Application Note

Design Guide for Automotive Door Crash Power Module (CPM)

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ABSTRACT

This document was translated from a simplified Chinese source. (ZHCAG59)

The automotive Crash Power Module (CPM) is a safety subsystem that provides emergency power, signals, and control at the exact moment of a vehicle collision. It achieves millisecond-level response and failover through dual-power redundancy, ensuring that critical functions such as door unlocking operate reliably under extreme impacts to facilitate the rapid escape of occupants. With the widespread adoption of electric doors and hidden/semi-hidden door handles in new energy vehicles, the CPM has taken on an increasingly vital practical significance. Combining the characteristics of supercapacitors and unlock motors within the CPM module, this paper introduces the basic architecture and system configurations, and provides circuit designs and experimental verifications based on the electrical characteristics of 3-cell and 5-cell supercapacitors in series (3s and 5s configurations).

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1 Introduction

1.1 Function and Significance

As a dedicated crash protection module, the CPM primarily ensures redundant door unlocking in the event that the low-voltage battery is disconnected post-collision, which is achieved through coordinated operation with sensors, control modules, and actuators as part of the automotive safety system.

- Ensuring Passenger Safety: Doors can be unlocked post-collision, enabling passengers to evacuate swiftly and increasing the success rate of escape.
- Improving Rescue Efficiency: Once the doors are unlocked, rescue personnel can quickly gain access to the vehicle interior, minimizing the risk of casualties.

1.2 Regulatory Requirements

GB 20072-2024 (Requirements for Passenger Cars in Rear-End Collision Safety) explicitly mandates that automatically activated door locking systems must satisfy specific criteria during crash tests, such as requiring doors to be in an unlocked state after a collision while being automatically locked prior to the impact.

GB 20071-2025 (Passenger Protection in Lateral Collision) introduces new requirements for automatically activated door locking systems, dictating that doors must be capable of being unlocked post-collision to facilitate rescue operations, which will come into effect on July 1, 2026.

2 System Architecture

2.1 CPM Structure and Application Challenges

The architecture of CPM modules can be categorized into centralized and distributed configurations based on their physical location within the vehicle body. If a single module is located at the center of the vehicle and connects to the locking mechanisms of all four doors, it is defined as a centralized architecture. Alternatively, if two ECU units control the left and right side doors respectively, or if four separate units correspond individually to the four doors, it constitutes a distributed layout.

	Centralized	Distributed
Advantages	Single ECU utilizing 5s/3s capacitors, offering superior cost-efficiency Flexible placement with a lower probability of module damage during collisions	Can be integrated into the left/right Zone Control Units (ZCUs), achieving higher integration and faster response times Fewer cables, reducing electrical risks and enhancing reliability
Disadvantages	Located further from the doors, leading to a slower response time Longer wiring harnesses are prone to wear and tear, increasing the risk of open/short circuits	Multiple ECU units, leading to increased costs High complexity in coordinating control among individual control units

The centralized CPM acts as an independent ECU unit that communicates with the ZCU via the CAN bus to verify its functional status. Because both the CPM and the ZCU target the same door unlock motor, they are configured in a parallel relationship within the control circuit. The figures below illustrate the structural schematics for driving the motor using an H-bridge driver IC and a high-side switch IC, respectively.

Schematic of Parallel Relationship between ZCU/BCM and CPM

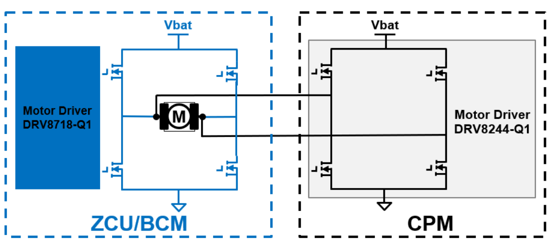

Figure 2-1. H-Bridge Driver DRV8244-Q1 Scheme

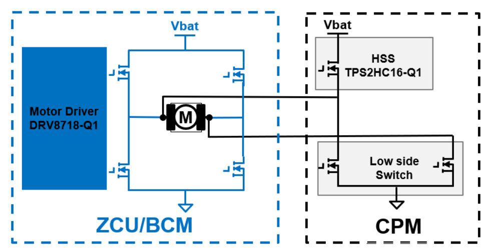

Figure 2-2. High-Side Switch TPS2HC16-Q1 Scheme

Redundant control under a parallel topology introduces electrical coupling challenges. The potential risks and their corresponding mitigation measures are outlined below.

