AF3251

2-In-1 Single-Cell Lithium Battery Charge And Discharge Protection Chip with shipping mode

➢ Description

AF3251 is a high-precision 2-in-1 single-cell lithium battery charge and discharge protection chip. The chip integrates high-precision over-voltage charging protection, over-voltage discharge protection, charging over-current protection, discharge over-current protection, load short-circuit protection, Shipping Mode,0V lithium battery charging allowing, over-temperature protection and charger detection to ensure the safety, stability and reliability of lithium batteries.

The AF3251 sets a certain delay time for the detection of each protection function, and the corresponding protection action will only respond after the protection condition has occurred until the corresponding delay time. Similarly, the AF3251 also sets a certain delay time for the restoration of each protection function. This guarantees the precision and reliability of each protection function of the AF3251.

The AF3251 integrates a power transistor with an equivalent on-resistance of 55mΩ and uses an ultra-compact DNF1X1-4L package. It requires very few external components in the application circuit, greatly reducing the cost and size of the solution. It is highly suitable for smart wearable devices with very limited PCBA space.

The operating current of the AF3251 is extremely low, featuring a sleep function after overvoltage discharge protection, and it also supports an ultra-low standby current shipping mode. This meets the application requirements of smart wearable device solutions equipped with small-capacity lithium batteries, as well as the needs of maritime transport and long-term storage.

➢ Features

- Integrated 55mΩ Power Tube
- Support Shipping Mode
- Chip Enters Sleep Mode After Overvoltage Discharge Protection
- Overvoltage Charge Protection Voltage Accuracy: ±25mV
- Overvoltage Discharge Protection Voltage Accuracy: ±35mV
- Overvoltage Charge Protection Recovery Voltage Accuracy: ±50mV
- Overvoltage Discharge Protection Recovery Voltage Accuracy: ±70mV
- Low Chip Operating Current, Typical: 0.9μA
- Sleep Current After Overvoltage Discharge Protection: <10nA
- Overvoltage Charge Protection Recovery Does Not Need To Unplug The Charger First
- Discharge Overcurrent Protection Current: 330mA
- Charging Overcurrent Protection Current: 420mA
- Load Short Circuit Protection Current: 900mA
- Chip Over-Temperature Protection
- 0V Lithium Battery Charging Allows Function
- Lithium Battery Reverse Connection Protection Function
- Charger Reverse Polarity Protection Function
- Charger Detection Function

➢ Applications

- Bluetooth Headset Charging Case
- Smart Wearable Devices
- Electronic Devices Powered By A Single Lithium Battery

➢ Device Information

AF 3251 T/M/H C/S D4

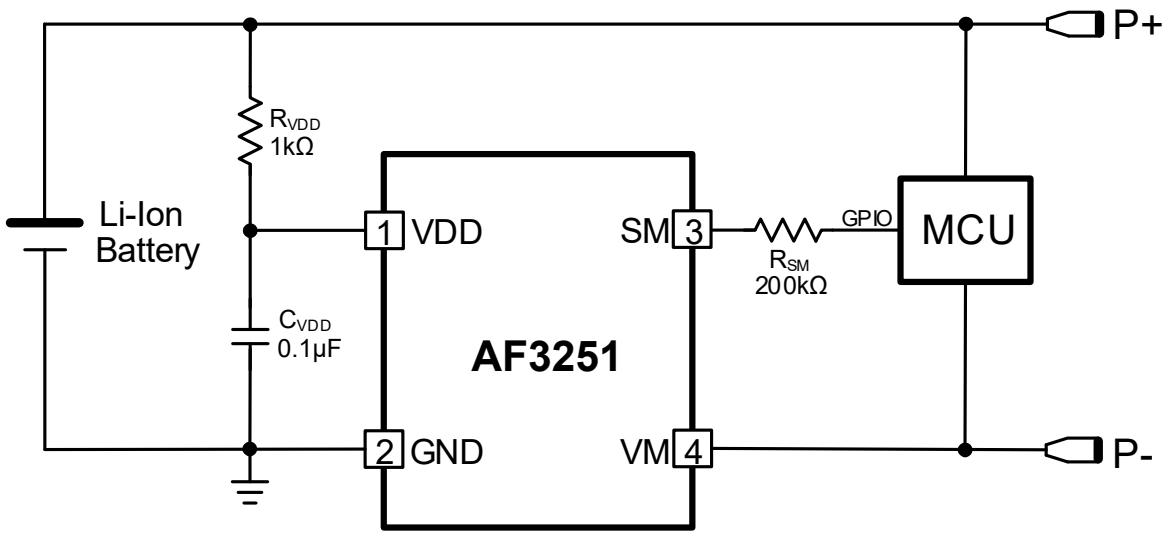
① ② ③ ④ ⑤

①	Standard
②	Product Name
③	T : V_{OC}=4.275V，V_{OD}=2.720V M : V_{OC}=4.425V，V_{OD}=2.800V H : V_{OC}=4.475V，V_{OD}=2.850V
④	C : T_{OVC}=1000ms，T_{OVD}=64ms S : T_{OVC}=128ms，T_{OVD}=40ms
⑤	D4 : DFN1×1-4L package

