

E-latch Using 5S Supercaps Design with Buck-Boost Converter



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ABSTRACT

This application note describes an emergency backup power system for an electronic door lock (E-latch) using five series-connected supercapacitors (5S). It also details the design and considerations of a buck-boost converter with constant current/constant voltage (CC/CV) charging for the supercapacitors. This design provides critical safety redundancy for automotive applications, by verifying that the door can still be unlocked in the event of a collision or main battery failure.

Table of Contents

1 E-latch System Introduction	2
1.1 Supercapacitor Characteristic.....	2
1.2 Typical Block Diagram of E-latch System.....	2
2 Supercapacitor Charging with Buck-boost Converter Based on CC/CV Control	3
2.1 Advantages of CC/CV Regulators for Supercapacitor Charging.....	3
2.2 Buck-Boost Dual-Loop With CC/CV.....	4
2.3 Output Current Monitoring.....	6
3 Design Process	7
3.1 TPS5528x Family Part Selection.....	7
3.2 Charge Voltage and Charge Current Setting.....	8
4 Experimental Results	9
5 Summary	10
6 References	10

List of Figures

Figure 1-1. Typical Block Diagram of E-latch System.....	2
Figure 2-1. Block Diagram and Charging Curve of Traditional Voltage Source.....	3
Figure 2-2. Block Diagram and Charging Curve of CC/CV Regulator.....	4
Figure 2-3. Internal Voltage Control Loop of the TPS5528X.....	5
Figure 2-4. Internal Current Control Loop of the TPS5528X.....	5
Figure 2-5. CC-CV Performance Characteristics of the TPS5528x.....	5
Figure 2-6. TPS5528X Output Current Monitoring Circuit.....	6
Figure 3-1. TPS5528X Typical Application Circuit for Supercapacitor Charging.....	7
Figure 4-1. TPS552892: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 2.5A$, Super cap = 5.4F.....	9
Figure 4-2. TPS552892: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 5A$, Super cap = 5.4F.....	9
Figure 4-3. TPS55289: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 5A$, Super cap = 5.4F.....	10

List of Tables

Table 3-1. Average Inductor Current of TPS5528X.....	7
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1 E-latch System Introduction

The E-latch system represents a critical automotive safety component designed to address emergency scenarios where the main battery of the vehicle becomes unavailable. Modern vehicles, particularly those with hidden door handles and electronic latch mechanisms, require reliable backup power to ensure passengers can escape during emergencies.

1.1 Supercapacitor Characteristic

As a backup power, supercapacitors (also known as Electric Double Layer Capacitors or EDLCs) offer significant advantages over traditional battery, which is why they are the main design used for E-latch backup power.

- Higher power density (W/L): 10^2 to 10^4 compared to batteries
- Extended lifecycle: 500k-1000k cycles vs. 300k-10k for batteries
- Wider operating temperature range: -40°C to $+85^{\circ}\text{C}$ vs. -20°C to $+60^{\circ}\text{C}$
- Faster charging/discharging capability
- Simple CC/CV charging with no special requirements

1.2 Typical Block Diagram of E-latch System

Figure 1-1 is a typical diagram of E-latch system with super-cap system. A typical 12V car battery supplies power to motor and charge into super cap. When emergency scenarios such as collisions occur, the super cap discharges to the motor through a power diode.

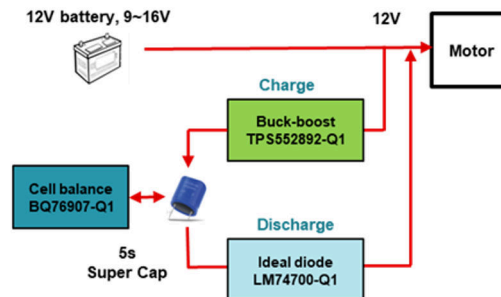


Figure 1-1. Typical Block Diagram of E-latch System

As the demand for centralized power supply to electric motors in electric vehicles increases, the requirements for the energy capacity of the super cap also increase. It is popular to have a 5S super cap for wider operation voltage and larger energy. Because one super cap has typical voltage from 2.5V to 3V, the total charge voltage of the 5S super cap can be up to 12V. A buck boost converter with CC/CV charging function is preferred for this application.

