2A 1 Cell Lithium-Ion Battery Switching Charger

FEATURES

- Complete Switching Charger for 1 Cell Lithium-Ion Battery
- No External MOSFET, Blocking Diode Required
- Up to 2A Programmable Charge Current
- Reverse Leakage Protection Prevents Battery Drainage
- Integrated Current and Voltage Regulation
- Charge Operation Indicators
- Programmable Safety Timer
- Status Outputs for LED or System Interface Indicates Charge and Fault Conditions
- Battery Insertion and Removal Detection
- Available in Tiny Thermally Enhanced TSSOP-16 Exposed Pad Package

APPLICATIONS

- Cellular Phones
- Handheld Devices
- Digital Still Cameras
- MP3 Players
- PDAs
- Charging Docks and Cradles
- USB Chargers

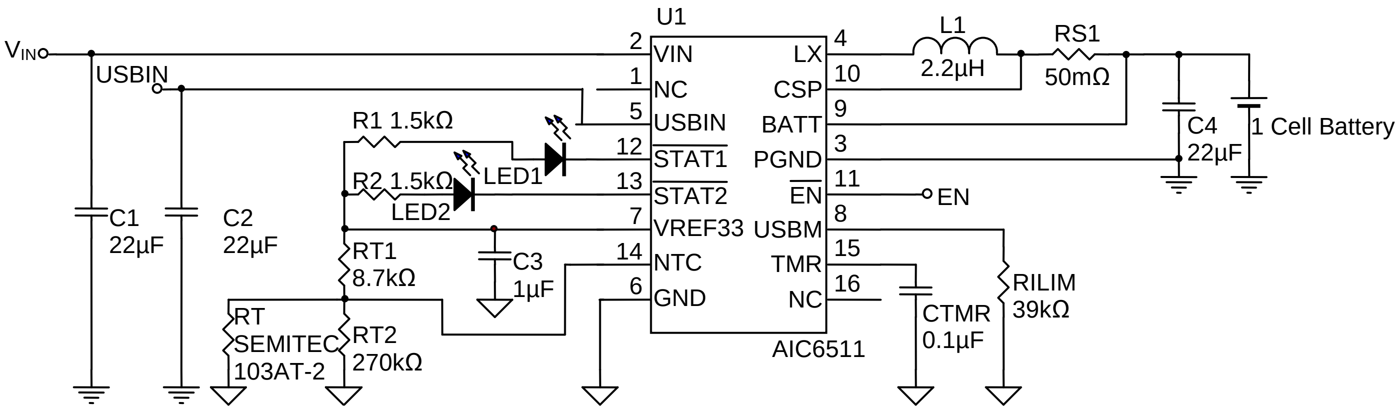
GENERAL DESCRIPTION

The AIC6511 is highly integrated Li-ion and Li-Pol switching charge devices targeted at space limited portable applications. It offers integrated power MOSFETs, reverse blocking protection, high accuracy current and voltage regulation, charge status, and charge termination, in a small package.

The AIC6511 regulates the charge current and battery voltage using two control loops to realize highly accurate constant-current charge and constant-voltage charge. A 100% duty cycle can be achieved when battery voltage is close to the input voltage due to the high-side P-Channel MOSFET.

In addition to the standard features, AIC6511 offers a multitude of additional features. These include temperature-sensing input for detecting hot or cold battery packs and programmable safety timer.

TYPICAL APPLICATION CIRCUIT



Typical Application Circuit

ORDERINGIN FORMATION

AIC6511-XXXXXXX

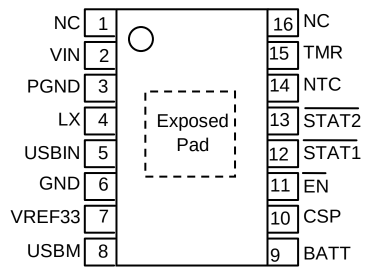
- PACKING TYPE
  TR: TAPE & REEL
  TB: TUBE
- PACKAGING TYPE
  LT : TSSOP-16 Exposed Pad
- G: Green Package
- Output Voltage
  Default: 4.2V
  -35: 4.35V

Example: AIC6511GLTTR
→ 4.2V Output Voltage, in TSSOP-16 Exposed Pad Green Package and Tape & Reel Packing Type

AIC6511-35GLTTR
→ 4.35V Output Voltage, in TSSOP-16 Exposed Pad Green Package and Tape & Reel Packing Type

PIN CONFIGURATION

TSSOP-16 Exposed Pad
TOP VIEW



Note:
The exposed pad should be connected with GND pin.

ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage, VIN, USBIN 6.5V
LX Pin Switch Voltage .... -0.3V to (V_{IN} + 0.3V)
CSP,BATT Pin Voltage .... -0.3V to 6V
Other I/O Pin Voltage .... -0.3V to 6V
Operating Ambient Temperature Range T_A .... -40ºC~85ºC
Operating Maximum Junction Temperature T_J 150ºC
Storage Temperature Range T_{STG} .... -65ºC~150ºC
Lead Temperature (Soldering 10 Sec.) 260ºC
Thermal Resistance Junction to Case TSSOP-16 Exposed Pad * .... 24°C/W
Thermal Resistance Junction to Ambient TSSOP-16 Exposed Pad * .... 40°C/W
(Assume no Ambient Airflow)

Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.
*The package is place on a two layers PCB with 2 ounces copper and 2 square inch, connected by 8 vias.

ELECTRICAL CHARACTERISTICS

(V_{IN}=5V, T_A=25°C, Unless otherwise specified.) (Note1)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
VIN Input						
Operation Voltage		V_{IN}	4.5	5	6	V
Oscillator Frequency		f_{OSC}	1.275	1.5	1.725	MHz
P-Channel On-Resistance		$R_{DSH(ON)}$		130		mΩ
N-Channel On-Resistance		$R_{DSL(ON)}$		150		mΩ
Supply Current	$\overline{EN}$=0V, No Load	I_{IN}			2.0	mA
Supply Current	$\overline{EN}$=4V				20	μA
USBIN Input						
USBIN Operating Range		V_{USBIN}	4.5	5	6	V
P-Channel On-Resistance		$R_{DSH(ON)}$		95		mΩ
Supply Current	$\overline{EN}$=0V, No Load	I_{IN}			2.0	mA
Supply Current	$\overline{EN}$=4V				30	μA
Current Regulation						
Output Current Range	RS1=50mΩ	$I_{O(OUT)}$	1800	2000	2200	mA
Peak Inductor Current		I_{PK}	3000	3800		mA
USB Input Current Limit	R_{ILIM}=82.5KΩ, V_{USBIN}=5V, V_{BATT}=4V	I_{USB_LIM}		450	500	mA
	R_{ILIM}=45.3KΩ, V_{USBIN}=5V, V_{BATT}=4V			810	900	mA

■ ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
Battery Charger						
Terminal Battery Voltage	For AIC6511GLT	V_{BATT_FULL}	4.179	4.2	4.221	V
	For AIC6511-35GLT		4.328	4.35	4.372	
Battery Over-Voltage Threshold	For AIC6511GLT	V_{BOVP}	4.26	4.34	4.42	V
	For AIC6511-35GLT		4.412	4.50	4.578	
Recharge Threshold at V_{BATT}	For AIC6511GLT	V_{RECHG}		4.0		V
	For AIC6511-35GLT			4.14		
Recharge Hysteresis				100		mV
Trickle-Charge Threshold	For AIC6511GLT	V_{TC}		3		V
	For AIC6511-35GLT			3.107		
Trickle-Charge Hysteresis				300		mV
Trickle-Charge Current		I_{TC}		10	15	% I_{CC}
Termination Charge Current		I_{BF}	5	10	15	% I_{CC}
Maximum Current-Sense Voltage(CSP to BATT)				100		mV
$\overline{\text{STAT1}}$/$\overline{\text{STAT2}}$ Open-Drain Sink Current	V_{DRAIN}=0.3V,			20		mA
VIN Min Head-room(Reverse Blocking)	VIN- VBATT			200		mV
CSP,BATT Current	Charging Disabled	ICSP, IBATT			1	*A
EN Logic						
$\overline{\text{EN}}$ Input Low Voltage					0.8	V
$\overline{\text{EN}}$ Input High Voltage			1.2			V
$\overline{\text{EN}}$ Input Current	$\overline{\text{EN}}$=4V			4		μA
	$\overline{\text{EN}}$=0V			0.2		μA
VREF33 Output Voltage		V_{VREF33}	3.23	3.3	3.37	V

ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
VREF33 Load Regulation	I_{LOAD}=0 to 20mA,	ΔV_{VREF33}		0.05		V
Protection						
VIN Under Voltage Lockout Protection	V_{IN} rising		3.55	3.75	3.95	V
VIN UVLO Hysteresis				200		mV
USBIN Under Voltage Lockout Protection	V_{USBIN} rising		3.55	3.75	3.95	V
USBIN UVLO Hysteresis				200		mV
Trickle-Charge Time	C_{TMR}=0.1μF,			30		min
Total Charge Time	C_{TMR}=0.1μF,			180		min
NTC High Temperature Rising Threshold			30	32	34	$\%V_{REF33}$
NTC Low Temperature Falling Threshold			72	74	76	$\%V_{REF33}$
Thermal Shutdown				150		℃

Note 1: Specifications are production tested at T_A=25°C. Specifications over the -40°C to 85°C operating temperature range are assured by design, characterization and correlation with Statistical Quality Controls (SQC).

