Li-ion Battery Charger Protection IC

MP267x Series

Application Note

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ABSTRACT

This application note discusses MPS's MP267x series Li-ion battery charger protection chips. This note discusses battery-charging safety considerations that include input over-voltage, output over-current, battery over-voltage, input reverse polarity and reverse leakage. This note focuses on three chips in particular, which include features such as automatic reverse-leakage blocking. Each feature discussed includes experimental results.

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1. INTRODUCTION

The adoption of a wide variety of battery-powered portable devices—such as mobile phones and smartphones, portable media players, and notebook computers—into daily consumer use has proliferated over the past two decades. With increased adoption and use, the variety of power adapters that charge the batteries has increased thanks to variations in battery specifications and device power requirements. The relatively limited standardization of such requirements increases the probability of power-related accidents, especially among devices using Li-ion batteries. System designers are therefore required to design power systems with special considerations for product safety and reliability and interchangability given recent pubic attention to battery explosions in portable consumer electronics. This application note illustrates how MPS protection chips (MP267x series) improve the safety and reliability of Li-ion battery charging.

2. MAIN SAFETY CONCERNS IN BATTERY CHARGING

Damage to the battery charging system can occur as a result of faults such as input over-voltage, output over-current, battery over-voltage, or reverse-input voltage. Reverse leakage is also a common consideration when developing power systems that protect the battery and prolong its working time even when the input is shorted.

2.1. INPUT OVER VOLTAGE

Input over-voltage can occur as a result of either a voltage surge or steady-state over-voltage; the former is mainly caused by hot-swapping the adapter, while the latter is usually caused by using an unsuitable adapter.

Figure 1 illustrates this issue, where V_{IN} is the input voltage to the device while V_{OUT} is both the output voltage of the protection circuit and the input voltage of the battery charger IC. To avoid the damage due to input over-voltage, the input power must be cut off immediately once over-voltage occurs. The response time should be less than 1μs.

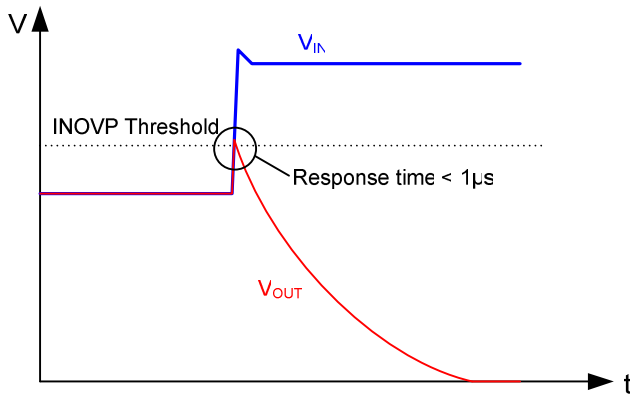

Figure 1: Key waveform of input over-voltage protection during steady state

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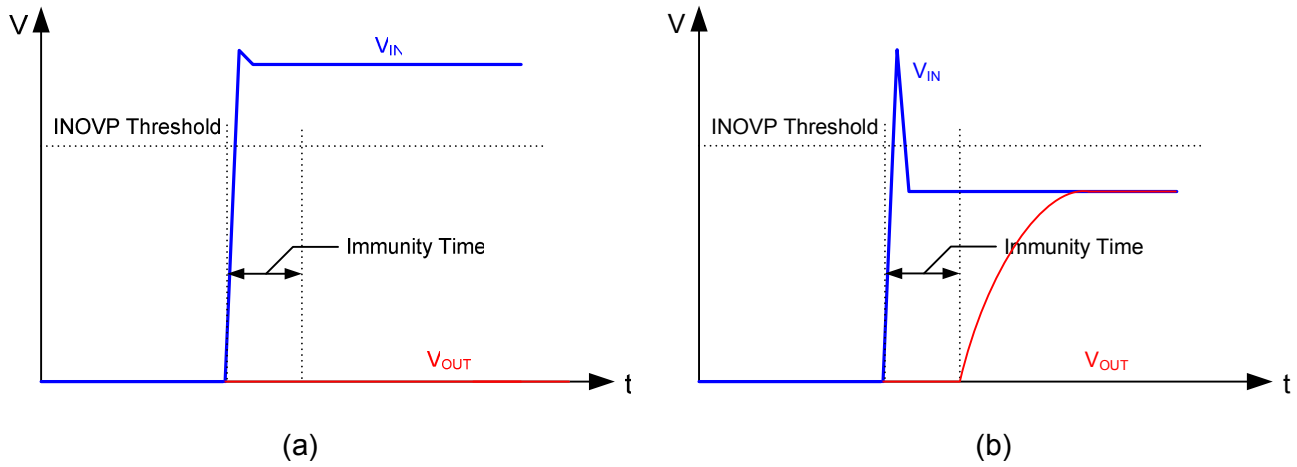

Figure 2: Key waveform of input over-voltage protection during start-up

An immunity time blanks the input power during start up before V_{OUT} responds. As shown in Figure 2(a), if the input voltage is still higher than the input over-voltage protection (INOVP) threshold, V_{OUT} does not increase. If the input voltage falls below the INOVP threshold during this immunity time, V_{OUT} rises normally, as shown in Figure 2(b).

