AF3101

High-Precision Li-ion Battery Protection IC

➢ Description

AF3101 is a high-precision single-cell Li-ion battery protection IC. It integrates high-precision over-charge protection, over-discharge protection, charge over-current protection, discharge over-current protection, short-circuit protection, 0V battery charging enable, and charger detection functions to ensure the safety, stability, and reliability of Li-ion batteries.

AF3101 features a delay timing for both protection triggering and recovery. Each protection function will only respond when the detected abnormal condition persists beyond its preset delay time. Similarly, normal operation resumes only after the fault condition has been absent for the preset recovery delay time. This delay feature ensures the precision and reliability of all protection mechanisms in AF3101.

AF3101 uses a SOT package and requires minimal external components, significantly reducing solution costs. The operating current of AF3101 is very low，consumes only 0.7μA after over-discharge protection is triggered. This makes it perfect for small-capacity Li-ion battery applications.

➢ Features

- VOC Protection Threshold: 4.3V±25mV
- VOC Recovery Threshold: 4.1V±50mV
- VOD Protection Threshold: 2.4V±30mV
- VOD Recovery Threshold: 3.0V±75mV
- IOC Protection Threshold: -170mV±30mV
- IOD Protection Threshold: 160mV±30mV
- Short Protection Threshold: 1.25V±0.25V
- Low Operation Current, 2.3μA Typically
- Only 0.7μA Current After VOD Protection
- VOC Recovery Without Charger Removal
- Auto-recovery After VOD Protection
- Auto-recovery After IOD Protection
- Auto-recovery After Short-circuit Protection
- No Activation Required for Initial Installation
- 0V Battery Charging Enable
- Battery Reverse Connection Protection
- Charger Reverse Connection Protection
- Charger Detection Function

➢ Applications

- Li-ion Battery Protector for Battery Pack
- Li-ion Battery Protection Module
- Li-ion Battery Applications

➢ Device Information

AF 3101 T S6

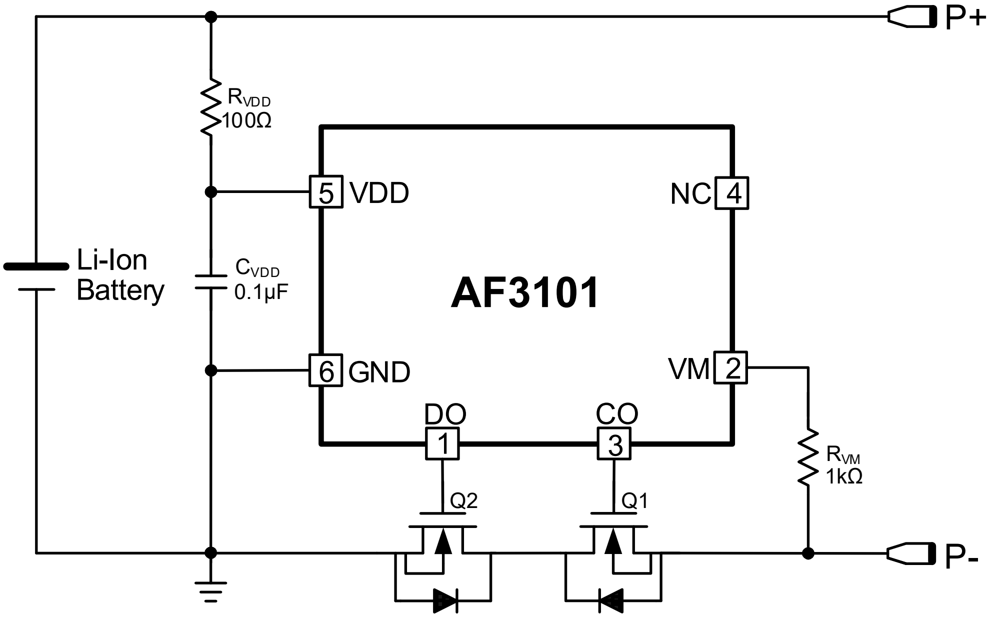
① ② ③ ④

①	Standard
②	Product Name
③	T : V_{OC}=4.300V，V_{OCR}=4.100V V_{OD}=2.400V，V_{ODR}=3.000V
④	S6 : SOT23-6L package

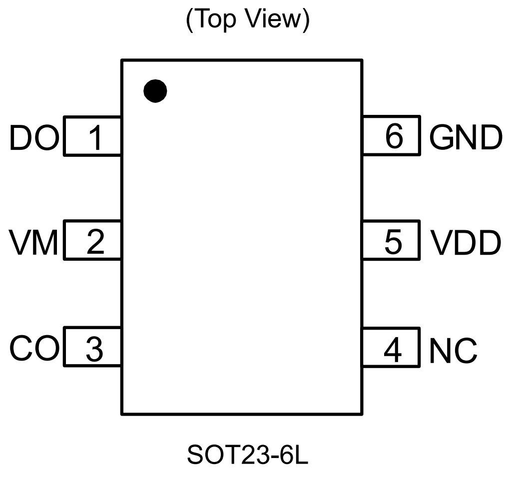
Marking Information

Device	Ordering Number	V_{OC}/V_{OCR} (V)	V_{OD}/V_{ODR} (V)	Marking	Package	Quantity	Packing
AF3101	AF3101TS6	4.30/4.10	2.40/3.00	AF3101	SOT23-6L	3000pcs	Tape and Reel