TYPICAL PERFORMANCE CHARACTERISTICS

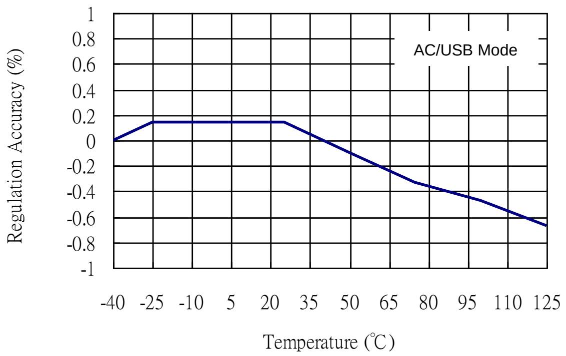


Fig. 1 V_{BATT} Accuracy vs. Temperature

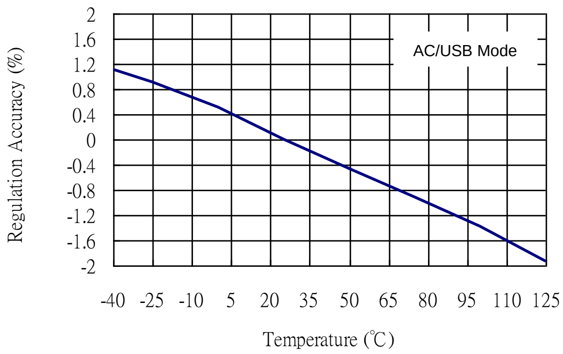


Fig. 2 Charge Current Accuracy vs. Temperature

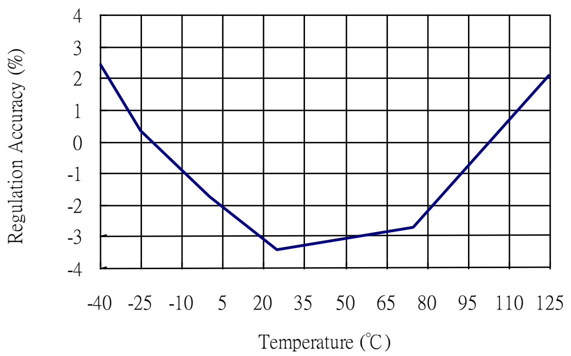


Fig. 3 USB Current Limit Accuracy vs. Temperature

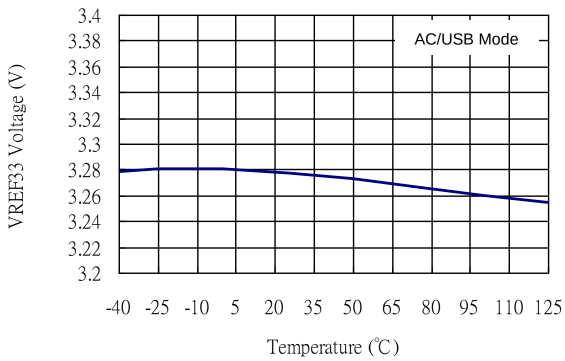


Fig. 4 VREF33 Voltage vs. Temperature

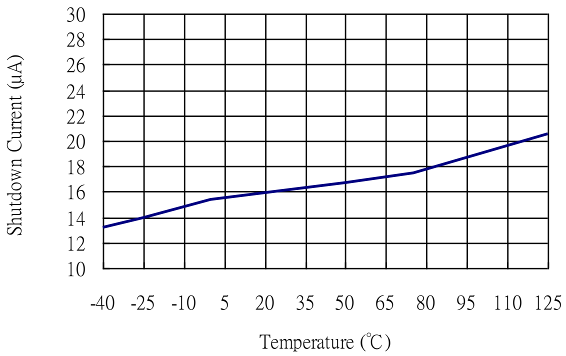


Fig. 5 Shutdown Current vs. Temperature

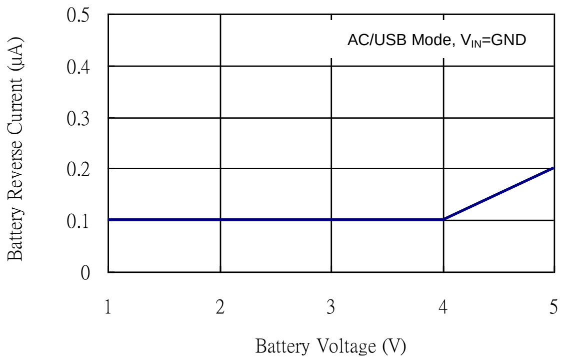


Fig. 6 Battery Reverse Current vs. Battery Voltage

■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

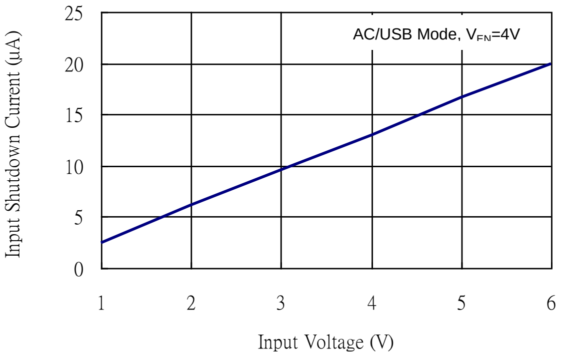


Fig. 7 Shutdown Current vs. Input Voltage

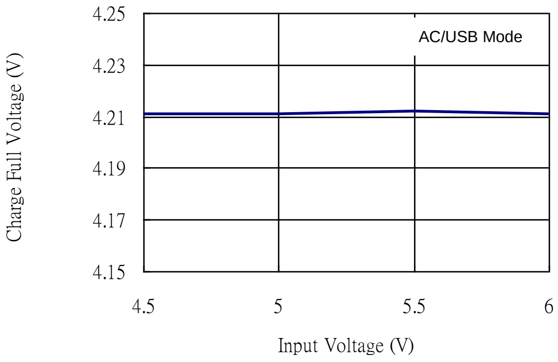


Fig. 8 Charge Full Voltage vs. Input Voltage

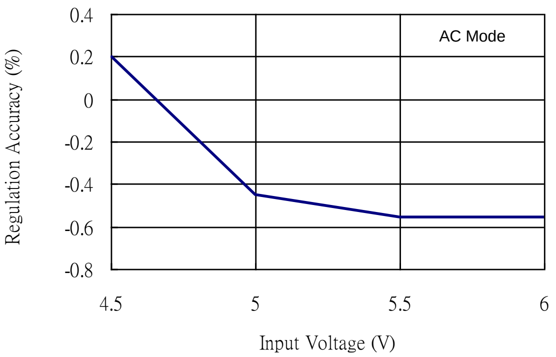


Fig. 9 Charge Current Accuracy vs. Input Voltage

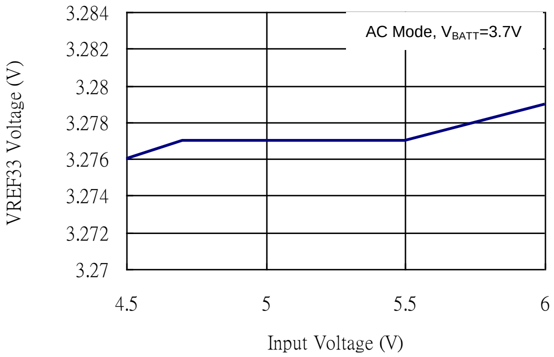


Fig. 10 VREF33 Voltage vs. Input Voltage

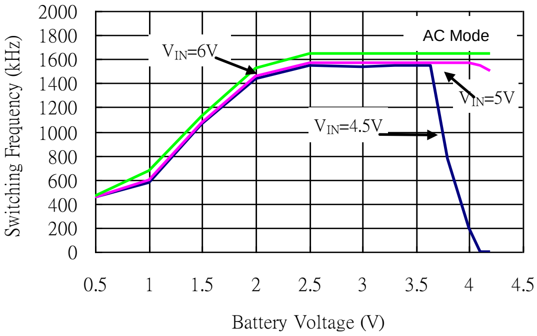


Fig. 11 Switching Frequency vs. Battery Voltage

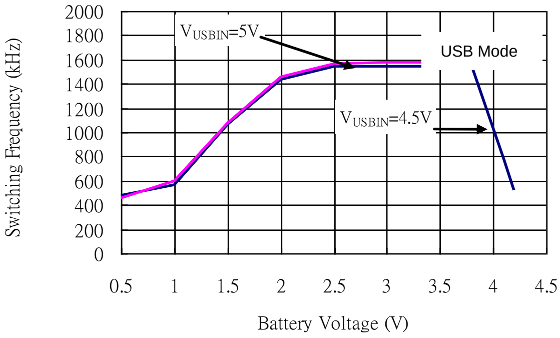


Fig. 12 Switching Frequency vs. Battery Voltage

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

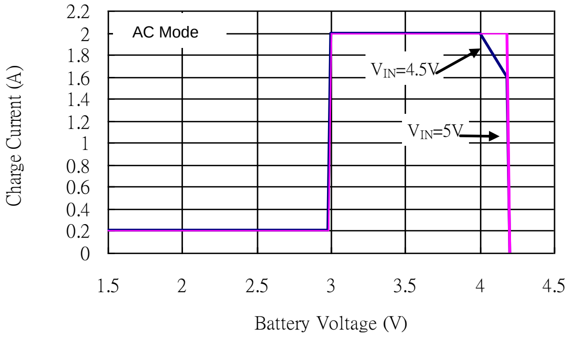


Fig. 13 AC Mode Charge Current

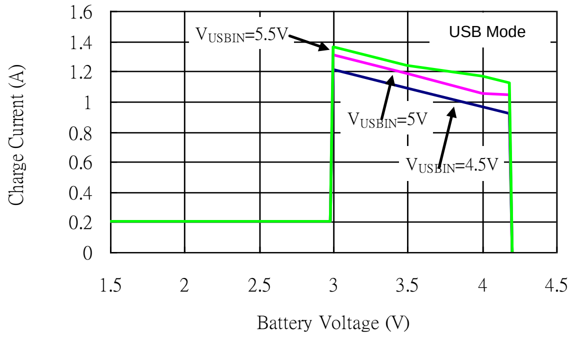


Fig. 14 USB Mode Charge Current

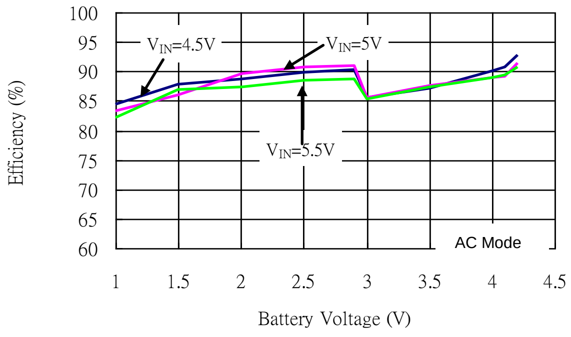


Fig. 15 AC Mode Efficiency

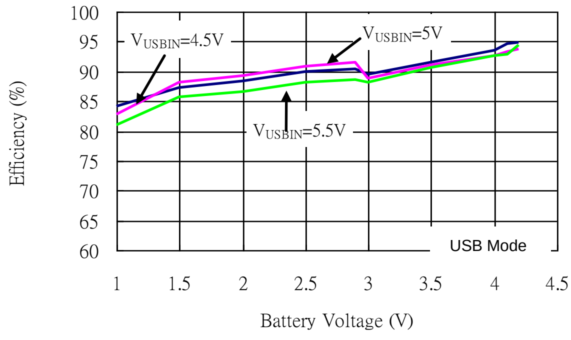


Fig. 16 USB Mode Efficiency

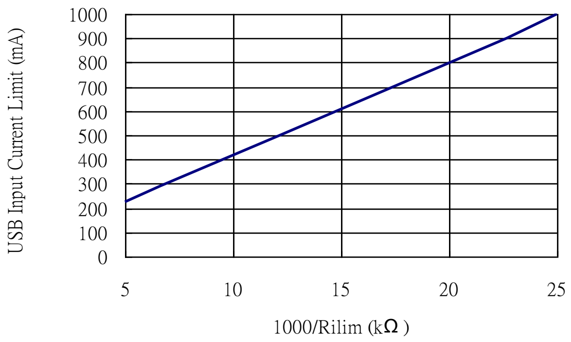


Fig. 17 USB Input Current Limit vs. 1000/R_{ILIM}

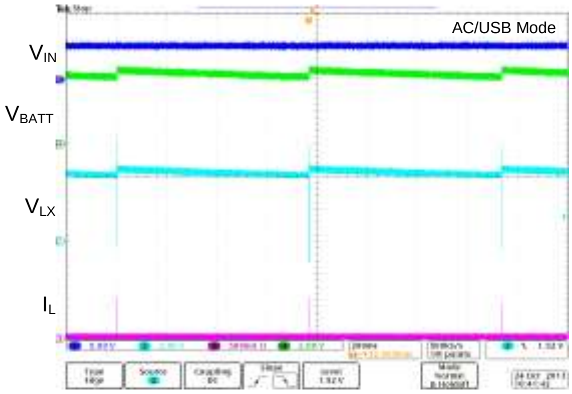


Fig. 18 BATT Float Waveform

■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