2.2. OUTPUT OVER-CURRENT

Output over current can be caused by an unexpected short across the battery ports or damage to some device in the system that can lead to a large current and increase the chip and battery temperatures rapidly and to dangerous levels; both the rapid rise and high temperatures can lead to fires or explosions. Additionally, over-current can occur if there is a path from the input to the system directly without any loop current limit, as shown in Figure 3. As a result of the dangers of output over-current conditions, such systems require a programmable output-current–limit circuit to ensure normal adapter operation to protect both the device and the adapter.

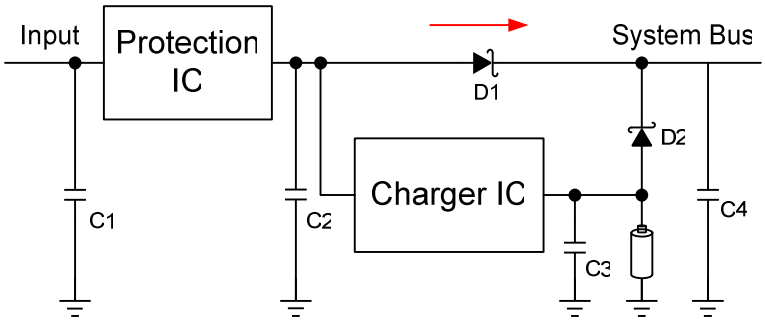

Figure 3: Battery charging system with power selector

The circuit requires a blanking time to avoid mistaking a current spike for an over-current event and to enhance anti-jamming. After this blanking time, the circuit disconnects the input power if the over-current event remains. After over-current protection triggers, there are three common ways to deal with the system: (1) latch-off, (2) auto-recovery, and (3) latch-off after protection triggers repeated (around 16 times).

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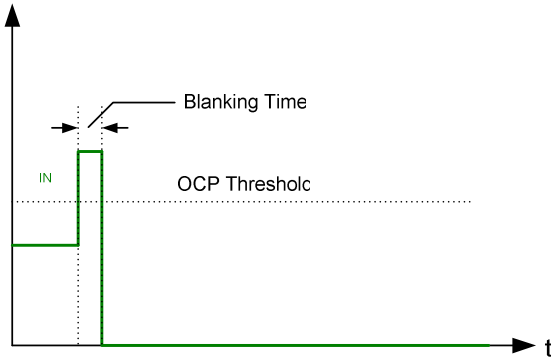
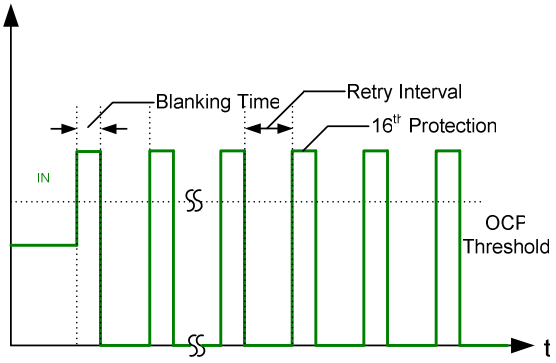
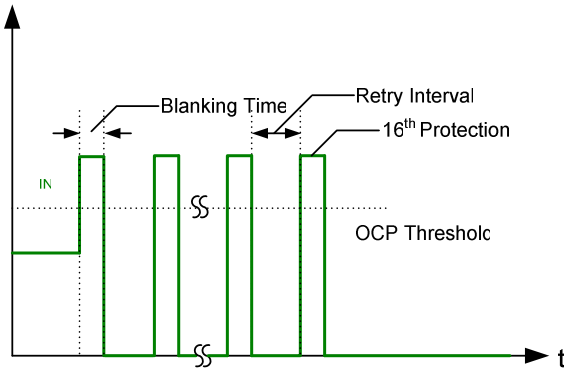