Typical Application



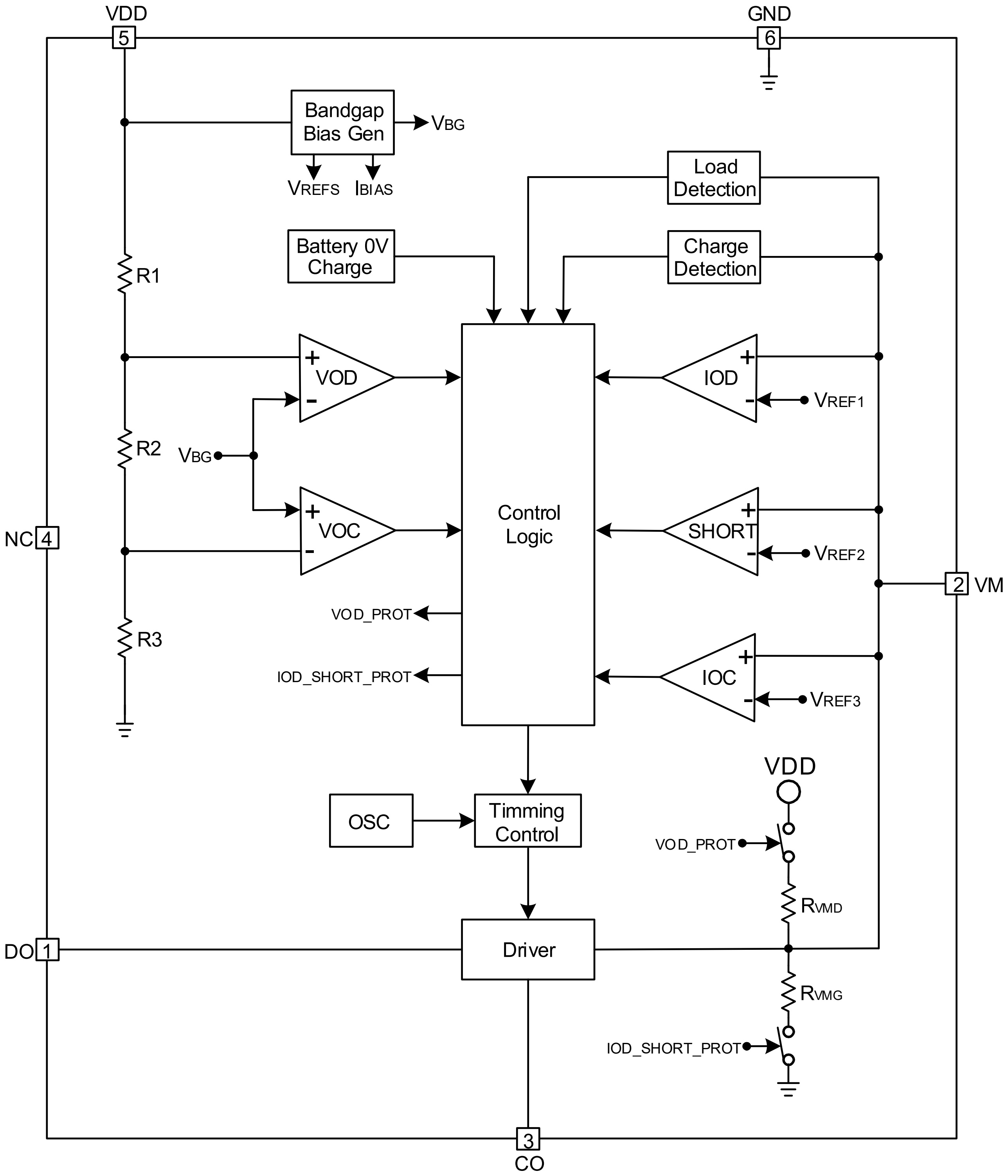
PIN Configuration



Pin Description

Pin Name	Pin No.	Pin Function
DO	1	Discharge control output terminal. Connected to the gate terminal of the external discharge control Power-MOS Q2
VM	2	Current sense input terminal. Connected to the source terminal of the external charge control Power-MOS Q1 with a resistor.
CO	3	Charge control output terminal. Connected to the gate terminal of the external charge control Power-MOS Q1
NC	4	No connected.
VDD	5	Power supply. Connected to the positive electrode of the battery with a RC filter.
GND	6	The ground terminal. Connected to the negative electrode of the battery and the source terminal of the external discharge control Power-MOS Q2.