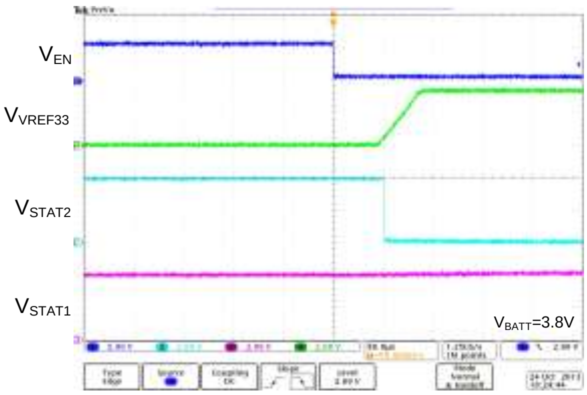


Fig. 19 VREF33 Startup Waveform

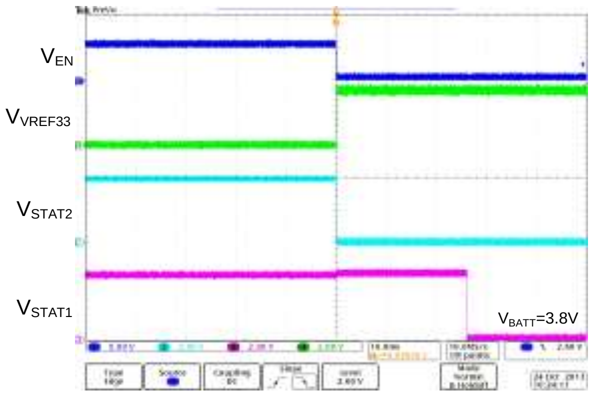


Fig. 20 STAT1 & STAT2 Startup Waveform

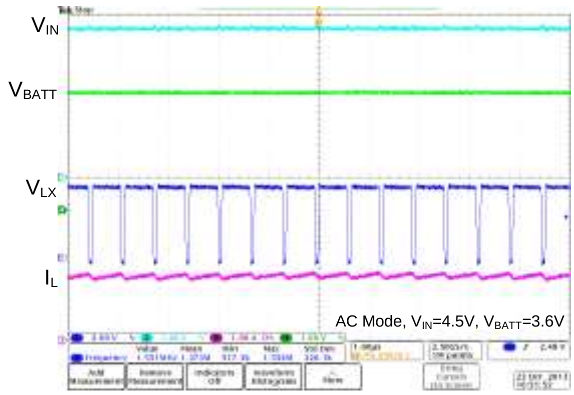


Fig. 21 Low Input Voltage Charge State

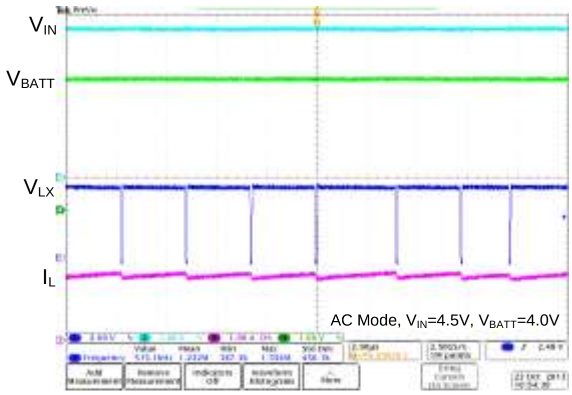


Fig. 22 Low Input Voltage Charge State

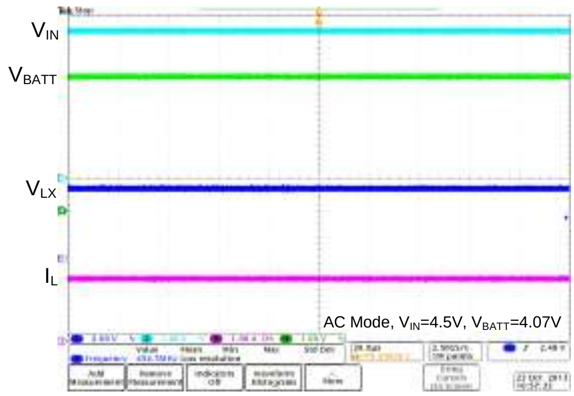


Fig. 23 Low Input Voltage Charge State

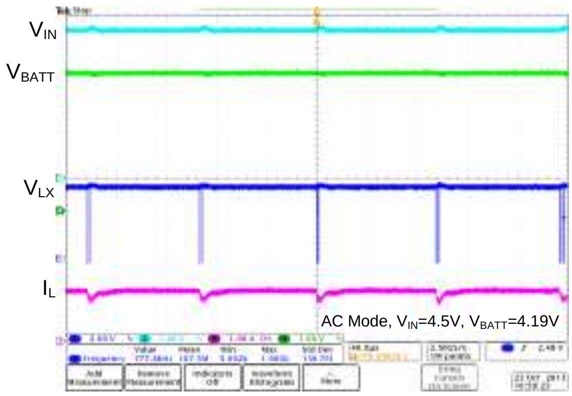


Fig. 24 Low Input Voltage Charge State

■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

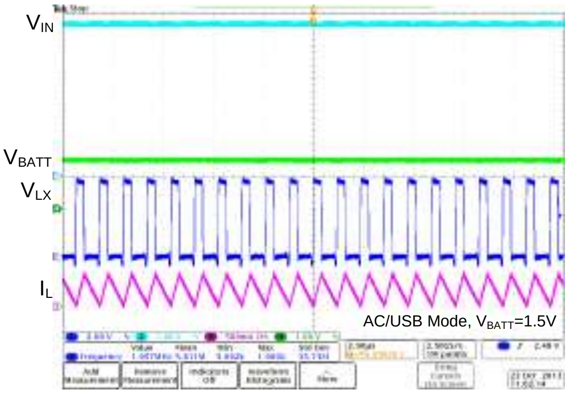


Fig. 25 TC Charge Steady State

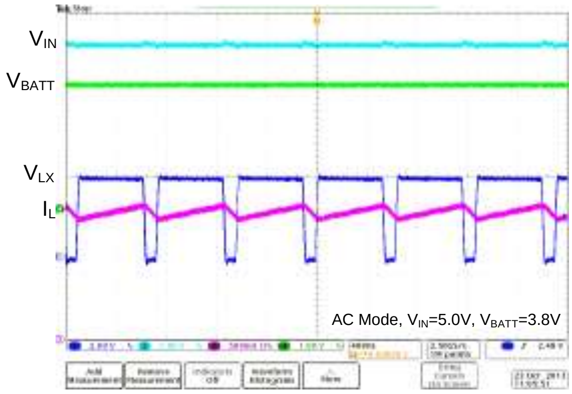


Fig. 26 CC Charge Steady State

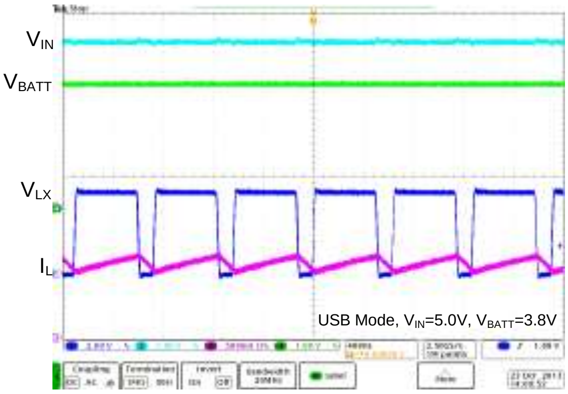


Fig. 27 CC Charge Steady State

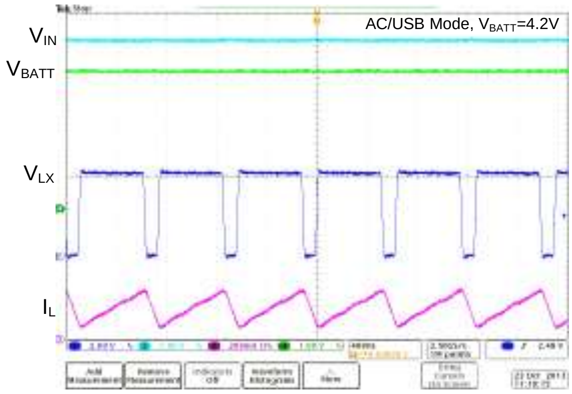


Fig. 28 CV Charge Steady State

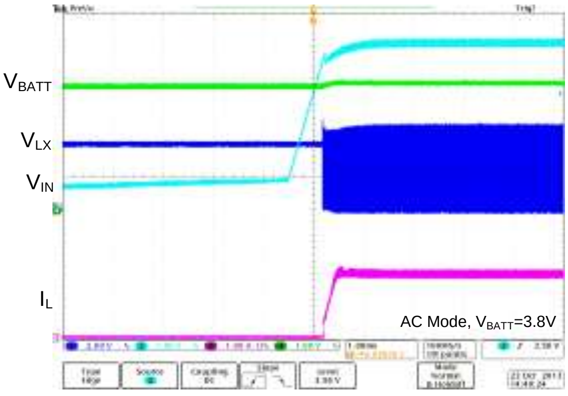


Fig. 29 Power On

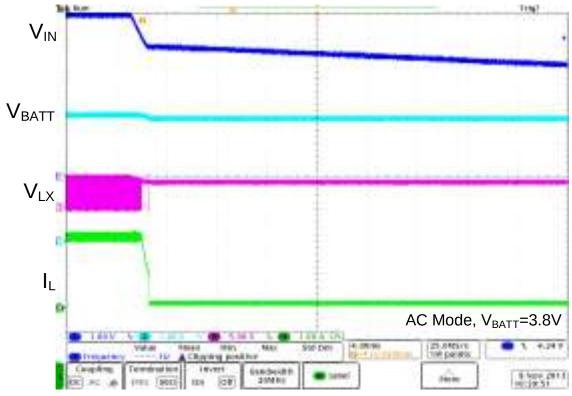


Fig. 30 Power Off

■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

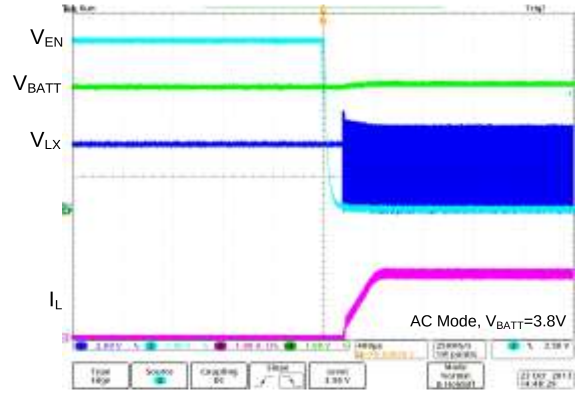


Fig. 31 Enable On

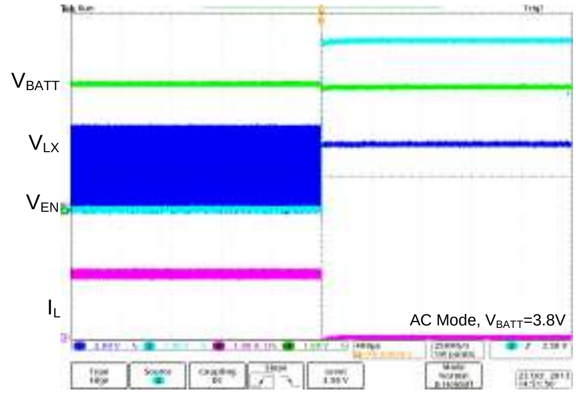


Fig. 32 Enable Off

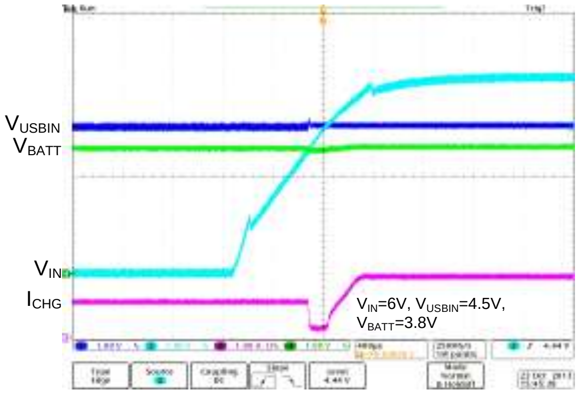


Fig. 33 AC Adapter Insertion

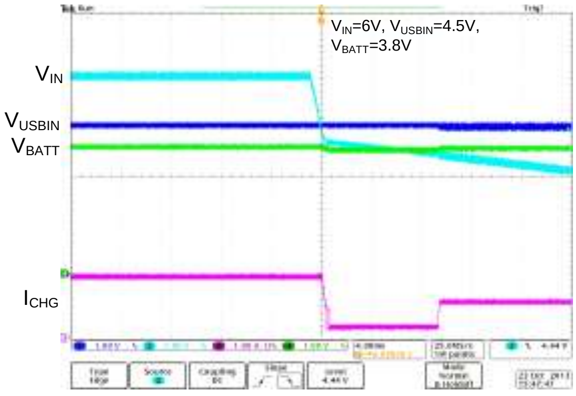


Fig. 34 AC Adapter Removal

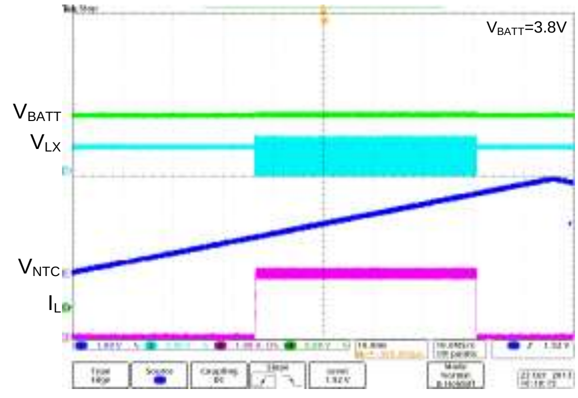


Fig. 35 NTC Control

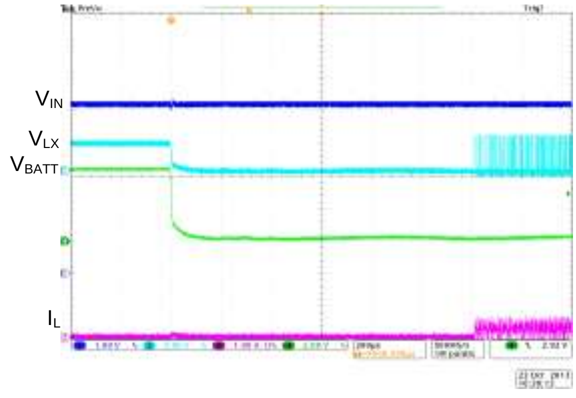
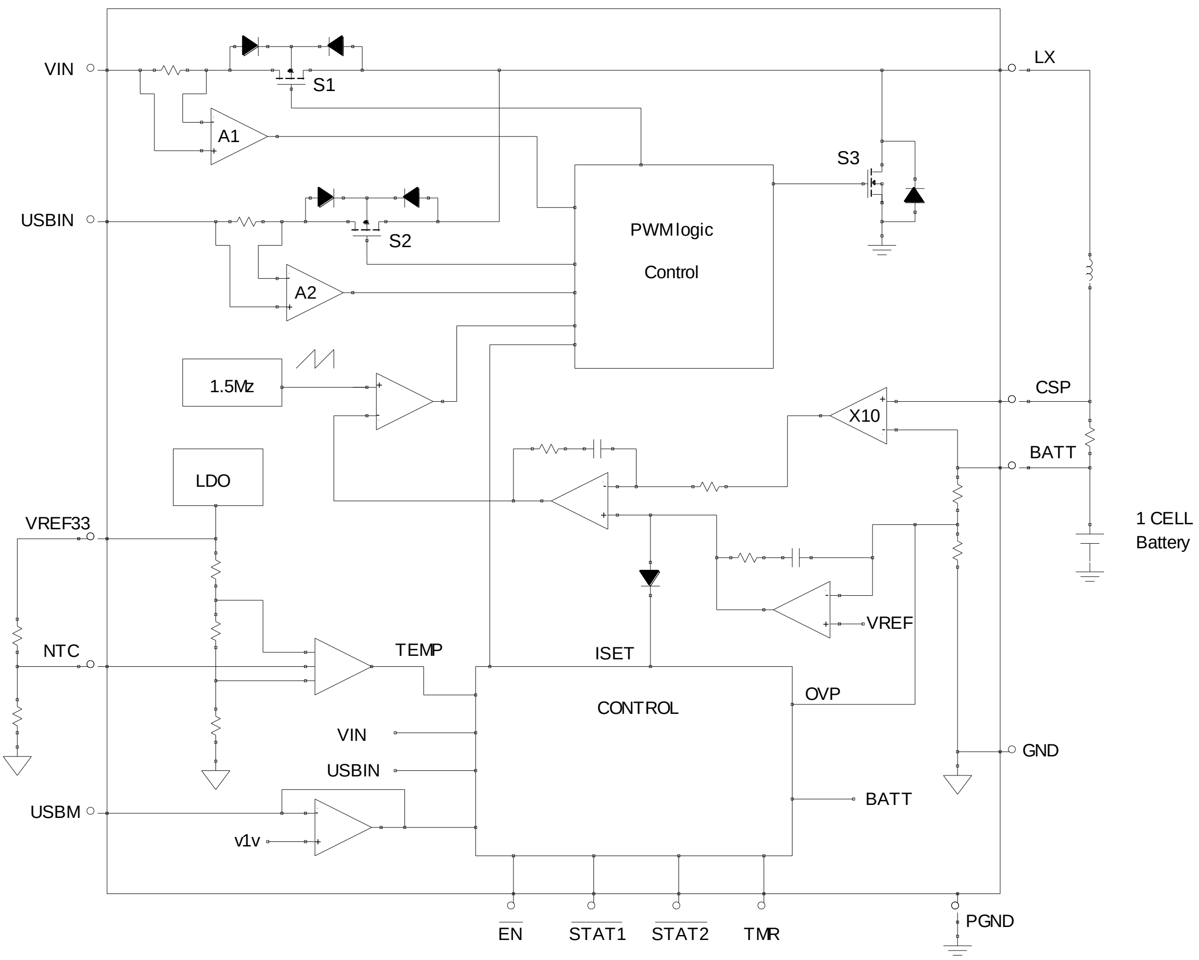


Fig. 36 Short-Circuit Protection

■ BLOCK DIAGRAM



Functional Block Diagram of AIC6511

PIN DESCRIPTIONS

Pin Number	Pin name	Pin Function
1	NC	No connection.
2	VIN	Power Supply Input. Decouple this pin to PGND with a capacitor.