1. When the CPM attempts to unlock the motor, if the H-bridge within the ZCU is in a low-side conduction state to lock the motor, it may cause the supercapacitor output to short directly to ground.
2. While the CPM drives the motor, the back electromotive force (back-EMF) can reverse-charge the low-voltage battery through the body diodes of the ZCU's H-bridge. The same reverse-charging risk applies in the direction from the ZCU to the CPM.
3. Door unlock motors typically require periodic offline diagnostics to confirm the health status of the motor and its wiring harness. The principle of offline diagnostics involves the driver IC providing an excitation signal via an internal current source and detecting the voltage status of each MOSFET. If the ZCU and CPM execute offline diagnostics simultaneously, erroneous diagnostic results may occur, or the driver ICs could be directly damaged.
4. During the process where the ZCU controls the motor's switching cycle, voltage spikes or pulses may be generated at the switching nodes. This poses a risk of electrical overstress damage to the control ICs within the CPM unit. Consequently, the CPM driver IC must possess sufficient voltage rating, or designers must add external Transient Voltage Suppressor (TVS) diodes to absorb the transient energy.

2.2 Main Functional Units

1. Crash Detection and Trigger Unit: Detects collision events via crash sensors such as accelerometers and Inertial Measurement Units (IMUs), generating trigger signals that are transmitted to the ZCU and CPM.
2. Redundant Power Supply and Monitoring Unit: Composed of supercapacitors, a charge/discharge topology, and a fuel gauge module. It serves as a backup power system for the vehicle's low-voltage battery, ensuring the motor has sufficient energy to complete the unlocking sequence following a crash.
3. Unlock Execution Unit: Includes electromagnetic locks, motor drivers, or mechanical unlock mechanisms, which must meet the requirements of rapid response (<1 second) and high reliability.
4. Control and Communication Unit: The MCU monitors the crash trigger signals and manages the control and diagnostics of the motor driver. Concurrently, it reports its functional status to the ZCU via the CAN bus.

3 Critical CPM Parameters

3.1 Basic Parameters of 3s and 5s Supercapacitors

Supercapacitors are energy storage components positioned between conventional capacitors and batteries. They store electrical energy primarily through electric double-layer capacitance and pseudocapacitance redox reactions, offering high power density, long cycle life, a wide operating temperature range, and rapid charge/discharge capabilities. Supercapacitors commonly used in CPMs have capacities of 25F or 30F with rated voltages of 2.7V or 3V. These supercapacitors are connected in series; as the number of cells increases, the total voltage increases while the total capacitance decreases. Taking a rated voltage of 2.7V and a capacitance of 25F per cell as an example:

	3s	5s
Capacitance Value	8.33F	5F
Rated Voltage	8.1V	13.5V
Operating Voltage Range	3V - 7.5V	9V - 12.5V
Stored Energy	196.79J	188.12J

Using the formula, $W = 1/2\ CU^2$, the energy stored by the 3s and 5s configurations can be calculated as 196.79J and 188.12J, respectively. Overall, the energy storage of the 3s topology is slightly higher than that of the 5s topology. Regarding the operating voltage range, the 5s supercapacitor can be charged up to 12.5V, which is close to the operating voltage range of typical motor loads (typically 9–16V). Therefore, the 5s capacitor can directly power the motor. If it needs to discharge below 9V to extract more energy output, a boost circuit must be added between the supercapacitor and the motor load; conversely, the 3s supercapacitor can only be charged up to a maximum of 7.5V, necessitating a boost circuit to satisfy the motor operating voltage requirements. Thus, the 3s scheme can support a lower capacitor discharge voltage. However, a lower boost input voltage results in a higher input current; limited by the boost input-side current and the maximum discharge current of the supercapacitor, the minimum discharge voltage is set to 3V.

3.2 Door Unlock Motor Parameters and Power Consumption Calculation

A typical door lock system includes at least four door locks, and depending on the vehicle type, it may also feature four door-handle locks and two safety locks. The motors used are brushed unlock motors operating in a single direction, and a half-bridge topology can be employed for the motor drive.