➢ Block Diagram



Operation

Overview

The AF3101 is a high-precision single-cell Li-ion battery protection IC. It integrates advanced functions such as high- precision over-charge protection, over-discharge protection, charge over-current protection, discharge over-current protection, load short-circuit protection, 0V battery charging enable, and charger detection to ensure the safety, stability, and reliability of Li-ion battery. Designed to work with external charge and discharge control Power-MOS Q1 and Q2, the AF3101 is particularly suitable for the protection of single-cell Li-ion battery.

During normal operation, when charging a Li-ion battery, the AF3101 may activate over-charge protection or charge over-current protection. Once specific recovery conditions are met, the AF3101 automatically resumes normal operation. Similarly, during discharge, the AF3101 may trigger over-discharge protection or discharge over-current protection, and will return to normal operation once specific recovery conditions are satisfied.

Normal Operation Mode

When the Li-ion battery voltage is within the range between the over-charge protection threshold V_{OC} and the over-discharge protection threshold V_{OD}, and the voltage at the VM pin remains between the charge over-current protection threshold V_{IOC} and the discharge over-current protection threshold V_{IOD}, the charge control output CO and discharge control output DO of AF3101 both output high-level logic signals. This causes the charge control Power-MOS Q1 and discharge control Power-MOS Q2 to conduct. This state is defined as the "normal operation mode", during which the Li-ion battery can be safely charged and discharged under standard conditions.

Over-charge Protection

During normal operation, when charging a Li-ion battery, if the battery voltage exceeds the over-charge protection threshold V_{OC} and remains above this threshold for longer than the specified detection delay time T_{VOC}, the charge control output CO of AF3101 will immediately switch from a high level to the VM pin level (low level). This action turns off the charge control Power-MOS Q1 and terminates the charging process. The AF3101 then enters the over-charge protection state.

The AF3101 exits this over-charge protection state under the following conditions:

1. If the battery voltage drops below the over-charge recovery threshold V_{OCR} due to self-discharge and remains below V_{OCR} for longer than the recovery delay time T_{VOCR}, the protection state is released, and the AF3101 returns to normal operation.
2. If the charger is removed and a load is connected to discharge the battery, causing the voltage to fall below the over-charge protection threshold V_{OC} for longer than T_{VOCR}, the protection state is released, and the AF3101 returns to normal operation.

After the AF3101 returns to normal operation, the charge control output CO will output a high-level logic signal, turning the external charge control Power-MOS Q1 back on to resume charging.

Over-discharge Protection

During normal operation, when discharging a Li-ion battery, if the battery voltage falls below the over-discharge protection threshold V_{OD} and remains below V_{OD} for longer than the specified detection delay time T_{VOD}, the discharge control output DO of AF3101 will immediately output a low-level logic signal to turn off the discharge control Power-MOS Q2 and terminate the discharge process. The AF3101 then enters the over-discharge protection state. After entering this state, the voltage at the VM pin is pulled up to VDD via the internal pull-up resistor R_{VMD}, and the AF3101 enters a low-power mode with a standby current of just 0.7μA.

The AF3101 exits this over-discharge protection under the following conditions:

1. When a charger is connected to charge the battery, if the VM pin voltage drops below the charger detection threshold V_{CHG} and the battery voltage rises above the over-discharge protection threshold V_{OD} for longer than the recovery delay time T_{VODR}, the protection state is released, and the AF3101 returns to normal operation.
2. Without a charger, the battery voltage may naturally rise above the over-discharge recovery threshold V_{ODR} due to its "self-recovery" characteristic after load removal. If the voltage remains above V_{ODR} for longer than T_{VODR}, the protection state is released, and the AF3101 returns to normal operation.

After the AF3101 returns to normal operation, the discharge control output DO outputs a high-level logic signal, turning the external discharge control Power-MOS Q2 back on to resume discharge.

Charging Over-current Protection

During normal operation, when charging a Li-ion battery, if the charging current exceeds safe limits, causing the VM pin voltage of the AF3101 to drop below the charge over-current protection threshold V_{IOC} for longer than the charge over-current protection detection delay time T_{IOC}, the charge control output CO of AF3101 will immediately switch from a high level to the VM pin level (low level). This action turns off the charge control Power-MOS Q1 and terminates the charging process. The AF3101 then enters the charge over-current protection state.

After entering this state, if the charger is disconnected and a load is connected to discharge the battery, causing the VM pin voltage to rise above the charge over-current protection threshold V_{IOC}, the charge over-current protection state is released, and the AF3101 returns to normal operation.

After the AF3101 returns to normal operation, the charge control output CO outputs a high-level logic signal, turning the external charge control Power-MOS Q1 back on to resume charging.