3	PGND	Power Ground. Connect this pin to the negative terminal of input capacitor and output capacitor.
4	LX	Internal Power MOSFET Switches Output. Connect this pin to the inductor.
5	USBIN	USB Power Input. Decouple this pin to PGND with a capacitor.
6	GND	Signal Ground. All small-signal components should connect to this ground, which in turn connects to PGND at one point.
7	VREF33	Reference Voltage Output.
8	USBM	USB Input Current-Limit Set.
9	BATT	Positive Battery Terminal.
10	CSP	Charge Current Sense Positive Terminal.
11	$\overline{EN}$	Enable Pin.
12	$\overline{STAT1}$	Charge Status Indicator: 1.Charging; 2. End of charge; 3. Charging Suspended; 4. Fault; 5. Invalid Input Supply.
13	$\overline{STAT2}$	
14	NTC	Temperature Sense Input
15	TMR	Internal Safety Timer Set.
16	NC	No connection.

APPLICATION INFORMATIONS

The AIC6511 is a Li-ion and Li-Pol switching charge device with built-in power MOSFETs. It supports a precision Li-Ion, Li-Pol charging system suitable for single-cells. The AIC6511 integrates an internal synchronous rectifier, which eliminates the external Schottky diode and increases efficiency. During normal operation, the AIC6511 can regulate the charge current and battery voltage through two feedback control loops. This feedback control circuit will determine the duty cycle of internal high-side power switch (P-channel MOSFET). While the high-side power switch is turned on, the low-side power switch (N-channel MOSFET) will be turned off. Similarly, when the high-side power switch is turned off, the low-side power switch will be turned on until the beginning of the next switching cycle or the inductor current starts to reverse.

