UM11847

RD772BJBTPL8EVB battery junction box

Rev. 1 — 2 May 2023

User manual

Document Information

Information	Content
Keywords	battery junction box, high voltage, 800 V, measurement, isolation, current, contactor, shunt, accuracy, temperature
Abstract	This user manual targets the RD772BJBTPL8EVB board. It is a typical battery junction box (BJB) solution used in high-voltage battery management system (BMS). The RD772BJBTPL8EVB is part of the high-voltage BMS reference design offered by NXP.

Revision history

Rev	Date	Description
1	20230502	initial version

1 Important notice

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2 Introduction

The RD772BJBTPL8EVB is a BJB reference design around two NXP MC33772C. The board is ideal to quickly prototype the hardware and the software of a high-voltage BMS.

This document describes the RD772BJBTPL8EVB features.

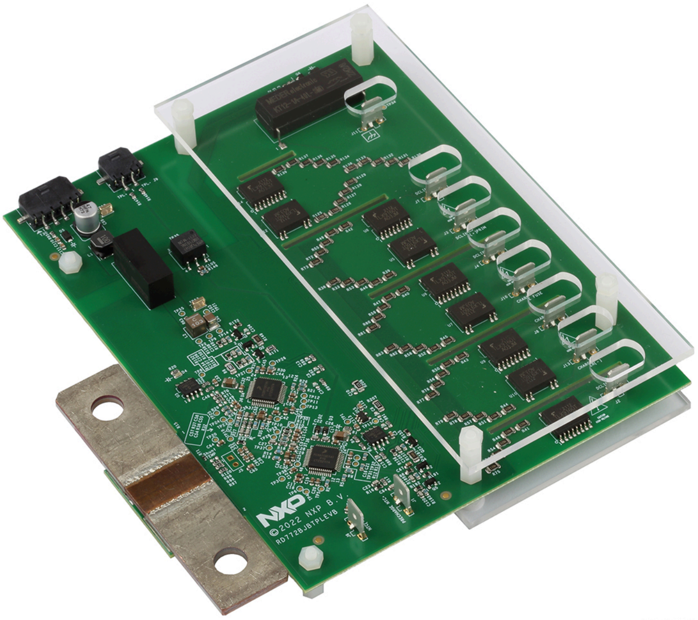
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Figure 1. RD772BJBTPL8EVB

3 Getting to know the hardware

3.1 Board overview

The RD772BJBTPL8EVB supports battery current measurement, contactor and fuse monitoring, isolation monitoring, and temperature measurement.

The battery management unit (BMU) communicates and controls the two MC33772CTC1AE. These ICs provide the necessary features to fulfill the various measurements.

Figure 2 presents the block diagram of the board and its interaction with the rest of the system.