(a) Latch-off



(b) Auto-recovery

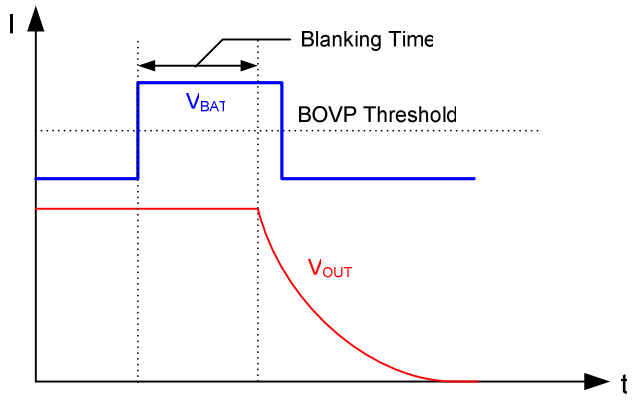


(c) Latch-off after 16th over-current protection event

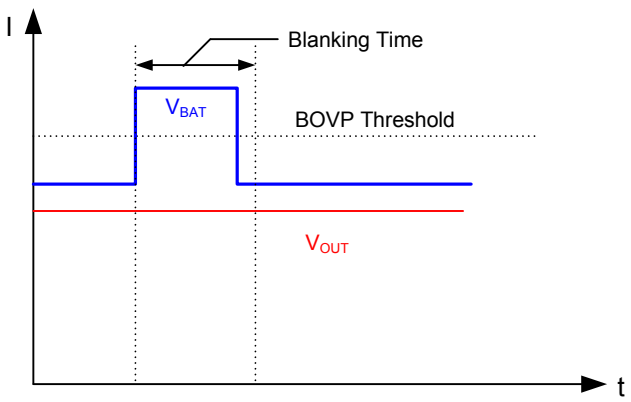
Figure 4: Key waveform of output over current protection

As illustrated in Figure 4(a), the part can be latched off once over-current protection (OCP) occurs. Only resetting the input power or setting the enable signal high can restart the part. Another method to protect the circuit is to always auto-restart after a retry interval until the OCP ceases, as shown in Figure 4(b). The third method combines the two former methods, as shown in Figure 4(c), where the part is latched-off after the OCP has triggered16 times.

2.3. BATTERY OVER-VOLTAGE



(a)



(b)

Figure 5: Key waveforms for battery over-voltage protection

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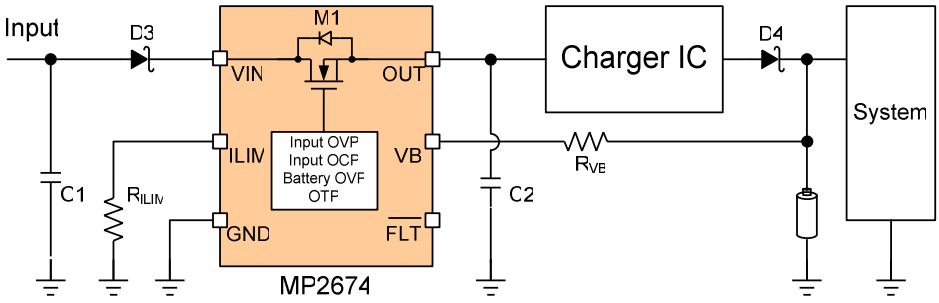
Li-ion and Li-polymer batteries, because of their reusability and high power density, are now common in portable devices. However, they are also a known cause fires and explosions when overcharged; i.e., excessive voltage across the battery ports. Battery over-voltage protection (BOVP) prevents such accidents from occurring by disconnecting the input power source when the battery voltage rises above threshold. BOVP requires a blanking time to prevent falsely detections, as shown in Figure 5(a). However, if a BOVP condition extends beyond the blanking time, the BOVP cuts off power immediately. If the level drops below threshold, the voltage rises as shown in Figure 5(b). Similar to OCP, a counter can also be added to accumulate the times of BOVP event to latch the circuit off if the BOVP condition occurs repeatedly.

2.4. INPUT REVERSE POLARITY

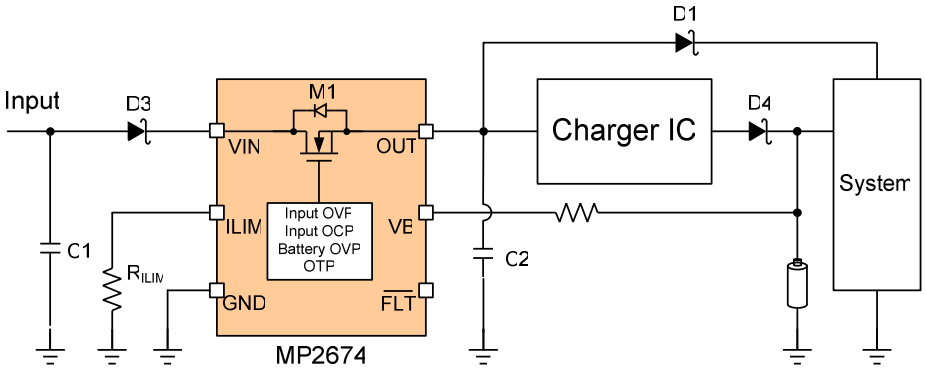
The use of universal connectors runs the risk reversing the connector polarities when switching between different adapters or different devices. For these cases, the parasitic diode between the substrate and the charger IC input becomes forward-biased, which ruins the IC and makes this an important issue for designers. One solution uses a blocking switch (D3 in Figure 6) in series with the input of the protection IC, and to replace the diode with a MOSFET to minimize any unexpected voltage drops.