➢ Marking Information

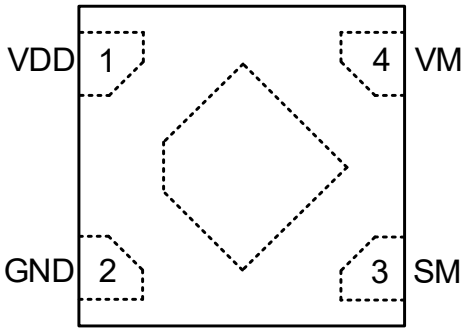
Device	Ordering Number	V_{OC}/V_{OCR} (V)	V_{OD}/V_{ODR} (V)	T_{VOC}/T_{VOD} (ms)	Marking	Package	Quantity	Packing
AF3251 Series	AF3251TCD4	4.275/4.075	2.720/2.900	1000/64	51T	DFN1×1-4L	10000pcs	Tape and Reel
	AF3251MCD4	4.425/4.225	2.800/3.000	1000/64	51M			
	AF3251HCD4	4.475/4.275	2.805/3.050	1000/64	51H			
	AF3251TSD4	4.275/4.075	2.720/2.900	128/40	51t			
	AF3251MSD4	4.425/4.225	2.800/3.000	128/40	51m			
	AF3251HSD4	4.475/4.275	2.805/3.050	128/40	51h			

➢ Typical Application



➢ PIN Configuration

(Top View)

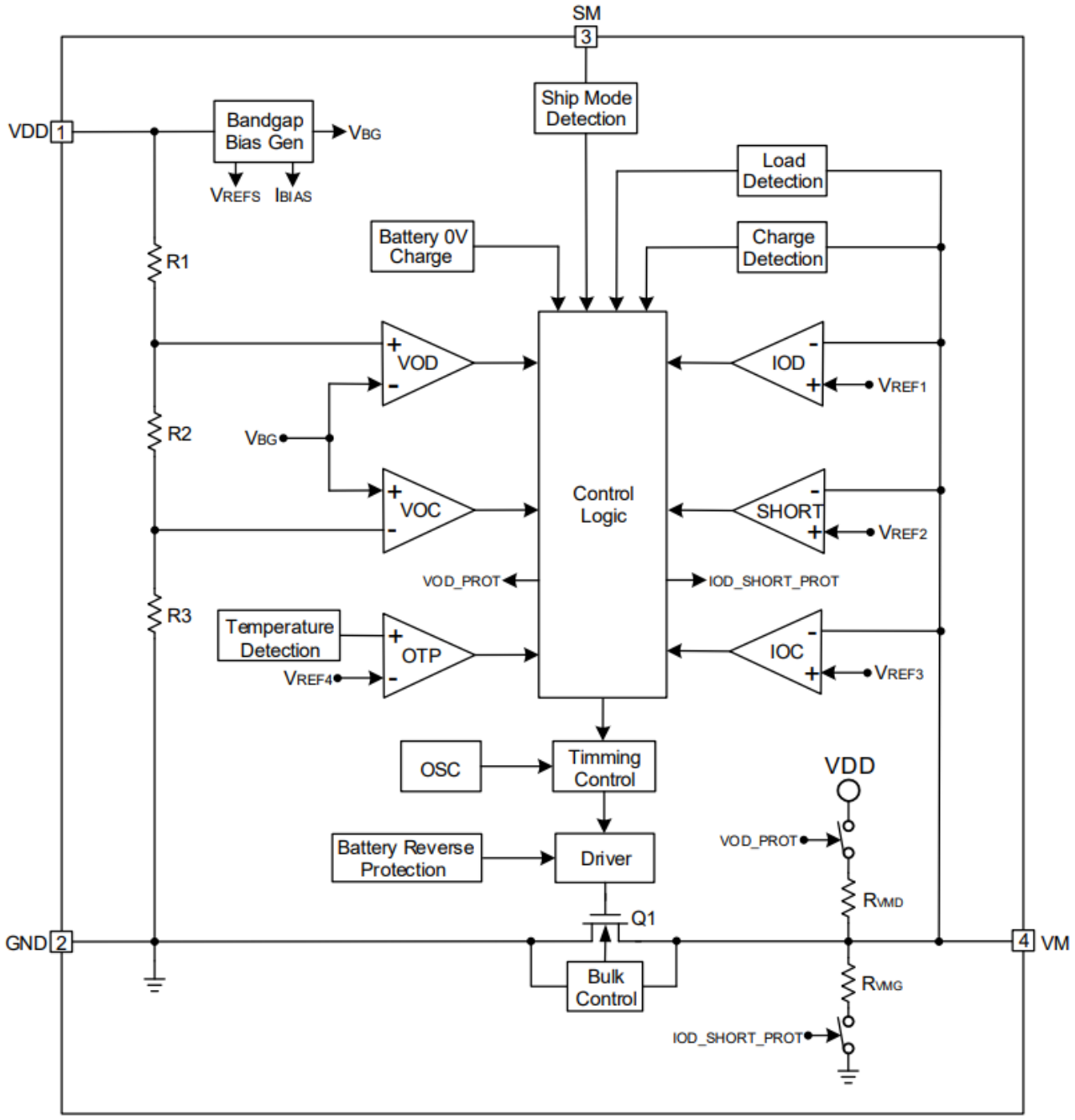


DFN1X1-4L

➢ Pin Description

Pin Name	Pin No.	Pin Function
VDD	1	At the power input, the positive terminal of the lithium battery is connected to this pin after an RC filter.
GND	2	The chip ground, which is connected to the negative electrode of the lithium battery.
SM	3	Shipping mode input control pin.
VM	4	The charge-discharge current detection input is connected to the negative end of the charger or to one end of the load.
Thermal Pad	-	The heatsink is connected to the chip ground and must be well soldered to the PCB ground.

