Propose MOSFET Optimized for Protection Circuitry of Lithium-Ion Batteries Used in Mobile Devices

Overview

This document explains the selection of suitable MOSFETs for switch applications in the protection circuitry of Lithium-ion secondary batteries used in mobile devices, with examples using protection ICs such as MM3860 manufactured by MITSUMI ELECTRIC paired with our MOSFETs: SSM6N951L, SSM10N954L, and SSM14N956L. The items described in this manual include circuit behavior when overcharge, overdischarge voltage is applied, charging overcurrent, discharging overcurrent is applied, and when short-circuit current is applied.

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1. Introduction

Lithium-ion rechargeable batteries are used in many mobile devices because their high energy density makes it possible to increase the capacity of batteries per unit volume, making them compact, thinner, and lighter. Recent advanced technological innovations have made it possible for batteries to increase capacity, allowing mobile devices to last longer while maintaining the same size, but one of the challenges is the long charging time due to large-capacity batteries. In order to solve this problem, quick charging technology has been developed and is now becoming mainstream.

Lithium-ion batteries are generally equipped with protection circuitry (PCBs: Protection Circuit Board) for safe use. This protection circuit includes a circuit that monitors the battery status, such as heat generation during charging and discharging, and a switch that stops charging and discharging when abnormalities are detected. The switch is used in series with the battery, between the battery and the charger or load. As such, it is required to minimize the power loss at the switch for efficient charging and discharging. For mobile applications, it is also important that Lithium-ion battery be thin, so the protection circuit must also be small and thin. For this reason, a low on-resistance, compactly packaged MOSFETs is used for the switch in the protection circuitry.

This application note explains the selection of suitable MOSFETs for the protection circuitry of Lithium-ion battery used in mobile devices, with examples using protection ICs paired with our SSM6N951L, SSM10N954L, and SSM14N956L.

2. Outline of Lithium-ion Battery and Protection Circuit

Figure 2.1 shows an image of a Lithium-ion battery. Pouch-type Lithium-ion batteries, which are commonly used in mobile devices, are packaged with battery elements in a laminated outer package. Although it is effective for thinning because it is a soft package, the space for the protection circuit is extremely limited.

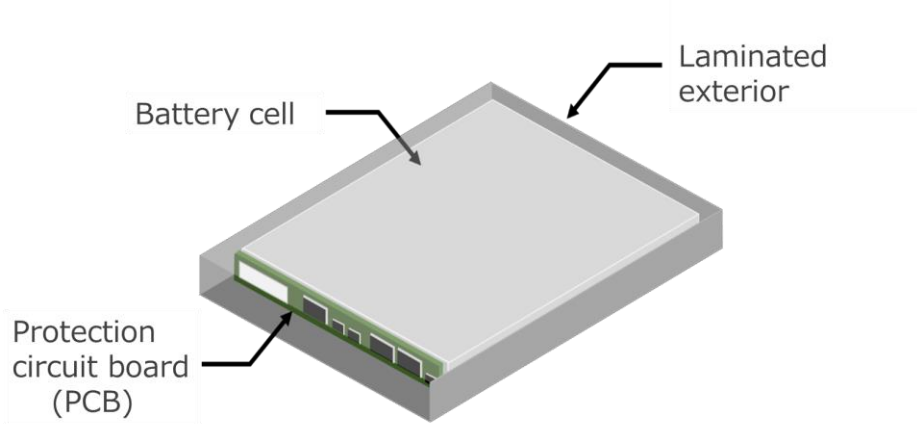


Figure 2.1 Image of Lithium-Ion Battery

The protection circuit is composed of a battery protection IC that monitors the charge/discharge status, detects abnormalities such as overcharge and overdischarge, performs switch control, and a MOSFET used as a low side switch. Figure 2.2 shows an example of a block diagram of a typical protection circuit. There are two types of protection circuits: one is to detect the current using the on-resistance of MOSFET, and the other is to use a shunt resistor. When MOSFETs are used, the on-resistance of the MOSFET varies depending on the discharge voltage and operating temperature. As such, the accuracy is lower than when the shunt resistor is used. For this reason, as the charging current increases and higher precision is required, a method using a shunt resistor is often used.

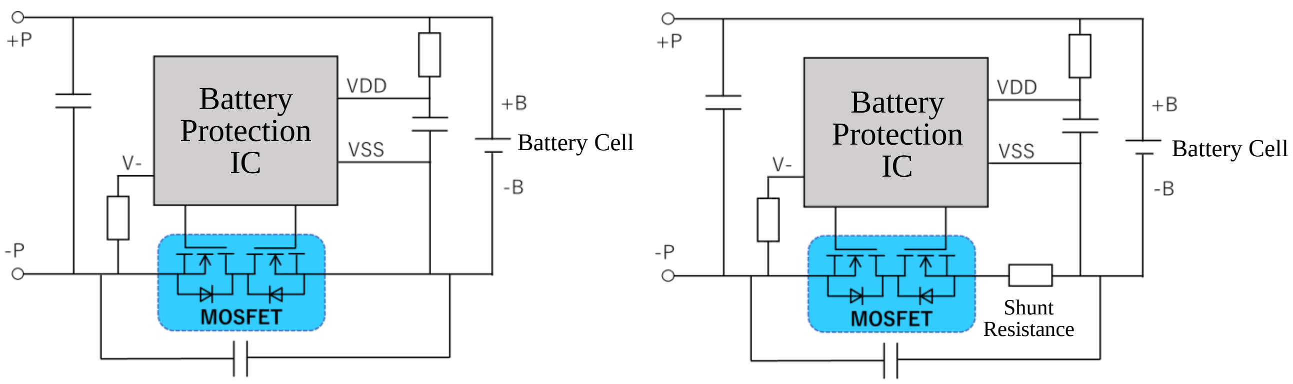


Figure2.2 Example of Typical Protection Circuit Block Diagram

In the next section, we will examine the performance required of MOSFET as a switching part of the protection circuitry for typical Lithium-ion rechargeable batteries.