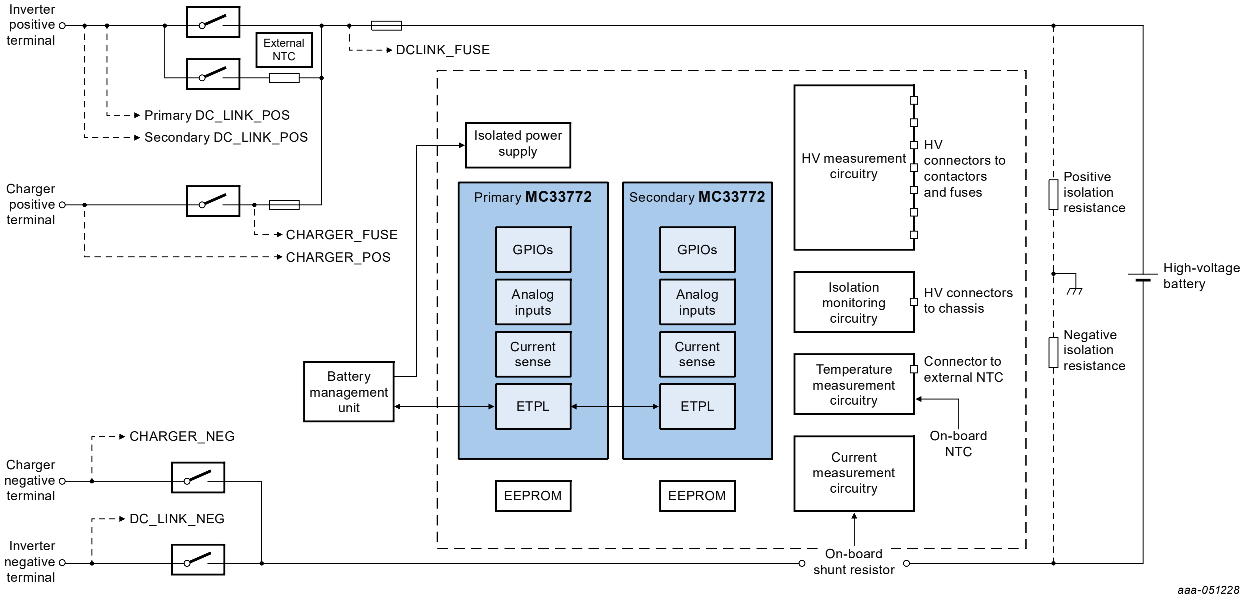

Figure 2. RD772BJBTPL8EVB block diagram

3.2 Board features

The RD772BJBTPL8EVB offers the following features:

- Five positive high-voltage measurement inputs (up to +1000 V)
- Two bipolar high-voltage measurement inputs (from −1000 V to +1000 V)
- Isolation monitoring between high-voltage and low-voltage domains
- Redundant current measurement with a 100 µΩ shunt resistor (from −1500 A to +1500 A)
- Shunt resistor temperature estimation
- Pre-charge resistor temperature measurement with an external sensor
- Two EEPROMs for calibration data storage
- Galvanically isolated electrical transport protocol link (ETPL) for communication
- Printed-circuit board designed according to IEC 60664 (pollution degree 2, material group IIIa)

3.3 Kit featured components

The Figure 3 lists the connectors and the LEDs available on the RD772BJBTPL8EVB.

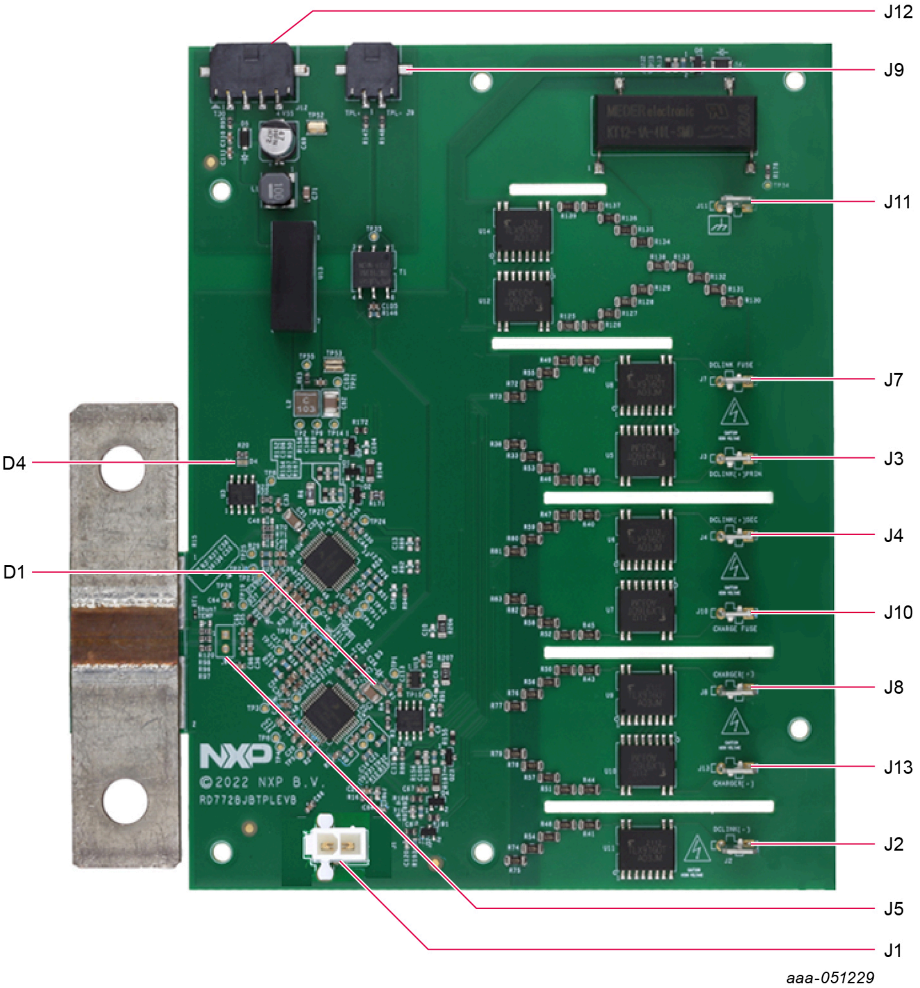

Figure 3. Connectors and LEDs location

3.3.1 Connectors

Table 1 lists the high-voltage connectors used for high-voltage measurement or isolation monitoring. Section 5 describes the associated cables.