➢ Block Diagram



➢ Operation

Overview

AF3251 is a high-precision 2-in-1 single-cell lithium battery charge and discharge protection chip. The chip integrates high-precision overvoltage charge protection, overvoltage discharge protection, charge overcurrent protection, discharge overcurrent protection, load short-circuit protection, shipping mode, 0V lithium battery charging allowance, over-temperature protection, and charger detection functions to ensure the safety and stable reliability of the lithium battery. The AF3251 integrates a power transistor with an equivalent on-resistance of 55mΩ and uses an ultra-compact DNF1X1-4L package. The application circuit requires very few external components, greatly saving the cost and size of the solution. It is particularly suitable for smart wearable devices with very limited PCBA space.

Under normal operating conditions, if the lithium battery is being charged, the AF3251 may enter overvoltage charging protection or overcurrent charging protection; at the same time, after certain recovery conditions are met, the AF3251 will return to normal operating status. If the lithium battery is being discharged, the AF3251 may enter overvoltage discharging protection or overcurrent discharging protection; likewise, after certain recovery conditions are met, the AF3251 will return to normal operating status.

Normal Working Condition

If the voltage of the lithium battery is between the overcharge protection voltage threshold VOC and the over-discharge protection voltage threshold VOD, and the current flowing through the chip's internally integrated charge-discharge power transistor Q1 is between the charge overcurrent protection threshold IIOC and the discharge overcurrent protection threshold IIOD, the internally integrated charge-discharge power transistor Q1 of the AF3251 remains on. This state is called the normal operating state, during which the lithium battery can be charged and discharged normally.

When a lithium battery is installed for the first time, it may not be able to discharge. In this case, it needs to be activated by connecting a charger. The charger activation voltage should be 4.5V~5V, and the activation time must be longer than 10ms. After the chip is activated, it can return to the normal operating state.

Overvoltage Charging Protection

If the voltage of the lithium battery is greater than the overvoltage charge protection voltage threshold VOC under normal working conditions, and the duration exceeds the overvoltage charge protection detection delay time TVOC, the charge and discharge power tube Q1 integrated inside the chip will be shut down immediately, the substrate of the power tube will be connected to the VM, and the charging process will be terminated. AF3251 starts to enter the overvoltage charge protection state.

There are two recovery conditions for the AF3251's overvoltage charge protection state:
1. When the lithium battery voltage drops to lower than the overvoltage charge recovery voltage threshold VOCR through self-discharge, and the duration exceeds the overvoltage charge protection recovery delay time TVOCR, the overvoltage charge protection state is released, and AF3251 returns to the normal

working state.

2. Remove the charger and connect the load to discharge the lithium battery, when the voltage of the lithium battery drops to lower than the overvoltage charge protection voltage threshold VOC, and the duration exceeds the overvoltage charge protection recovery delay time TVOCR, the overvoltage charge protection state is released, and AF3251 returns to the normal working state.
After AF3251 returns to normal working state, the charge-discharge power tube Q1 integrated in the chip will return to the conduction state.

Overvoltage Discharge Protection

Under normal operating conditions, when discharging a lithium battery, if the battery voltage drops below the over-discharge protection voltage threshold VOD and the duration exceeds the over-discharge protection detection delay time TVOD, the internal integrated charge-discharge power transistor Q1 will immediately turn off. The substrate of the power transistor is connected to GND, terminating the discharge process. The AF3251 then enters the over-discharge protection state. After entering this state, the voltage at the VM pin is pulled up to VDD by the chip's internal pull-up resistor RVMD, and the chip enters a low-power sleep mode, with a standby current of less than 10nA. At this point, even if a charger is not connected, and the VDD voltage 'self-boosts' to above the over-discharge protection recovery voltage threshold VODR, the AF3251 will still remain in sleep mode.

There are three recovery conditions for the AF3251's overvoltage discharge protection status:
1. Connect the charger to charge the lithium battery, and make the VM pin voltage of AF3251 lower than the charger detection voltage threshold VCHG; When the voltage of the lithium battery rises to higher than the VOD threshold of the overvoltage discharge protection voltage, and the duration exceeds the overvoltage discharge protection recovery delay time TVODR, the overvoltage discharge protection state is released, and the AF3251 returns to the normal working state.

2. When the charger is connected to charge the lithium battery, but the VM pin voltage of AF3251 is higher than the charger detection voltage threshold VCHG and less than 0.7V, when the lithium battery voltage rises to higher than the overvoltage discharge protection recovery voltage threshold VODR, and the duration exceeds the overvoltage discharge protection recovery delay time TVODR, the overvoltage discharge protection state is released, and the AF3251 returns to the normal working state.
After AF3251 returns to normal working state, the charge-discharge power tube Q1 integrated in the chip will return to the conduction state.

