Application Note

Relay Weld Detection for OBCs in V2L With Opto-emulators

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ABSTRACT

With the global shift toward vehicle electrification, vehicle to load (V2L) applications are becoming more popular. The market demand for on-board chargers (OBCs) - the key component in EVs/HEVs - is also rising. Relays, a core part of OBCs, are used to connect or disconnect the power between the high-voltage AC or high-voltage DC circuits. However, frequent use and external environmental factors can cause relay contacts to weld, or stick, affecting the reliability of the OBC or even the entire vehicle. The traditional method for relay weld detection is to compare the voltages at the front and rear ends of the relay, which requires two channels of high-voltage sampling, increasing system cost and design challenges. The ISOM811x-Q1 family of opto-emulators leverages TI's latest generation of SiO2-based isolation technology and can emulate the current-driven input structure of an optocoupler without the poor reliability of the LED. This article focuses on how to build a low-cost relay weld detection scheme with the ISOM8118-Q1, saving one voltage sampling channel and reducing system complexity.

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1 Relay Contact Sticking in OBCs

1.1 Relays Used in OBCs

An on-board charger, or OBC, is an automotive power electronics device that achieves electrical power conversion through high-frequency switching operations. OBCs are classified into unidirectional OBCs and bidirectional OBCs. The unidirectional OBCs can only charge traction batteries, while the bidirectional OBCs can invert the direct current from high-voltage traction batteries to alternating current (220V AC 50Hz/110V AC 60Hz). An electromagnetic relay is a switch-controlled component that operates through electromagnetic effect and consists of a set of input terminals for single or multiple control signal(s) and a set of operating contact terminals. In an OBC, the AC input and the high-voltage DC output are usually configured with one relay each. Before confirming with the charging pile to initiate charging, the relays ensure the electrical isolation of the OBC from the power grid; in V2L mode, the relays in the same position control whether power is released to AC loads, to ensure the safety of the user and the external loads.