Table 1. High-voltage connectors

Connector name	Description
J11	chassis connection for isolation monitoring
J7	DCLINK_FUSE input for voltage measurement
J3	primary DCLINK_POS input for voltage measurement
J4	secondary DCLINK_POS input for voltage measurement
J10	CHARGER_FUSE input for voltage measurement
J8	CHARGER_POS input for voltage measurement
J13	CHARGER_NEG input for voltage measurement
J2	DCLINK_NEG input for voltage measurement

Table 2 to Table 5 describe the remaining connectors and their pinout.

Table 2. Power supply connector

Connector name	Pin	Description
J12	1	power supply positive input (T30)
	2	do not connect
	3	do not connect
	4	power supply negative input (VSS)

Table 3. Communication connector

Connector name	Pin	Description
J9	1	positive ETPL input
	2	negative ETPL input

Table 4. Current emulation connector

Connector name	Pin	Description
J5	1	current measurement positive input
	2	current measurement negative input

Table 5. Pre-charge resistor temperature sensor connector

Connector name	Pin	Description
J1	1	temperature sensor positive input
	2	temperature sensor negative input

3.3.2 LEDs

Figure 3 highlights two LEDs:

- D1 (powered by the V_{COM} of the primary MC33772C)
- D4 (powered by the V_{COM} of the secondary MC33772C)

These components give information on the MC33772C operation mode. If an LED is on, the associated MC33772C is in active mode. If an LED is off, the integrated circuit is either unpowered, in reset, or in sleep.

3.4 Schematic, board layout, and bill of materials

The schematic, board layout, and bill of materials for the RD772BJBTPL8EVB are available at http://www.nxp.com/rd772bjbtpl8evb.

4 Features description

4.1 Power supply

The RD772BJBTPL8EVB usually receives power from the BMU on the connector J12. The power supply must follow the characteristics described in Table 6.

Table 6. Power supply characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{T30}	supply voltage		11	12	13	V
I_{T30}	supply current	RD772BJBTPL8EVB in normal mode; TPL communication active; all high-voltage switches enabled	-	160	200	mA
		RD772BJBTPL8EVB not active	-	20	-	mA

The BMU is in the low-voltage domain, whereas the BJB is in the high-voltage domain. Therefore, the RD772BJBTPL8EVB embeds an isolated DC-DC converter to power the MC33772C and the measurement circuitry. This converter is by default an industrial component. The designer must consider using an automotive DC-DC when the board is in an automotive environment.

4.2 Current measurement

The RD772BJBTPL8EVB measures redundantly the battery current with a single shunt resistor.

4.2.1 Current measurement characteristics

Table 7 describes the characteristics of the current measurement feature.

Table 7. Current measurement characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
R_{shunt}	shunt resistor value		-	100	-	μΩ
I_{BAT}	battery current under measurement	measurement with shunt resistor	−1500	-	+1500	A
V_{ISENSE}	voltage on ISENSE inputs measurement	measurement with shunt resistor or with voltage across J5	−150	-	+150	mV
$f_{ISENSE\text{-}DIFF}$	current measurement filter cut-off frequency	differential voltage; −3 dB attenuation	-	600	-	Hz
$f_{ISENSE\text{-}COMM}$	current measurement filter cut-off frequency	common-mode voltage; −3 dB attenuation	-	26.7	-	kHz

4.2.2 Current measurement circuit description

The RD772BJBTPL8EVB provides a shunt resistor to measure the battery current (from the battery to the inverter or from the battery to the charger). Typically, the shunt resistor is on the high-voltage battery negative terminal. It serves as a ground for the high-voltage section of the RD772BJBTPL8EVB (MC33772C, measurement circuitry...).

Each MC33772C measures the voltage drop across the shunt resistor to bring redundancy. As the current measurement is bipolar, the user can link the ISENSE+ and ISENSE− measurements pins to any side of the shunt resistor.

To ease the evaluation of the RD772BJBTPL8EVB, a connector (J5) is available in parallel of the shunt resistor. Then, a voltage source can replace a high-current source to validate the current measurement feature.

Figure 4 describes the current measurement circuitry.