2 Supercapacitor Charging with Buck-boost Converter Based on CC/CV Control

2.1 Advantages of CC/CV Regulators for Supercapacitor Charging

When a traditional voltage source is used to charge a supercapacitor, this can lead to a large inrush current at first. Then charging current decreases as the charging voltage increases, resulting in a longer charging time, as shown in the [Figure 2-1](#).

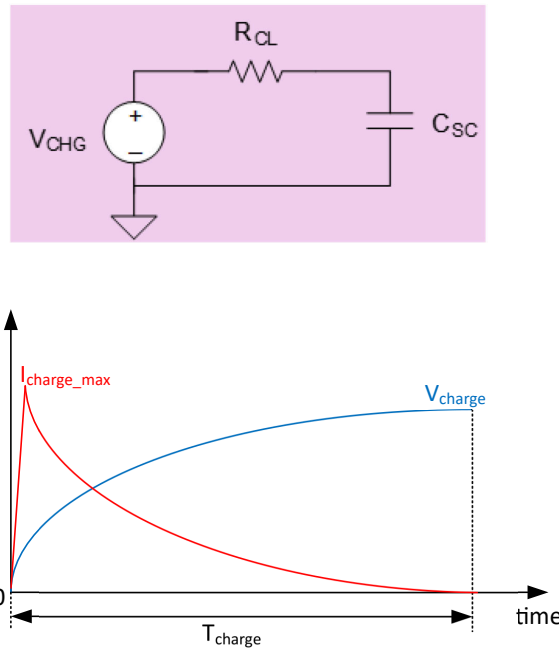


Figure 2-1. Block Diagram and Charging Curve of Traditional Voltage Source

To limit the inrush current, a current-limiting resistor R_{CL} is used to mitigate inrush current, the inrush current as shown in . The maximum charging current can be calculated by [Equation 1](#):

$$I_{\text{chargemax}} = \frac{V_{\text{CHG}}}{R_{\text{CL}}} \quad (1)$$

And charging time can be calculated by [Equation 2](#):

$$T_{\text{CHG_PASSIVE}} = 4.6 \times C_{\text{SC}} \times \frac{V_{\text{CHG}}}{I_{\text{chargemax}}} \quad (2)$$

This is based on an approximation of the charging time to 99% of the final voltage. Using a CC/CV regulator can solve the problem of charging supercapacitors with the typical voltage source. [Figure 2-2](#) shows the block diagram and charging curve of the CC/CV regulator. Supercapacitor experiences a constant charging current, and then maintains a constant voltage after reaching the charging voltage set.

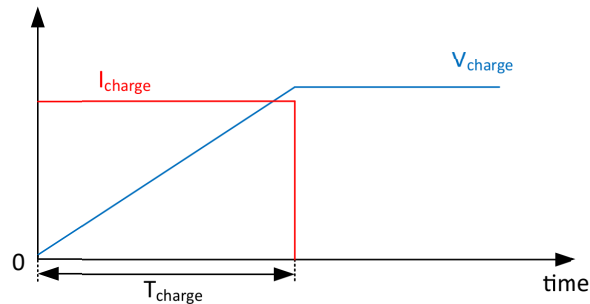
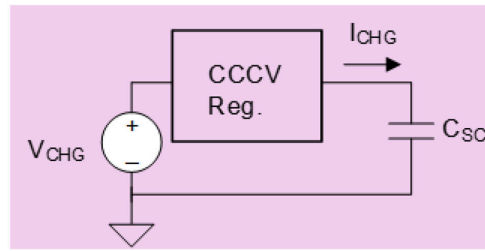


Figure 2-2. Block Diagram and Charging Curve of CC/CV Regulator

Charging time can be calculated by [Equation 3](#):

$$T_{\text{CHG_CCCV}} = C_{\text{SC}} \times \frac{V_{\text{CHG}}}{I_{\text{charge}}} \quad (3)$$

The comparison of the formulas shows that using a CC/CV circuit results in a charging time 4.6 times faster than using a constant voltage source. Shorter charging time means that in the event of an accident, the supercapacitor can provide energy to the motor more quickly, thus improving safety.