3. Performance Requirements for MOSFET Used in Switching Parts of Protection Circuits

3.1. Low On-Resistance for Loss Reduction

In the protection circuit for Lithium-ion batteries, the direction of the current changes during charging and discharging as shown in Fig. 3.1. Both charge and discharge current paths require low side MOSFETs. One of the way is to use a common-drain MOSFET connected Drain pin to Drain pin to create a bidirectional switch. However, the conduction loss would be double due to two MOSFETs, so it would be good to use MOSFETs with the lowest on-resistance to reduce the loss. The on-resistance becomes increasing important to performance as current increases, with some fast-charging protocols require a charge current as high as 5A.

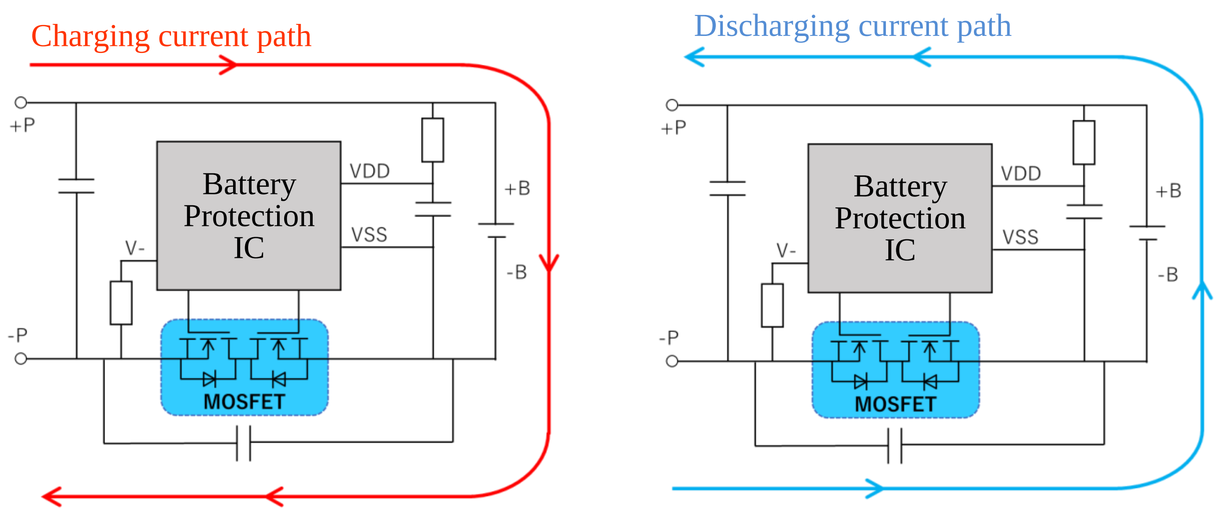


Figure 3.1 Current Direction during Charging and Discharging

3.2. Small and Thin Packages to Reduce Mounting Space

The protection circuit of the Lithium-ion battery is generally mounted on the side of the battery, and components are mounted on a board with a width of approximately 3mm. Therefore, it is subject to strict mounting space restrictions. As discussed earlier, the common-drain connection is commonly used to configure the bidirectional switch in a MOSFET, but since two MOSFET are used, selected components must fit within the mounting space constraints. Therefore, MOSFET of the smallest and thinnest packaging should help.

3.3. Minimization of On-Resistance Change to Improve Error Detection Accuracy

In the protection circuit without the shunt resistor shown in Figure 2.2, the battery protection IC monitors the voltage between the VSS pin and the V-pin to monitor the overcharge and overdischarge, and detects the overcurrent. In this detection method, the on-resistance change of MOSFET appears as a change in the detection voltage. Therefore, in order to improve the detection accuracy, the on-resistance change of MOSFET must be minimized.

The on-resistance of MOSFET varies with the gate-drive voltage. Since the voltage of the battery cell is used for gate-drive, the on-resistance of MOSFET varies with changes in the battery cell voltage. In addition, the on-resistance change caused by the operating temp of MOSFET must also be considered. Therefore, it is desirable to use a MOSFET that minimizes on-resistance changes caused by gate-drive voltages and operating temperatures.

In the next section, we will propose solutions to these performance requirements by referring to our SSM6N951L.

4. Proposing the Optimal MOSFET for Protection Circuitry

4.1. CSP Structure with Low On-Resistance Performance

As previously mentioned, MOSFET used in the protection circuitry of Lithium-ion secondary batteries require low on-resistance to minimize the loss in the switch. By adopting a CSP (Chip Scale Package) construction, SSM6N951L is able to eliminate the resistance of bonding wires used in molded resin packages. In addition, because larger semiconductor chips can be used compared to the chips used in similarly sized mold resin packages, this structure is even more advantageous in reducing on-resistance. Furthermore, the CSP structure has excellent heat dissipation characteristics because heat sources of semiconductor chips are directly mounted on the PCB.

Figure 4.1 shows a comparison image of the molded resin package and CSP structure.