2.5. REVERSE LEAKAGE

Reverse leakage must be blocked to prolong the battery operating time. Most designs include a block switch (D4 in Figure 6) in the path from the input power to battery directly behind the output of the charger IC. However, integrating this block switch with the pass element into the charger IC provides a better and more effective way to improve the efficiency and simplify the design.



(a) Battery-fed application



(b) Power-selector application

Figure 6: Battery charging system using MP2674 for circuit protection

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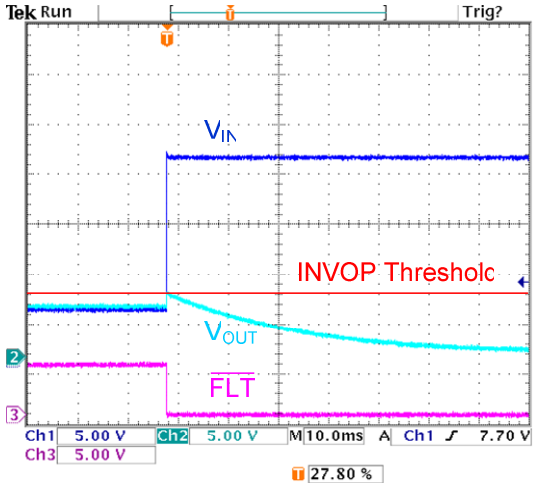
3. MPS BATTERY CHARGER PROTECTION SOLUTION

To protect the battery charging system, MPS has developed a series of battery charger protection ICs that include the MP2674, the MP2678, and the MP2676.

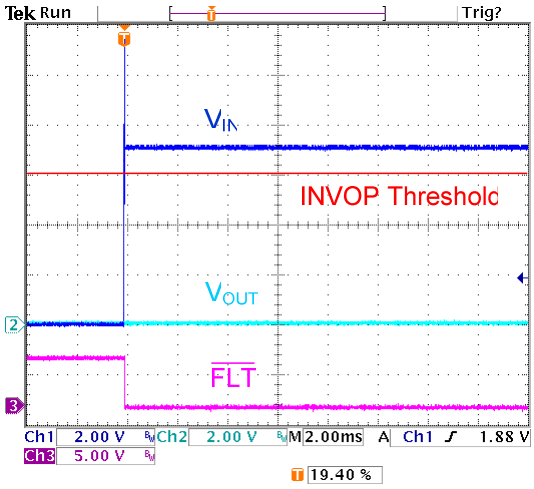
3.1. MP2674 PROTECTION SOLUTION

Figure 6 shows two typical battery-charging circuits using the MP2674. For both applications, the MP2674 provides reliable INOVP, OCP, BOVP, and fault indication when any protections trigger. MP2674 also has an integrated soft-start to avoid inrush current.

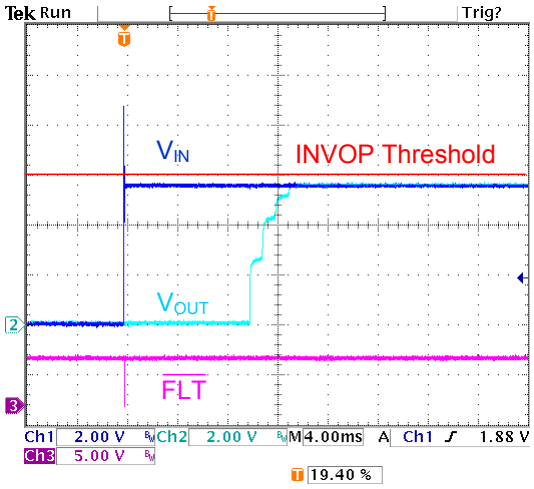
Under normal conditions, VIN connects directly to the output through the internal MOSFET. Once the input voltage reaches the preset INOVP threshold, the internal MOSFET immediately turns off with a <1μs delay to disconnect the input voltage. Figure 7 shows the typical response to input over-voltage.