2.2 Buck-Boost Dual-Loop With CC/CV

The TPS5528x-Q1 is an automotive, four-switch buck-boost converter featuring independent CC/CV (Constant Current/Constant Voltage) dual-loop control, both for precise output voltage and current regulation. This advanced control architecture makes it preferred for supercapacitor charging applications in automotive E-latch systems.

[Figure 2-3](#) illustrates the internal voltage control loop of the TPS5528X. During normal operation, the output current is sensed by the resistor R_{sense} in the output path. When the voltage across the sensing resistor is below the internal current limit reference voltage, the output of the current loop error amplifier EA2 is zero, effectively disabling the current regulation loop. In this case, only the voltage control loop remains active. The voltage loop error amplifier EA1 compares the output feedback voltage (V_{FB}) with the internal reference voltage (V_{ref}) to generate a compensation voltage (COMP), which then modulates the duty cycle of the converter to maintain stable and accurate output voltage regulation.

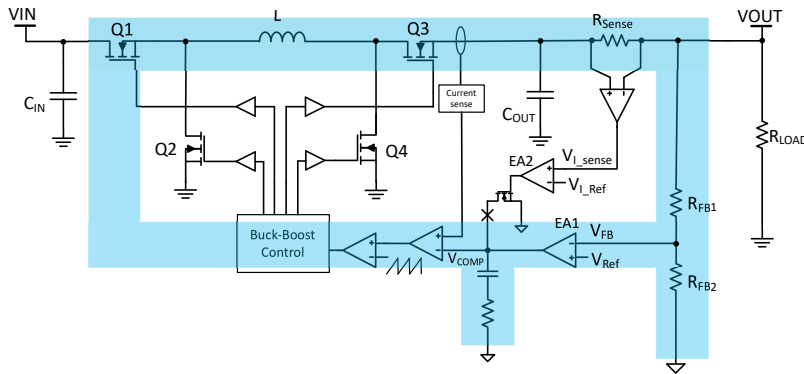


Figure 2-3. Internal Voltage Control Loop of the TPS5528X

Figure 2-4 illustrates the internal current control loop of the TPS5528X. When the sampled voltage (V_{sense}) across the current sensing resistor exceeds the internal current limit reference voltage (V_{Iref}), the current loop error amplifier EA2 starts operating, absorbing comp network current. This causes the COMP voltage to drop, and the output voltage to decrease accordingly, leading to the gradual saturation of the voltage loop error amplifier EA1. Therefore, the voltage regulation loop is effectively disabled. At this point, the current control loop takes over, determining the compensation voltage (COMP), which then modulates the duty cycle to maintain stable and accurate output current regulation.