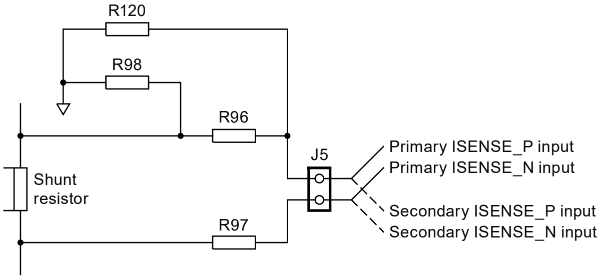

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Figure 4. Current measurement circuitry

The resistors placement defines whether the two MC33772C measure the voltage drop across the shunt resistor or across the connector, as explained in Table 8.

Table 8. Resistor placement for current measurement

Resistor	Placement when using shunt resistor	Placement when using a voltage source on J5
R120	do not place	0 Ω
R98	0 Ω	do not place
R96	0 Ω	do not place
R97	0 Ω	do not place

4.2.3 Current measurement layout guideline

The layout of the current measurement paths is compatible with the use of an external voltage source. Due to this option, both paths are dependent.

In a real application, the current measurement paths must be independent. The connection points to the sense element of the shunt resistor have to be redundant as shown in Figure 5.

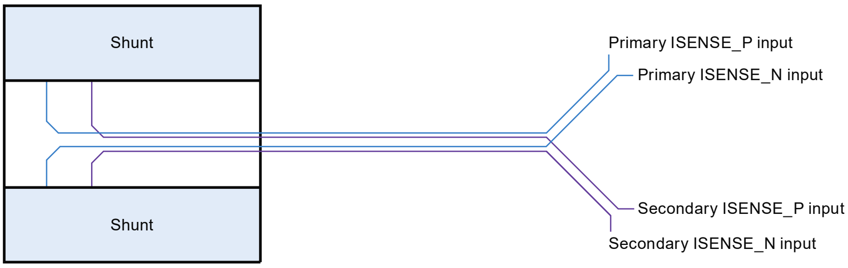

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Figure 5. Current measurement layout guideline

4.2.4 Current measurement conversion

After a current measurement, both MC33772C return a 19-bit signed value available in the registers MEAS_ISENSE1 and MEAS_ISENSE2. The microcontroller in the BMU computes the result following below equation:

$$I_{MEAS} = \frac{MEAS\_ISENSE \times V_{2RES}}{R_{SHUNT}}$$

Where:

- I_{MEAS} is the result of the current measurement in A
- MEAS_ISENSE is the result of the analog-to-digital converter (ADC) of the MC33772C (19-bit two's complement signed value, status bit removed)
- V_{2RES} is the resolution of the current measurement ADC in V/LSB (see MC33772C data sheet)
- R_{SHUNT} is the value of the shunt resistor in Ω
  - If the current measurement uses the shunt, R_{SHUNT} = 100 µΩ
  - If the current measurement uses the connector J5, R_{SHUNT} = 1 and the result unit is V

4.3 High-voltage measurement

The RD772BJBTPL8EVB measures several high voltages in the system. The BMU can compute the result and proceed, for instance, to contactor monitoring.

4.3.1 High-voltage measurement characteristics

Table 9 describes the characteristics of the high-voltage measurement feature.

Table 9. High-voltage measurement characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$V_{HV\text{-}MAX}$	maximum off-state voltage	high-voltage switch disabled	−1500	-	+1500	V
V_{HV+}	positive voltage measurement range	high-voltage switch enabled	0	-	1000	V
$V_{HV+/-}$	bipolar voltage measurement range	high-voltage switch enabled	−1000	-	+1000	V
t_s	voltage measurement settling time		-	5	-	ms
f_{HV+}	positive voltage measurement cut-off frequency	−3 dB attenuation	-	600	-	Hz
f_{HV-}	bipolar voltage measurement cut-off frequency	−3 dB attenuation	-	500	-	Hz

4.3.2 High-voltage measurement circuit description

The RD772BJBTPL8EVB measures up to seven high voltages in the system.

The five positive inputs typically monitor the voltage across the high side contactors and fuses (ex: contactor between battery positive terminal and inverter positive terminal). These inputs accept high-voltages meeting V_{HV+} (see Section 4.3.1). Two inputs can monitor the same point in order to provide redundancy and increase the overall safety integrity level.

The two bipolar inputs typically monitor the voltage across the low side contactors (ex: contactor between battery negative terminal and charger negative terminal). These inputs accept high-voltages meeting $V_{HV+/-}$ (see Section 4.3.1).