(a) V_{IN} jumping from 5V to 20V



(b) V_{IN} jumping from 0V to 7V



(c) V_{IN} jumping from 0V to 5.5V

Figure 7: MP2674's responses to input over-voltage conditions

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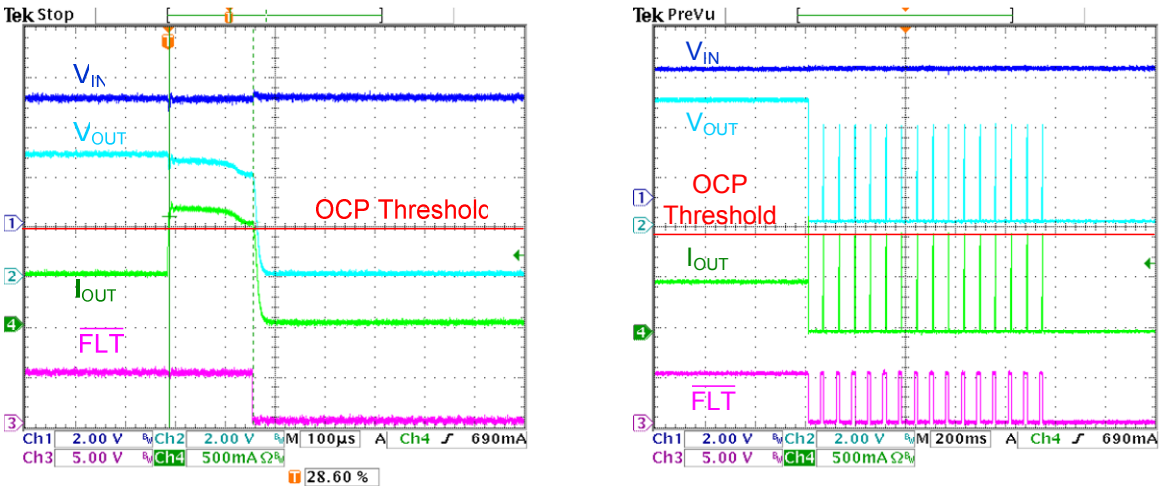
When the total output current exceeds the current limit programmed from the ILIM pin, the internal MOSFET turns off after a built-in blanking time of 170μs that prevents false triggering caused by transient signals. After OCP triggers, the internal MOSFET turns off for about 40ms and then the MP2674 initiates the restart process (10ms delay then soft-start). If the OCP condition remains after 170μs, the MP2674 turns off the MOSFET again. The MP2764 has a 4-bit binary counter to count the OCP events. If the number of restarts reaches 16, the MOSFET is turned off permanently until the part undergoes power cycling. The typical response to input over current is shown in Figure 8.



(a) Output OCP blanking time **(b) Output OCP counter**

Figure 8: MP2764 response to input over-current

As discussed, another important IC protection feature is battery over-voltage protection (BOVP). The VB pin monitors the battery voltage, and when the battery voltage exceeds the preset battery over-voltage threshold beyond the 180μs blanking time, the internal MOSFET turns off immediately. Similar to the OCP counter, if BOVP events occur 16 times the MOSFET turns off permanently and will not restart the MP2674 without a complete power cycle. Figure 9 illustrates the response of MP2674 to battery over-voltage.

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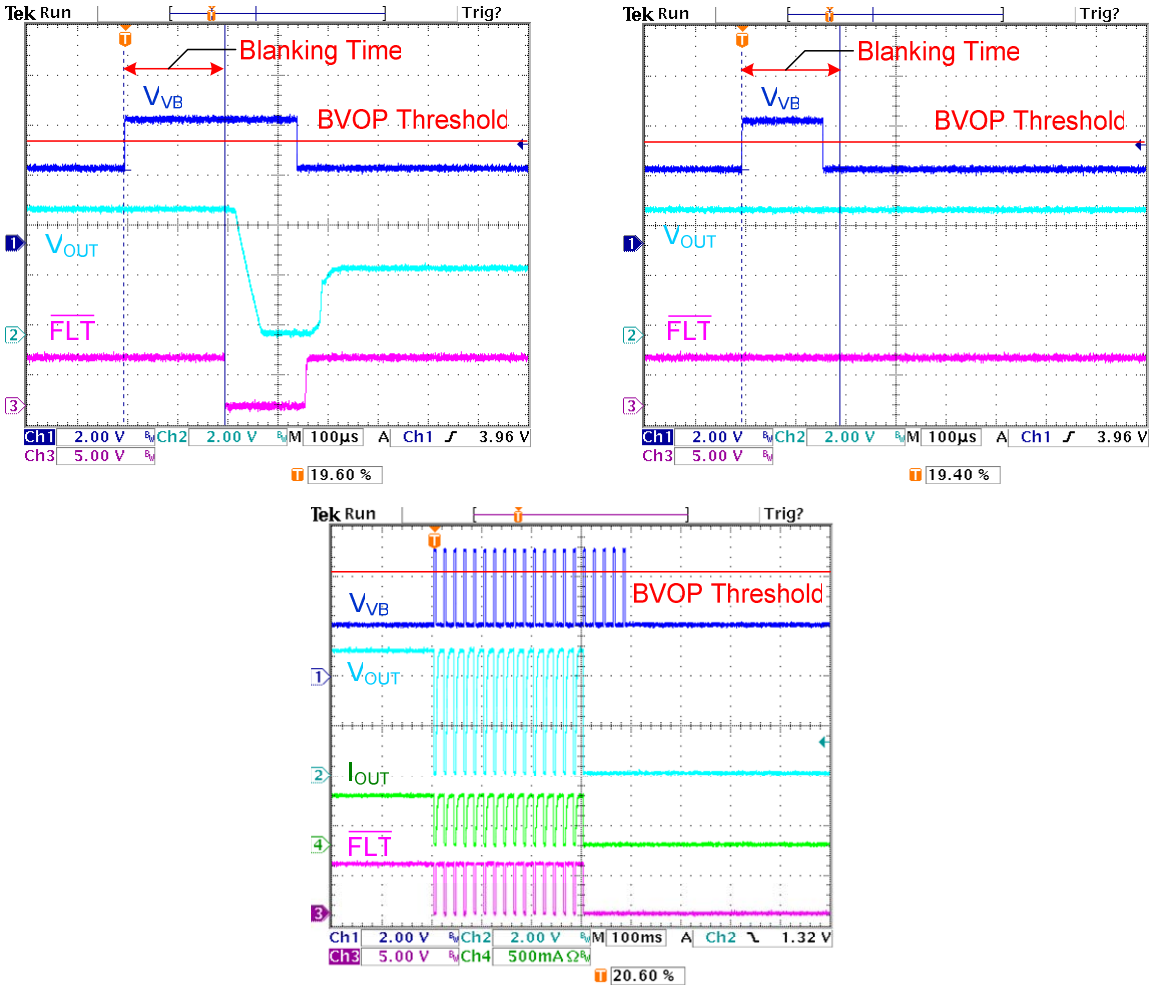