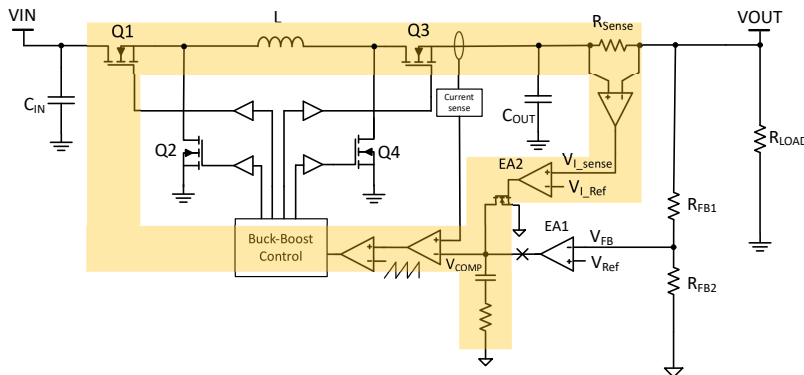


Figure 2-4. Internal Current Control Loop of the TPS5528X

Figure 2-5 shows the CC-CV performance characteristics of the TPS5528X, demonstrating a distinctive *brick wall* profile between output voltage and output current. This characteristic curve illustrates that independent operation of output voltage and current regulation loops without mutual interference, while simultaneously achieving seamless transition between CC and CV operation modes.

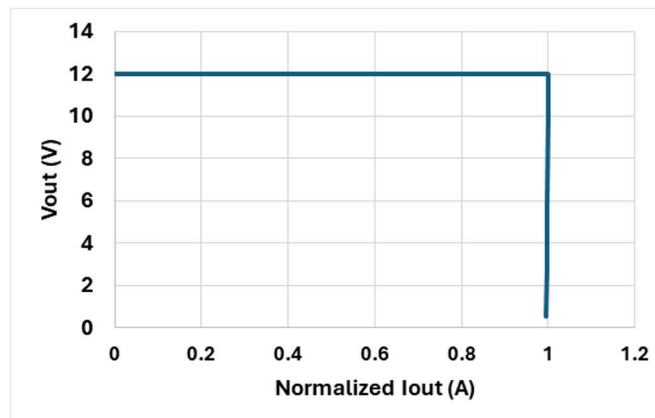


Figure 2-5. CC-CV Performance Characteristics of the TPS5528x

2.3 Output Current Monitoring

The TPS5528x outputs a voltage at the CDC pin that is proportional to the sensed output current sensing resistor between the ISP and ISN pins, as shown in the [Figure 2-6](#). This allows the MCU to monitor the output current in real time by sampling the CDC output voltage, thus ensuring the safe charging of the supercapacitor.

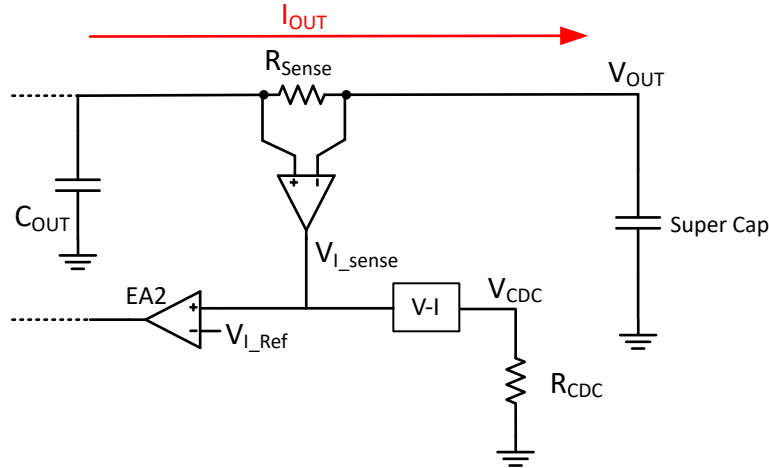


Figure 2-6. TPS5528X Output Current Monitoring Circuit

Equation 4 shows the output voltage rise related to the sensed output current, the resistance at the CDC pin, and the up resistor of the output voltage feedback resistor divide.

$$V_{OUT_CDC} = 3 \times R_{FB_UP} \times \left(\frac{V_{ISP} - V_{ISN}}{R_{CDC}} \right) \quad (4)$$

3 Design Process

This chapter introduces how to calculate and select the corresponding Buck-Boost model based on the customer circuit's supercapacitor capacitance, set output voltage, and desired charging time, as well as how to set the charging voltage and charging current.