Discharge Over-current And Load Short-Circuit Protection

During normal operation, when discharging a Li-ion battery, if the discharge current exceeds safe limits, causing the VM pin voltage of the AF3101 to exceed the discharge over-current protection threshold V_{IOD} for longer than the discharge overcurrent detection delay time T_{IOD}, the discharge control output DO of AF3101 will immediately output a low-level logic signal to turn off the discharge control Power-MOS Q2 and terminate the discharge process. The AF3101 then enters the discharge over-current protection state.

If a short-circuit occurs in the discharge load, causing a further increase in discharge current and raising the VM pin voltage above the load short-circuit protection threshold V_{SHT} for longer than the short-circuit detection delay time T_{SHT}, the discharge control output DO of AF3101 will immediately output a low-level logic signal to turn off the discharge control Power-MOS Q2 and terminate the discharge process. The AF3101 enters the load short-circuit protection state.

After entering either discharge over-current or load short-circuit protection state, the VM pin voltage is pulled up to VDD by the load. Internally, the VM pin is also connected to GND via a pull-down resistor R_{VMG}. If the discharge load is removed, the VM voltage gradually decreases due to the R_{VMG} pull-down. When the VM voltage drops below the short-circuit protection threshold V_{SHT} for longer than the short-circuit recovery delay time T_{SHTR}, both protection states are released, and the AF3101 returns to normal operation.

Under discharge over-current or load short-circuit protection, once all discharge loads are removed, the AF3101 self-recovers. After the AF3101 returns to normal operation, the discharge control output DO outputs a high-level logic signal, turning the external discharge control Power-MOS Q2 back on to resume discharge.

Charger Detection

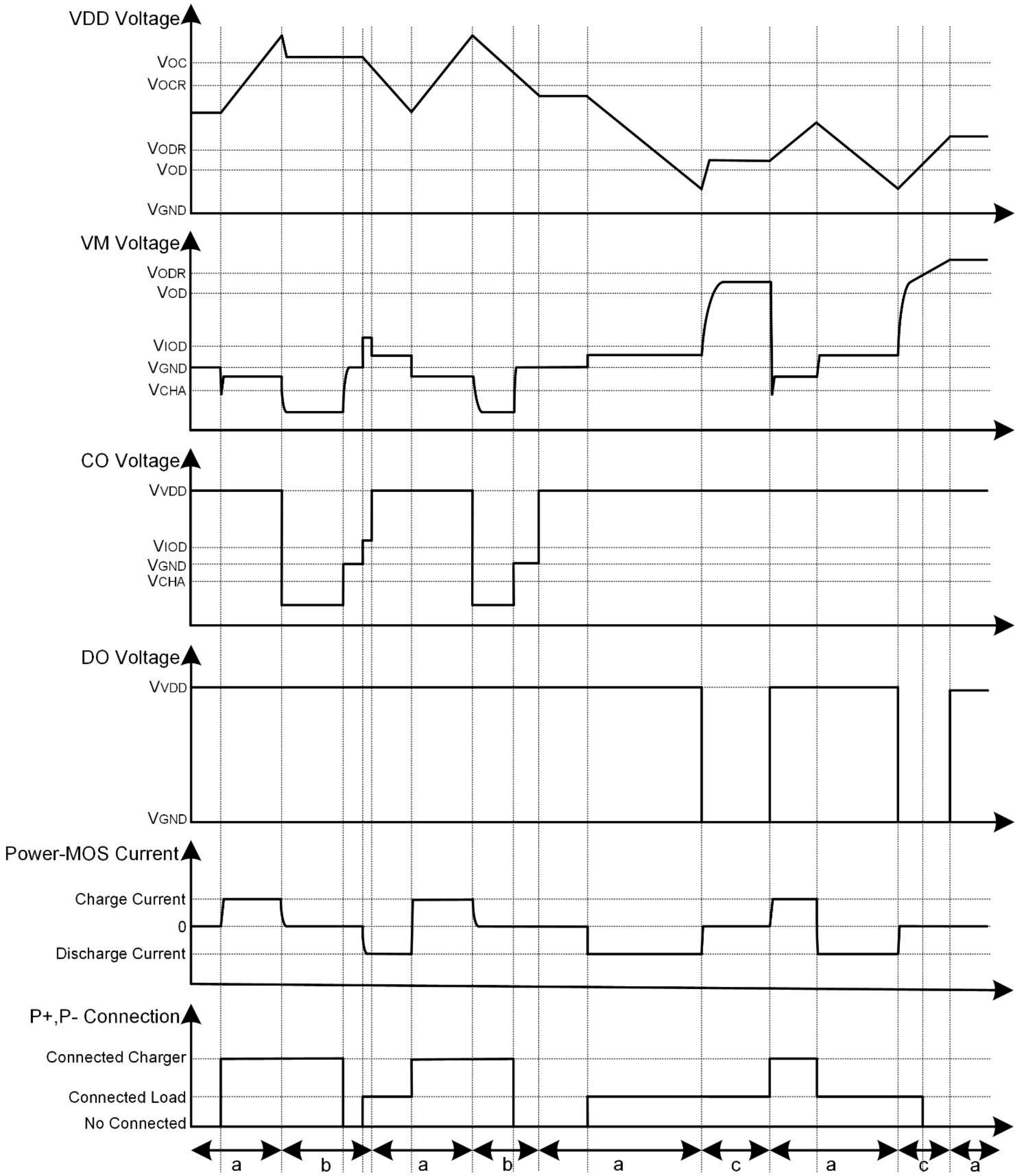
When the AF3101 is in the over-discharge protection state, if a charger is connected externally, causing the VM pin voltage to drop below the charger detection threshold V_{CHG}, the AF3101 will return to normal operation as long as the battery voltage exceeds the over-discharge protection threshold V_{OD}. If the charger cannot pull the VM pin voltage below V_{CHG}, the battery voltage must rise above the over-discharge recovery threshold V_{ODR} for the AF3101 to resume normal operation. Thus, this is called charger detection function of AF3101.