(a) BOVP blanking time **(b) BOVP counter**

Figure 9: MP2674 response to battery over-voltage

For input reverse-polarity protection, the most common solution is to add an external diode in series with the input to block any reverse current, as shown in Figure 6. Furthermore, replacing this diode with a MOSFET with low on-resistance can minimize power dissipation.

3.2. MP2678 PROTECTION SOLUTION

Some adapters have unique output electrical specifications, such as their output voltage ranges may be wider than other common devices (e.g. 5V to 10V) but the output current at high VIN is not very high. Figure 10 shows the output characteristics of a Nokia adapter as an example.

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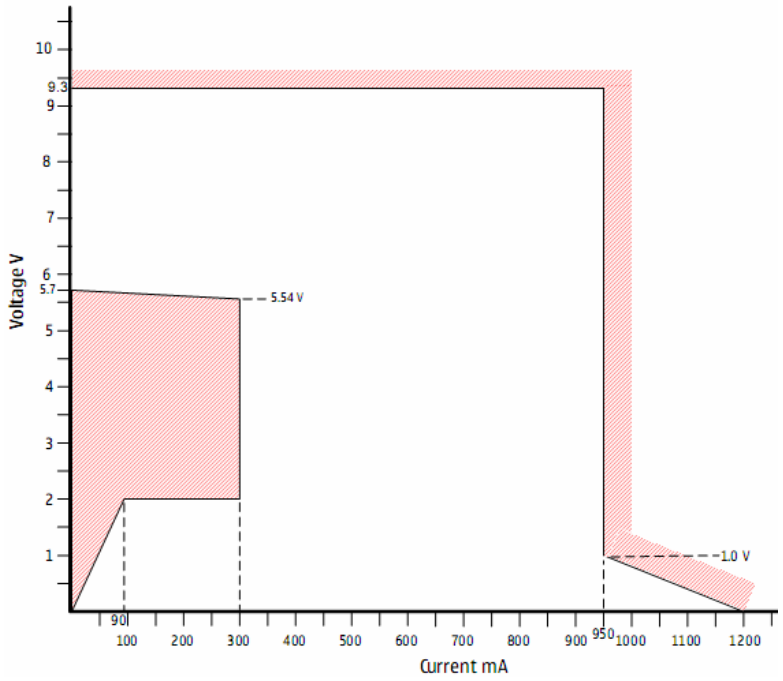

Figure 10: Charging current/voltage window for constant-current–type chargers [1]

As shown in the diagram, the charger is expected to work even when the adapter output goes high to ~9V. MPS recommends the MP2678 for this type of application to maintain the input of charger IC at a constant 5V over the whole input range of the adapter.