The maximum current of lock motors varies from 7A to 20A. The figure below depicts a typical profile of door unlock motor current over time, which is divided into four stages from startup to shutdown: an inrush current of 7A lasting approximately 3ms; normal motor operation at 5A lasting 60ms; a heavy-load current of 7.5A lasting 40ms; and a locked-rotor current of 8A lasting 150ms.

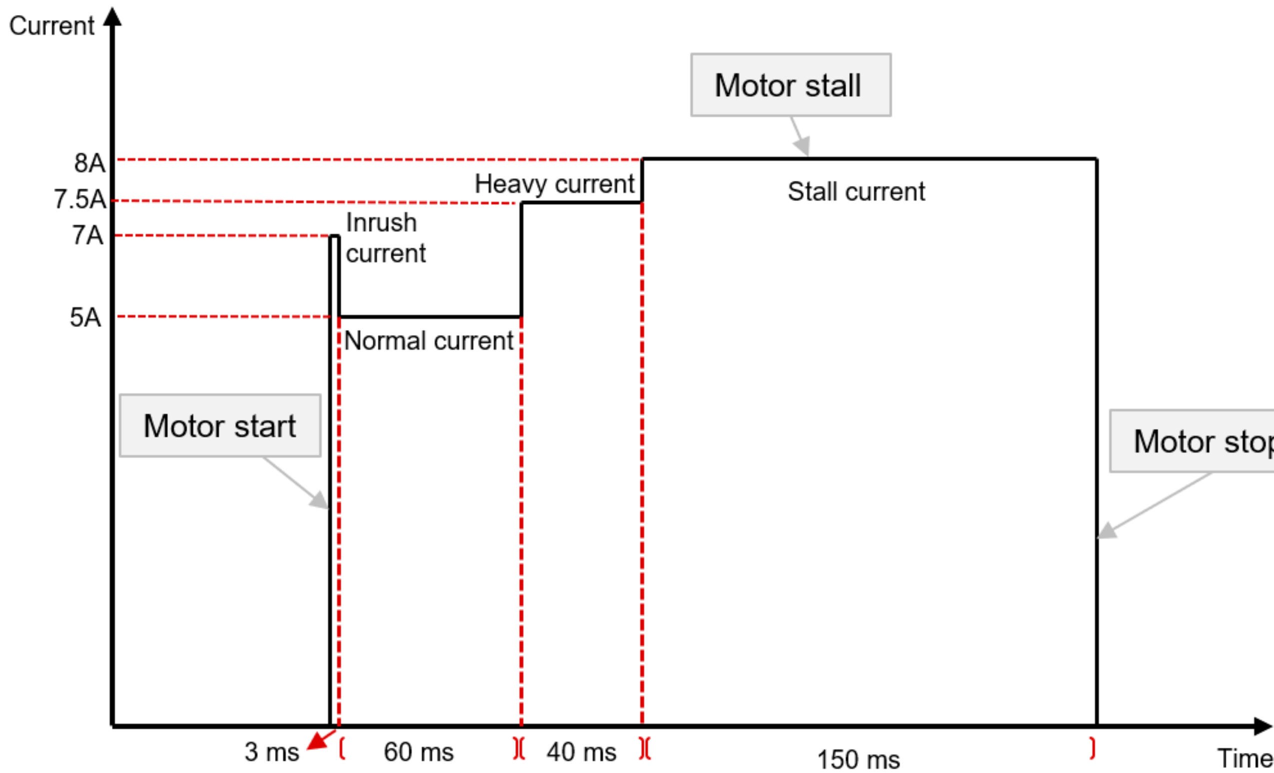

Figure 3-1. Diagram of Unlock Motor Current over Time

Taking the 5s supercapacitor as an example, the energy consumption and voltage variation during motor operation are calculated for a setup including four door locks and two safety locks, with an initial capacitance of 5F and a voltage of 12.5V. Since the motors are started sequentially and the voltage continuously drops during the unlocking process of each motor, for simplicity of calculation, the voltage is approximated as constant during a single motor's unlocking sequence (i.e., it does not fluctuate with actions like startup, rotation, or locked-rotor conditions). Additionally, the duty cycle of the motor's PWM control is approximated at 50%. The calculation process for one round of discharge is as follows:

$\Delta W = UI \times t$	W	$U = \sqrt{2W/C}$
	390.63J	12.50V
$12.50V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 11.38$	379.25J	12.32V
$12.32V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 11.21J$	368.04J	12.13V
$12.13V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 11.05J$	356.99J	11.95V
$11.95V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 10.88J$	346.11J	11.77V
$11.95V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 10.71J$	335.40J	11.58V
$11.58V \times 50\% \times (7A \times 3ms + 5A \times 60ms + 7.5A \times 40ms + 8A \times 150ms) = 10.54J$	324.85J	11.40V

A single round of discharge for the six locks consumes a total of 65.78J, leaving a residual voltage of 11.40V after discharge. To satisfy redundant safety requirements, the system is generally required to support at least two rounds of discharge. Since the energy storage of the 3s and 5s topologies is 196.79J and 188.12J respectively, both can support at least two rounds of discharge.

3.3 Charging Time Requirements

The charging curves of supercapacitors differ from those of batteries, primarily in the initial charging phase. A battery must undergo trickle charging and pre-charging before entering constant-current charging, whereas a supercapacitor transitions directly into constant-current charging. The supercapacitor charging process is shown in the following figure:

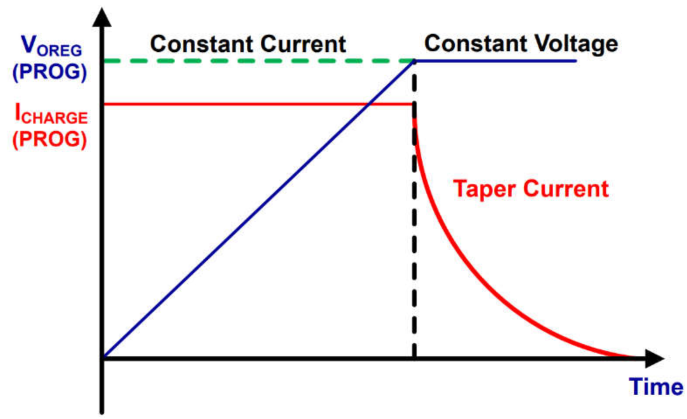

Figure 3-2. Schematic of Supercapacitor Charging Process

Different OEMs specify varying scenario configurations and charging time requirements, with typical charging times ranging from a dozen seconds to several minutes. A shorter charging time implies a larger charging current, which influences the choice of charging topology. For charging currents of a few hundred milliamperes, a linear charging topology can be selected, while switching-mode power supply topologies are preferred for currents of 1A and above.

4 5s System Scheme

The table below highlights an example of the system requirements for a 5s supercapacitor CPM. The operating voltage range of the supercapacitor aligns with the motor voltage requirements, allowing it to connect directly to the power supply terminal of the motor. The CPM module integrates chips such as a charger, AFE, motor driver, MCU, and SBC. The recommended system block diagram is shown in Figure 4-1.

Charging Time	120s
Total Supercapacitor Capacitance	5F
Supercapacitor Operating Voltage Range	9~12.5V
System Input Voltage Range	9~16V
Motor Operating Voltage Range	9~16V