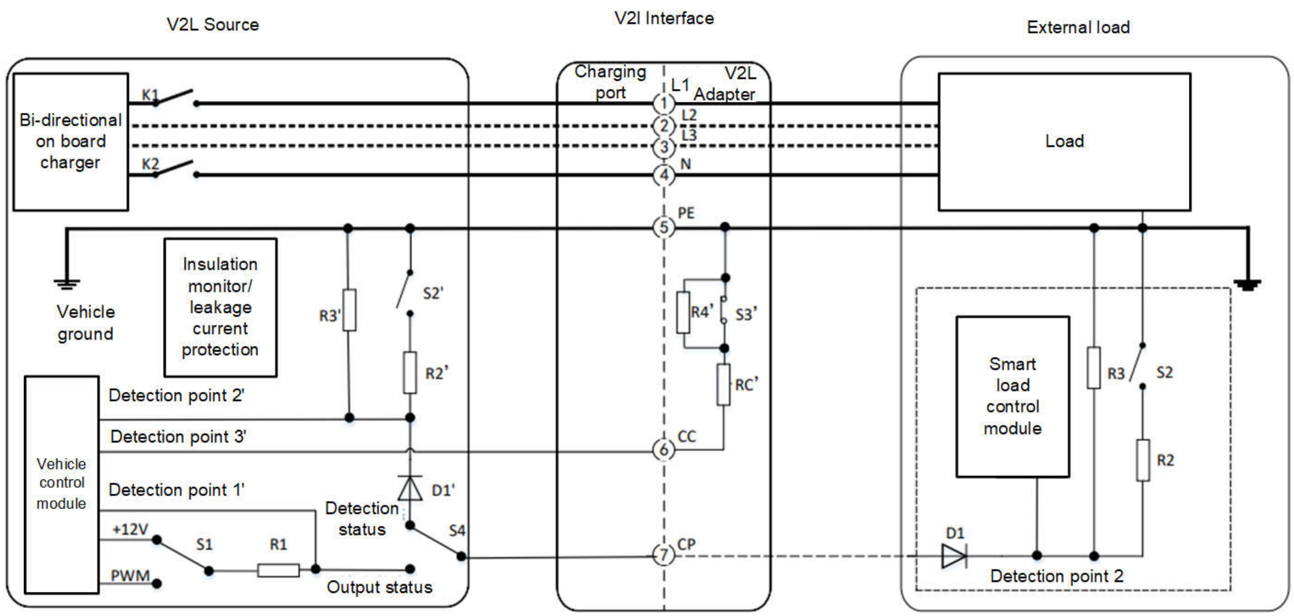


Figure 1-1. V2L Mode Control Pilot Circuit Schematic [1]

Taking a 6.6kW, 400V single-phase OBC as an example, the current is $32A_{RMS}$ at 220V rated input and the maximum output current is about $30A_{DC}$ during battery discharge. High-power operation requires the relays in the OBC to withstand approximately 400Vpk voltage and carry 60A over-current. An electromagnetic relay mainly consists of a coil, core, contacts, and springs. When the coil is energized, the core generates a magnetic field, closing the contacts; when the coil is de-energized, the core loses its magnetic field and the contacts are disconnected by the spring.

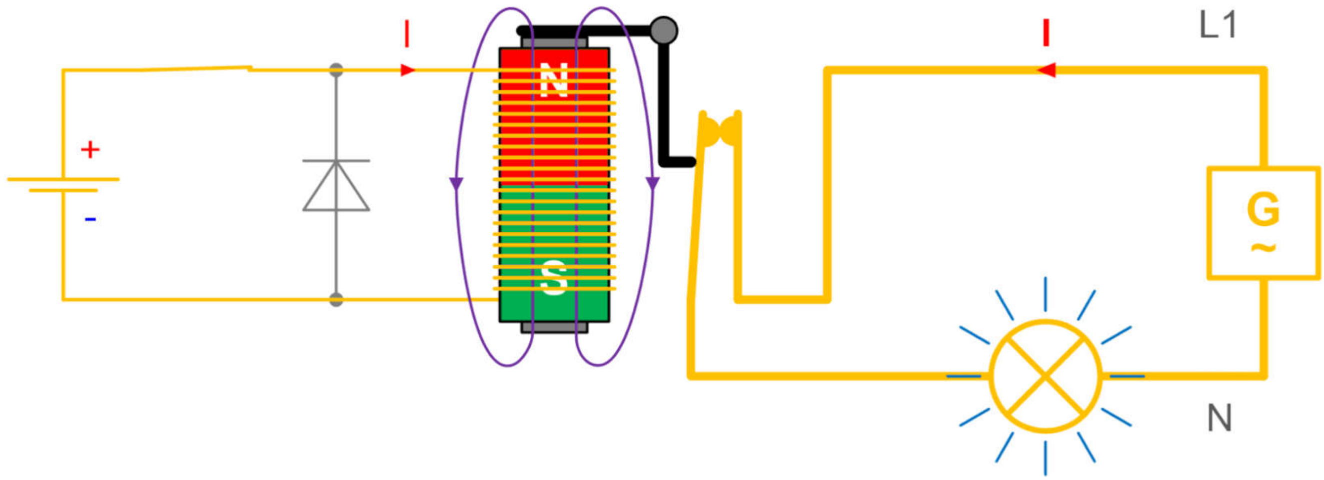


Figure 1-2. Common Electromagnetic Relay Control Loop and Load Loop [2]

1.2 Causes and Hazards of Relay Contact Sticking

Arcing may occur in a relay while the contact switching current is flowing through. High load, frequent operation, or relay aging are all likely to cause contact sticking, preventing contacts from properly disconnecting or closing, thus preventing the relay from correctly switching the circuit. Safety hazards such as circuit malfunction and equipment damage may be caused.

