Technical White Paper

Crash Power Module Power Management Design Analysis

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ABSTRACT

In the era of new energy vehicles, after a car collision, the doors may fail to unlock, delaying the critical rescue time. The Crash Power Module (CPM) is a key redundancy system specifically designed for vehicles, with the core function serving as an emergency power unit in the event of a collision or main car battery failure, building the *last line of defense* for vehicle safety.

This article mainly focuses on the systematic study of the Crash Power Module system, introducing the main functions of the CPM and providing power management solutions for different architectures, offering a reference for customers in the engineering development and solution selection of CPM.

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1 Crash Power Module Introduction

Crash Power Module(CPM) is one of the most important components of the vehicle's safety system. CPM plays a key role in quickly opening car doors after a collision and clearing the path for lifesaving rescue. After a car collision, CPM quickly completes the door unlocking in very short time by working with body sensors, control system and actuators to ensure that the doors can be opened when the occupants are unconscious, thereby reducing the difficulty of external rescue. To cope with extreme situations, CPM often uses a dual-redundant power supply design. As shown in Figure 1-1. Under normal conditions, the 12V car battery is used to drive the motor for unlocking. When a collision occurs, 12V car battery may fail due to collision damage or circuit failure. At this time, the backup battery such as super-cap can serve as an independent power source to provide power to the motor driver, ensuring that the car door can be opened in emergencies.

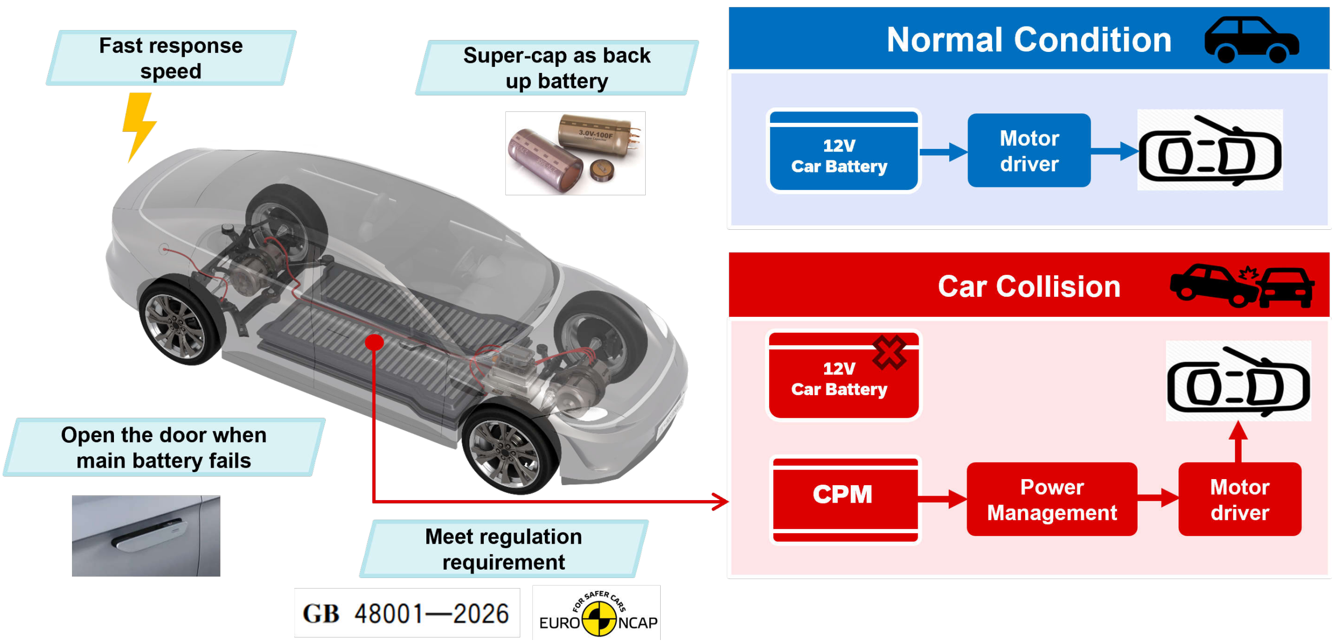

Figure 1-1. CPM Introduction

In terms of regulations, the European Union, the United States, and China all have corresponding regulatory requirements that car doors can be normally opened after a collision. China formulated the mandatory national standard *Technical Requirements for Car doors Handles* in 2026, requiring that car doors can be manually opened after a collision. This promotes the adoption of dual redundant power supply designs in CPM and accelerates the market development of CPM.

CPM is not only a regulatory requirement but also a key module for ensuring passenger safety and improving rescue efficiency. CPM has promoted the upgrade of car safety from *basic protection* to *full-scenario reliable assurance*, becoming an important indicator for measuring vehicle safety levels.

2 CPM System Block and Design Requirements

2.1 System Block

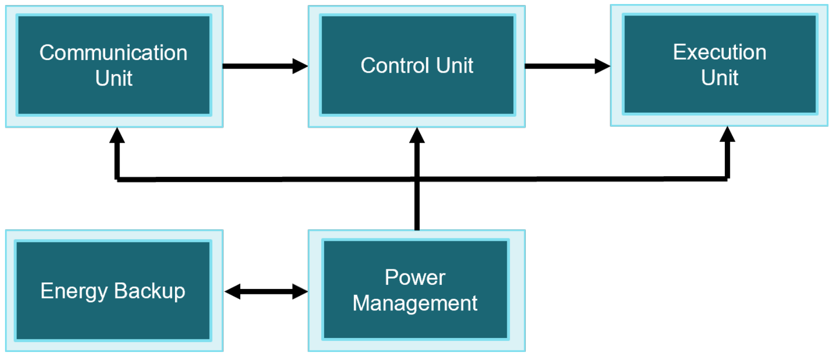

Figure 2-1. CPM System Block

Figure 2-1 is the system block of the CPM and it is composed of five units.

The communication unit is responsible for data distribution and command coordination. It transmits the received trigger signals to the control unit through in-vehicle buses such as CAN/LIN, driving the control unit to initiate power switching and unlocking; at the same time, it also monitors the operating status of each unit within the module in real time.

The energy backup unit is the supercapacitor. Under normal conditions, the main battery supplies power to the system. If a collision causes the main battery to be disconnected, the backup power quickly kicks in to verify the stable output of unlocking energy.