The typical application circuit for supercapacitor charging based on the TPS5528X is shown in [Figure 3-1](#).

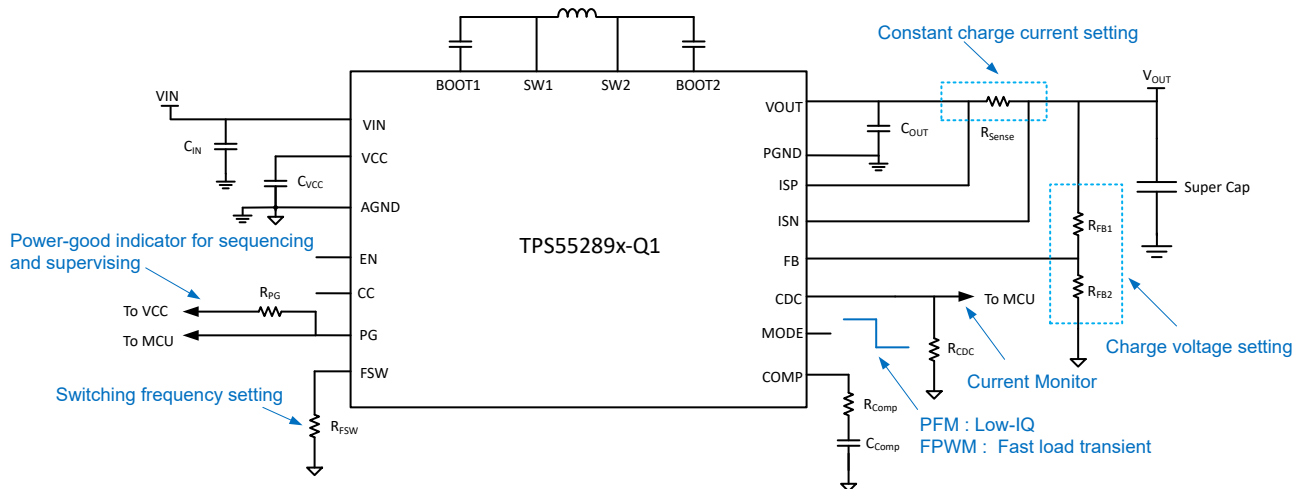


Figure 3-1. TPS5528X Typical Application Circuit for Supercapacitor Charging

3.1 TPS5528x Family Part Selection

3.1.1 Current Capability

The TPS5528x features average inductor current protection, requiring that the average inductor current does not exceed the current limit.

[Table 3-1](#) shows the differences in inductor current for part number TPS55287/288/289.

Table 3-1. Average Inductor Current of TPS5528X

Part Number	Average Inductor Current Limit
TPS55287x	4A
TPS55289x	8A
TPS55288x	16A

3.1.2 I2C Version and Non-I2C Version

The super capacitor charging current equals the output current of the buck-boost. The TPS5528x-Q1 family uses output current limit function to set the charging current.

For the TPS5528x-Q1 family, there are I2C versions and non-I2C versions. For non-I2C version, the VISP-VISN voltage is fixed to 50mV. For I2C version, the VISP-VISN limit can be adjusted from 0mV to 63.5mV.

When using the non-I2C version, customers must set the output current limit based on available current sensing resistor values. With the I2C version, the limit can be seamlessly adjusted by configuring the ISP-ISN voltage limit.