The application specifications of the relay should be strictly followed in the design to prevent relay failure in out-of-specification applications. Given frequent switching on and off of the OBC relays and possible unintended contact due to vehicle vibration, developers often design a detection circuit for contact status monitoring. The most common solution is to sample voltages at each end of the contacts and verify that the relay is in the expected idle state based on the voltage difference. However, as the OBC relays are located in the high-voltage section, additional high-voltage detection circuits will significantly increase the cost, so more cost-effective detection solutions are required.

2 About Opto-emulators

2.1 Introduction to ISOM811x-Q1 and Key Parameters Like CTR

The ISOM811x-Q1 family of devices are TI’s opto-emulators with emulated LED input and transistor output. This family is compatible with a variety of traditional optocoupler packages and supports pin-to-pin upgrades. The ISOM811x-Q1 uses an emulated LED as the input stage, with a silicon dioxide (SiO_2)-based isolation barrier between the input and output, effectively inhibiting signal transmission degradation found in traditional optocoupler technologies.

The current transfer ratio (CTR) is an important parameter for opto-emulators, defined as:

$$CTR(\%) = \frac{I_C}{I_F} \times 100\% \quad (1)$$

Where I_C is the collector current through the output stage and I_F is the forward current through the input stage. At the same minimum input current I_{Fmin}, a higher CTR could lead to a more saturated secondary “transistor” and a smaller conduction voltage drop. The ISOM811x-Q1 family offers several CTR options from 100% to 560%. Due to the stability of the SiO_2-based isolation barrier, this key metric is stable across the full temperature range and full input current I_F range, facilitating designers to design boundary conditions based on actual input.

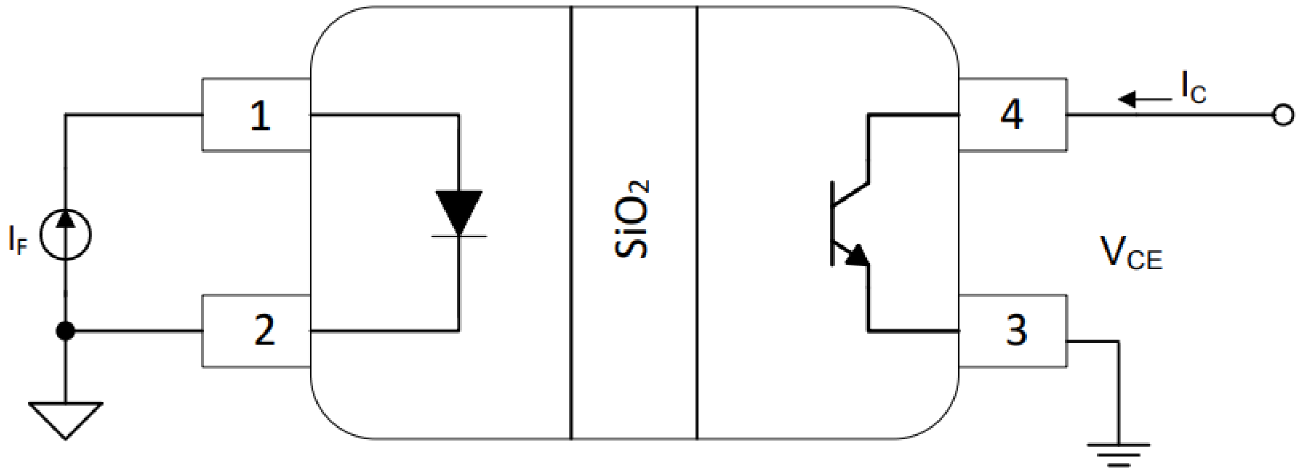


Figure 2-1. Input I_F and Output I_C of the Opto-emulator

2.2 Performance Comparison with Optocoupler and Single-Channel Digital Isolator

Compared to single-channel digital isolators, the ISOM811x-Q1 opto-emulators require no input and output power supply and have no reference ground limitations, thus allowing flexibility in configuration in both high-side and low-side applications, greatly simplifying the design of high-voltage side power supply circuits. In addition, high-frequency common-mode interference in strong electrical systems is mostly coupled through parasitic capacitance, while the opto-emulators' feature of current-driven input facilitates signal immunity.