The power management unit charges and discharges the supercapacitor. Under normal conditions, the main car battery charges and stores energy in the supercapacitor. After a collision occurs, it releases the energy of the supercapacitor, while also considering the cell balance and battery health detection.

The control unit is the center of the system. It receives the collision signals, while dynamically calculating the number of unlock cycles based on the remaining energy of the supercapacitor, and providing real-time feedback on the voltage and energy consumption data.

The execution unit drives different locks to unlock in sequence according to the different current and time requirements of the door lock, child lock and door handle lock components.

2.2 Design Requirements

As the key component of the vehicle's passive safety system, CPM must be designed around the core objective of "reliable unlocking under extreme conditions", while also considering the adaptability to the onboard environment and the synergy of the entire vehicle system. In the process of technology implementation, issues such as power reliability, response timelines, and environmental adaptability constitute the core challenges of module design.

a) High reliability and Redundancy: Dual power supply redundancy design and functional safety

CPM must support dual power supply architecture. The main power supply (12V low-voltage battery) provides power to system under normal conditions. In the event of a collision causing the main power supply to short-circuit or power off, the backup battery such as supercapacitor needs to switch in seamlessly. Moreover, the backup power supply must meet the "low self-consumption" requirement, maintain its power supply capability throughout the vehicle's entire lifecycle, and at the same time have sufficient energy output to support multiple unlocking operations. CPM must pass rigorous reliability tests, such as 500,000 charge-discharge cycles, stable operation in a wide temperature range of -40°C~85°C, vibration, electromagnetic interference, and other complex automotive environments. The success rates of main and backup battery switching and unlock execution must both reach 100%.

b) Fast response speed: ms level speed

The total response time from the detection of a collision signal to unlocking all car door locks, child locks, and door handle locks must be controlled within 200ms, with the power switching time not exceeding 10ms. The drive execution unit must rapidly drive multiple types of locks according to the preset timing sequence to ensure the effectiveness of unlocking within the golden escape window after a collision.

c) Cost and Reliability: Trade Off

CPM needs to balance cost and reliability. Redundant design will significantly increase the cost and size of the module; Therefore, it is necessary to optimize the circuit architecture by selecting highly integrated chips and simplifying redundant logic to control the cost and size while meeting functional safety and reliability requirements.

2.3 System Architecture

CPM can be divided into three architectures according to its location: centralized, semi-distributed, and distributed, as shown in Figure 2-2, Figure 2-3, and Figure 2-4

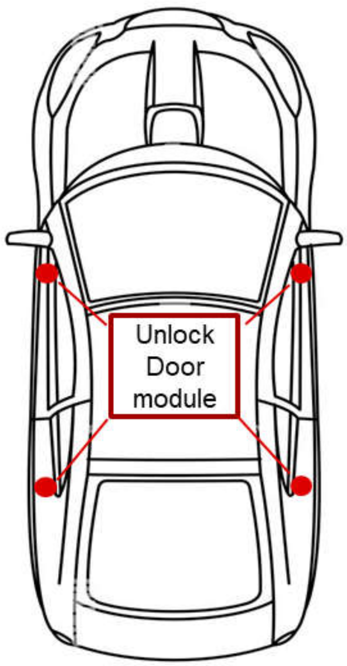

Figure 2-2. Centralized

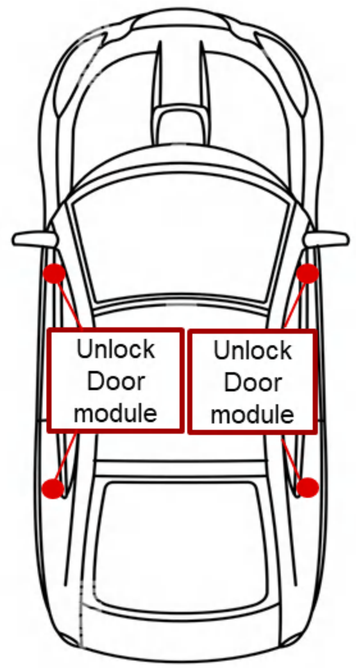

Figure 2-3. Semi-Distributed

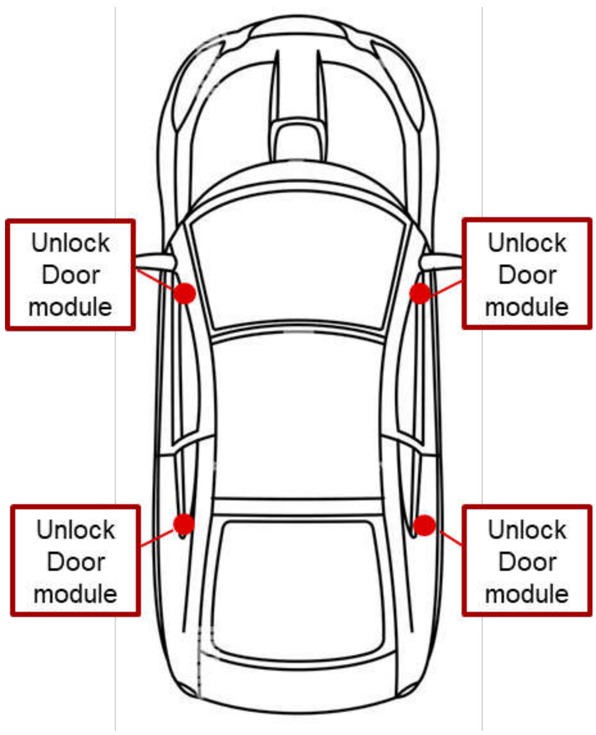

Figure 2-4. Distributed

If the CPM is placed at the center of the car and uses one module to unlock the four doors, it is called centralized architecture. Centralized architecture has a simple structure, is simple to develop, has low costs, can be placed anywhere inside the vehicle without space limitations, and is less likely to be damaged in a collision. However, the CPM is far from the door, resulting in slower response speed. The cable is easily damaged after a collision, the risk of single-point failure is high and redundancy is low.

If the CPM is placed on each door, it is called distributed architecture. In distributed architecture, the module is close to the door and has a fast response speed. When one module is damaged due to a collision, other modules can still function normally, so distributed architecture has high reliability and high redundancy. But due to four CPMs are needed, the cost will be increased. Additionally, the four door locks need to coordinate with each other, making the collaborative logic complex.

The last is semi-distributed architecture. Semi-distributed architecture is divided into a left domain and a right domain, with each domain containing a module that controls the locks. Its cost and redundancy are both between that of centralized and distributed architectures, making it a compromise solution.