When the input voltage approaches the output voltage, the AIC6511 smoothly transits to 100% duty cycle operation. This allows AIC6511 to regulate the charge current and battery voltage until AIC6511 completely enters 100% duty cycle operation. In 100% duty cycle mode, the high-side power switch is turned on continuously to deliver charge current to the battery.

VIN and USBIN Detection

The AIC6511 can operate with two separate input power source: VIN for the AC adapter and USBIN for the USB port. The VIN is used as the charger primary input power source. When the VIN voltage is higher than VIN UVLO, the internal power switch S2 is turned off and the internal power switch S1 is used as the high-side power switch of the synchronous step-down DC/DC converter. In AC adapter mode, the input power source can charge the battery with up to 2A constant charge current through the synchronous step-down converter.

On the other hand, when the VIN voltage is lower than VIN UVLO or absent, the USBIN is used as the charger input power source. In USB port mode, the internal power switch S1 is turned off and the internal power switch S2 is used as the high-side power switch of the synchronous step-down DC/DC converter. When operating at the USB port mode, the input current limit can be set to 500mA and 900mA for both USB2.0 and USB3.0, respectively. The input current limit threshold can be set by the resistor connected between the USBM pin and GND pin, R_{ILIM}.

$$I_{USB\_LIM} = \frac{37000}{R_{ILIM}(k\Omega)} \times \frac{50(m\Omega)}{RS1(m\Omega)}$$

Note that in USB port mode, the AIC6511 will not monitor the charge current through RS1 during CC charge period, but regulates the constant input current at the limitation value I_{USB_LIM}. Thus the CC charge current varies with different input and battery voltages.