0V Battery Charging Enable

The 0V Battery Charging Enable Function of AF3101 is designed to charge Li-ion batteries that have been discharged to 0V. When a charger voltage applied between terminals P+ and P- exceeds the 0V charging enable threshold V_{0V_CHG}, the charge control output CO of AF3101 is internally connected to the VDD terminal. This creates a gate-to-source voltage difference across the external charge control Power-MOS Q1 that exceeds its turn-on threshold voltage V_{TH}. Thereby, the external charge control Power-MOS Q1 is turned on.
During this process, the discharge control Power-MOS Q2 remains in the off state. Charging current flows through the parasitic body diode of Power-MOS Q2, enabling the 0V battery to begin charging. Once the battery voltage rises above the over-discharge protection threshold V_{OD}, the discharge control Power-MOS Q2 turns on, and the AF3101 resumes normal operation, allowing both charge and discharge control circuits to function as designed.

Working Timeline Diagram

Overvoltage Charge Protection and Overvoltage Discharge Protection:

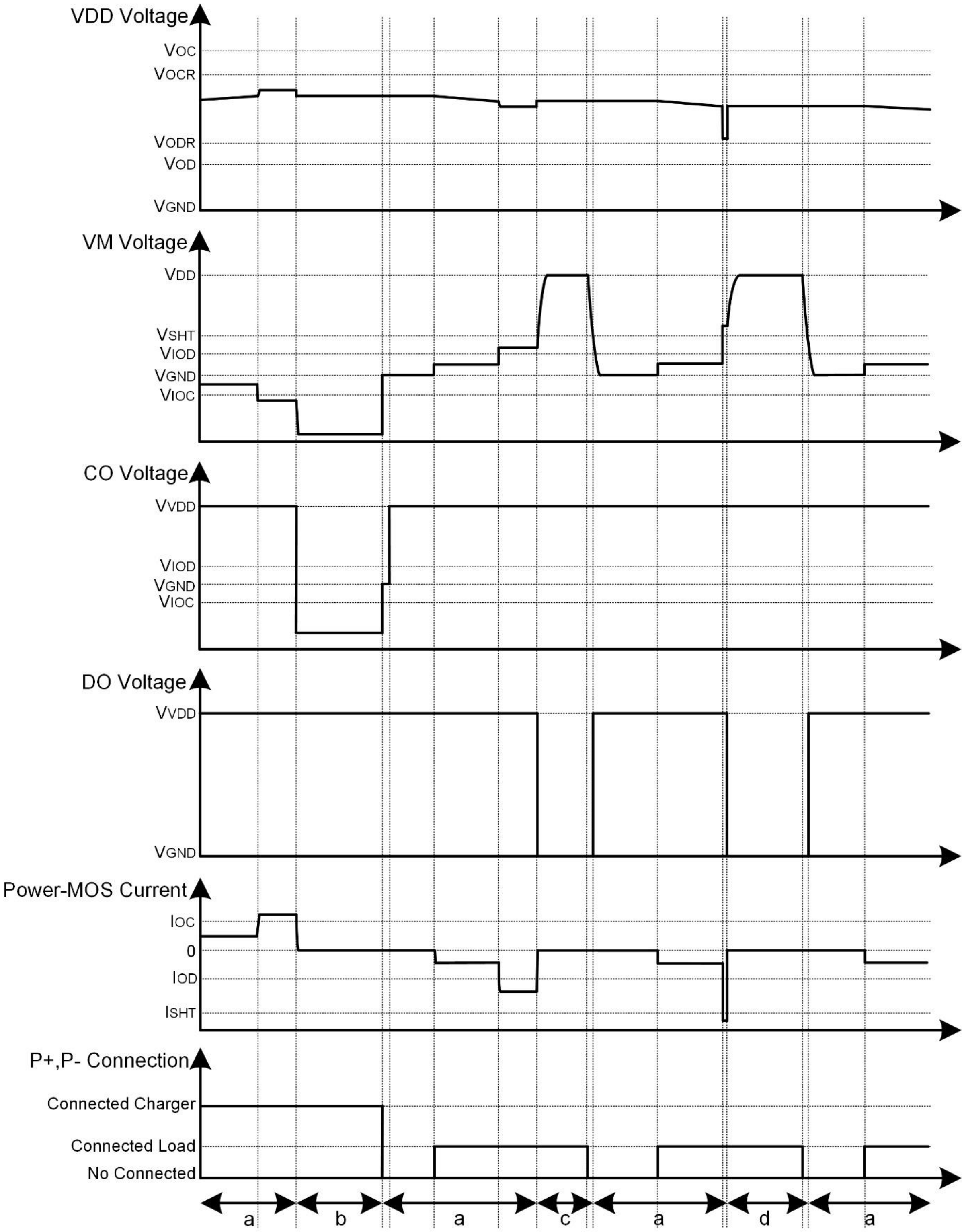


a: Normal Operation State;

b: Over-charge Protection State;

c: Over-discharge Protection State.

Charge Over-Current Protection, Discharge Over-Current And Short-Circuit Protection:



a：Normal Operation State；

b：Charge Over-Current Protection State；

c：Discharge Over-Current Protection State；

d：Load Short-Circuit Protection State.

➢ Absolute Maximum Ratings (Note 1)

- VDD (with respect to GND)-- -0.3V to 8.0V
- DO (with respect to GND) -- -0.3V to VDD+0.3V
- CO,VM (with respect to GND) -- -20V to 0.3V
- Package Thermal Resistance

  SOT23-6L, θJA-- 300℃/W

  SOT23-6L, θJC-- 32℃/W
- Junction Temperature Range-- -40℃ to +125℃
- Storage Temperature Range-- -55℃ to +150℃
- Lead Temperature (Soldering, 10 sec.) -- +260℃
- ESD Susceptibility (Note 2)

  HBM (Human Body Model) ---±2000V

Note 1: Stresses exceeding the absolute maximum ratings may damage the device. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specification is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