Figure 6 describes the circuitry of positive and bipolar high-voltage measurement paths.

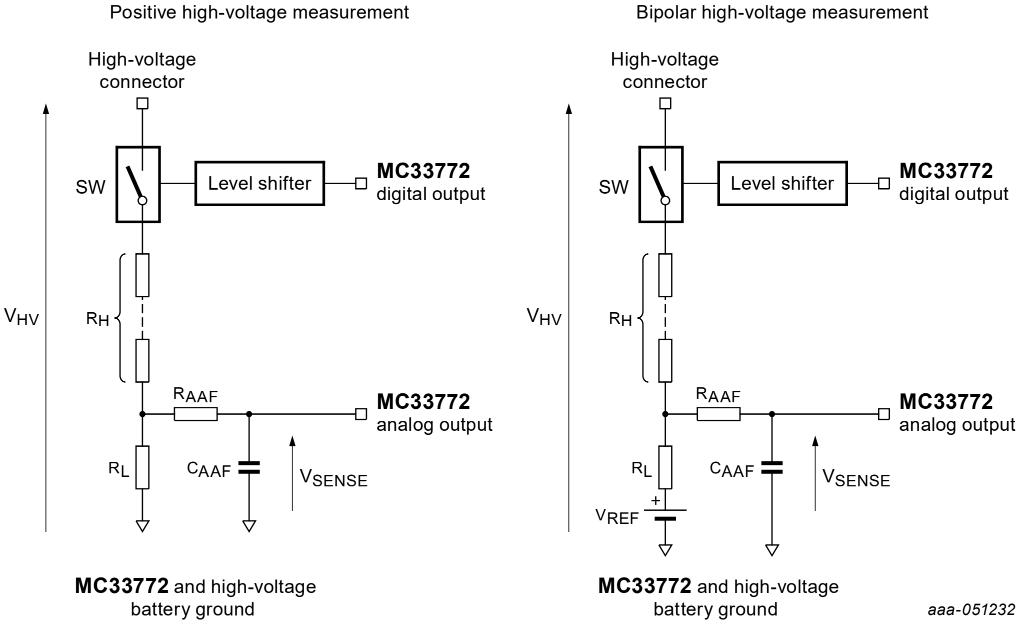

Figure 6. High-voltage measurement circuitry

In order to reduce the leakage current in the resistors when there is no measurement, a high-voltage switch can disconnect the bridge. A MC33772C digital output and a level-shifter control this switch.

A resistor bridge divides the high voltage down to the MC33772C input voltage range. The resistors forming R_H must withstand the high voltage.

For bipolar voltage measurement, a voltage reference shifts the output of the resistor bridge to half of the MC33772C input voltage range.

An analog antialiasing filter improves the noise performance. Due to the filter and the switch circuitry response time, the BMU must wait t_s before starting a voltage measurement (see Section 4.3.1).

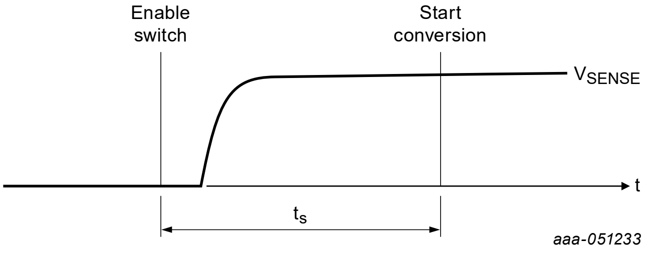

Figure 7. High-voltage measurement settling time

The MC33772C measures the divided voltage. To improve the accuracy, the user should configure the analog input as a single-ended input.

Table 10 describes the allocation of the MC33772C inputs and outputs for high-voltage measurement.

Table 10. High-voltage measurement channel allocation

High-voltage switch control signal	High-voltage measurement	MC33772C measurement input
Primary GPIO4	primary DCLINK_POS	primary CT1
	DCLINK_FUSE	primary GPIO2
	DCLINK_NEG	primary GPIO0
Secondary GPIO4	CHARGER_POS	secondary GPIO1
	CHARGER_NEG	primary GPIO1
Secondary GPIO5	secondary DCLINK_POS	secondary CT1
	CHARGER_FUSE	secondary GPIO2