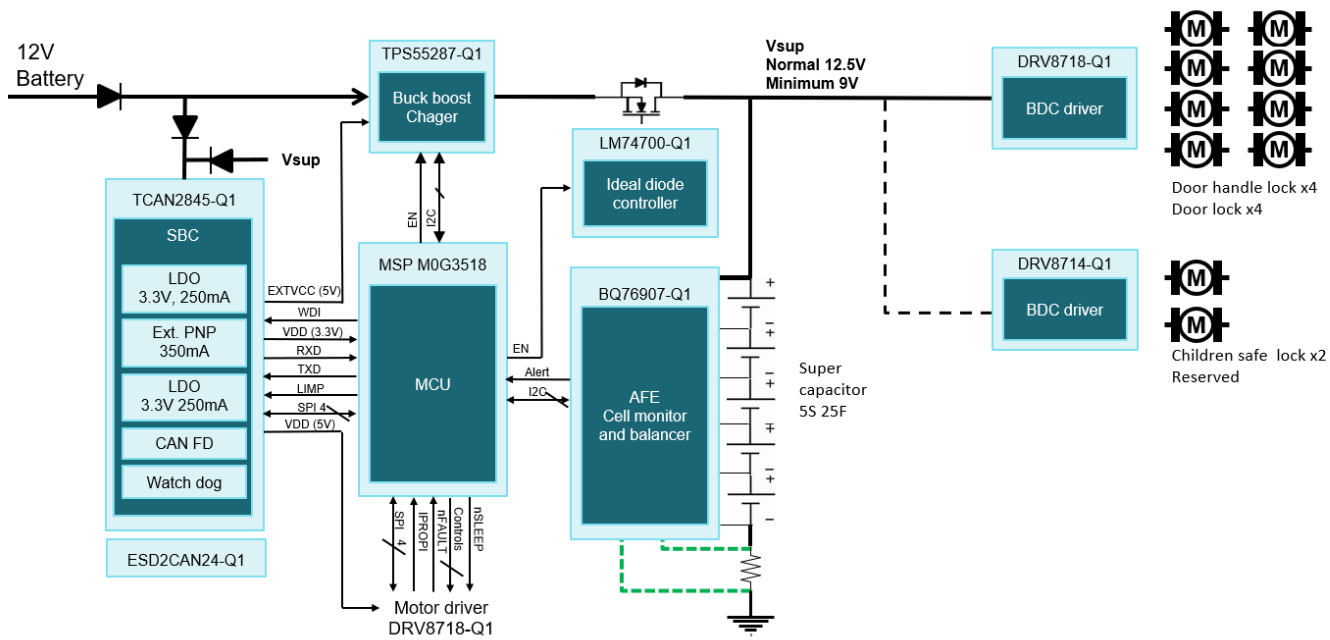

Figure 4-1. 5s Supercapacitor System Block Diagram

The BQ76907-Q1 serves as the AFE chip, monitoring the individual cell voltages of the supercapacitor and reporting the capacitor status to the MCU in real time via I2C and Alert outputs. Additionally, this chip supports a cell balance function, ensuring voltage uniformity across all capacitor cells through passive balancing. Its integrated shunt input can be utilized for charging current monitoring and low-current system wake-up.

It is recommended to place a diode on the output side of the charger. The LM74700-Q1, acting as an ideal diode controller, serves the following purposes here:

1. Supercapacitors are prone to overcharging, which can cause their voltage to exceed that of the 12V battery. The LM74700-Q1 provides reverse-polarity and reverse-current protection.
2. The output side of a buck-boost charger features a voltage divider resistor network. If directly connected to the supercapacitor, it would incur a leakage current close to 100uA, thereby degrading the capacitor's energy retention capability and increasing total system standby power. The LM74700-Q1 effectively blocks this current leakage path.

For the initial charge from 0V to 12.5V within a mandated 120s charging time, the required charging current must be no less than 520.83mA. The TPS55287-Q1 is selected as the charger chip, featuring an average inductor current capability of 4A. The constant-current output value is established via a current sense resistor, $I_{OUT\_LIMIT} = \frac{V_{SNS}}{R_{SNS}}$, with V_{SNS} at 50mV, a 20mΩ resistor corresponds to a charging current of 2.5A. The voltage divider resistor string sets the constant output voltage value R_{top} = 95kΩ, R_{bot}= 10kΩ. Once the chip is powered up and enabled, the internal current loop initiates, clamping the output at the designated current limit. The output voltage increases linearly from zero until it reaches the set target, at which point the current begins to decrease until it decays close to zero.

The DRV8718-Q1 serves as the motor driver chip, integrating an 8-channel half-bridge gate driver capable of simultaneously controlling 4 H-bridges to drive 4 unlock motors. Users can select different MOSFETs based on the operating current of the unlock motors to accommodate various vehicle platforms.

The MSPM0G3518-Q1 is an Arm Cortex-M0+ core MCU operating at a main frequency of 80MHz. It features 128KB RAM and 256KB Flash, integrates a CAN-FD controller, and is responsible for managing the execution of the CPM system.

The Table 4-1 below display the voltage and current waveforms over time during the charging process under various input voltages. Upon power-up, the current exceeds the configured output current limit because there is a 128µs delay before the current limit triggers. The ripple in the inductor current is attributed to the device operating in PFM mode during the soft-start period.