Compared to optocouplers, the ISOM811x-Q1 opto-emulators offer significant reliability and performance advantages, including high bandwidth, low switching delay, wider temperature ranges, flat CTR, and tight process control, resulting in minimal variations. In addition, the LED input stage of the opto-emulator consumes less power in applications than optocouplers, since there is no aging effect and temperature variation to compensate for. A comparison is shown in the table below:

Parameter	ISOM811X	Optocoupler A	Optocoupler B
Isolation technology	SiO2	Optical	Optical
Input type	Uni & bidirectional	Unidirectional	Unidirectional
VF (Typ) (V)	1.2	1.2	1.25
Switching time (µs)	5/3	3/3	3/3
CTR range @ IF = 5mA	100% to 560%	50% to 600%	50% to 600%
Bandwidth (Typ) (KHz)	680	30	NA
Temperature range (°C)	-55 to +125	-55 to +110	-55 to +100
Pin pitch (mm)	2.54 (DFG) & 1.27 (DFH)	1.27	2.54

3 AC Relay Weld Detection in V2L Circuit for OBCs Based on ISOM8118-Q1

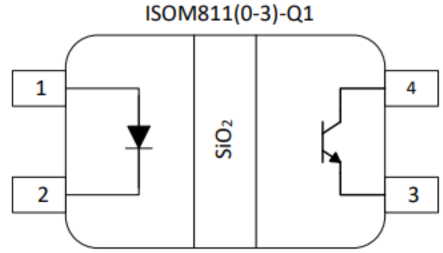
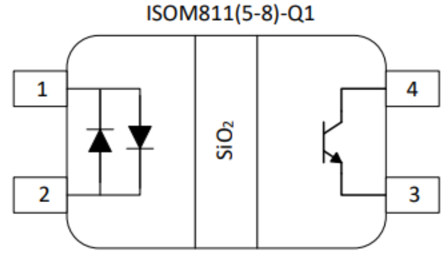
3.1 What Is V2L for OBCs

In traditional fuel vehicles, 12V low-voltage batteries provide power to various low-voltage consuming loads inside the vehicle, such as wipers, headlights, or displays. These batteries tend to have small capacity and low discharge power, typically tens of AH and less than 1kW respectively. In new energy vehicles (EVs), however, the capacity of traction batteries tends to be tens of kWh. The Vehicle to Load (V2L) feature of bidirectional OBCs can provide external load equipment with the energy from the traction batteries. The inverter generates 220V (most national standards)/110V (North American standard) AC power of a few kW (depending on the inverter capacity of the OBC), which can power loads such as outdoor electric camping equipment. V2L can also be expanded to other application scenarios such as Vehicle to Grid (V2G) and Vehicle to Home (V2H), enabling new EV owners to sell the redundant power of their vehicles to the grid or supplement household electricity, improving energy resilience and emergency response.

To optimize space in new EVs, the V2L's AC discharge scocket shares a connector with the AC input charging interface. Since AC charging and V2L discharge cannot occur simultaneously, relays are used to diconnect the circuits and ensure independence between them. Given the possibility of direct contact between the discharge socket and the human body, the V2L circuit of the OBC must monitor the safety state of the output voltage, in addition to the structural design for protection against electric shock. Therefore, it is critical to detect whether the AC relay contacts on the V2L circuit are sticking, and the system needs to confirm that the AC discharge socket only outputs 220V/110VAC after the discharge initialization sequence is complete.