Table 2-1 lists the comparison of three architectures. Centralized architecture is suitable for the car that is cost-sensitive and has high system integration requirements. A distributed architecture is more suitable for scenarios that require high response speed and redundancy, as well as diverse vehicle configurations.

Table 2-1. Comparison of Different System Architecture for CPM

Architecture	Centralized	Semi-distributed	Distributed
Advantages	Simple structure. Low development difficulty Low cost Flexible positioning Low collision probability.	Moderate cost Moderate reliability.	High redundancy High reliability. Fast response speed.
Disadvantages	Slow response speed. High single point of failure rate.	Poor scalability.	High cost. Difficult coordinating control.

3 Supercapacitor Parameters and Door Lock Load Profile

3.1 Supercapacitor Parameters

In CPM, the supercapacitors serve as the core energy storage component, and its selection directly determines the reliability, timeliness, and safety of the unlocking action. Compared with lithium batteries, supercapacitors are based on a double-layer physical energy storage mechanism, which allows millisecond-level charging and discharging without chemical reactions. Their stability and instantaneous power output capability under extreme conditions better meet the core requirements of collision unlocking, making them the preferred energy storage solution for this scenario.

When selecting supercapacitors, the key factor should be the energy requirement for unlocking. The first considerations are capacitance, voltage, and the number of supercapacitors. Considering the size of supercapacitors, commonly selectable capacitances are 25F and 30F; rated voltages are 2.5V, 2.7V or 3V. Supercapacitors can be connected in series to increase energy, with common series numbers being 1 to 5. The energy calculation formula is:

$$E = \frac{1}{2}CV^2 \tag{1}$$

Taking example of three 2.7V, 25F supercapacitors connected in series to calculate the energy that can be released.

Equivalent capacitance：

25F/3 = 8.33F

Operation voltage range ：

8.1V ~ 3V

Released energy：

$$E = \frac{1}{2}C\left(V_1{}^2 - V_2{}^2\right) = 236J \tag{2}$$

When a supercapacitor discharges, considering the impact of internal resistance, the voltage can drop to as low as 3V. Therefore, the operating range is from 8.1V to 3V. At different voltages, capacity and series combinations can meet different energy requirements. Therefore, when selecting a supercapacitor, it is necessary to choose according to the energy required by the system, while leaving a certain margin, generally considered to be around 30%.

The equivalent series resistance (ESR) of supercapacitors is also a key factor affecting the unlocking response speed. Collision unlocking requires driving the door lock motor to generate an instantaneous large current, and low ESR can reduce energy loss and heating. For automotive-grade selection, priority should be given to products with an ESR of less than 30mΩ at room temperature, ensuring that the instantaneous discharge current reaches above 15A, and even in a -40°C low-temperature environment, it can still maintain an output capacity of over 10A to meet the normal driving requirements of the door lock motor.

Supercapacitors must meet automotive-grade reliability and safety standards when selecting models. CPM needs to work throughout the entire vehicle lifecycle; therefore, the cycle life of the supercapacitor should reach more than 500,000 times. Temperature adaptability is also essential, and the supercapacitor needs to cover a wide operating temperature range of -40°C to 105°C.

3.2 Charging Time Requirements

As an emergency power for collision unlocking, the supercapacitor needs to be charged to more than 90% of its rated voltage within a very short time after the vehicle is powered on, ensuring that the vehicle remains in a *ready for emergency unlocking* state throughout the journey. Different OEMs have different requirements for charging time, generally within 10s to 60s. Figure 3-1 shows the charging characteristic curve of the supercapacitor, divided into two stages: constant current (CC) charging and constant voltage (CV) charging. In CC stage, the main power supply charges the supercapacitor with a constant current, rapidly increasing the capacitor voltage. When the supercapacitor approaches a constant value, it automatically switches to constant voltage mode, limiting the charging current to prevent overvoltage damage to the capacitor while maintaining a fully charged state. The relationship between supercapacitor charging current and charging time is as below:

$$I = C\frac{dU}{dT} \tag{3}$$

The larger the charging current, the shorter the charging time. Taking a 3s, 2.7V, 25F capacitor as an example, the equivalent capacitance is 8.3F. If it is necessary to charge the supercapacitor from 0V to the rated voltage of 8.1V within 10 seconds, the required charging current should be 6.7A. Considering the margin, it is necessary to select an IC that can support 7A constant current charging, such as TPS552892-Q1.

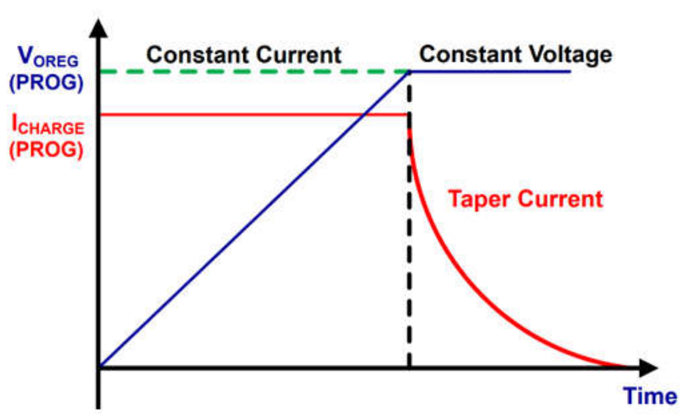

Figure 3-1. Supercapacitor Charging Characteristics

3.3 Door Lock Load Profile

In the car door system, common locks include the door lock, the door handle lock and the child lock. The number of locks that need to be unlocked in CPM depends on the system architecture. If it is a centralized architecture, then one CPM needs to drive all locks, including four door locks, two child locks and four door handle locks. If it is distributed architecture, each CPM only needs to drive one door lock, one child lock and one door handle lock. The number of locks is different, the energy required is different.