Charging Overcurrent Protection

If the charging current is too large, so that the current flowing through the charging and discharging power tube Q1 integrated in AF3251 is greater than the charging overcurrent protection current threshold IIOC, and the duration exceeds the charging overcurrent protection detection delay time TIOC, then the charging and discharging power tube Q1 integrated in the chip will be closed immediately, the substrate of the power tube is connected to the VM, the charging process is terminated, and the AF3251 begins to enter the charging overcurrent protection state.

After AF3251 enters the charging overcurrent protection state, if the charger is disconnected and the load is connected at the same time to discharge the lithium battery, when the current flowing through the charging and discharging power tube Q1 integrated into the AF3251 is less than the charging overcurrent protection current threshold IIOC, the charging overcurrent protection state is released, and the AF3251 returns to the normal working state.After AF3251 returns to normal working state, the charge-discharge power tube Q1 integrated in the chip will return to the conduction state.

Discharge Overcurrent Protection And Load Short-Circuit Protection

If the discharge current is too large, so that the current flowing through the AF3251 integrated charge and discharge power tube Q1 is greater than the discharge overcurrent protection current threshold IIOD, and the duration exceeds the discharge overcurrent protection detection delay time TIOD, then the charge and discharge power tube Q1 integrated inside the chip will be closed immediately, the substrate of the power tube is connected to GND, and the discharge process is terminated. The AF3251 starts to enter the discharge overcurrent protection state.

If the discharge load is short-circuited, the discharge current of the lithium battery is further increased, resulting in the current flowing through the AF3251 integrated charge-discharge power tube Q1 is greater than the load short-circuit protection current threshold ISHT, and the duration exceeds the load short-circuit protection detection delay time TSHT, then the integrated charge-discharge power tube Q1 inside the chip will be shut down immediately and the discharge process will be terminated. The AF3251 starts to enter the load short-circuit protection state.

After the AF3251 enters the discharge overcurrent protection state or the load short-circuit protection state, the VM pin voltage of the AF3251 will be pulled up to the VDD level by the load. At the same time, the VM pin is connected to GND through a pull-down resistor RVMG inside the chip. When the VM voltage is lower than the load short-circuit/over-current protection recovery voltage threshold VSHTR, and the duration exceeds the load short-circuit/over-current protection recovery delay time TSHTR, the discharge over-current protection and load short-circuit protection state are released, and the AF3251 returns to the normal working state.

Therefore, in the state of discharge overcurrent protection or load short-circuit protection, the AF3251 can self-recover when all the discharge loads are removed. After AF3251 returns to normal working state, the charge-discharge power tube Q1 integrated in the chip will return to the conduction state.

Charger Detection

When AF3251 is in the overvoltage discharge protection state, if the external access to the charger makes the VM pin voltage of AF3251 lower than the charger detection voltage threshold VCHG, the voltage of the lithium battery only needs to be greater than the overvoltage discharge protection voltage threshold VOD, and AF3251 can be restored to normal working state; If the charger voltage cannot make the VM pin voltage of AF3251 lower than the charger detection voltage threshold VCHG, but can make the VM voltage less than 0.7V, the voltage of the lithium battery must be greater than the overvoltage discharge protection

recovery voltage threshold VODR before AF3251 can return to normal working state. This is the charger detection function of the AF3251.

Shipping Mode

The shipping mode function of the AF3251 is designed to address the problem where small-capacity lithium batteries may experience a significant drop in voltage, or even become completely discharged, after long periods of sea transportation. When the AF3251 needs to enter shipping mode, the MCU can input a high-level pulse signal to the SM pin of the chip. If the high-level duration of this pulse signal exceeds the chip's shipping mode entry delay time TSM, the AF3251 will immediately enter shipping mode. In shipping mode, the standby current of the AF3251 is extremely low, less than 10nA. After connecting a charger and waiting for the shipping mode exit delay time TSMR, the AF3251 will exit shipping mode and return to normal operation.

