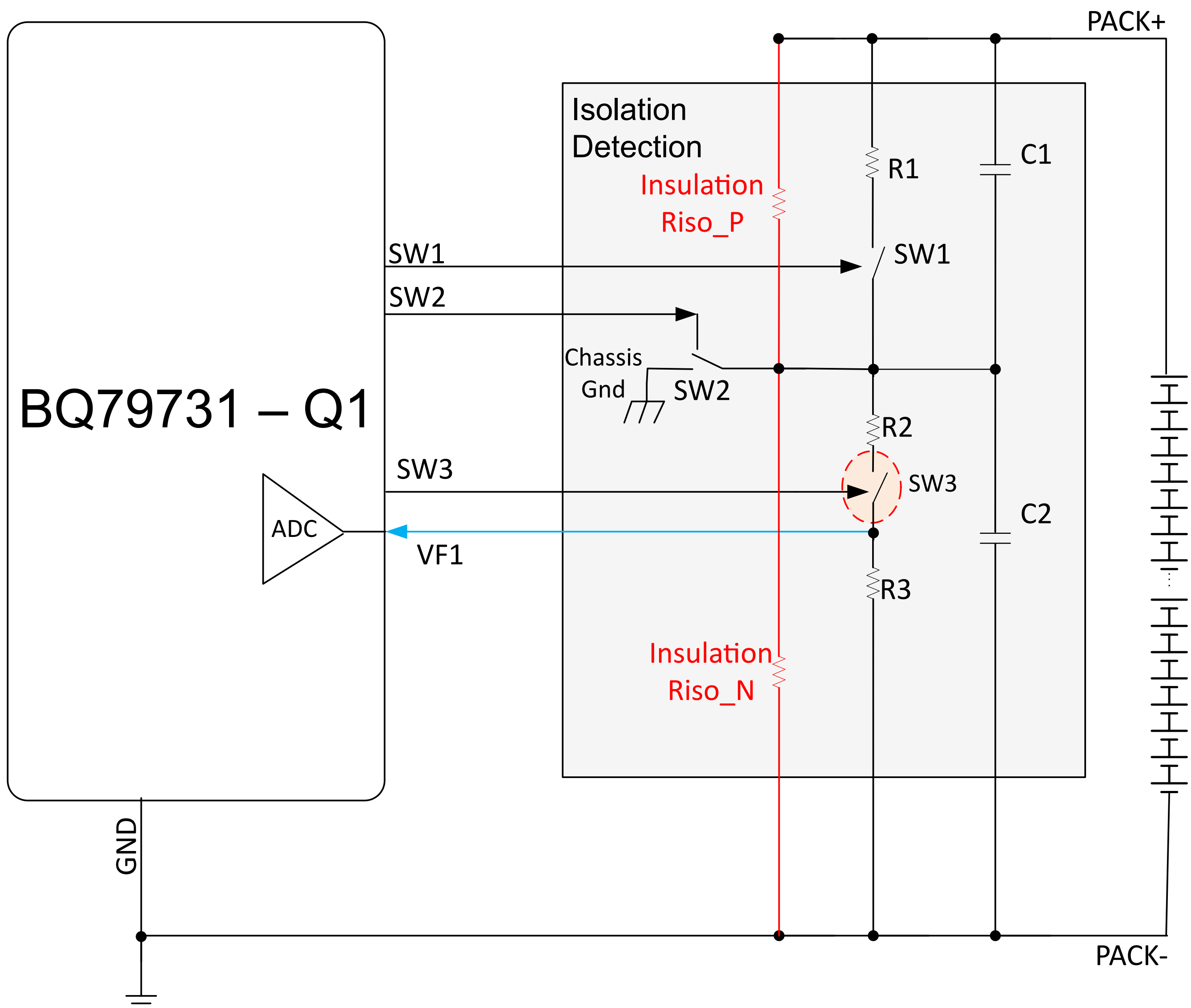

Figure 2-2. BQ79731-Q1 Insulation Resistance Detection Scheme

For this suggested design the biggest sources of error are variations in the pack voltage, resistor ladder mismatch, and ADC voltage accuracy, respectively. Variations in the pack voltage can cause changes in the insulation resistance determined since insulation resistance drops as voltage increases. Therefore, it is important that the pack voltage and GPIO voltage measurements be in sync to minimize error. Resistor ladder mismatch is caused by tolerance and temperature variations in the resistor values and is inevitable. The ADC voltage error contributes to about 1% of the estimation error.

The insulation resistance is created by the wiring insulation and is modeled with two resistors: $R_{iso,p}$ and $R_{iso,n}$. To determine their approximate values, two equations are needed relating them to known quantities. To extract this system of equations, this circuit operates in two states controlled by SW_3 and then measures the voltages in each state. From these measurements, the system of equations can be created and solved to approximate the insulation resistances $R_{iso,n}$ and $R_{iso,p}$.