If the VIN and USBIN are both present, the AIC6511 will select the VIN as the input power source of the charger. However, this condition should be avoided.

Trickle Charge

Figure 38 is the typical charging profile. During a charge cycle, the AIC6511 provides a trickle charge current to revive the deeply discharged battery if the battery voltage is lower than the TC threshold. In the trickle charge mode, the trickle charge current is the 10% of the constant charge current.

$$I_{TC} = 0.1 \times I_{CC} = \frac{10mV}{RS1(m\Omega)}(A)$$

During the trickle charge period, the safety timer of trickle charge mode, $t_{(Trickle\_tmr)}$, can be activated. If the battery voltage cannot reach the TC threshold within the timer period, the AIC6511 can terminate the trickle charge action and indicates FAULT on the $\overline{STAT1}$ pin.

The safety time of trickle charge mode can be set by the capacitor connected between the TMR pin and GND pin, C_{TMR}.

$$t_{Trickle\_tmr} = 30 \times \frac{C_{TMR}}{0.1\mu F}(Minutes)$$

Constant Current Charge

The AIC6511 provides a constant charge current to charge the battery when the battery voltage is between the TC threshold and CV charge threshold. The constant charge current can be determined by the resistor connected between the CSP pin and BATT pin, RS1.

$$I_{CC} = \frac{100mV}{RS1(m\Omega)}(A)$$

Constant Voltage Charge

The AIC6511 monitors the battery voltage through the BATT pin. When the battery voltage rises to CV charge threshold, the AIC6511 will enter constant voltage charge mode and the charge current will begin to decrease.

During the charge period, the total charge safety timer, $t_{(Total\_tmr)}$, can be activated. If the termination threshold, I_{BF}, is not detected within the timer period, the AIC6511 can terminate the charge action and indicates FAULT on the $\overline{STAT1}$ pin. The safety time of CC/CV charge mode can be set by C_{TMR}.

$$t_{Total\_tmr} = 3 \times \frac{C_{TMR}}{0.1\mu F}(hr)$$

The safety timer can be disabled by pulling the TMR pin to GND.

Charge Termination and Recharge

The AIC6511 can terminate the charge action and $\overline{STAT1}$ pin can become an open drain when the charge current falls below the termination threshold, I_{BF}, during the constant voltage charge period. The safety timer will also be turned off and reset. After the charge action is terminated, the AIC6511 can restart the charge action once the voltage on the BATT pin falls below the recharge threshold V_{RECHG}, as shown in Figure 39.

Timer Fault Recovery

As shown in the figure 40, the AIC6511 can exit from the timer fault state and enter a new charge cycle when one of the following conditions occurs.

(1) The battery voltage falls below the recharge threshold V_{RECHG}.

(2) The EN is toggled.

Battery Temperature Detection

During the charge period, the AIC6511 continuously monitors the battery temperature by measuring the voltage on the NTC pin. A negative temperature coefficient thermistor and a resistor-divider, R_{T1} and R_{T2}, typical develop this voltage, as shown in figure 37. The AIC6511 compare the voltage on the NTC pin against the NTC high temperature threshold and NTC low temperature threshold to determine whether charge action is allowed. Once the battery temperature outside the normal temperature range is detected, the AIC6511 immediately suspends charge action. The charge action is suspended by turning off the synchronous step-down converter. The charge action is resumed when the battery temperature returns to the normal range.

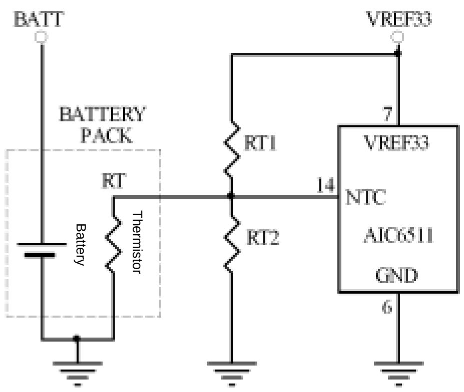


Fig. 37 Battery Temperature Sense Circuit

For R_{T1} and R_{T2} in the circuit, the below equations provide the calculations.

$$R_{T1} = \frac{525}{296} \times \frac{R_{TL} \times R_{TH}}{(R_{TL} - R_{TH})}$$

$$R_{T2} = \frac{525}{104} \times \frac{R_{TL} \times R_{TH}}{\left(R_{TL} - \frac{629}{104} \times R_{TH}\right)}$$

Where R_{TL} is the resistance of thermistor at lower limit of temperature protection and R_{TH} is the resistance of thermistor at upper limit of temperature protection.

By applying a constant voltage between the NTC high temperature threshold and NTC low temperature threshold to NTC pin, the battery temperature detection function can be disabled.

Under Voltage Lockout and Sleep Mode

The AIC6511 includes an under voltage lockout circuit, which monitors the input power source and keeps the charger in shutdown mode until VIN or USBIN rises above the under voltage lockout threshold. In addition, in order to prevent battery drainage, the AIC6511 can enter sleep mode if the VIN or USBIN falls below the sleep mode entry threshold.

Short Circuit Protection

The AIC6511 provides battery short circuit protection function. While the battery voltage is lower than 1.5V, the AIC6511 can indicate FAULT on the $\overline{\text{STAT1}}$ pin. During the battery short circuit period, the peak inductor current limit and the switching frequency will be reduced to minimize the power loss.

THERMAL PROTECTION

The AIC6511 includes a thermal-limiting circuit, which is designed to protect the device from excessive temperature. When the junction temperature exceeds T_J=150ºC, the thermal-limiting circuit suspends the charge action and allows the IC to cool. The charge action is resumed when the junction temperature falls below approximately T_J=120ºC.

Status Outputs

The AIC6511 provides two open-drained outputs: $\overline{\text{STAT1}}$ and $\overline{\text{STAT2}}$. The $\overline{\text{STAT1}}$ and $\overline{\text{STAT2}}$ can indicate the charging status of the charger, as shown in the following table. These status pins can be used to drive an LED or communicate to the host processor.

Table 3. Status Pins Summary

CHARGE STATE	$\overline{\text{STAT1}}$	$\overline{\text{STAT2}}$
Charge-in-progress	Low	Low
End of Charge; Faults (Thermal Shutdown, Timer Fault, Battery Temperature Detection Fault, V_{BATT}<1.5V)	High	Low
Under Voltage Lockout (UVLO), Sleep Mode, EN Disabled	High	High

Inductor

The inductor selection depends on the current ripple of inductor, the input voltage and the output voltage.

$$L \geq \frac{V_{BATT}}{f_{OSC} \cdot \Delta I_L}\left(1 - \frac{V_{BATT}}{V_{IN}}\right)$$

Accepting a large current ripple of inductor allows the use of a smaller inductance. However, higher current ripple of inductor can cause higher output ripple voltage and large core loss. By setting an acceptable current ripple of inductor, a suitable inductance can be obtained from above equation.