0V Lithium Battery Charging Is Allowed

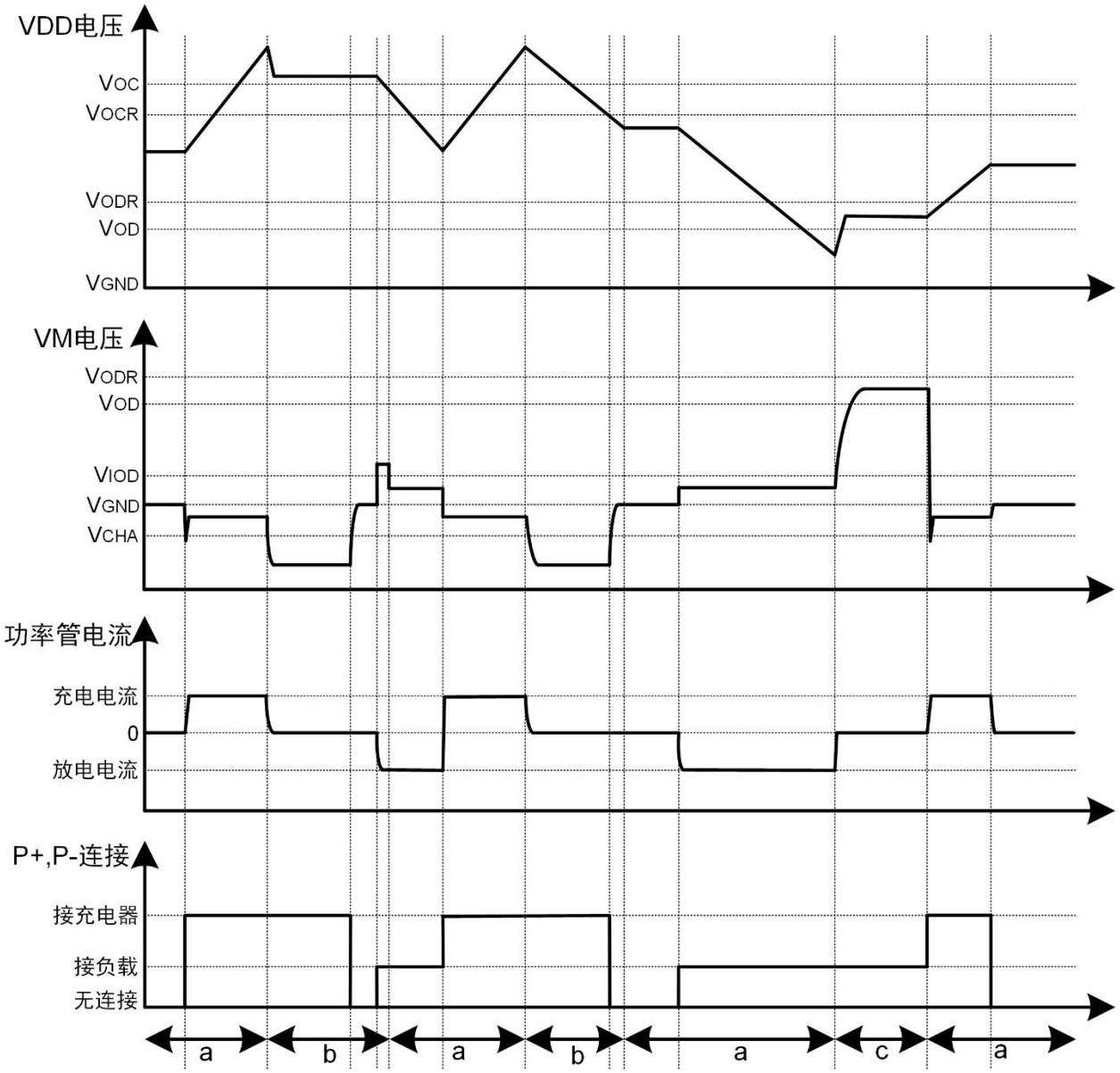
The AF3251's 0V Li-ion Battery Charging Allow function is used to charge a Li-ion battery that has been discharged to 0V. When the charger voltage connected between P+ and P- is higher than the charger voltage threshold V0VCHG allowed for 0V charging, the charge/discharge power tube Q1 integrated inside the AF3251 will start to turn on. This allows the 0V lithium battery to be charged. When the voltage of the lithium battery rises to a voltage greater than the overvoltage discharge protection voltage threshold VOD, the AF3251 returns to its normal working state.

Over-Temperature Protection

AF3251 has over-temperature protection function to ensure the stability and reliability of the system. When the junction temperature of the chip reaches the typical value of 140°C, the integrated charge-discharge power tube Q1 of AF3251 will be turned off immediately, and the substrate of the power tube will be connected to VM or GND according to the charge-discharge state, and AF3251 will enter the over-temperature protection state. When the chip junction temperature drops to the typical value of 120°C, the AF3251 reopens the integrated charge-discharge power tube Q1, and the AF3251 exits the chip over-temperature protection state and returns to the normal working state.