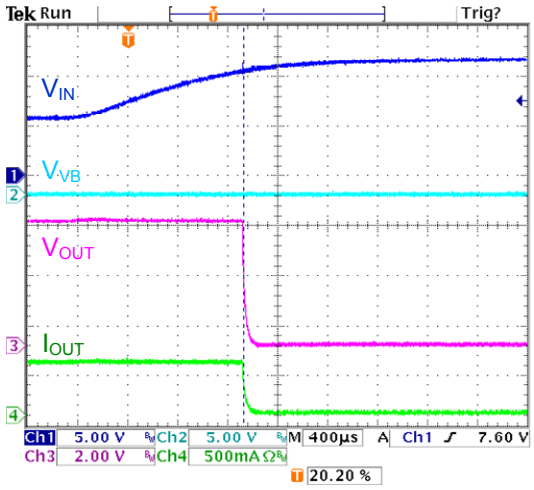

Figure 11: MP2678 response to input over voltage

3.3. MP2676 PROTECTION SOLUTION

In some applications that adopt a PMIC (power management IC), the charger solution involves a discrete power MOSFET driven by a driver inside the PMIC. Figure 12 shows this circuit configuration. The PMIC controls the discrete power MOSFET to realize CC (constant current) and CV (constant voltage) charge to the battery. To block the battery reverse leakage current and prolong the battery running time, a diode is usually in series with the MOSFET.

[1] Copied from Nokia 2-mm DC Charging Interface Specification, Version 1.1, Figure 5

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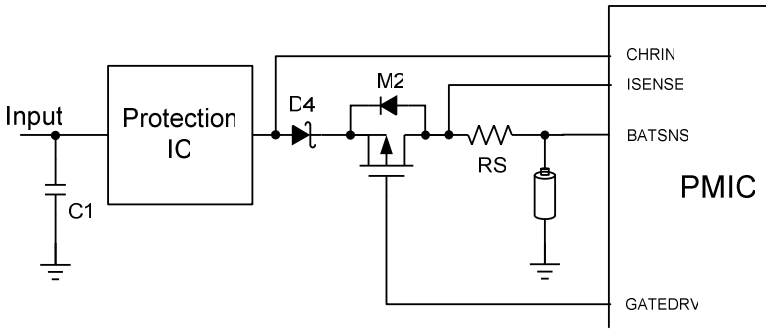


Figure 12: Battery charging system using PMIC

MPS promotes the MP2676, which integrates the protection IC with a P-channel MOSFET; an external signal from the PMIC drives the MOSFET's body switch to act as a charger. The simplified block diagram in Figure 13 shows the higher integration. The integration also reduces the PCB footprint.

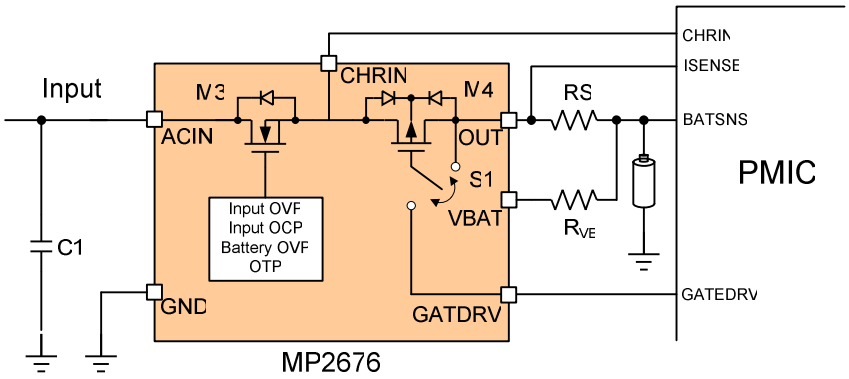


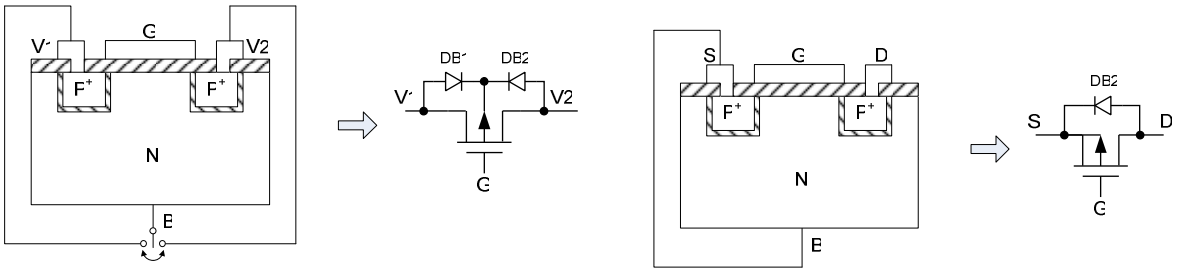
Figure 13: Battery charging system using the MP2676

Figure 14 illustrates the structural and circuit diagrams of the P-channel MOSFET. The voltage differential across the MOSFET controls the body switch as shown in Figure 14 (b):

1) If V1 > V2, the body switch blocks the voltage from the left side (DB2 is the body diode).

2) While if V1 < V2, the body switch blocks the voltage from the right side (DB1 is the body diode).

In both situations, the body diode always blocks the higher voltage.