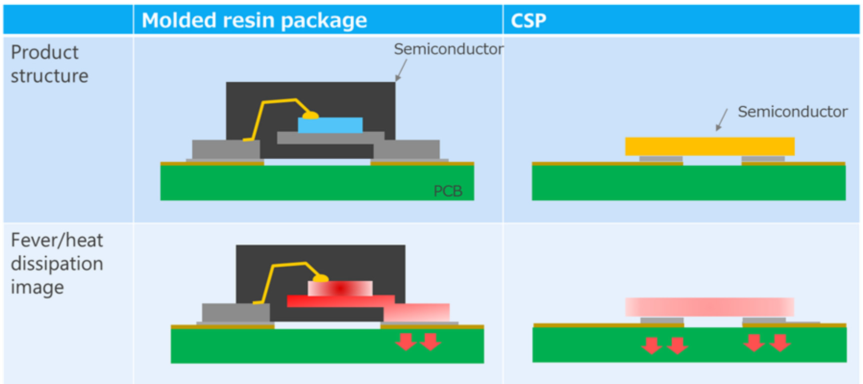


Figure 4.1 Comparison Image of Molded Resin Package and CSP Package

4.2. 1-chip Common-Drain Product Effective in Reducing Mounting Space

Although SSM6N951L employs a CSP structure to reduce on-resistance, the CSP structure also contributes to a reduction in package-size and thickness. SSM6N951L has two MOSFETs connected together at the drain, so a common-drain switch can be configured with a single SSM6N951L. SSM6N951L is very small and thin 2.14mm x 1.67mm x 0.11mmt (typical) and ideal for use in the protection circuitry of Lithium-ion rechargeable batteries limited by mounting space. Fig. 4.2 shows an image comparing the mounting area when single MOSFETs are used to when a SSM6N951L is used.

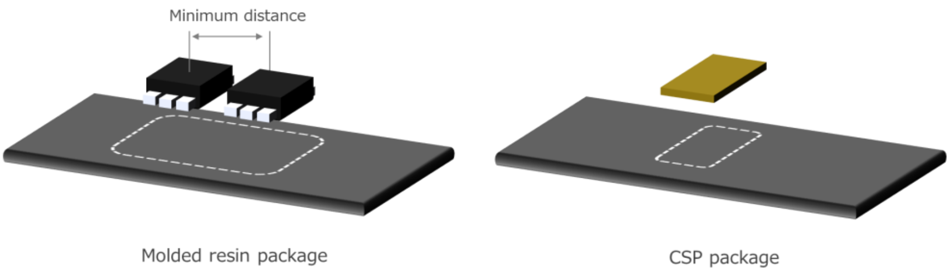
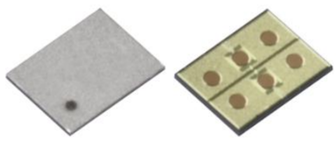
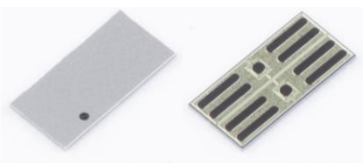
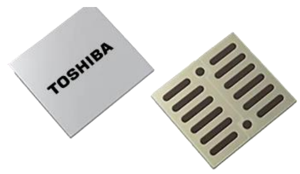


Figure 4.2 Image of Comparison of Mounting Areas

4.3. Characteristics of Toshiba Common-Drain MOSFET

Table 4.1 shows MOSFET properties of our drain common MOSFET: SSM6N951L, SSM10N954L, and SSM14N956L during mass production. Similar to SSM6N951L described in 4.2, the CSP structure is used in SSM10N954L and SSM14N956L, enabling compact package-size and high-density mounting. In addition, by adopting a newly developed fine-process technique, low on-resistance of 4.6mΩ (Typ., V_{GS}=3.8V) is achieved for SSM6N951L, 2.2mΩ (Typ., V_{GS}=3.8V) for SSM10N954L, and 1.1mΩ (Typ., VGS=3.8V) for SSM14N956L. Another feature is the extremely small gate-source leakage current of ±1μA (max, V_{GS}=±8V), which allows the battery to run for long periods of time.

Table 4.1 Characteristics of Toshiba Common-Drain MOSFET

Part number	SSM6N951L	SSM10N954L	SSM14N956L
Package Size	2.14 x 1.67 x 0.11t mm 	2.98 x 1.49 x 0.11t mm 	3.0×2.74×0.085t mm 
$V_{(BR)SSS}$	12V		
V_{GSS}	±8.0 V		
I_S	8A	13.5A	20.0A
I_{SSS} max	1μA@12V		
I_{GSS} max	±1μA@±8V		
V_{th}	0.35 / 0.90 / 1.4V		
$R_{ss(on)}$(4.5V) Min/Typ./Max	3 / 4.4 / 5.1mΩ @4A	1.55 / 2.1 / 2.75mΩ @6A	0.70 / 1.00 / 1.35mΩ @10A
$R_{ss(on)}$(3.8V) Min/Typ./Max	3.2 / 4.6 / 5.5mΩ @4A	1.6 / 2.2 / 2.85mΩ @6A	0.75 / 1.10 / 1.50mΩ @10A
$R_{ss(on)}$(3.1V) Min/Typ./Max	3.5 / 4.9 / 6.8mΩ @4A	1.65 / 2.4 / 3.95mΩ @6A	0.80 / 1.25 / 2.15mΩ @10A
$R_{ss(on)}$(2.5V) Min/Typ./Max	3.8 / 5.5 / 10mΩ @4A	1.9 / 3.1 / 6.1mΩ @6A	0.9 / 1.60 / 3.20mΩ @10A
$V_{F(S-S)}$ Min/Typ./Max	- / 0.7 / 1.2V	- / 0.8 / 1.2V	- / 0.7 / 1.2V

5. Evaluating Common-Drain MOSFET Using Battery Protection ICs Evaluating Board Made by MITSUMI ELECTRIC

Here we describe the actual operation of our SSM6N951L, SSM10N954L, and SSM14N956L on the protection circuitry of Lithium-ion secondary batteries using Mitsumi Electric's Battery Protection ICs (MM3860).

5.1. Overcharge, Overdischarge Voltage Measurement

・Measurement details

Table 5.1 lists the detection and recovery voltages of the protection ICs. The circuit shown in Figure 5.1 was used for the measurement. In the test, the voltage of the stabilized power supply of the battery cell was varied while the current was kept constant at 1A.