3.2 Design Reference for AC Relay Weld Detection Circuit in V2L

The ISOM811X-Q1 family features DC and AC inputs and different CTR metrics, with the selection reference shown in the following table:

<table>
<tr><th>Part Number</th><th>CTR</th><th>Input Type</th></tr>
<tr><td>ISOM8110-Q1</td><td>100%~155%</td><td rowspan="4">Single-direction - DC Input
ISOM811(0-3)-Q1
</td></tr>
<tr><td>ISOM8111-Q1</td><td>150%~230%</td></tr>
<tr><td>ISOM8112-Q1</td><td>255%~380%</td></tr>
<tr><td>ISOM8113-Q1</td><td>375%~560%</td></tr>
<tr><td>ISOM8115-Q1</td><td>100% to 560%</td><td rowspan="4">Bidirectional - AC Input
ISOM811(5-8)-Q1
</td></tr>
<tr><td>ISOM8116-Q1</td><td>150%~230%</td></tr>
<tr><td>ISOM8117-Q1</td><td>255%~380%</td></tr>
<tr><td>ISOM8118-Q1</td><td>375%~560%</td></tr>
</table>

The V2L scenario requires adaptation to the bidirectional AC input on the power grid and load sides, hence the need for the ISOM811[5-8]-Q1 family. A higher CTR means that the change in output current I_C is more sensitive to the relay weld on the high-voltage input side. The subsequent example uses the ISOM8118-Q1 with the largest CTR value as a reference for calculation, while other options can be selected based on actual application requirements.

In the application reference circuit, the output pull-up resistor R2 is designed to convert a single current change into a voltage change, and the recommended procedure for relay weld detection is as follows:

1. The MCU sends a command to disconnect the relay;

2. The OBC's inverter generates a safe voltage for the human body of $36V_{pk\text{-}pk}$ which is connected to the chip input through the current-limiting resistor R1;
3. If there is a current in excess of I_{Fmin} generated on the input side of the ISOM8118 at this time, the secondary-side voltage drop will change;
4. If the MCU's GPIO port detects a falling edge, it could be determined that the relay contacts are in contact and are at risk of sticking.

If not, it will be determined that the relay contacts are disconnected well at this time and a command should be sent to close the relay. In addition, the OBC enters the V2L state.

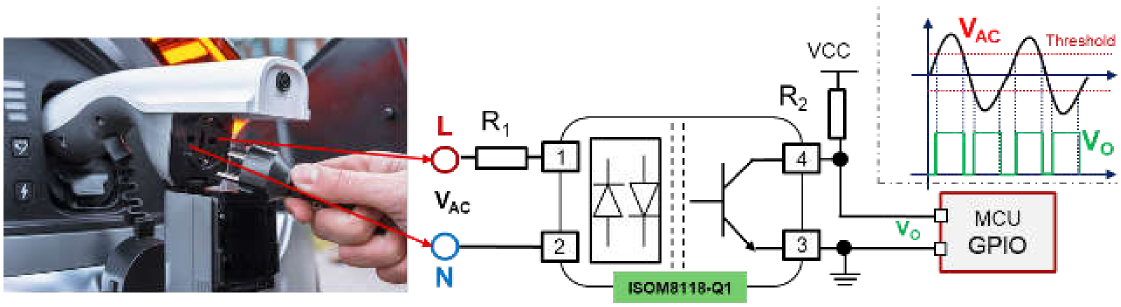


Figure 3-1. Typical Reference Circuit for Relay Weld Detection Based on ISOM8118-Q1

3.3 Design Examples and Selection Guidelines Based on Typical Circuits

Following the design concept outlined in Section 3.2, the overall circuit for relay weld detection based on ISOM8118-Q1 is recommended as follows. In this circuit, the AMC0330S-Q1 is an isolated sampling operational amplifier that samples the AC port voltage. Its single-ended output simplifies the design of conditioning circuits, providing a reference for monitoring the actual voltage on the relay contact side. In the event of a relay weld, the current flows through the current-limiting resistor R1 and into the ISOM8118-Q1 chip input, and the ISOM8118-Q1 generates output current I_C with reference to I_F, creating a voltage drop across the pull-up resistor R2 connected to the MCU's input. The MCU's GPIO port determines a possible weld with edge signals and finally confirms the relay contact status in conjunction with the ADC sample result from the AMC0330S-Q1 and the MCU's command sent to the relay.