During the unlocking process, the operating voltage of the motor is generally set to 12V, and the current changes over time, divided into startup stage, steady-state stage and stall stage. Figure 3-2 shows the current changes during the operation of a typical car door unlocking motor. During startup stage, the counter electromotive force has not been established, and the current rapidly rises to 2 times the rated current, reaching up to 5A, forming a transient surge spike. This stage lasts for only 10ms short time. After the inrush current, the motor's back electromotive force is established, the current quickly falls back and stabilizes in the rated current range, generally around 3A, with a duration of 150ms. The worst case is motor stall, with current reaching 8A and lasting for 50ms. Therefore, the total energy required to unlock this motor is:

$$E = UIt = 12V \times (5A \times 10ms + 3A \times 150ms + 8A \times 50ms) = 10.8J \quad (4)$$

If a CPM is needed to unlock all the doors, considering the number of locks is 10 and the rounds is 2, the total energy required is:

$$E_{total} = 10 \times 2 \times 10.8J = 216J \quad (5)$$

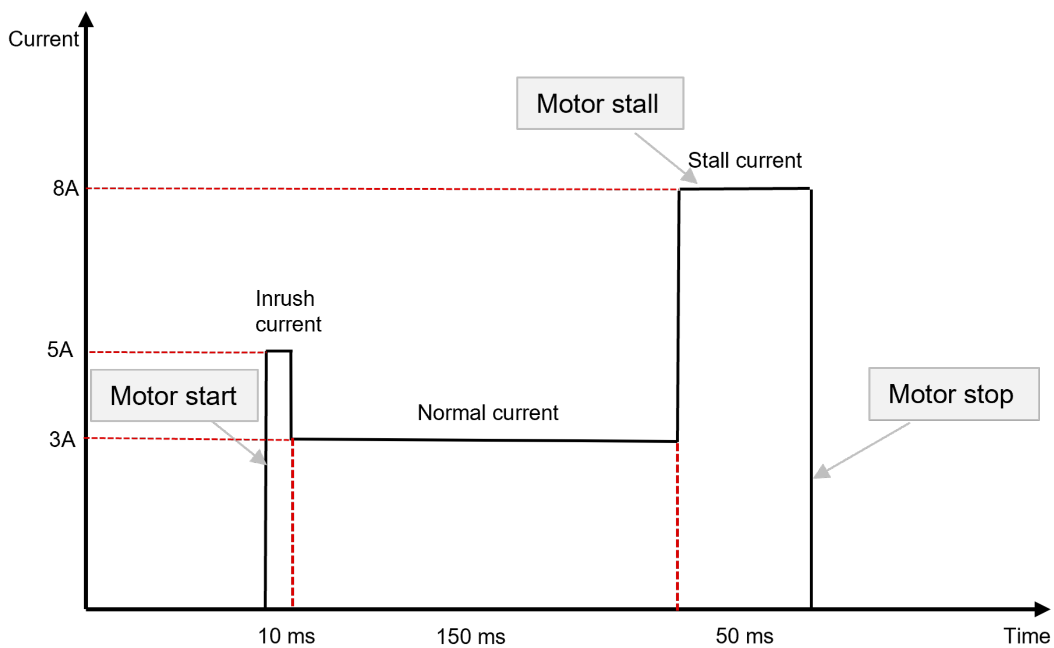

Figure 3-2. Typical Diagram of Current Change Over Time During the Operation of a Car Door Lock Motor

4 Power Management Designs

4.1 5s Supercapacitor Design

5s supercapacitor design can provide more energy, so it is mainly used in centralized architecture. The following section shows three different power management designs for 5s supercapacitors.

- Buck-boost charge + Diode discharge

Buck-boost converter is used to charge supercapacitor. Diode is used to discharge the energy of supercapacitor to motor driver. Taking a 5s, 2.7V, 25F supercapacitor as an example, the rated voltage of the supercapacitor is 13.5V. The operating voltage range of a car's 12V main battery is 9V-16V, so a buck-boost charger is needed, such as TPS552892-Q1. A diode LM74700-Q1 is used as discharge to power the motor. Since the operating range of the motor is 9V to 16V, the supercapacitor can only discharge down to 9V, and energy below 9V cannot be utilized. Due to differences in supercapacitor production and manufacturing, when supercapacitors are connected in series, the voltage across each series may become unbalanced. Therefore, a cell balance IC such as BQ79607-Q1 / BQ78709-Q1(ASIL-B version) is needed to monitor the voltage of each cell in real time and perform passive discharge to balance the voltage of each cell and extend the life of the supercapacitors.

CPM also needs MCU, SBC and motor driver. MCU operates as the central system controlling the CPM, and it is recommended to use the MSPM0G3107-Q1. SBC can be the TCAN2845-Q1, which integrates a CAN-FD transceiver and a 3.3V LDO, used to power the MCU and communicate with the ZCU. The motor driver is used to drive the motor, such as DRV8244-Q1. The recommended system block diagram is shown in Figure 4-1 .

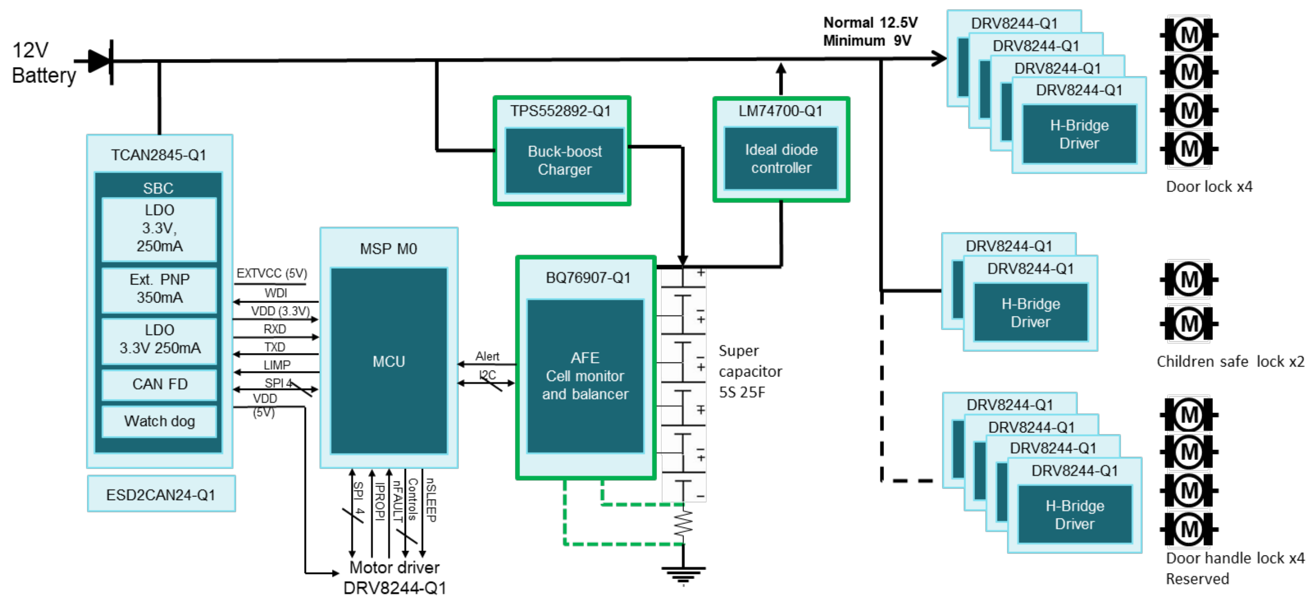

Figure 4-1. 5s Supercapacitor System Block: Buck-Boost Charge and Diode Discharge