4.3.3 High-voltage measurement conversion

After a voltage measurement, the MC33772C returns a 15-bit signed value available in the register MEAS_ANx or MEAS_CT1 depending on the channel (see Table 10). The microcontroller in the BMU computes the result following below equations:

$$V_{HV} = \frac{R_L+R_H}{R_L} \times \left(V_{MEAS} - \frac{R_H}{R_L+R_H} \times V_{REF}\right)$$

$$V_{MEAS} = MEAS\_XXX \times V_{CT\_ANx\_RES}$$

Where:

- V_{HV} is the result of the high-voltage measurement in V
- R_L is the low-side resistor of the voltage divider in Ω (see Table 11)
- R_H is the high-side resistor of the voltage divider in Ω (see Table 11)
- V_{REF} is the voltage to which the voltage divider is referenced in V (see Table 11)
- V_{MEAS} is the MC33772C input voltage, measured by the ADC, in V
- MEAS_XXX is the result of the ADC conversion (15-bit unsigned value, status bit removed)
- $V_{CT\_ANx\_RES}$ is the resolution of the ADC in V/LSB (see MC33772C data sheet)

Table 11 describes the conversion parameters depending on the type of measurement.

Table 11. Voltage conversion parameters

Parameter	Positive voltage measurement channel	Bipolar measurement channel
R_L	10 kΩ	5.1 kΩ
R_H	2.01 MΩ	2.01 MΩ
V_{REF}	0 V	2.5 V

4.3.4 Adapting circuitry for low-voltage measurements

Using a low-voltage source can ease the RD772BJBTPL8EVB evaluation. However, as the board typically measures high voltages, the user should adapt the circuitry.

The simplest solution is to change the low-side resistor of the voltage divider (R_L in Figure 6). By choosing a bigger resistor, the divider ratio increases, allowing to measure smaller voltages.

The time constant of the antialiasing filter depends on the divider impedance. In order to keep the same cut-off frequency, the user should adapt the capacitor of the filter (C_{AAF} in Figure 6) along with R_L.

Table 12 presents typical values for R_L and C_{AAF} to measure low voltage. Following these values ensures meeting the MC33772C measurement range.

Table 12. Component values to measure low voltage

Low voltage to measure	Positive measurement channel		Bipolar measurement channel	
	R_L	C_{AAF}	R_L	C_{AAF}
+12 V	1.3 MΩ	470 pF	620 kΩ	1 nF
+24 V	470 kΩ	1 nF	240 kΩ	2.2 nF
+48 V	220 kΩ	2.2 nF	100 kΩ	4.4 nF

The user must clearly identify the modified RD772BJBTPL8EVB. **Applying high voltage to a modified board can lead to injuries and permanent damage to the board**.

4.4 Isolation monitoring

The RD772BJBTPL8EVB is in between the low-voltage section (car chassis, +12 V battery) and the high-voltage section (high-voltage battery, inverter) of the car. The board embeds the circuitry to monitor the isolation between the two sections. It helps detecting any isolation failure that could put the car user in danger.

4.4.1 Isolation monitoring characteristics

Table 13 describes the characteristics of the isolation monitoring feature.

Table 13. Isolation measurement characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$V_{Chassis\text{-}MAX}$	maximum chassis off-state voltage	high-voltage switch disabled	−3000	-	+3000	V
t_s	voltage measurement settling time		-	10	-	ms

4.4.2 Isolation monitoring circuit description

Figure 8 describes the isolation monitoring circuitry.