(a) Regular P-channel MOSFET (b) P-channel MOSFET with automatic body switch

Figure 14: The structural and circuit diagrams of the P-channel MOSFET

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To avoid turning on the P-channel MOSFET by mistake when GATDRV is floating, the MP2676 also includes a smart switch at the gate of the P-channel MOSFET. The voltage differential across the MOSFET also determines the direction of the smart switch. The body switch and the gate switch as shown in Figure 15.

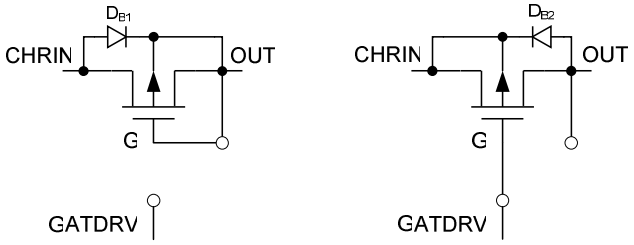

Figure 15: P-channel MOSFET behavior under different conditions

For example, when V_{IN} is floating and V_{OUT} = 4.2V, the output voltage does not return to the input as shown in Figure 16 (a) even when GATDRV connects to GND. If the body diode is reverse-biased and the gate is disconnected from GATDRV and connected to OUT internally (shown in Figure 15), the MOSFET will not turn on. When V_{IN}=5V, and V_{OUT} is floating, the output depends on the drive signal at GATDRV pin; connecting the GATDRV to GND causes the MOSFET to remain on so that V_{OUT} equals V_{IN}. Connecting GATDRV to CHRIN turns the MOSFET off completely such that V_{OUT} is equal to zero. Figures 16(b) and (c) show the operation waveforms.

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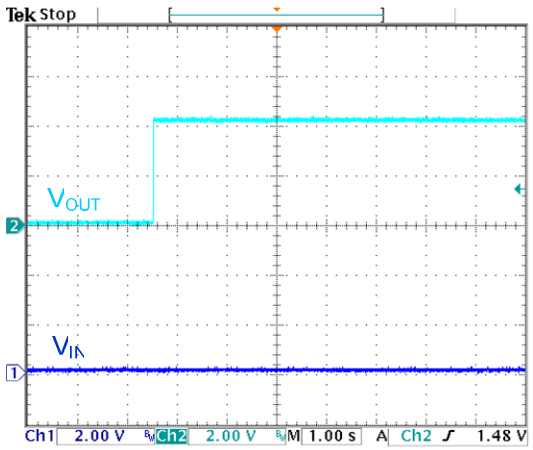
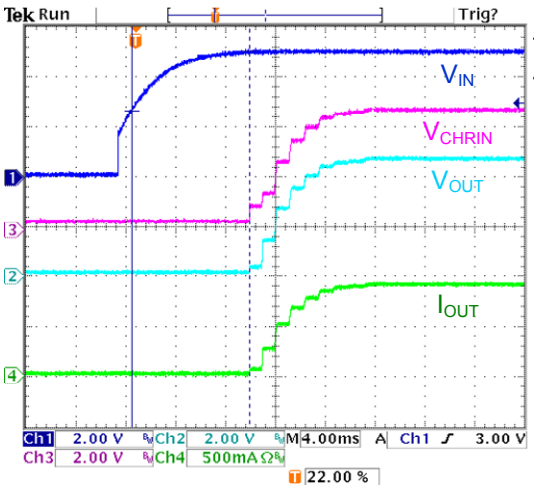
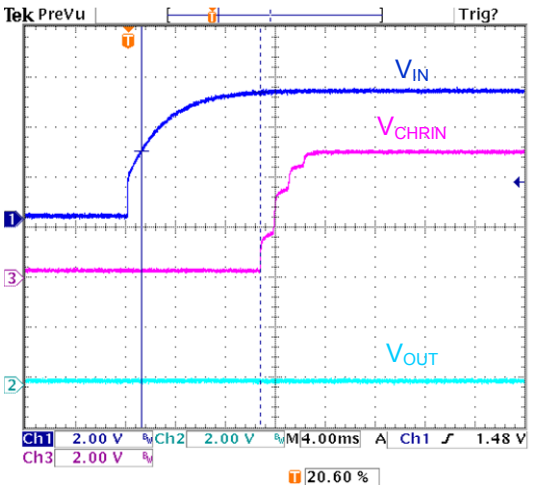


(a) V_{IN}=float, V_{OUT}=4.2V, GATDRV=GND



(b) V_{IN}=5, GATDRV=GND



(c) V_{IN}=5V, GATDRV=CHGRIN

Figure 16: MP2676 performances under different conditions

4. SUMMARY

Protection ICs are widely used in battery charging systems to protect against many dangerous situations including input over-voltage, output over-current, battery over-voltage, among others. MPS products provide protection solutions for battery charging system in portable devices, such as smartphones and notebook computers. The experimental results verify the effectiveness of the protection.

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