Figure 4-2 is the test waveforms of TPS552892-Q1 charging a supercapacitor. Channels 1-3 are the enable pin EN, supercapacitor voltage VOUT, charging current IOUT, respectively. From the waveform, after the enable pin is high, TPS552892-Q1 enters constant current charging phase, charging the supercapacitor with a constant current of 2.5A until the voltage reaches about 12.5V. Then IC enters the constant voltage charging phase, during which the charging current gradually decreases. The entire charging process lasts for 25 seconds. For more detailed application information, please refer to E-latch with 5S SuperCaps Solution Using Buck-Boost Converter.

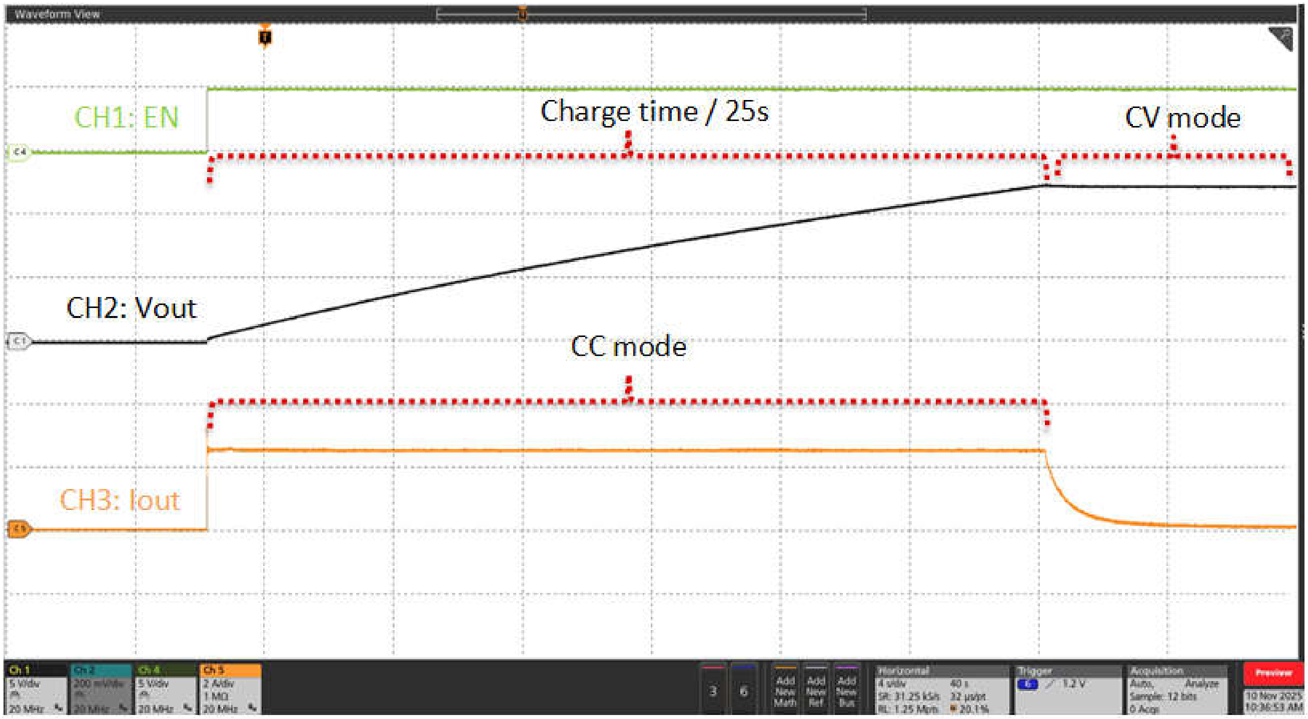

Figure 4-2. Test Waveform of TPS552892-Q1 for Charging the Supercapacitor

- Buck-boost charge + Boost discharge

During discharging, using a boost controller such as LM5122-Q1 to replace diode can make full use of the energy of the supercapacitor. When the supercapacitor voltage is below 9V, the output can be boosted to 12V through a boost controller to drive the motor. The system block diagram is shown in Figure 4-3.