3.1.3 Part Selection

To calculate the required charging current and select the appropriate IC, customers need provide the following parameters: supercapacitor capacitance (C), target charging voltage (U), desired charging time (T), and the minimum input voltage ($V_{IN_{min}}$), estimated efficiency(eff). The charging current can be determined using the [Equation 5](#):

$$I_{charge} = \frac{C \times U}{T} \quad (5)$$

Then maximum average inductor current I_{Lmax} should be [Equation 6](#):

$$I_{Lmax} = \frac{U \times I_{charge}}{V_{INmin} \times \text{eff}} \quad (6)$$

By comparing I_{Lmax} and table, select the corresponding Buck-Boost model. Use the following as an example case:

Minimum Input Voltage (V_{INmin}): 9V

Target Charging Voltage (U): 12.5V

Supercapacitor (C): 5.4F

- Charging time(C) = 10s

$$I_{charge} = \frac{5.4 \times 12.5}{10} = 6.75A \quad (7)$$

$$I_{Lmax} = \frac{12.5 \times 6.75}{9 \times 0.9} = 10.42A \quad (8)$$

Select TPS55288x-Q1.

- Charging time(C) = 15s

$$I_{charge} = \frac{5.4 \times 12.5}{15} = 4.5A \quad (9)$$

$$I_{Lmax} = \frac{12.5 \times 4.5}{9 \times 0.9} = 6.9A \quad (10)$$

Select TPS55289x-Q1.

- Charging time(C) = 60s

$$I_{charge} = \frac{5.4 \times 12.5}{60} = 1.125A \quad (11)$$

$$I_{Lmax} = \frac{12.5 \times 1.125}{9 \times 0.9} = 1.73A \quad (12)$$

Select TPS55287x-Q1.

3.2 Charge Voltage and Charge Current Setting

With the target charging voltage (U) known, set the IC output voltage using the [Equation 13](#):

$$U = V_{ref} \times \left(1 + \frac{R_{FB1}}{R_{FB2}}\right) \quad (13)$$

Having derived the charging current from the prior equation, the sense resistor value is calculated according to [Equation 14](#):

$$R_{sense} = \frac{V_{ISP_ISN}}{I_{charge}} \quad (14)$$

For the non-I2C version, $V_{ISP_ISN} = 50mV$. For I2C version, it can be adjusted between 0mV and 63.5mV.

4 Experimental Results

This chapter presents the charging waveforms of the TPS55289(2)-Q1 for supercapacitor applications. Additionally, it highlights the operational differences between the non-I2C version entering hiccup mode and the I2C version with hiccup mode disabled.

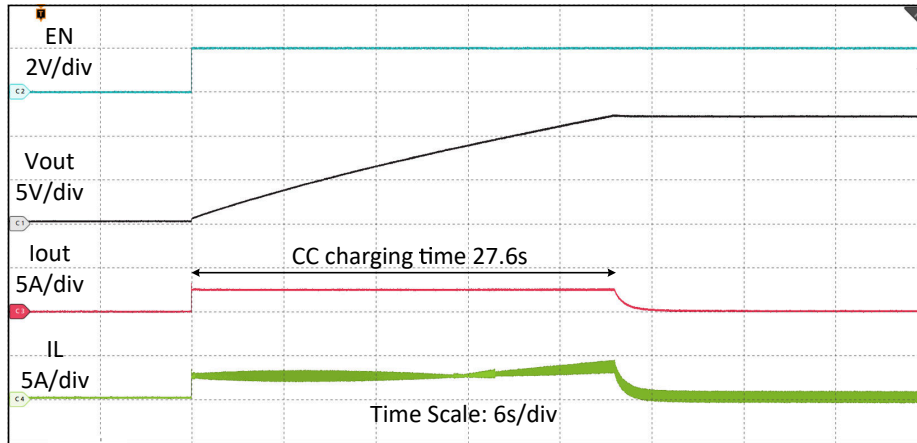


Figure 4-1. TPS552892: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 2.5A$, Super cap = 5.4F

Figure 4-1 illustrates the supercapacitor charging waveforms of the TPS552892-Q1 configured for a 2.5A output current. Because the current limit is set to a low value, the device avoids entering hiccup mode during the initial phase of charging.