・Overcharge detection, overcharge recovery voltage

Raise the voltage gradually from VDD=3.6V, and measure whether MOSFET of COUT is turned off at the overcharge detect voltage and the charge current stops flowing.

Then, the VDD is then gradually decreased, and MOSFET of COUT is turned on at the overcharge recovery voltage. This is measured when the charge current begins to flow.

・Over Discharge Detection, Over Discharge Recovery Voltage

Lower the voltage gradually from VDD=3.6V, and measure whether MOSFET of DOUT turns off at the overdischarge detect voltage and the charge current stops flowing.

Then, the VDD is gradually increased, and MOSFET of DOUT is turned on at the overdischarge recovery voltage. It is measured whether the charge current begins to flow.

Table 5.1 Detection/Recovery Voltage for Overcharging and Overdischarging

Item	Typ. value
Overcharge detection voltage	4.445 V
Overcharge recovery voltage	4.245 V
Overdischarge detection voltage	2.500 V
Overdischarge recovery voltage	2.900 V

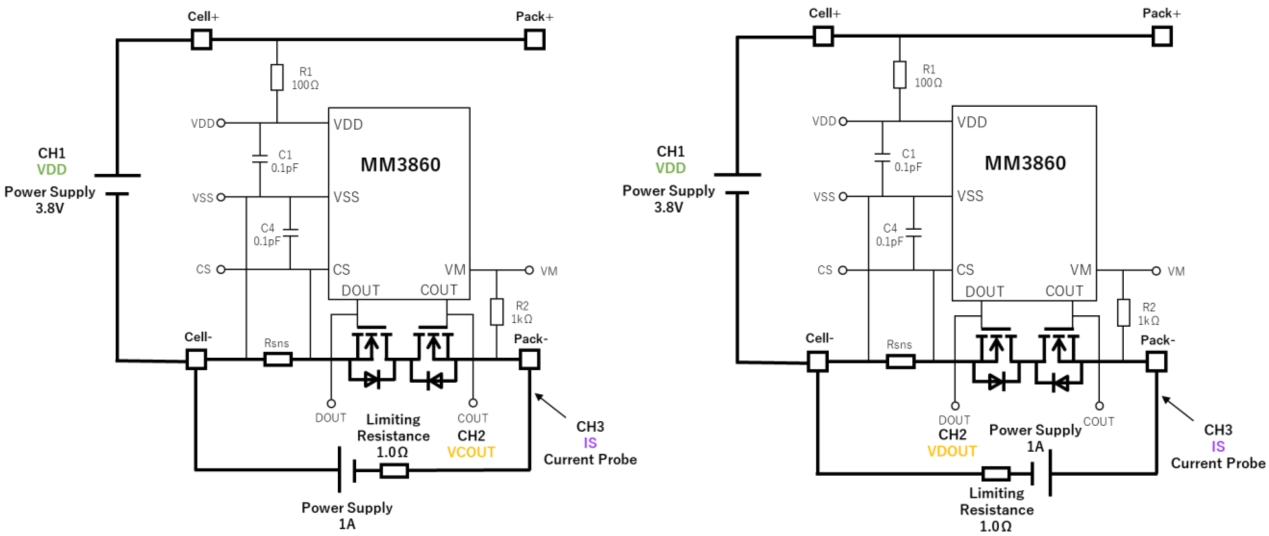


Figure 5.1 Overcharge Voltage Measurement Circuit (Left) and Overdischarge Voltage Measurement Circuit (Right)

・Measurement results

Overcharge measurement: The results of overcharge measurement are shown in Figure 5.2 below. For any MOSFET of SSM6N951L, SSM10N954L, and SSM14N956L, it can be seen that MOSFET is turned off when the overcharge voltage is detected and MOSFET is turned on when the recovery voltage is detected.

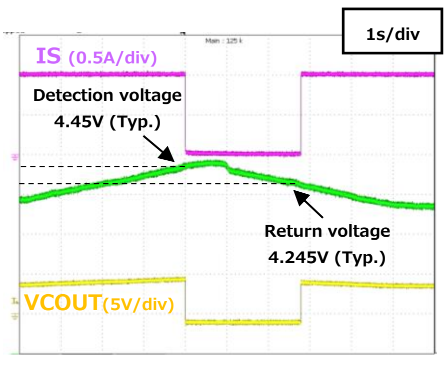
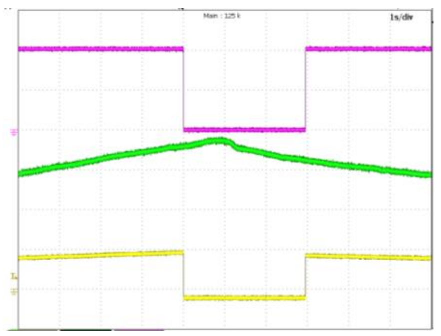
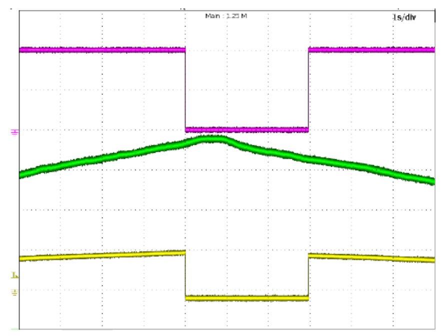
Overcharge detection voltage and recovery voltage measurement		
SSM6N951L	SSM10N954L	SSM14N956L
		

Figure 5.2 Overcharge Voltage Measurement Results

Overdischarge measurement: The results of overcharge measurement are shown in Figure 5.3 below. For any MOSFET of SSM6N951L, SSM10N954L, and SSM14N956L as well as the overcharge measurement, it can be seen that MOSFET is turned off when the overdischarge voltage is detected and MOSFET is turned on when the recovery voltage is detected.