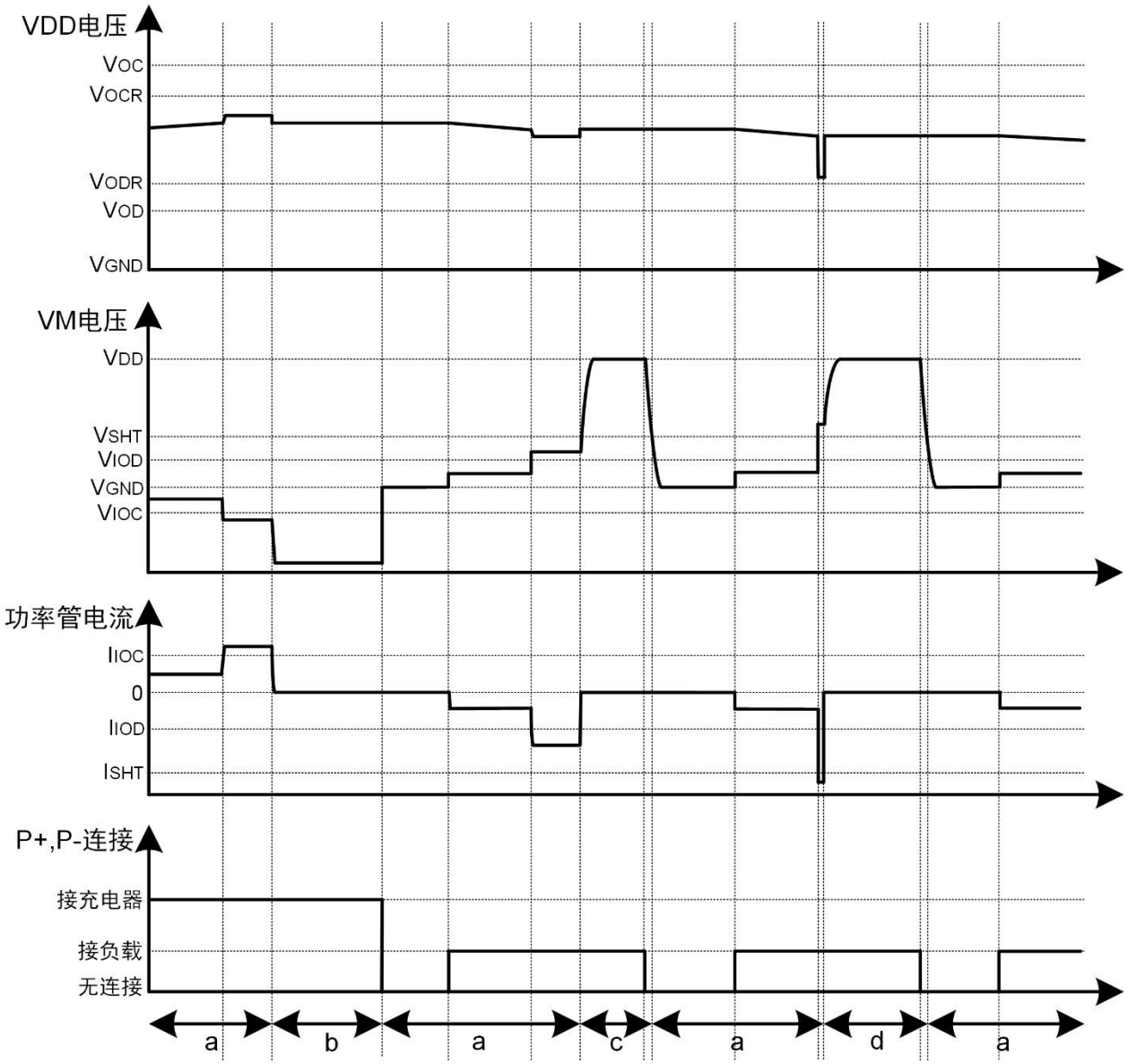
➢ **Working Timeline Diagram**

Overvoltage Charge Protection and Overvoltage Discharge Protection:



a：正常工作状态；
b：过电压充电保护状态；
c：过电压放电保护状态；

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



a：正常工作状态；
b：充电过流保护状态；
c：放电过流保护状态；
d：负载短路保护状态；

➢ Absolute Maximum Ratings (Note 1)

- VDD (with respect to GND)---------- -0.3V to 8.0V
- VM (with respect to GND) ---------- VDD-9.5V to 9.5V
- SM (with respect to GND) ---------- -0.3V to 8.0V
- Package Thermal Resistance
  DFN1×1-4L, θJA---------- 250℃/W
  DFN1×1-4L, θJC---------- 130℃/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. The absolute maximum ratings are stress ratings only.

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	0.7	0.9	1.2	μA
Sleep Current After VDD Overvoltage Discharge Protection	I_{SD}	V_{VDD}=2.0V, VM floating			10	nA
Overvoltage Charge Protection Voltage Threshold	V_{OC}	AF3251TC/SD4	4.250	4.275	4.300	V
		AF3251MC/SD4	4.400	4.425	4.450	V
		AF3251HC/SD4	4.450	4.475	4.500	V
Overvoltage Charge Protection Restores The Voltage Threshold	V_{OCR}	AF3251TC/SD4	4.025	4.075	4.125	V
		AF3251MC/SD4	4.175	4.225	4.275	V
		AF3251HC/SD4	4.225	4.275	4.325	V
Overvoltage Discharge Protection Voltage Threshold	V_{OD}	AF3251TC/SD4	2.685	2.720	2.755	V
		AF3251MC/SD4	2.765	2.800	2.835	V
		AF3251HC/SD4	2.815	2.850	2.885	V
Overvoltage Discharge Protection Restores Voltage Threshold	V_{ODR}	AF3251TC/SD4	2.830	2.900	2.970	V
		AF3251MC/SD4	2.930	3.000	3.070	V
		AF3251HC/SD4	2.980	3.050	3.120	V
Discharge Overcurrent Protection Current Threshold	I_{IOD}	V_{VDD}=3.6V, Increasing load current	150	330	500	mA
Load Short-Circuit Protection Current Threshold	I_{SHT}	V_{VDD}=3.6V, Increasing load current		0.9		A
Load Short-Circuit/Overcurrent Protection Recovery Voltage Threshold	V_{SHTR}	V_{VDD}=3.6V, load floating		1.4		V
Charge Overcurrent Protection Current Threshold	I_{IOC}	V_{VDD}=3.6V , Increasing charging current	180	420	650	mA
The Charger Detects The Voltage Threshold	V_{CHG}	V_{VDD}=2.8V ,VM from 0V to -0.3V		-190		mV
The Charger Voltage Threshold Allowed For 0V Charging	V_{0VCHG}	V_{VDD}=0V, VDD relative to VM applied voltage	1.5			V
The Equivalent On-Impedance Of The Power Tube Is	$R_{SS(ON)}$	V_{VDD}=3.6V， I_{VM}=0.1A		55	70	mΩ