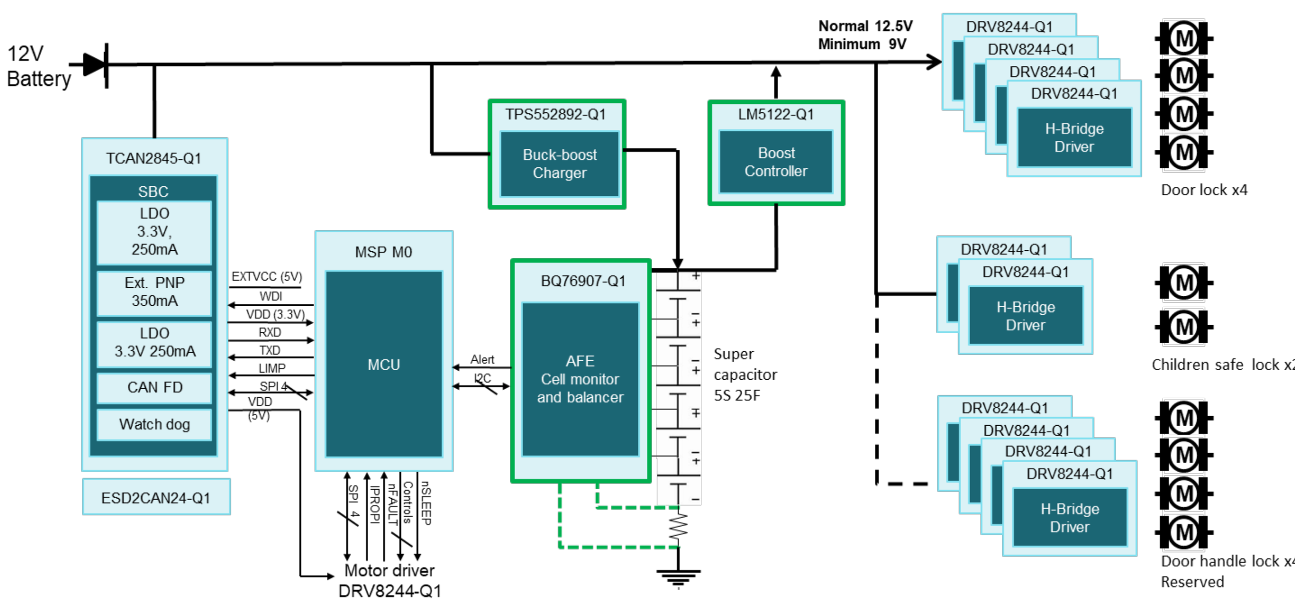

Figure 4-3. 5s Supercapacitor System Block: Buck-Boost Charge + Boost Discharge

- Bi-directional buck-boost controller to charge and discharge

In the below design, it needs a buck-boost charger and a boost controller to discharge. TI launched a bi-directional buck-boost controller LM51772-Q1, which uses the same circuit for charging and discharging. It has higher integration and can significantly reduce system costs. The system block diagram is shown in Figure 4-4. The detailed application note is Battery or Capacitor Backup Operation with the LM51772.

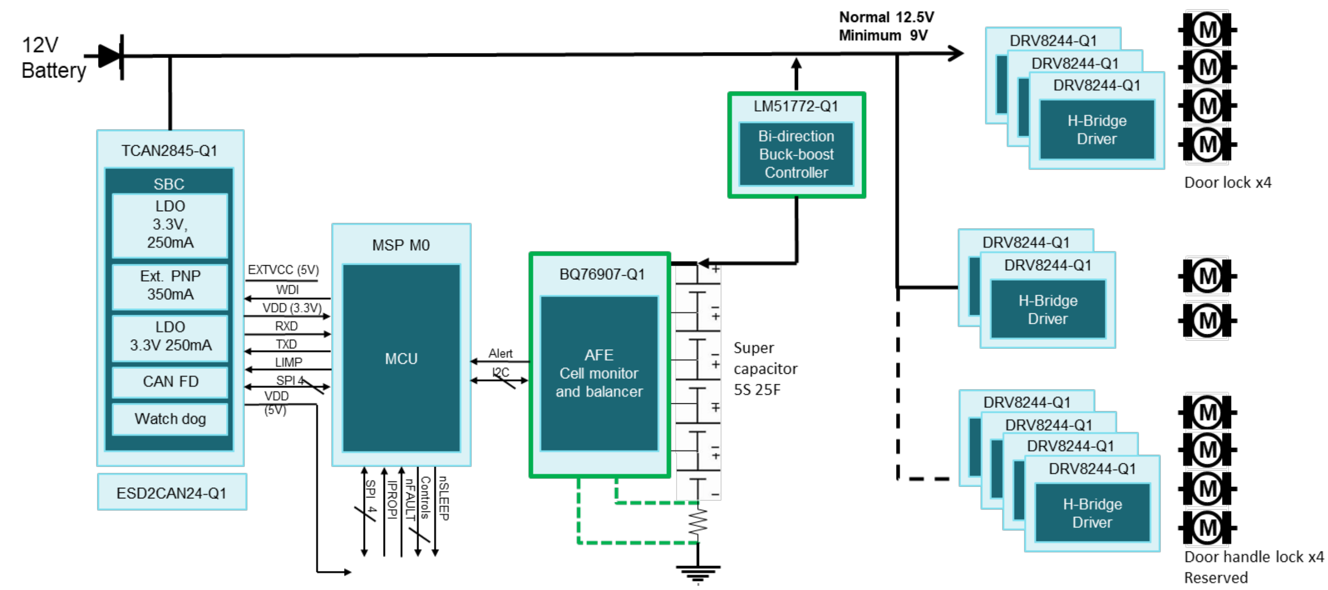

Figure 4-4. 5s Supercapacitor System Block: Bi-directional Buck-Boost Controller to Charge and Discharge

4.2 3s Supercapacitor Design

3s supercapacitor design can balance energy while reducing the number of supercapacitors. This is designed for both centralized and distributed architecture. Below are two different power management designs for 3s supercapacitors.

- Buck charge + Boost Discharge

Taking a 3s, 2.7V, 25F supercapacitor as an example, the rated voltage of the supercapacitor is 8.1V, so a buck charging such as LM5190-Q1 is required. During discharge, a boost controller LM5152-Q1 is used to raise the voltage to 12V to drive the motor. Similarly, the system still requires a cell balance IC, MCU, SBC and motor driver. The recommended system block diagram is shown in Figure 4-5.