To preserve the charge of the battery additional transistors are added: SW_1 and SW_2. These switches can be programmed to disrupt the flow of current from the battery during periods when it may not be pertinent to measure the insulation resistance. For example, when the car is parked. This can extend the battery life of the car. When the circuit is operating to detect the insulation resistance, both of these switches should be turned on.

In this system additional capacitances need to be added to mitigate EMI noise. As a result, the time constant of this system must be considered. The sampling period of the voltage measured at the GPIO pin must be greater than the charge/discharge period of the RC circuit created by the resistors and capacitors. To find the time constants for the first state (when all of the switches are on) the following equations can be used:

$\tau_{s1,c1} = C_1 \times (R_{iso,p} \parallel (R_1))$

$\tau_{s1,c2} = C_2 \times (R_{iso,n} \parallel (R_2 + R_3))$

For the second state (when SW_1 is open and all others are closed), the equation for the time constant for each bypass capacitor is defined as follows:

$\tau_{s2,c1} = C_1 \times R_{iso,p}$

$\tau_{s2,c2} = C_2 \times (R_{iso,n} \parallel (R_2 + R_3))$

The sampling period should be greater than the maximum of these values to allow the capacitors ample time to charge and discharge.

3 Design Example

In this example the design of an insulation resistance circuit with respective calculations will be derived and explained. For this system, the resistors R_1, R_2, and R_3 are chosen to be similar in magnitude to the isolation resistances (hundreds of kiloohms to megaohm range). The transistors are chosen to have appropriate ratings and switching behavior. A low Rds,on is not necessary as the resistances of R_1, R_2, and R_3 are sufficiently large to mitigate any effect the on-resistance might have. The resulting circuit is depicted below:

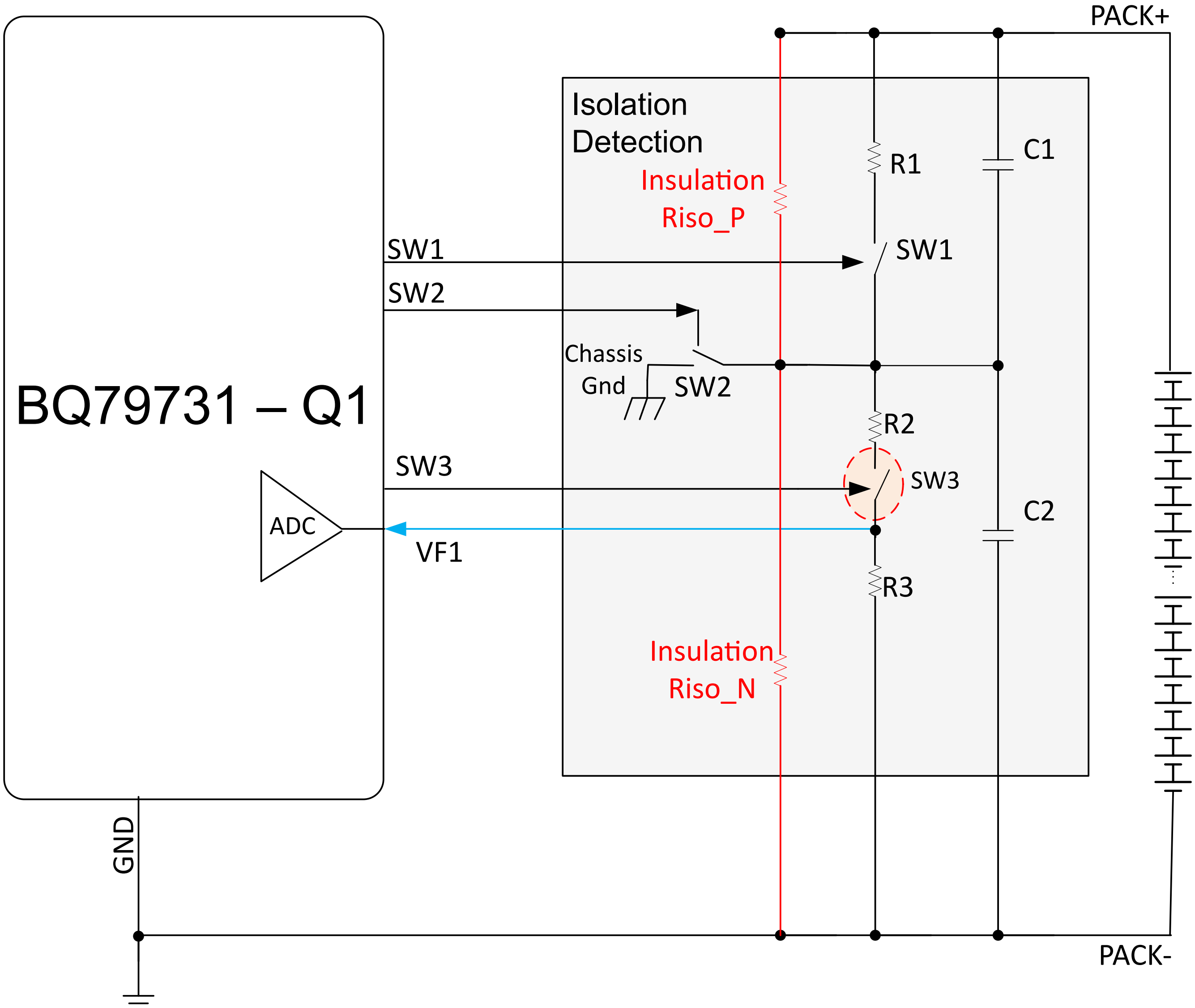

Figure 3-1. BQ79731-Q1 Insulation Resistance Detection Scheme

Next, the derivation of the system of equations for the circuit operation. This circuit will operate in two states depending on whether the switch SW3 is on or off. This is assuming that the car is not in an energy conserving state so both SW1 and SW2 are on in both states. In other words, the circuit will be in one of the following states:

1. When not monitoring the insulation resistance (i.e in a power conservation mode) SW1, SW2, SW3 are all off
2. When monitoring the insulation resistance there will be two circuit states:
   a. SW1, SW2, SW3 are all on
   b. SW2 and SW3 are on, SW1 is off

These two monitoring states result in the following two equations:

$$\frac{\frac{V_{pp1} - V_{F1}}{R_{iso,p}}}{r_1 \frac{R_{iso,p}}{R_{iso,p} + r_1}} = \frac{V_{F1}}{\left(r_3 + r_2\right) \frac{R_{iso,n}}{r_3 + r_2 + R_{iso,n}}} \tag{1}$$

$$\frac{V_{pp2} - V_{F2}}{R_{iso,p}} = \frac{V_{F2}}{\left(r_3 + r_2\right) \frac{R_{iso,n}}{r_3 + r_2 + R_{iso,n}}} \tag{2}$$

The first from the state in which all switches are on and the second when SW1 is off. Vpp is the pack measurement that the BQ79731-Q1 device monitors and VF is the GPIO measurement from the IR detection circuit. From these equations the following expressions can be derived for the insulation resistances:

$$R_{iso,p} = \frac{r_1 A V_{F2} V_{pp1} - r_1 A V_{F1} V_{pp2}}{A^2 V_{F1} V_{F2} - A V_{F2} V_{pp1}} \tag{3}$$

$$R_{iso,n} = \frac{(r_2 + r_3)(r_1 A V_{F1} V_{pp2} - r_1 A V_{F2} V_{pp1})}{r_2 A V_{F1} A V_{F2} + r_3 A V_{F1} A V_{F2} - r_1 A V_{F1} V_{pp2} + r_1 A V_{F2} V_{pp1} - r_2 A V_{F1} V_{pp2} - r_2 A V_{F2} V_{pp1} - r_3 A V_{F1} V_{pp2} - r_3 A V_{F2} V_{pp1} + r_2 V_{pp1} V_{pp2} + r_3 V_{pp1} V_{pp2}} \tag{4}$$

Where

$$A = \frac{r_2 + r_3}{r_3} \tag{5}$$

The synchronous extraction of the measurements (V_{pp} and V_F) and the calculations would be performed by the host MCU. The datasheet has more information on VI measurement synchronization. The approximation should then be compared to an appropriate threshold. Should the calculated insulation resistance be lower than the threshold, the MCU must be programmed to respond appropriately. The host MCU can also be programmed to turn off this circuit to minimize leakage current during idle or parking periods, although the SW2 may be omitted to reduce assembly cost.

4 Summary

In an automotive context, the insulation resistances are a measure of the efficacy of insulation measures for the battery pack. A circuit for insulation resistance detection was proposed using the BQ79731-Q1. This circuit can be used to gather critical information for the safety of the consumer and functionality of the HEV electronics. With this information the engineer(s) must design and program necessary safety responses in the event of dangerously low insulation resistance(s).

5 References

- Martindale, Lou. “Humidity and Insulation Resistance.” *PdMA*, 17 Nov. 2022, pdma.com/2022/11/17/humidity-and-insulation-resistance/. Accessed 21 Oct. 2022.
- Su, Jingang, et al. “Effects of Mechanical Stress on Insulation Structure and Performance of HV Cable.” *Polymers*, vol. 14, no. 14, 20 July 2022, p. 2927, www.ncbi.nlm.nih.gov/pmc/articles/PMC9317511/, 10.3390/polym14142927. Accessed 21 Oct. 2022.
- BQ79731-Q1 datasheet (SLUSEO5)

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