Integrated Into Chip						
Overvoltage Charge Protection Delay	T_{OVC}	AF3251T/M/HCD4	700	1000	1300	ms
		AF3251T/M/HSD4	88	128	168	ms
Overvoltage Charge Protection Recovery Delay	T_{OVCR}	VDD switched from 3.6V to 4.5V	3.0	4.5	6.0	ms
Overvoltage Discharge Protection Delay	T_{OVD}	AF3251T/M/HCD4	44	64	84	ms
		AF3251T/M/HSD4	28	40	52	ms
Overvoltage Discharge Protection Recovery Delay	T_{OVDR}	V_{VM}=0V, VDD switched from 2.5V to 3.6V	3.0	4.5	6.0	ms
Charging Overcurrent Protection Delay	T_{IOC}	V_{VDD}=3.6V	7	10	13	ms
Discharge Overcurrent Protection Delay	T_{IOD}	V_{VDD}=3.6V	7	10	13	ms
Load Short-Circuit Protection Delay	T_{SHT}	V_{VDD}=3.6V	100	190	300	μs
Load Short-Circuit/Over-Current Protection Recovery Delay	T_{SHTR}	V_{VDD}=3.6V	1.4	2.0	2.6	ms
VM To VDD Internal Resistor	R_{VMD}	After overvoltage discharge protection		300		kΩ
VM To GND Internal Resistor	R_{VMG}	After discharge overcurrent protection or load short-circuit protection		27		kΩ
SM Input High-Level Threshold Voltage	V_{SMH}	V_{VDD}=3.6V，R_{SM}=200KΩ	1.35			V
SM Input Low-Level Threshold Voltage	V_{SML}	V_{VDD}=3.6V，R_{SM}=200KΩ			0.4	V
SM High Level Enters Shipping Mode Delay	T_{SM}	V_{VDD}=3.6V，V_{SM}=H	90			ms
Connect The Charger To Exit Shipping Mode Delay	T_{SMR}	V_{VDD}=3.6V，connect the charger in shipping mode	8			ms
VDD Standby Current In Shipping Mode	I_{VDD_SM}	V_{VDD}=3.6V，shipping mode			10	nA
TIN Input Pull-Down Resistor	R_{TIN}	V_{VDD}=3.6V，Normal working condition		500		kΩ

The Junction Temperature Threshold At Which The Chip Is Protected From Overheating	T_{OTP}			140		°C
The Junction Temperature Threshold At Which The Chip Exits The Overtemperature Protection	T_{OTPR}			120		°C

➢ Application Information

R_{VDD} Resistance Selection

RVDD recommends a 1kΩ resistor. The overvoltage charge protection voltage threshold and overvoltage discharge protection voltage threshold of AF3251 in application are judged by detecting the voltage of the VDD pin, and the VDD pin is connected to the positive electrode of the lithium battery through RVDD. If the RVDD is too large, it will cause the overvoltage charge protection voltage threshold and overvoltage discharge protection voltage threshold to deviate too much from the actual voltage of the lithium battery. Therefore, the value of the RVDD resistor should not be too large, and should be controlled within 2.0kΩ.

On the other hand, the value of RVDD should not be too small, if the value of RVDD is too small, the RC filtering effect of the VDD pin will be worse. In addition, in the application of very small capacity lithium battery, when the abnormal situation of load short circuit occurs, the voltage of the lithium battery will immediately drop to a very low value, if the RVDD value is too small, the voltage of the VDD pin will also drop to a very low value, which may make the chip not work normally, resulting in the failure of the load short circuit protection function. Therefore, the value of RVDD resistance should be fully tested and verified according to the characteristics of lithium batteries in specific applications.

C_{VDD} Input Capacitor Selection

The input capacitance CVDD in the typical application circuit of the AF3251 plays an important role, mainly for filtering and decoupling the input voltage of the lithium battery. When there is a sudden change in the current of the discharge load or charger, the voltage ripple and overshoot will exist at the positive electrode of the lithium battery due to the existence of the ESR internal resistance of the lithium battery and the resistance of the connecting wire. CVDD prevents the AF3251 from being protected from overvoltage charging and overvoltage discharge due to input voltage ripple and overshoot. It is recommended to use at least 0.1μF of ceramic chip capacitors on the VDD input pins of the AF3251 and must be placed near the VDD pins. And it is connected in series with the resistor RVDD resistor to form an RC filter network to better absorb the voltage ripple of the lithium battery.