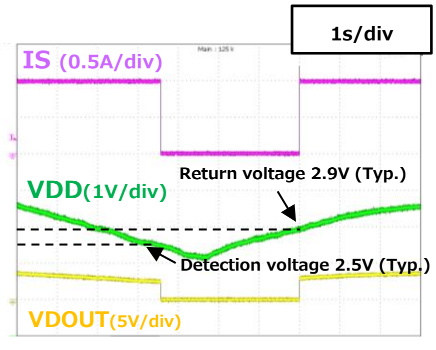
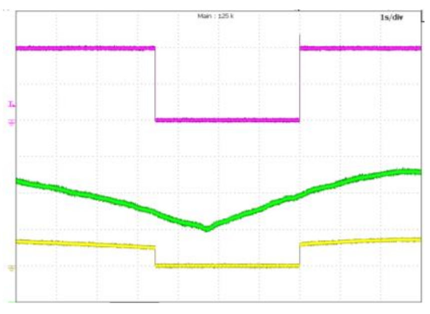
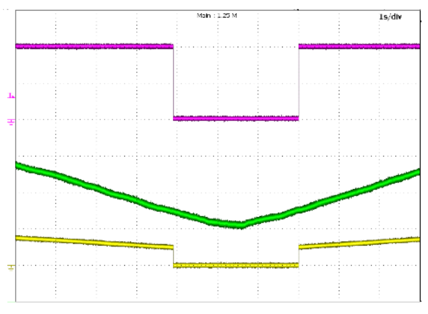
Overdischarge detection voltage and recovery voltage measurement		
SSM6N951L	SSM10N954L	SSM14N956L
		

Figure 5.3 Overdischarge Voltage Measurement Results

5.2. Charge Overcurrent and Discharge Overcurrent Measurements

・Measurement details

Table 5.2 lists the detection voltages and currents, and Figure 5.4 shows the measurement circuits. The test was performed by connecting a battery-like power supply between Cell + and Cell-, and a power supply that controls the current between Pack-and Cell-. Both DC current and pulse current were used for the measurement. As for pulse measurement, MOSFET for low side switch turns on and off.

・Charge overcurrent

VDD=3.8V, gradually increase the voltage of the stabilized power supply and measure whether MOSFET of COUT turns off when the voltage exceeds the charge overcurrent value.

・Discharge overcurrent measurement

VDD=3.8V, gradually increase the voltage of the stabilized power supply and measure whether MOSFET of DOUT turns off when the discharge overcurrent value is exceeded.

Table 5.2 Detection Voltage for Charge Overcurrent and Discharge Overcurrent

Item	Detection voltage Typ. value	Current conversion (Rsns=4mΩ)
Charge overcurrent detection	22.0mV	5.50 A
Discharge overcurrent detection	21.0mV	5.25 A

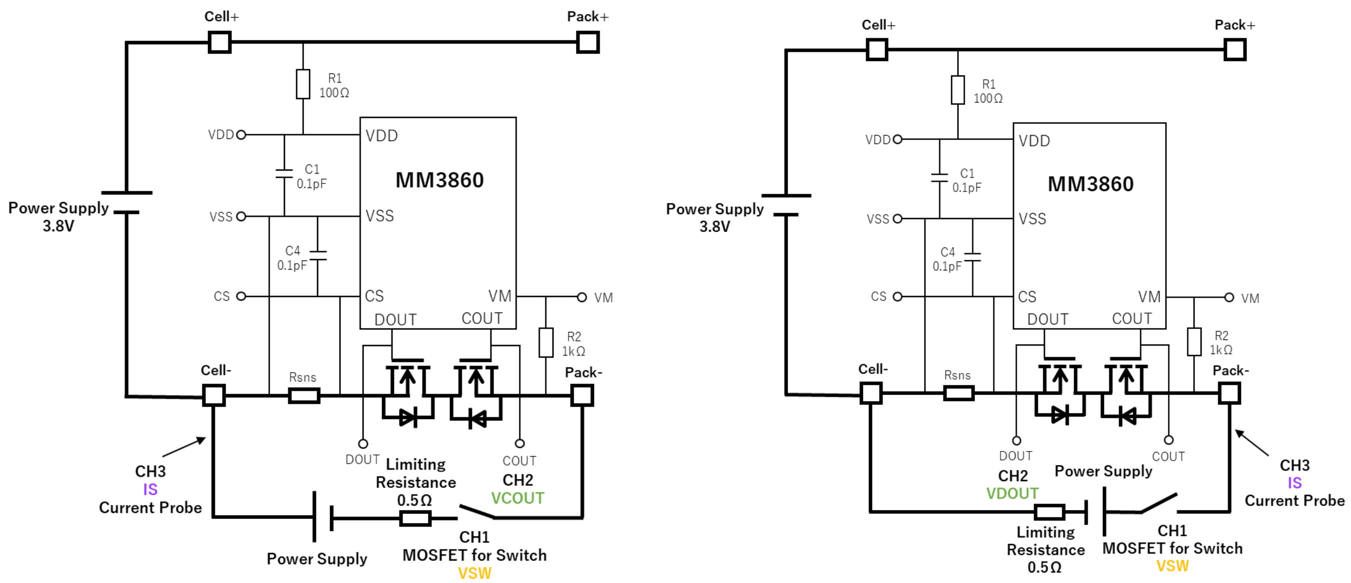


Figure 5.4 Charge Overcurrent Measurement Circuit (Left) and Discharge Overcurrent Measurement Circuit (Right)

5.2.1. Charge Overcurrent Measurement

DC measurement: Charge overcurrent DC measurement results are shown in Figure 5.5. Gradually raising the IS. After the value exceeds approximately 5.50A, overdischarge current is detected, and it can be seen that MOSFET is turned off. The voltage at VCOUT is approximately-4 V, as the voltage at the VM terminal is visible.