Note 2: Devices are ESD sensitive. This integrated circuit can be damaged by ESD if you don't pay attention to ESD protection. Handling precaution is recommended. ESD damage can range from subtle performance degradation to complete device failure.

➢ Recommended Operating Conditions (Note 3)

- VDD Voltage Range--- 1.0V to 5.5V
- Operating Temperature Range-- -40℃ to +85℃

Note 3: The device is not guaranteed to function outside its operating conditions.

➢ Electronics Characteristics (Unless otherwise specified, T_A=25°C, V_{DD}=3.6V)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
VDD Operating Voltage	V_{VDD}		1.0		5.5	V
VDD Operating Current	I_{VDD}	V_{VDD}=3.6V, VM=0V	1	2.3	5	μA
VDD Standby Current After VOD	I_{SD}	V_{VDD}=2.0V, VM Floating	0.4	0.7	1.0	μA
Over-charge Protection Threshold	V_{OC}	V_{VM}=0V, VDD from 3.6V to 4.5V	4.275	4.300	4.325	V
Over-charge Recovery Threshold	V_{OCR}	V_{VM}=0V, VDD from 4.5V to 3.6V	4.050	4.100	4.150	V
Over-discharge Protection Threshold	V_{OD}	V_{VM}=0V, VDD from 3.6V to 2.0V	2.370	2.400	2.430	V
Over-discharge Recovery Threshold	V_{ODR}	V_{VM}=0V, VDD from 2.0V to 3.6V	2.925	3.000	3.075	V
Discharge Over-current Threshold	V_{IOD}	V_{VDD}=3.6V, VM from 0V to 0.3V	130	160	190	mV
Load Short-Circuit Threshold	V_{SHT}	V_{VDD}=3.6V, VM from 0V to 1.6V		1.25		V
Charge Over-current Threshold	V_{IOC}	V_{VDD}=3.6V, VM from 0V to -0.3V	-200	-170	-140	mV
Charger Detection Threshold	V_{CHG}	V_{VDD}=2.6V, VM from 0V to -0.3V		-170		mV
0V Charging Enable Threshold	V_{0V_CHG}	V_{VDD}=0V, Increasing Voltage V_{VDD-VM}	1.2			V
VOC Protection Delay Time	T_{VOC}	V_{VM}=0V, VDD from 3.6V to 4.5V	40	80	120	ms
VOC Recovery Delay Time	T_{VOCR}	V_{VM}=0V, VDD from 4.5V to 3.6V	2.8	5.5	8.2	ms
VOD Protection Delay Time	T_{VOD}	V_{VM}=0V, VDD from 3.6V to 2.0V	20	40	60	ms
VOD Recovery Delay Time	T_{VODR}	V_{VM}=0V, VDD from 2.0V to 3.6V	2.8	5.5	8.2	ms
IOC Protection Delay Time	T_{IOC}	V_{VDD}=3.6V, VM from 0V to -0.3V	1.2	2.5	3.8	ms
IOD Protection Delay Time	T_{IOD}	V_{VDD}=3.6V, VM from 0V to 0.3V	4.7	9.5	14.3	ms
IOD Recovery Delay Time	T_{IODR}	V_{VDD}=3.6V, VM from 0.3V to 0V	1.2	2.5	3.8	ms
Short-circuit Protection Delay Time	T_{SHT}	V_{VDD}=3.6V, VM from 0V to 1.6V	80	160	260	μs