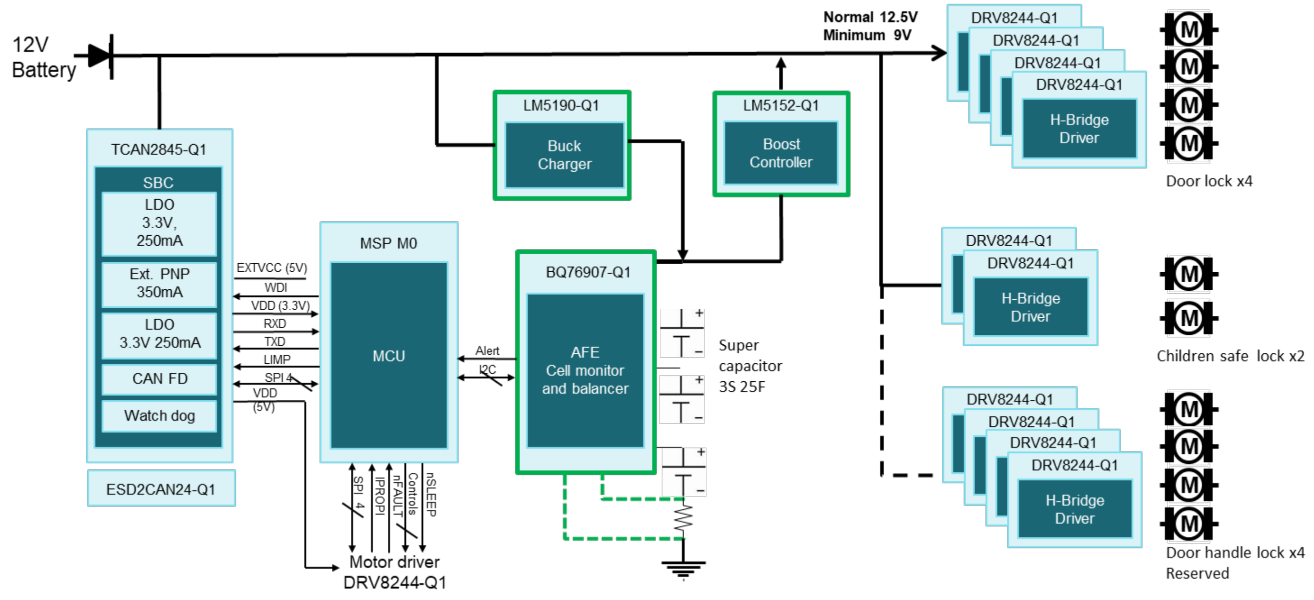

Figure 4-5. 3s Supercapacitor System Block: Buck Charge + Boost Discharge

- Bi-directional buck/boost converter to charge and discharge

The second design is to use highly integrated bi-directional buck/boost converter TPS61383-Q1, which integrates buck charger, boost discharger and battery health detection function. When 12V main battery is operating normally, the supercapacitor can be charged through the buck mode, with a maximum charging current of 7A. When the main battery fails, it automatically switches to boost mode by detecting the drop of the main battery terminal voltage, raising the voltage of the supercapacitor to 12V to power the motor, with a maximum input current of 30A. Moreover, this device has battery health detection function, which can detect the health status of the supercapacitor. Compared with the discrete design, TPS61383-Q1 has higher integration, smaller size and easier to design. The recommended system block is Figure 4-6. For more detailed application information, please refer to Automotive E-latch Systems Design Guideline using TPS61383-Q1.

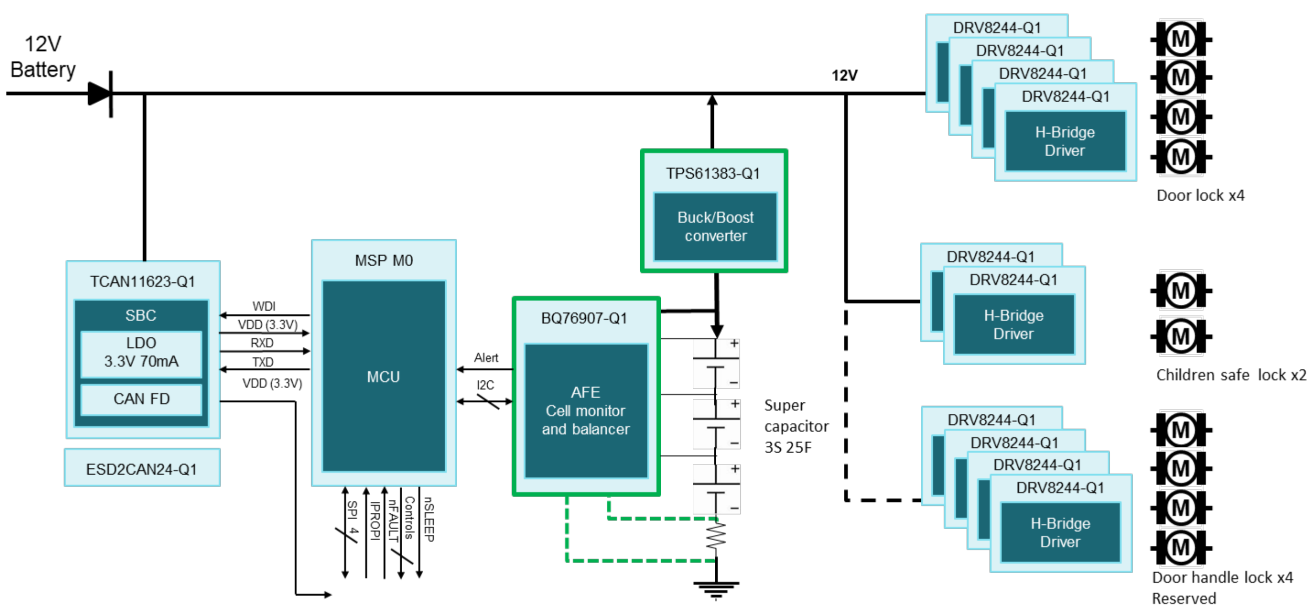

Figure 4-6. 3s Supercapacitor System Block: Bi-directional Buck/Boost Converter

Figure 4-7 and Figure 4-8 are the test waveforms. Figure 4-7 shows the waveforms during the charging process, with channel 1 and 2 representing the supercapacitor voltage and charging current respectively. TPS61383-Q1 uses a 3A charging current to charge the supercapacitor voltage from 0V to 8.1V, taking only 25 seconds.Figure 4-8 shows the waveforms of discharge process, with channels 1-4 representing the supercapacitor voltage, IC SW voltage, load voltage and load current. The load simulates the real unlocking process, with the lock voltage set to 10V, starting current at 5A for 10ms; steady-state current at 2.5A for 200ms, and stall current at 8A for 20ms. The number of locks is 10, unlocked in two rounds. As can be seen from Figure 4-7 and Figure 4-8, this device can support the entire unlocking process.

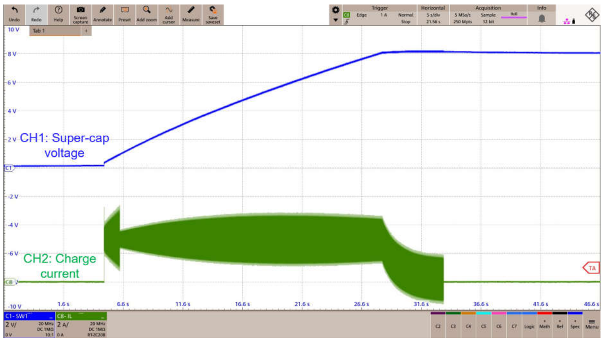

Figure 4-7. TPS61383-Q1 Charging Waveform

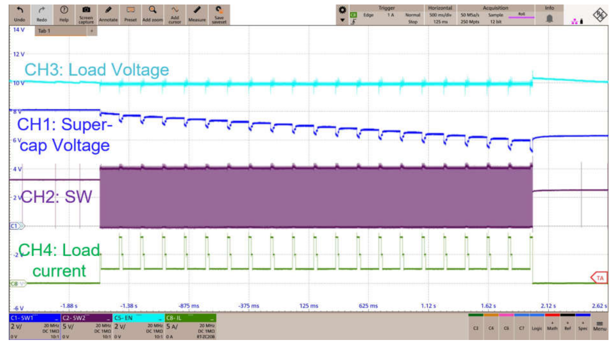

Figure 4-8. TPS61383-Q1 Discharging Waveform

4.3 1s Supercapacitor Design

When CPM adopts distributed architecture, each module only needs to unlock one door, so 1s supercapacitor can be used. Below is the design for 1s supercapacitor.