Charge Overcurrent Measurement (DC)		
SSM6N951L	SSM10N954L	SSM14N956L

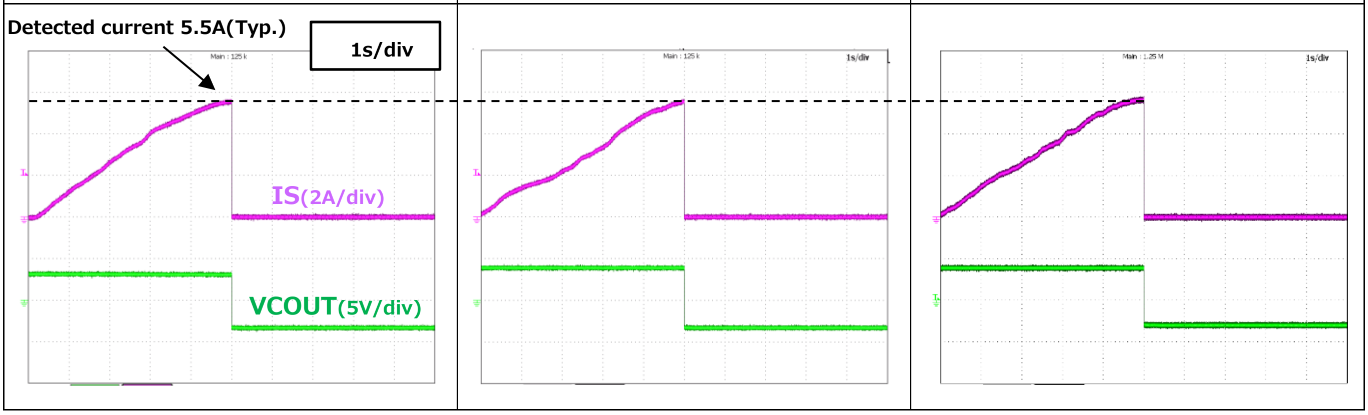


Figure 5.5 Charging Overcurrent DC Measurement Results

Pulse measurement: Charge overcurrent pulse measurement results are shown in Figure 5.6. In the pulse measurement, a VSW is added to MOSFET for opening and closing the circuit, and the circuit is connected only for a certain period of time to measure the pulse. When a current of about 5.50A or more flows, it can be seen that MOSFET is turned off after 8ms of the detect delay time. The return condition at this time was VM > VrelVM (approx. 0.250 V), and since the return condition was not met, the MOSFET remained turned off even after the current stopped flowing. The voltage at the VM-terminal is visible on VCOUT in the same way as the DC-measurement.

Charge overcurrent measurement (pulse)		
SSM6N951L	SSM10N954L	SSM14N956L

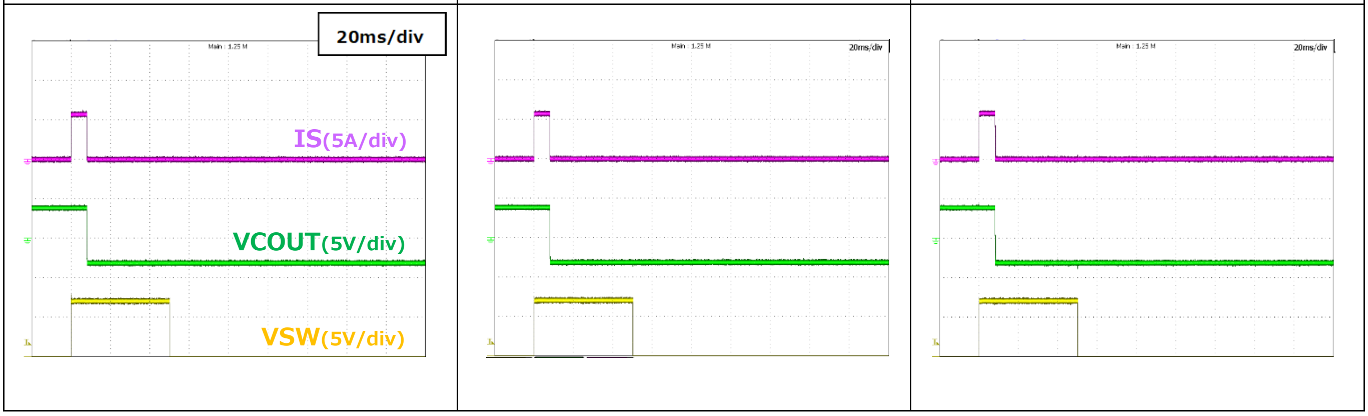


Figure 5.6 Charge Overcurrent Pulse Measurement Results

5.2.2. Discharge Overcurrent Measurement

DC measurement: Discharge overcurrent DC measurement is shown in Figure 5.7. Increase the IS gradually, and after approximately 5.25A the overdischarge current is detected, indicating that MOSFET is off.