Short-circuit Recovery Delay Time	T_{SHTR}	V_{VDD}=3.6V, VM from 1.6V to 0V	1.2	2.5	3.8	ms
Resistor between VM and VDD	R_{VMD}	After Over-discharge Protection		350		kΩ
Resistor between VM and GND	R_{VMG}	After IOD/Short-circuit Protection		20		kΩ
Resistor between VM and CO	R_{VMCO}	When CO Output Low Logic Level		4.0		MΩ
CO Output Logic High Threshold	V_{COH}	V_{VDD}=3.6V, V_{VM}=0V	3.4	3.58		V
CO Output Logic Low Threshold	V_{COL}	V_{VDD}=3.6V, V_{VM}=0V		0.1	0.4	V
DO Output Logic High Threshold	V_{DOH}	V_{VDD}=3.6V, V_{VM}=0V	3.4	3.58		V
DO Output Logic Low Threshold	V_{DOL}	V_{VDD}=3.6V, V_{VM}=0V		0.1	0.4	V

Application Information

Selection of R_{VDD} Resistor

The R_{VDD} recommends using a 100Ω resistor. The over-charge protection threshold and over-discharge protection threshold of AF3101 are determined by detecting the voltage at the VDD pin, which is connected to the positive electrode of the Li-ion battery through R_{VDD}. If R_{VDD} is too large, it will cause significant voltage difference between the VDD pin voltage and the actual voltage of the Li-ion battery. Additionally, if the charger is reversely connected in the application, the voltage between the VDD pin and GND pin of AF3101 may exceed the absolute maximum rating, resulting in the AF3101 damage. Therefore, the value of R_{VDD} should not be too large and must be limited to within 2.0kΩ.

On the other hand, R_{VDD} should not be too small. If R_{VDD} is too small, the RC filtering effect at the VDD pin will reduce. Furthermore, in small-capacity Li-ion battery applications, when a load short-circuit occurs, the battery voltage will drop rapidly to a very low level. If R_{VDD} is too small, the voltage at the VDD pin will also drop too low, may causing the chip to malfunction and leading to failure of the load short-circuit protection function. Thus, the selection of R_{VDD} resistance should under sufficient testing and verification based on the specific characteristics of the Li-ion battery in the actual application.

Selection of C_{VDD} Input Capacitor

The input capacitor C_{VDD} plays a critical role, primarily serving to filter and decouple the input voltage from the Li-ion battery. During abrupt current changes in discharge loads or charger operations, the equivalent series resistance (ESR) of the Li-ion battery and wiring resistance can induce voltage ripple and overshoot at the battery's positive terminal. C_{VDD} prevents input voltage ripple and overshoot from triggering false over-charge or over-discharge protection by the AF3101. A minimum 0.1μF ceramic capacitor should be used at the VDD input pin of AF3101 and must be placed in close proximity to the VDD pin. It should form an RC filter network in series with resistor R_{VDD} to effectively suppress Li-ion battery voltage ripple.

Selection of R_{VM} Resistor

The value of R_{VM} should not be too small in the typical application circuit of AF3101. When the charger is reversely connected or the voltage of charger is excessively high, R_{VM} acts as a current-limiting resistor to protect AF3101. Additionally, R_{VM} should not be too large. If R_{VM} is too large, a significant voltage difference will exist between the VM pin of AF3101 and the source terminal of the external charge control Power-MOS Q1 when the charger voltage is too high. In this case, the charge control Power-MOS Q1 may fail to turn off completely, and cannot effective cutoff the charging current. Therefore, the value of R_{VM} should be maintained within the range of 500Ω to 3.0kΩ and thoroughly tested and validated based on the specific application.

Selection of Power-MOS Q1 and Q2

The charge and discharge control Power-MOS Q1 and Q2 can be selected as NMOS devices of the same model. Their Ron resistance should be chosen based on specific application requirements. The gate-to-source threshold voltage V_{TH} of Q1 and Q2 should be selected between 0.4V and the over-discharge protection voltage threshold V_{OD}. If V_{TH}< 0.4V, during over-charge protection events, the charge control Power-MOS Q1 may fail to turn off effectively. If V_{TH}> V_{OD}, the discharge control Power-MOS Q2 might prematurely turn off before the system enters the over-discharge protection state.