Table 4-1. TPS55287-Q1 Voltage and Current Waveforms during Charging under Different Input Voltages

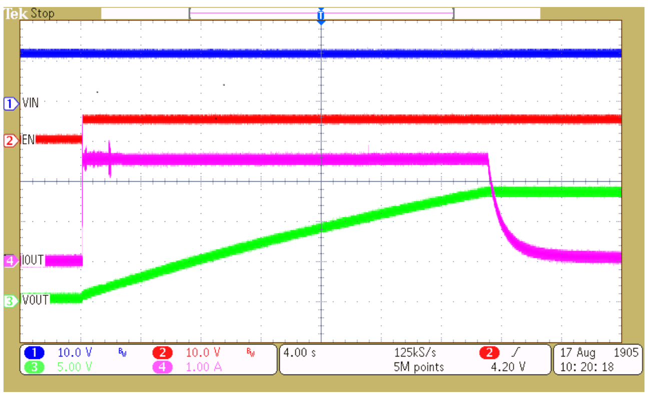

Figure 4-2. Charging Process at VIN = 12V

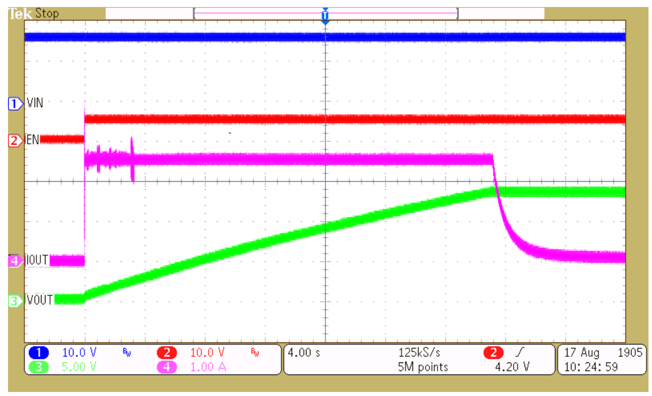

Figure 4-3. Charging Process at VIN = 16V

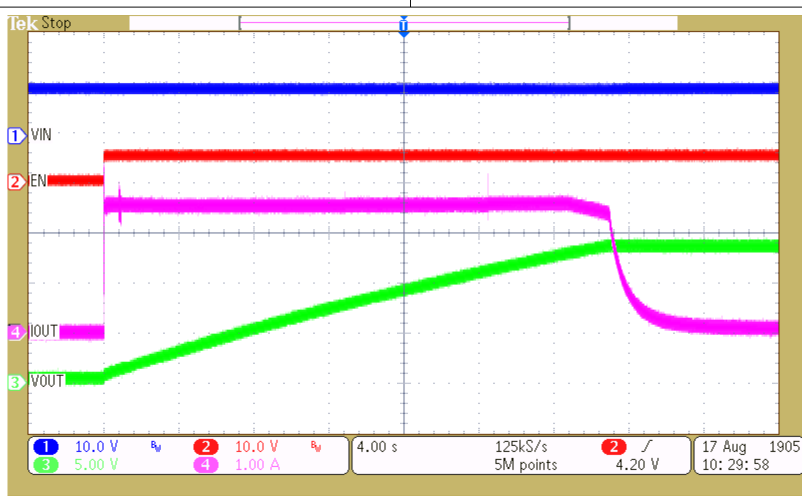

Figure 4-4. Charging Process at VIN = 9V

5 3s System Scheme

The table below presents an example of the system requirements for a 3s supercapacitor CPM:

Charging Time	60s
Total Supercapacitor Capacitance	8.33F
Supercapacitor Operating Voltage Range	3~7.5V
System Input Voltage Range	9~16V
Motor Operating Voltage Range	9~16V