Discharge overcurrent measurement (DC)		
SSM6N951L	SSM10N954L	SSM14N956L

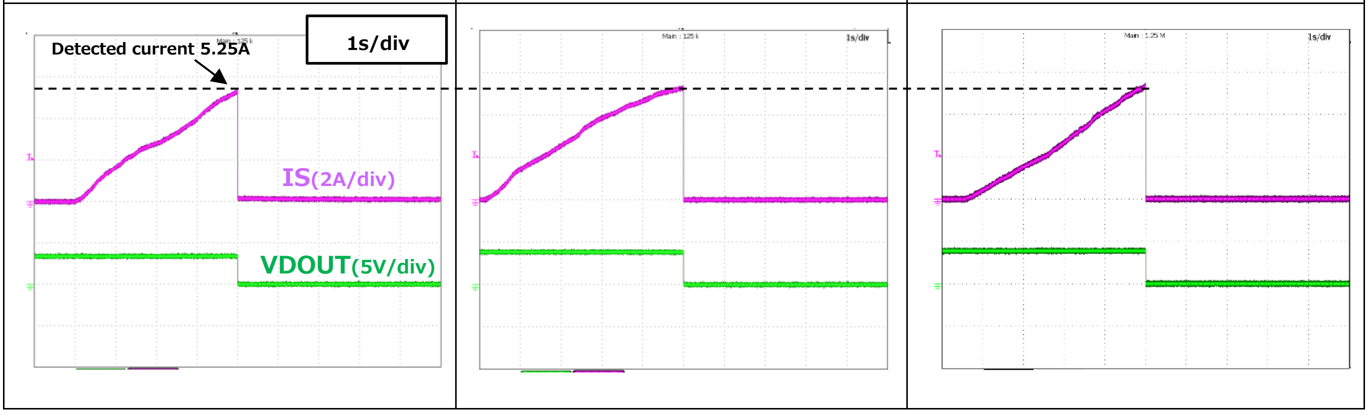


Figure 5.7 Discharge Overcurrent DC Measurement Results

Figure 5.8 shows the pulse measurement results and an enlarged view of the discharge overcurrent pulse measurement. The pulse measurement was performed in the same way as the charging overcurrent. When a current of about 5.25A or more is flows, an overcurrent is detected, and it can be seen that MOSFET is turned off 16ms after the detect delay. At this time, the return condition is VM<VrelVM2 (approx. VDD-1.10V), and the return condition is satisfied. Therefore, it can be seen that the circuit is in the restored state after closing, and the MOSFET is turned on after 4 ms, which is the delay time for restoration.

Discharge overcurrent measurement (pulse)		
SSM6N951L	SSM10N954L	SSM14N956L

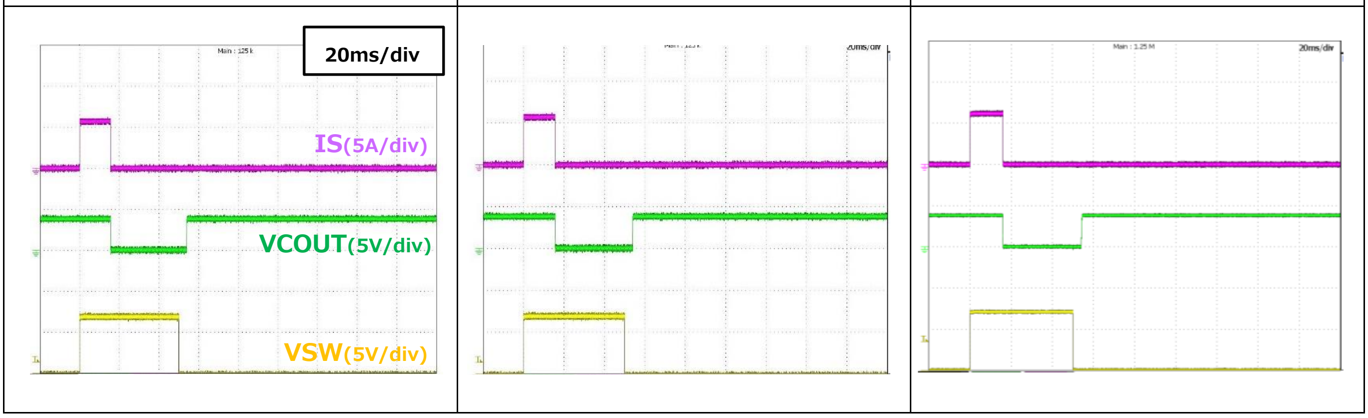


Figure 5.8 Discharge Overcurrent Pulse Measurement Results

5.3 Short-Circuit Measurement

・Measurement details

Table 5.3 shows the short-circuit detection voltage and current, and Figure 5.9 shows the measurement circuit. For measurement, a stabilized power supply that is similar to a battery cell is connected between Cell + and Cell-, and 3.8V is applied, and Pack + and Pack-are short-circuited with a conductor to perform measurement. In addition, a 100 mΩ load was added to prevent the current from flowing above the current limit of the regulated power supply.

Table 5.3 Short-Circuit Detection Voltage

Item	Detection voltage Typ. value	Current conversion (Rsns=4mΩ)
Short-circuit Detection	60.0mV	15.0 A