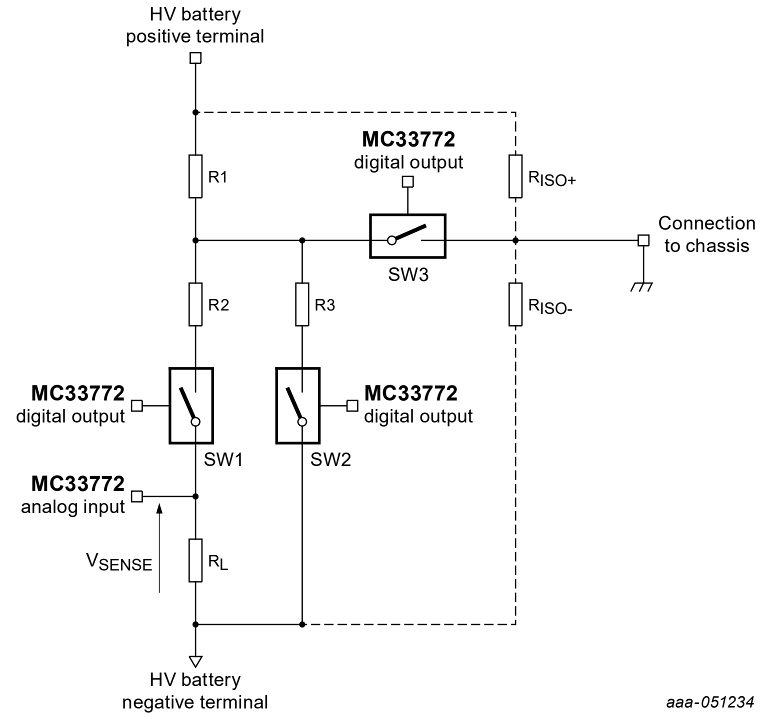

Figure 8. Isolation monitoring circuitry

This feature aims to evaluate the value of the equivalent resistance between:

- The battery positive terminal and the chassis (R_{ISO+})
- The battery negative terminal and the chassis (R_{ISO-})

A high-voltage switch (SW3) connects the chassis to the circuit prior doing the measurement. As the measurement resistors are high enough, closing SW3 does not lead to an isolation failure and does not put the car user in danger.

Another high-voltage switch (SW1) disconnects the resistor bridge to reduce the leakage current on the high-voltage battery when there is no measurement.

The circuit has to measure two resistors (R_{ISO+} and R_{ISO-}). Two voltage measurements are necessary to solve this two-unknown equation. The first measurement involves R1, R2, and R_L. Enabling R3 (with SW2) allows getting a second voltage measurement. Section 4.4.3 describes the measurement sequence.

The output voltage (V_{SENSE}) depends on the measurement circuitry (R1, R2, R_L, and R3 if enabled), the battery voltage, and the isolation resistors. The MC33772C measures this voltage. To improve the accuracy, the user should configure the analog input as a single-ended input.

Table 14 describes the allocation of the MC33772C inputs and outputs for isolation monitoring.

Table 14. Isolation monitoring channel allocation

Function	Channel
SW1 control	secondary GPIO6
SW2 control	primary GPIO6
SW3 control	primary GPIO5
V_{SENSE} measurement	secondary GPIO0

Due to the switch circuitry response time, the BMU must wait t_s before starting each voltage measurement (see Section 4.4.1).

After running the sequence, the BMU computes the voltage measurements to determine the isolation resistors as explained in Section 4.4.4.

4.4.3 Isolation monitoring sequence

Table 15 describes the steps of the isolation monitoring sequence.

Table 15. Isolation monitoring sequence

Step	Description
1	measure the battery voltage (ex: DCLINK_FUSE), as explained in Section 4.3
2	convert the high-voltage measurement (as explained in Section 4.3.3); name the result V_{BAT}
3	close SW3
4	close SW1
5	wait t_s (see Section 4.4.1)
6	measure V_{SENSE}
7	convert the voltage measurement (as explained in Section 4.4.4); name the result V_1
8	close SW2
9	wait t_s (see Section 4.4.1)
10	measure V_{SENSE}
11	convert the voltage measurement (as explained in Section 4.4.4); name the result V_2
12	open SW1, SW2, and SW3
13	to calculate the isolation resistors, compute the V_{BAT}, V_1, and V_2 (as explained in Section 4.4.4)

4.4.4 Isolation monitoring conversion

During the isolation monitoring sequence, the MC33772C proceeds to voltage measurements. The IC returns a 15-bit signed value available in the register MEAS_ANx. The microcontroller in the BMU computes the result in V following below equation:

$$V_{MEAS} = MEAS\_XXX \times V_{CT\_ANx\_RES}$$

Where:

- V_{MEAS} is the MC33772C input voltage, measured by the ADC, in V
- MEAS_XXX is the result of the ADC conversion (15-bit unsigned value, status bit removed)
- $V_{CT\_ANx\_RES}$ is the resolution of the ADC in V/LSB (see MC33772C data sheet)

Once the sequence is over, the BMU computes the measurements to calculate the isolation resistors. To ease the calculation, the formula uses the conductance instead of the resistance. Below equation describes the relationship between resistance and conductance.

$$Y_x = \frac{1}{R_x}$$

Where:

- Y_X is the conductance in S
- R_X is the resistance in Ω

The formula expressing the isolation resistances in function of the measurements is as follows:

$$\begin{cases} Y_{ISO+} = \dfrac{V_1 \times V_2}{V_{BAT} \times (V_2 - V_1)} \times \dfrac{Y_3 \times (Y_L + Y_2)}{Y_2} - Y_1 \\ Y_{ISO-} = -Y_{ISO+} - Y_1 - \dfrac{Y_L \times Y_2}{Y_L + Y_2} - Y_3 \times \dfrac{V_2}{V_2 - V_1} \end{cases}$$