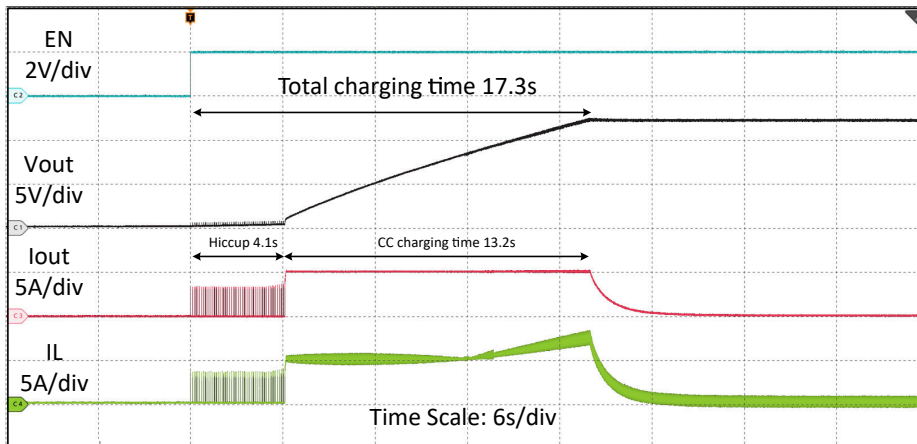


Figure 4-2. TPS552892: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 5A$, Super cap = 5.4F

When the output current is set to 5A, hiccup mode is triggered during the initial charging stage as Figure 4-2 shows. Once the capacitor voltage is charged above 0.8V, TPS552892-Q1 exits hiccup mode and proceeds with CCCV charging.

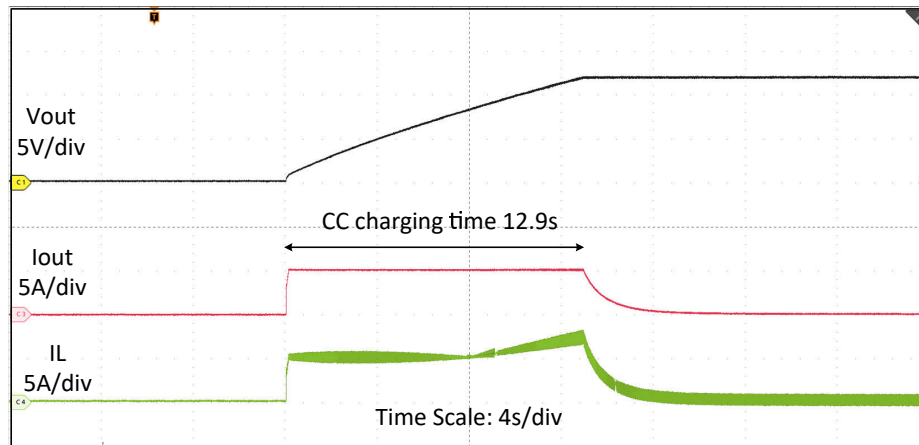


Figure 4-3. TPS55289: $V_{in} = 9V$, $V_{charge} = 12V$, $I_{charge} = 5A$, Super cap = 5.4F

After deactivating hiccup mode through the I2C interface, TPS55289-Q1 immediately begins 5-A constant-current charging once the device is enabled as [Figure 4-3](#).

5 Summary

The E-latch with 5S supercapacitor design provides a robust, reliable emergency backup power system for automotive door mechanisms. The integration of advanced buck-boost converter technology with CC/CV control enables efficient supercapacitor charging while maintaining system simplicity and cost-effectiveness.

Key advantages of this design include:

- Compliance with automotive safety standards
- Fast emergency response capability
- Long service life and minimal maintenance
- Scalable architecture for various vehicle configurations

6 References

1. Texas Instruments, [Crash Power Module Global Market Trend and Power Management Design Analysis](#), technical white paper.
2. Texas Instruments, [TPS552892-Q1, Automotive, 36-V, 8-A, Fully Integrated Buck-boost Converter](#), datasheet.
3. Texas Instruments, [TPS552892EVM-111 EVM User's Guide](#), user's guide

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