R_{SM} Resistance Selection

Before AF3251 enters shipping mode, the input at the SM pin is at a low level, with the low-level voltage equal to the voltage at the VM pin. When AF3251 experiences overvoltage charging protection or overcurrent charging protection, the voltage at the VM pin becomes lower than GND, turning negative. At this time, the voltage at the SM pin is also negative. When the SM pin is at a negative voltage, the parasitic ESD diode between SM and GND may become forward-biased. Therefore, resistor RSM is needed to limit the current. In the typical application circuit, the value of RSM should not be too small. Additionally, under normal operating conditions, there is a 500kΩ pull-down resistor from SM to GND, so RSM should not be too large; otherwise, it will affect the input high-level threshold voltage of SM. The larger the value of RSM, the higher the voltage required for the MCU output high level. Therefore, the value of RSM should be kept between 100kΩ and 330kΩ and thoroughly tested according to specific applications.

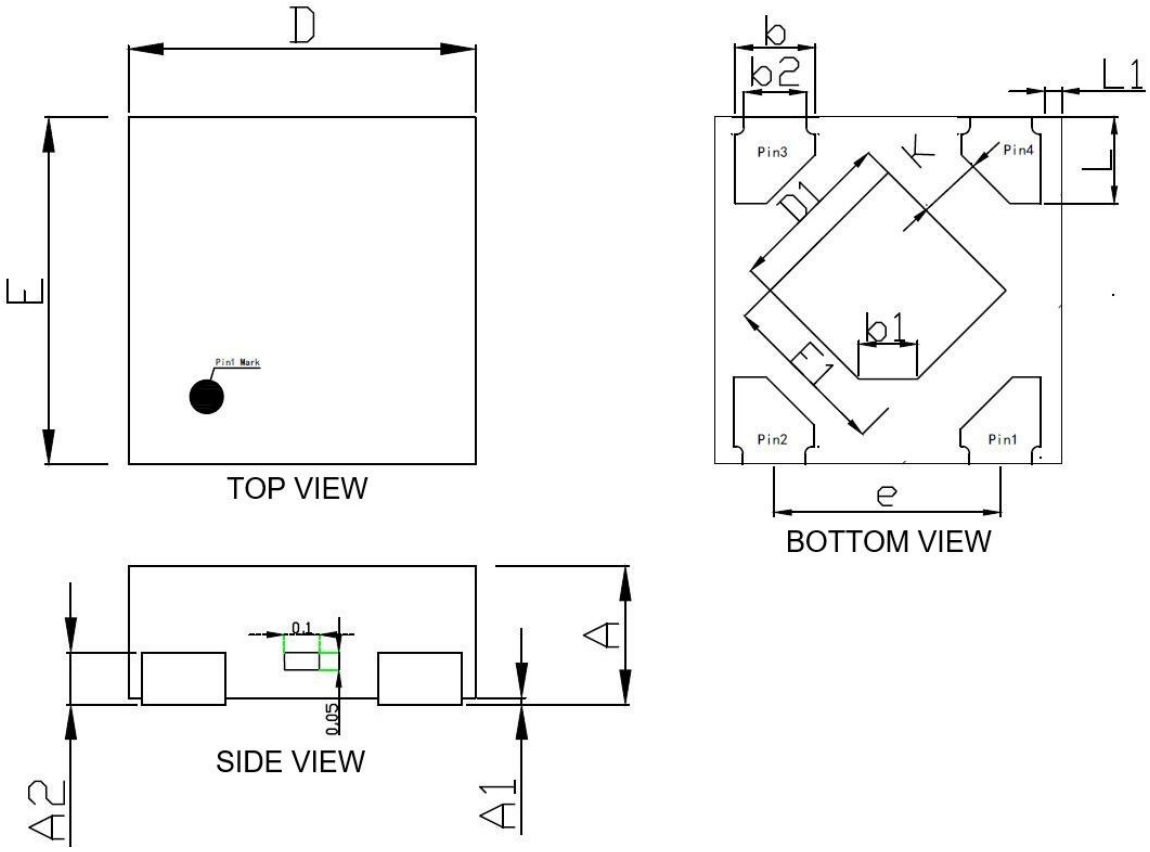
PCB Layout Guidelines

AF3251 is a high-precision 2-in-1 single-cell lithium battery charge and discharge protection chip, which can protect the voltage and current of lithium batteries during the charging and discharging process. In a practical application circuit, the layout and routing of the PCB should meet the following rules.

- The input capacitor CVDD should be as close as possible to the VDD pin and GND pin of AF3251, and the PCB trace of CVDD should avoid passing through vias, not passing through small ground wires and then to chip ground and large area.
- The PCB traces of the high-current power path should be as short and thick as possible; In order to achieve good heat dissipation performance of the power tube, the GND and P- traces can be poured copper as much as possible.

➢ Package Information

DFN1×1- 4L



符号	尺寸(mm)		
	最小值	标准值	最大值
A	0.35	0.38	0.40
A1	0.00	0.02	0.05
b	0.19	0.23	0.27
b1	0.12	0.17	0.22
D	0.95	1.00	1.05
E	0.95	1.00	1.05
D1	0.43	0.48	0.53
E1	0.43	0.48	0.53
e	0.65 BSC		
L	0.20	0.25	0.30
L1	0.05 REF		
K	0.18	0.20	0.22
A2	0.102 BSC		
b2	0.18 REF		

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