Additionally, both the gate-to-source voltage rating and drain-to-source voltage rating of Q1 and Q2 must exceed the input voltage of charger. Otherwise, the charge control Power-MOS Q1 and the discharge control Power-MOS Q2 may be damaged during Li-ion battery charging.

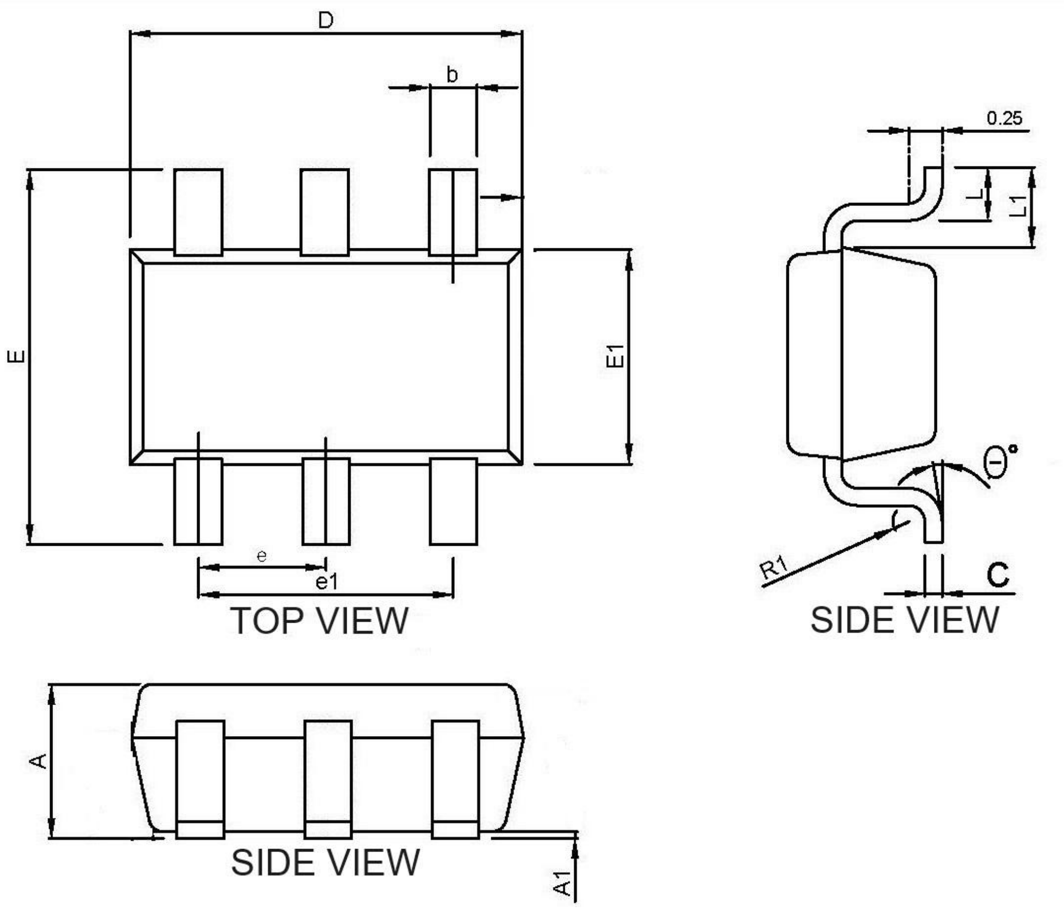
PCB Layout Guidelines

AF3101 is a high-precision single-cell Li-ion battery protection IC that can provide voltage and current protection during the charging and discharging process of Li-ion battery. In practical application circuits, the PCB layout should meet the following rules:

- The input capacitor C_{VDD} should be placed as close as possible to the VDD pin and the GND pin of AF3101. Avoid using vias for the input capacitor C_{VDD} connection. The ground of C_{VDD} should not pass through small ground wires before reaching the IC ground and large uninterrupted ground plane.
- The power trace should be as short and thick as possible. For good thermal performance of the Power-MOS Q1 and Q2, the GND and P- wires can be laid with copper as much as possible.

➢ Package Information

SOT23-6L



Symbol	Dimensions(mm)		
	Min.	Nom.	Max.
A	-	-	1.35
A1	0.01	-	0.15
b	0.30	-	0.50
c	0.152 BSC		
D	2.80	2.90	3.00
E	2.70	-	3.00
E1	1.50	1.60	1.70
e	0.95 BSC		
L	0.30	0.45	0.60
L1	0.52	0.60	0.68
R1	0.12 REF		
θ	0º	4º	8º
e1	1.90 BSC		

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