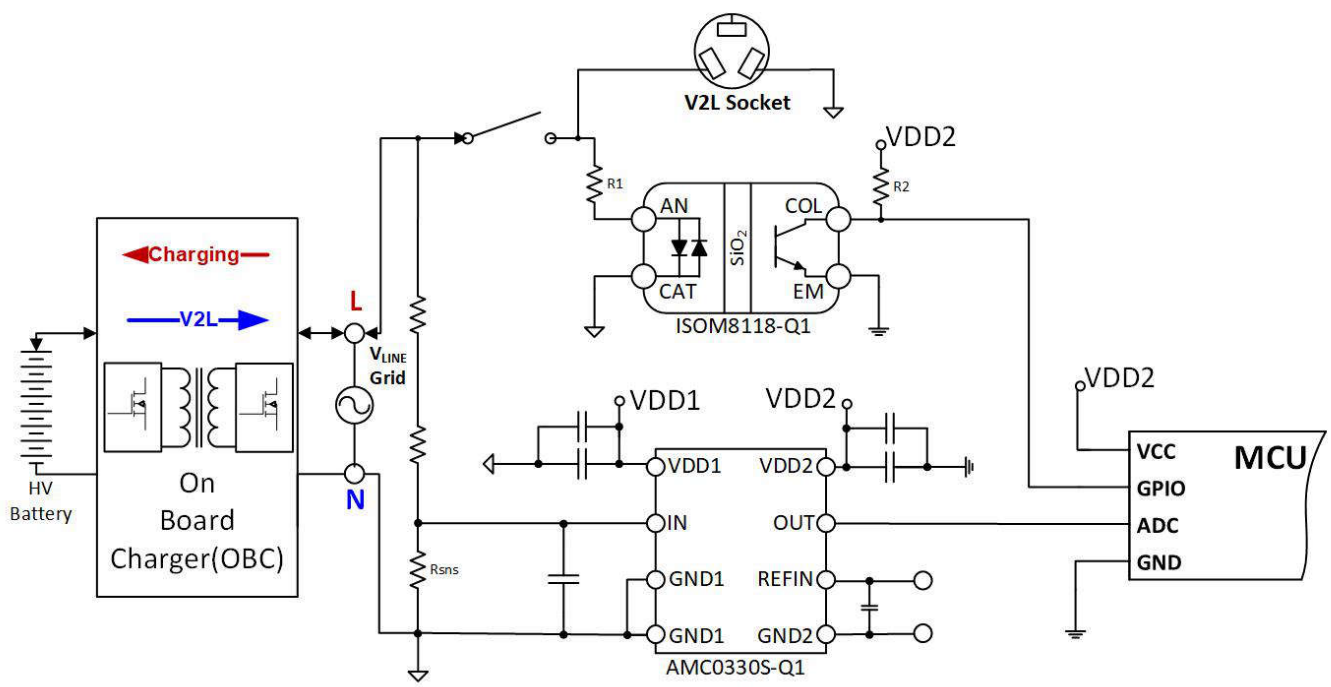


Figure 3-2. Overall Circuit for Relay Weld Detection Based on ISOM8118-Q1

In weld detection circuit designs, many variables affect how to properly use an opto-emulator, including grid voltage, MCU's supply voltage, and so forth. Specific parameters and selections are analyzed in the following sections, assuming the grid voltage is 220VRMS sinusoidal AC voltage and the MCU's supply voltage is 3.3V.

3.3.1 Select Voltage Judgment Threshold V_{TH} and I_{Fmin}

The minimum forward conduction current of the ISOM8118-Q1 at 25°C is 0.5mA, as noted in the data sheet. However, when the temperature rises above 40°C, its CTR will decrease rapidly, and by 125°C the CTR will be much lower than the nominal typical value noted in the sheet. To ensure circuit stability and reliability across wide temperature ranges, choose 1mA as the minimum I_F in designs. With the current-limiting resistor R1's resistance fixed, a higher input voltage leads to a larger input I_F. A higher CTR will result in a larger output I_C. The ISOM8118-Q1 features the largest CTR value, improving the judgment accuracy. Given that 36V is the maximum safe voltage for the human body, set the voltage judgment threshold V_{TH} to 36V.

$$\mathrm{V_{TH}} = \mathrm{I_{Fmin}} \times \mathrm{R_1} + \mathrm{V_F} \tag{2}$$

V_F is the input voltage drop of the emulated LED, with a typical value of 1.2V.