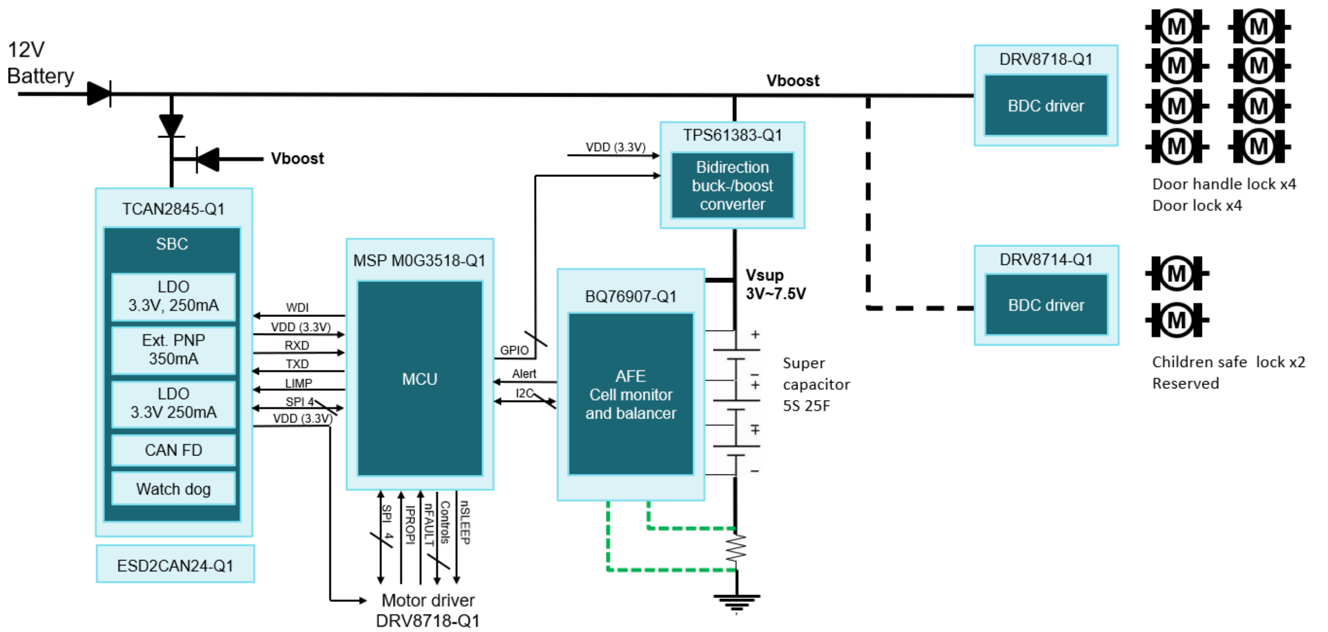

Figure 5-1. 3s Supercapacitor System Block Diagram

The TPS61383-Q1 is a bidirectional buck/boost converter equipped with battery health monitoring capabilities. The backup battery side can support an input voltage of up to 12V and accommodates up to 4 series-connected supercapacitor cells. When the 12V main battery operates normally, the TPS61383-Q1 charges the supercapacitor via its buck mode, delivering a maximum charging current of 7A. In the event of a 12V main battery failure, the TPS61383-Q1 automatically switches to boost mode by detecting a drop in the main battery terminal voltage. It elevates the supercapacitor voltage to 12V to power the motor, with a maximum input-side current capability of 30A. Simultaneously, the TPS61383-Q1 supports a battery health monitoring feature that evaluates the capacitance of the supercapacitor to determine its state of health (SOH). Compared to discrete solutions, the TPS61383-Q1 offers a higher level of integration, a smaller solution footprint, and a simplified design.

Table 5-1. TPS61383-Q1 Voltage and Current Waveforms during Charging under Different Input Voltages