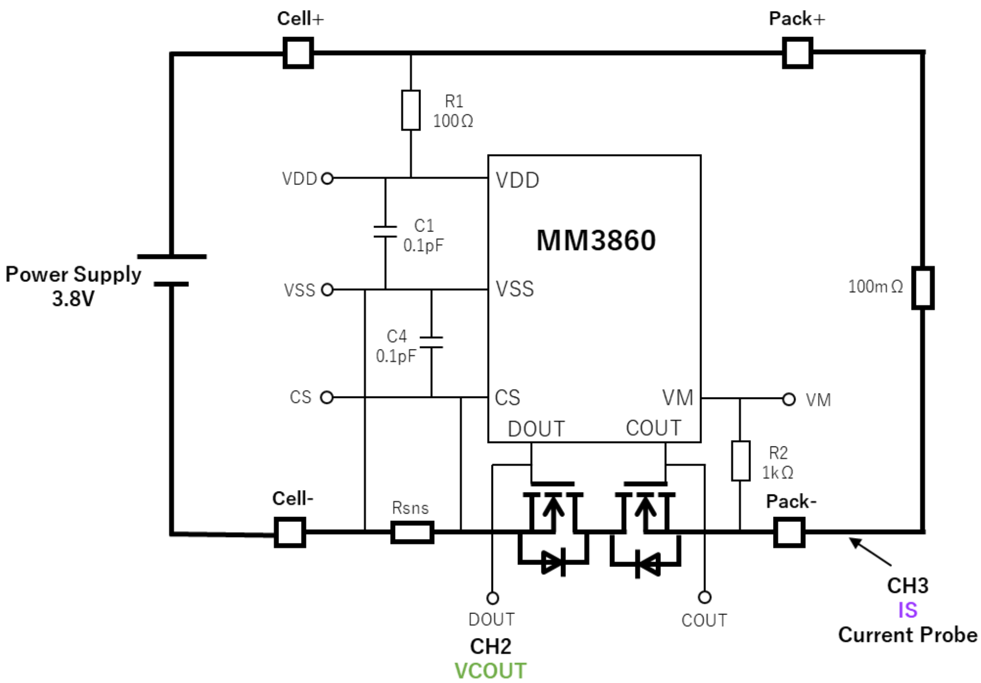


Figure 5.9 Circuit Diagram for Short-Circuit Measurement

・Measurement results

The results of short-circuit measurements are shown in Figure 5.10. For any MOSFET of SSM6N951L, SSM10N954L, and SSM14N956L, when the short-circuit detection current reaches 15A, short-circuit is detected, and it can be seen that MOSFET at DOUT terminal is turned off.

Looking at the rising waveforms of the short-circuit current, it can be seen that MOSFET is turned off after approximately 280μs, which is the delay time between detecting the short-circuit current and the MOSFET turning OFF.

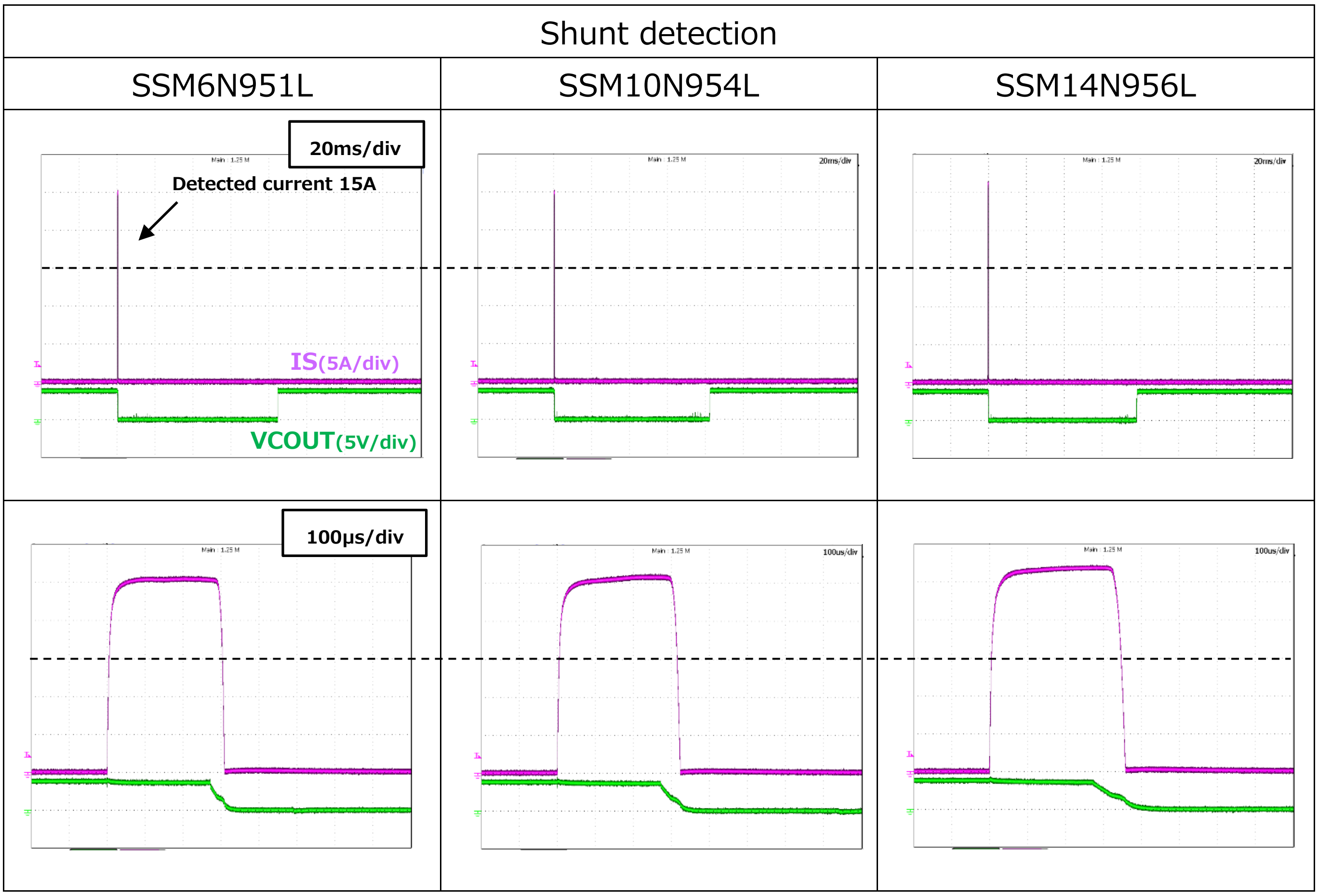


Figure 5.10 Short-Circuit Measurement Results

6 Summary

Lithium-ion batteries for mobile devices are becoming larger, smaller, and thinner because they operate mobile devices for a long time. Therefore, the protection circuit needs to balance low loss, mounting space, and improvement of abnormality detection accuracy to improve safety at a high level, and the difficulty of design is increasing. Our SSM6N951L, SSM10N954L, and SSM14N956L was developed to satisfy the required performance of the protection circuitry for Lithium-ion battery for mobile devices by adopting a CSP structure and a new miniaturization process. We have also confirmed that the system operates properly in the protection circuitry using the protection IC (MM3860) manufactured by MITSUMI ELECTRIC.

MOSFET ideal for use in protection circuits for Lithium-ion secondary batteries for mobile devices

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