Where:

- Y_{ISO+} is the conductance of the positive isolation resistance in S
- Y_{ISO-} is the conductance of the negative isolation resistance in S
- V_{BAT} is the converted high-voltage measurement of the battery in V
- V_1 is the first converted voltage measurement of the sequence in V
- V_2 is the second converted voltage measurement of the sequence in V
- Y_L, Y_1, Y_2, and Y_3 are the conductances of the measurement resistors in S

Table 16 describes the conversion parameters of the RD772BJBTPL8EVB.

Table 16. Isolation measurement conversion parameters

Parameter	Value
R_L	24 kΩ
R_1	4.03 MΩ
R_2	4.03 MΩ
R_3	685 kΩ

4.5 Temperature measurement

The RD772BJBTPL8EVB measures up to two temperatures with negative temperature coefficient (NTC) resistors.

The board embeds one sensor close to the shunt resistor. It allows estimating the shunt resistor temperature in order to proceed to temperature compensation of the current measurement.

The board offers the possibility to use an external NTC. This sensor could measure, for instance, the pre-charge resistor temperature.

4.5.1 Temperature measurement characteristics

Table 17 describes the characteristics of the temperature measurement feature.

Table 17. Temperature measurement characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$R_{NTC\text{-}board}$	onboard NTC resistor	value at 25 °C (B57232V5103F360, TDK)	-	10	-	kΩ
$R_{NTC\text{-}ext}$	external NTC resistor	value at 25 °C	-	10	-	kΩ

4.5.2 Temperature measurement circuit description

Figure 9 describes the temperature measurement circuitry.

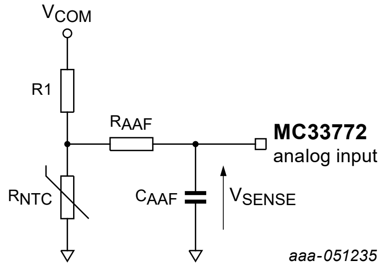

Figure 9. Temperature measurement circuitry

The regulated output voltage of the MC33772C (V_{COM}) powers the voltage divider with the NTC resistor. To improve the accuracy of the measurement, the user should configure the analog input as ratiometric input.

Table 18 describes the allocation of the MC33772C inputs for temperature measurement.

Table 18. Temperature measurement channel allocation

Function	Channel
Temperature measurement with external NTC	primary GPIO3
Temperature measurement with onboard NTC	secondary GPIO3

4.5.3 Temperature measurement conversion

After a temperature measurement, the MC33772C returns a 15-bit signed value available in the register MEAS_ANx. The microcontroller in the BMU computes the NTC resistor value following below equation:

$$R_{NTC} = \frac{R_1}{\frac{2^{15}}{MEAS\_ANx} - 1}$$

Where:

- R_{NTC} is the result of the NTC resistor measurement in Ω
- R_1 is the pullup resistor, R_1 = 6.8 kΩ in the RD772BJBTPL8EVB
- MEAS_ANx is the result of the ADC measurement (15-bit unsigned value, status bit removed)

After computing the NTC resistor value, the BMU can calculate the temperature with below equation:

$$T = \frac{\beta \times T_0}{T_0 \times \ln\left(\frac{R_{NTC}}{R_0}\right) + \beta}$$

Where:

- T is the result of the temperature measurement in K
- R_{NTC} is the NTC resistor measurement in Ω
- β in K, T_0 in K, and R_0 in Ω are the NTC parameters available in the NTC data sheet

4.6 Communication

The RD772BJBTPL8EVB communicates with the BMU with ETPL. A transformer galvanically isolates both boards. The ETPL lines between the two MC33772C do not require isolation as the two IC share the isolated ground. The MC33772C data sheet describes the required circuitry for the communication.

5 Kit accessories

Table 19 lists the available kit accessories.

Table 19. Available kit accessories

Part number	Description
600-77574	ETPL cable, 2 positions, 2000 mm
600-77576	power supply cable, 4 positions, 500 mm
600-77763	high-voltage measurement cable, 1 kV isolation, 1 position, 300 mm
600-77776	external NTC resistor cable, 1 kV isolation, 2 positions, 300 mm
600-77765	chassis cable, 1 position, 1 kV isolation, 300 mm

6 References

[1] Data sheet MC33772C http://www.nxp.com/MC33772C

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