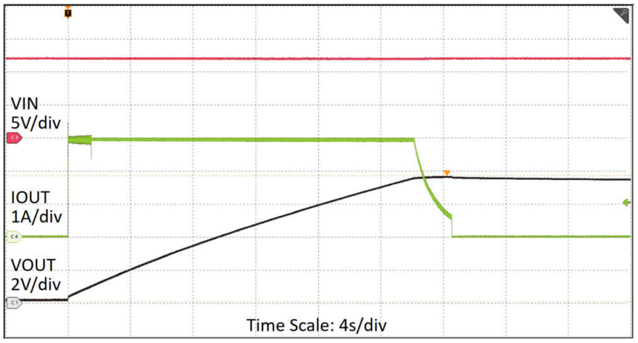

Figure 5-2. Charging Process at VIN = 12V

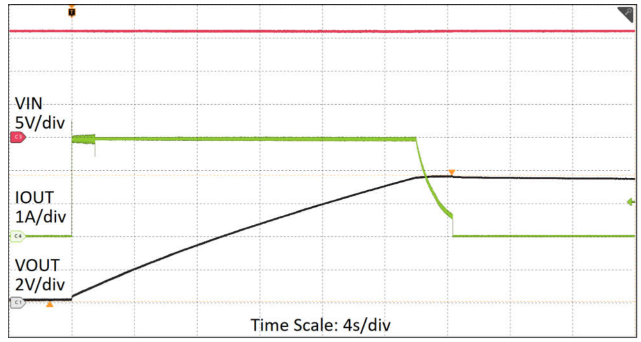

Figure 5-3. Charging Process at VIN = 16V

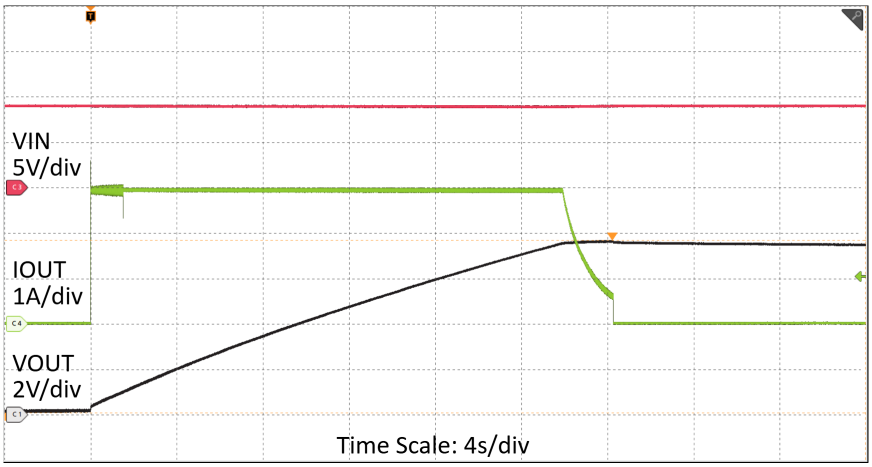

Figure 5-4. Charging Process at VIN = 9V

Table 5-1 illustrates the charging current profile of the TPS61383-Q1 when the 12V main battery voltage is at 12V, 16V, and 9V, respectively. As observed, the charging profile of the TPS61383-Q1 is divided into two distinct phases: constant-current (CC) charging and constant-voltage (CV) charging. In CC mode, the TPS61383-Q1 charges the supercapacitor with a steady current of 3A until the voltage reaches approximately 7.5V. Subsequently, the device enters CV mode, where the charging current gradually tapers down. The entire charging sequence finishes in roughly 25s, satisfying the designated charging time constraint.

6 Summary

CPM is an emerging application requirement in body systems, providing safety redundancy to occupants in the vehicle. Utilizing supercapacitors as a backup power source, the module activates when the low-voltage vehicle battery is disconnected, providing the necessary drive power to the door unlock motors to ensure that doors can be opened quickly and effectively. This paper first outlined the functional and positional relationships between the CPM and the Zone Control Unit (ZCU), followed by a breakdown of the individual module components. It further analyzed the charging characteristics of supercapacitors, and calculated as well as experimentally validated the charge/discharge processes and energy storage capabilities for both common 3s and 5s topologies. Finally, comprehensive system solutions encompassing MCUs, AFEs, power rails, communication ICs, and motor drivers were provided, offering a framework suitable for practical application deployment.

7 References

1. Datasheet "TPS55287-Q1 36V, 4A Buck-Boost Converter with I2C Interface datasheet"
2. Datasheet "TPS55289-Q1 36V, 8A Buck-Boost Converter with I2C Interface datasheet"
3. Datasheet "BQ76907-Q1 2-Series to 7-Series High Accuracy Automotive Battery Monitor and Protector for Li-Ion, Li-Polymer, LiFePO4 (LFP), and LTO Battery Packs and Supercaps datasheet"
4. Datasheet "MSPM0Gx51x Mixed-Signal Microcontrollers With CAN-FD Interface datasheet (Rev. B)"
5. Application note "Charging LiFePO4 Batteries and Supercapacitors Using the BQ25756"