3.3.2 Select Current-limiting Resistor R_1

The output state of an ISOM8118-Q1 opto-emulator depends on the primary-side input current. To limit the amount of current flowing into the AN pin, one resistor R_1 must be connected in series at the input. The selected current-limiting resistor should meet two criteria: One is to ensure that the GPIO port of the MCU can receive a low level after the voltage at the AC discharge port reaches the judgment threshold V_{TH}, and the other is that the $220V_{RMS}$ AC voltage will not burn out the ISOM8118-Q1 or the resistor R1 itself after the relay closes normally.

For judgment accuracy, R1 needs to satisfy:

$$R_1 < \frac{\mathrm{V_{TH}} - \mathrm{V_F}}{\mathrm{I_{Fmin}}} \tag{3}$$

The calculation with substituted values yields R1<34.8kΩ. When a maximum voltage is input, the current flowing into the AN equals $\frac{220\sqrt{2}\mathrm{V}}{34.8\mathrm{k\Omega}} = 8.9\mathrm{mA}$, which is less than the max. $I_{F(ON)}$ of 20mA and meets safety requirements.

The heat generation from the resistor should also be taken into account, and the power dissipation across the resistor R1 is calculated with the equation below:

$$P_{R1LOSS} = \frac{(V_{AC} - V_F)^2}{R_1} \tag{4}$$

The calculation with substituted values yields P_{R1LOSS}=1.375W. As a single 1206-package resistor is rated for a power dissipation of 0.25W, at least 6 × 200kΩ 1206-package resistors in parallel are needed for long-term stable operation, allowing for some safety margin.

3.3.3 Select the pull-up resistor R_2

The ISOM8118-Q1 has transistor output characteristics similar to a conventional transistor and can operate in active, saturation, reverse, and cutoff regions. To ensure that a low level is correctly output after the input drops below the threshold at the minimum CTR, the R2 resistance must satisfy:

$$R_2 < \frac{VDD2 - V_{CE(SAT)}}{I_{Fmin} \times CTR_{MIN}} \tag{5}$$

where $V_{CE(SAT)}$ = 0.3V and CTR_{MIN} = 295%, so that R2<1.02kΩ is calculated. In the meantime, the R2 resistance should not be too small to avoid over-current at the ISOM8118-Q1 output, so the R2 resistance should also satisfy:

$$R_2 > \frac{VDD2 - V_{CE(SAT)}}{I_{CMAX}} \tag{6}$$

The calculation yields R2>60Ω. With these considerations in mind, choosing R2 to be 1kΩ ensures that the circuit works properly while effectively avoiding any risk of over-current

4 Summary

Opto-emulators can save voltage sampling at one end, compared to traditional weld detection solutions that compare the voltages at both ends of a relay with two voltage sampling chips. The ISOM811X-Q1 requires no high-side power supply and allows flexibility in configuration on both the high side and low side, with fewer components required for the peripheral circuit. While meeting the needs of a certain sampling accuracy, it also saves the ADC for the MCU and uses a GPIO port instead, providing advantages in cost control of system design, reduced circuit complexity, and optimized resource utilization. This offers a more cost-effective solution for relay weld detection in V2L for OBC applications.

5 References

1. GB/T 18487.4-202X
2. Isolated Bias Power Supply Architecture for HEV and EV Onboard Chargers
3. Relay - Wikipedia
4. Contact Arcing Phenomenon | TE Connectivity
5. ISOM811x-Q1 Data Sheet
6. What Is Vehicle-to-Load?

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