- Buck charge + Boost Discharge

Taking a 1s, 2.7V, 25F supercapacitor as an example, Figure 4-9 is the recommend system block. LM5190-Q1 is a buck charger and LM5152-Q1 is a boost controller used to discharge. The minimum operating voltage of LM5152-Q1 is 3.8V. When the bias voltage is greater than 3.8V, the minimum input voltage is 0.8V. Therefore, an additional boost converter TPS61299-Q1 with low-voltage startup is required to bias LM5152-Q1. TPS61299-Q1 has only 95nA Iq, which hardly consumes the energy of the supercapacitor. When using 1s supercapacitor, there is no need for cell balance, but still need MCU, SBC and motor driver.

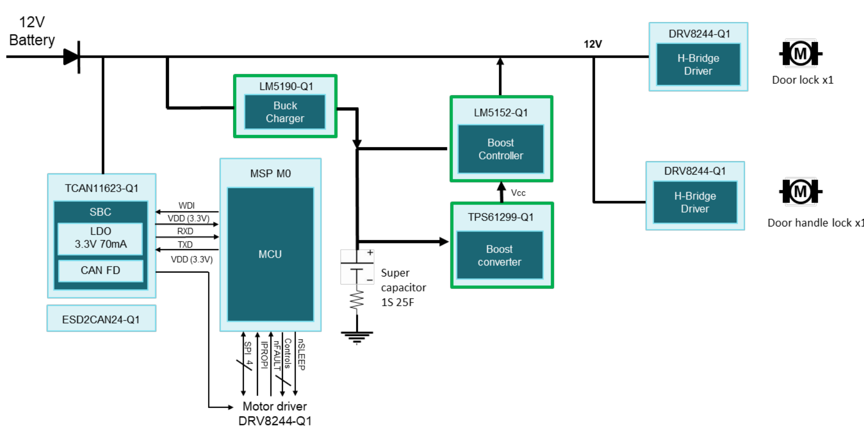

Figure 4-9. 1s Supercapacitor System Block: Buck Charge and Boost Discharge

- Bi-directional buck/boost converter to charge and discharge

Figure 4-10 shows the system block using the bi-directional buck/boost converter TPS61383-Q1 as charge and discharge chip. Compared with discrete design, the integrated design has lower costs, higher integration, and is also the trend in the future.

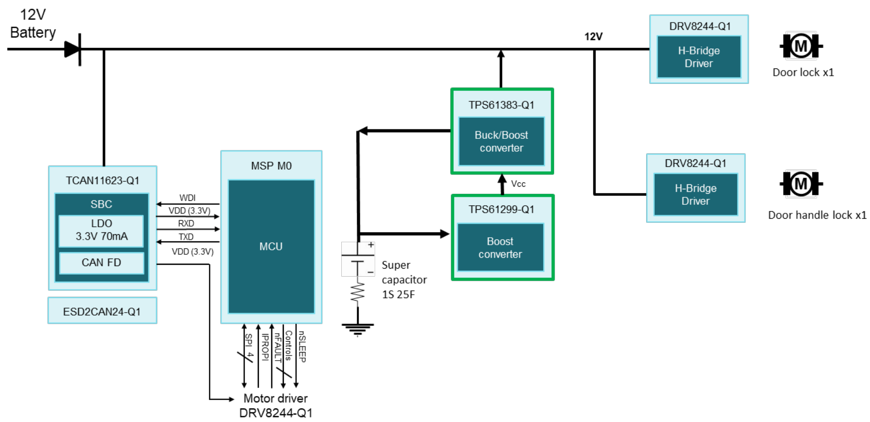

Figure 4-10. 1s Supercapacitor System Block: Bi-directional Buck/Boost Converter

4.4 Comparison and Summary of Different Designs

Previous sections provide the designs for 5s supercapacitors, 3s supercapacitors and 1s supercapacitor, respectively. Table 4-1 lists the advantages and disadvantages of different designs. 5s supercapacitors design has more energy and is suitable for centralized architecture. 3s supercapacitors design balances energy while reducing the number of supercapacitors, offering cost advantages and smaller size, is suitable for both centralized and distributed architectures. 1s supercapacitor design has higher redundancy and higher cost, is suitable for distributed architectures with higher safety requirements. And comprared with discrete design, bi-directional design has smaller solution size and lower BOM cost, which is the design trend in the future.

Table 4-1. Comparison of Different Designs

		5s supercapacitor	3s supercapacitor	1s supercapacitor
Discrete Design	Charge	Buck-Boost: TPS552892-Q1	Buck: LM5190-Q1	Buck: LM5190-Q1
	Discharge	Diode:LM74700-Q1/ Boost: LM5122-Q1	Boost: LM5152-Q1	Boost:LM5152-Q1
Bi-directional Design		Bi-directional buck-boost controller: LM51772-Q1	Bi-directional buck/boost converter: TPS61383-Q1	Bi-directional buck/boost converter: TPS61383-Q1
Advantages		More energy and better scalability	Cost advantage and small size	Does not need cell balance, high redundancy
Disadvantages		Need cell balance	Need cell balance	High cost
Application		Centralized architecture	Centralized/Semi-distributed/ Distributed architecture	Distributed architecture

5 Summary

As the *life support system* in new energy vehicle collision scenarios, CPM has its core value in providing power from backup battery to unlock the doors after the main battery fails, building the last line of defense for a passenger escape. With the popularity of E-latch and upgrade of safety regulations, CPM has become a necessary safety requirement, and the market size is expected to show a steady growth trend. In the future, CPM develops toward higher integration, longer lifespan and lower cost solutions.

6 References

1. Texas Instruments, E-Latch design resources, webpage.
2. Texas Instruments, E-latch with 5S SuperCaps Solution Using Buck-Boost Converter, application note.
3. Texas Instruments,Battery or Capacitor Backup Operation with the LM51772 , application note.
4. Texas Instruments,Automotive E-latch Systems Design Guideline using TPS61383-Q1 , application note.

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