In addition, it is important to ensure the inductor saturation current exceeds the peak value of inductor current in application to prevent core saturation. The peak value of inductor current can be calculated according to the following equation.

$$I_{PEAK} = I_{CC(max)} + \frac{V_{BATT}}{2 \times f_{OSC} \cdot L}\left(1 - \frac{V_{BATT}}{V_{IN}}\right)$$

Input Capacitor and Output Capacitor

To prevent the high input voltage ripple and noise resulted from high frequency switching, the use of low ESR ceramic capacitor for the maximum RMS current is recommended. The approximated RMS current of the input capacitor can be calculated according to the following equation.

$$I_{CINRMS} \approx \sqrt{I^2_{CC(MAX)} \times \frac{V_{BATT}(V_{IN} - V_{BATT})}{V^2_{IN}} + \frac{\Delta I^2_L}{12}}$$

For most AIC6511 applications, a 22μF ceramic input capacitor is used.

The selection of output capacitor depends on the required output voltage ripple. The output voltage ripple can be expressed as:

$$\Delta V_{OUT} = \frac{\Delta I_L}{8 \times f_{OSC} \cdot C_{OUT}} + ESR \cdot \Delta I_L$$

In order to ensure the +/- 0.5% battery voltage accuracy, the maximum output voltage ripple must be lower than 0.5%. The maximum output voltage ripple will occur at the minimum battery voltage of the CC charge and the maximum input voltage. For lower output voltage ripple, the use of low ESR ceramic capacitor is recommended.

When choosing the input and output ceramic capacitors, X5R and X7R types are recommended because they retain their capacitance over wider ranges of voltage and temperature than other types. In addition, when using the ceramic capacitor as the input capacitor, the high input voltage transient may be generated at some start-up conditions, such as connecting the input to a live power source. By adding a small resistor in series with the input ceramic capacitor, the high input voltage transient can be improved.

Layout Consideration

In order to ensure a proper operation of AIC6511, the following points should be managed comprehensively.

1. The input capacitors and VIN and USBIN pins should be placed as close as possible to each other to reduce the input noise.
2. The output loop, which is consisted of the inductor, the internal high-side power switch, the internal low-side power switch and the output capacitor, should be kept as small as possible.
3. The BATT pin should be connected to the battery pack directly and the route should be as short as possible.
4. The routes with large current should be kept short and wide.
5. Logically the large current on the charger should flow at the same direction.
6. The CSP and BATT pins should be connected to the RS1 resistor directly and the route should be away from the noise sources.
7. The USBM pin should be connected to the R_{ILIM} resistor directly and the route should be away from the noise sources.
8. The TMR pin should be connected to the C_{TMR} capacitor directly and the route should be away from the noise sources.
9. The NTC pin should be connected to the battery temperature measurement network directly and the route should be away from the noise sources.
10. All small-signal components should connect to GND, which in turn connects to PGND at one point.

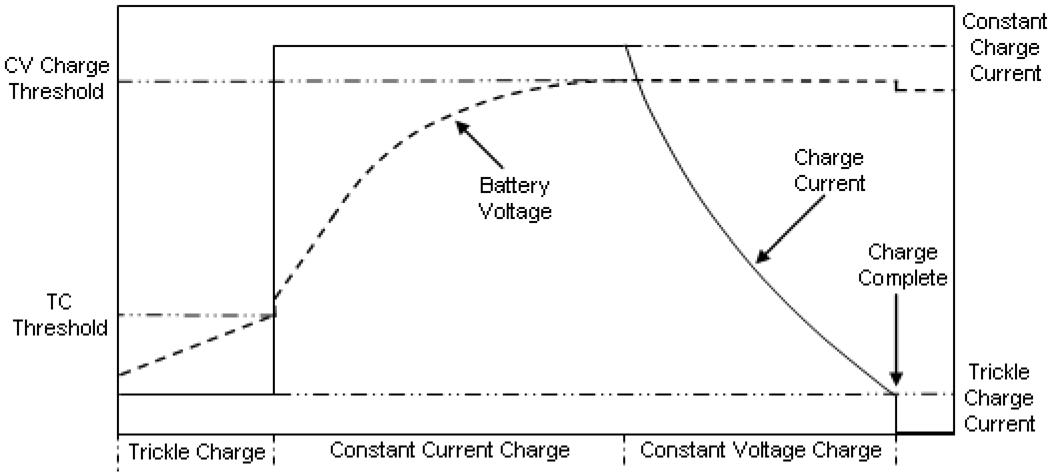


Fig. 38 Typical Charging Profile

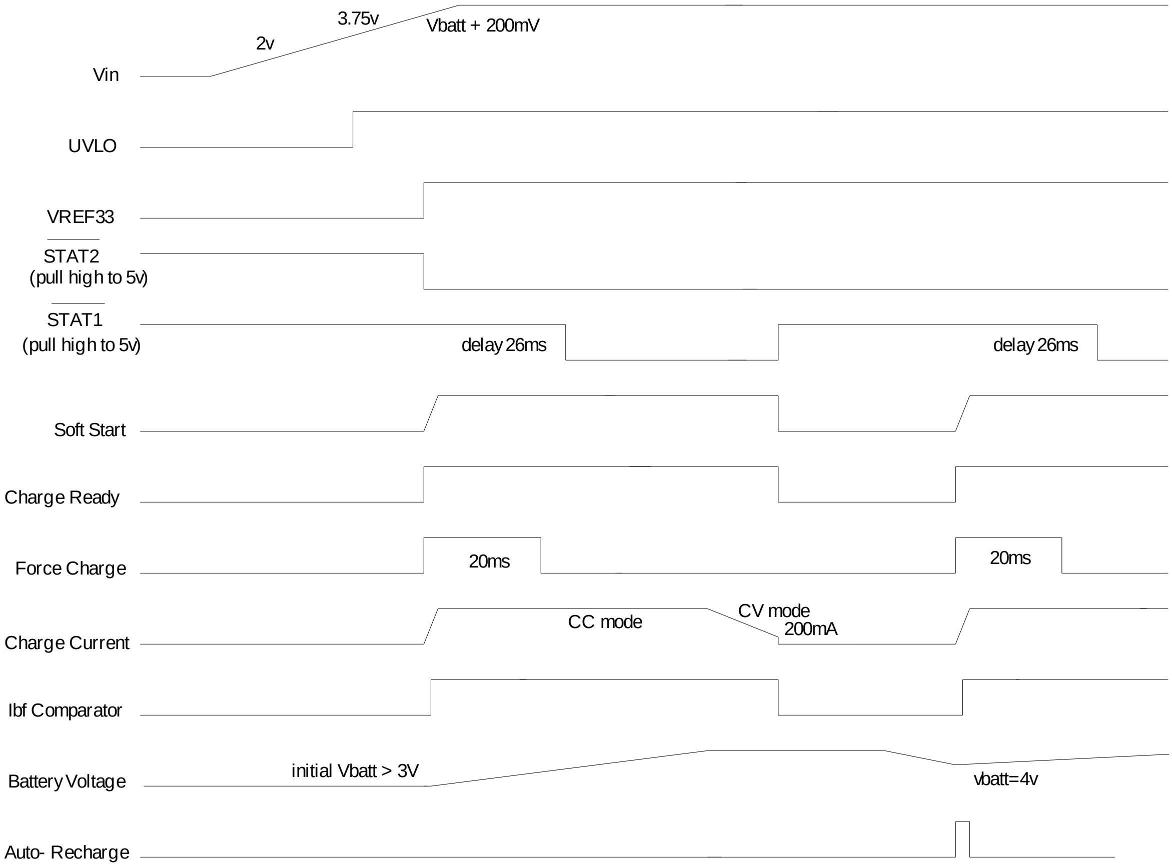


Fig. 39 Battery Charge Timing Diagram

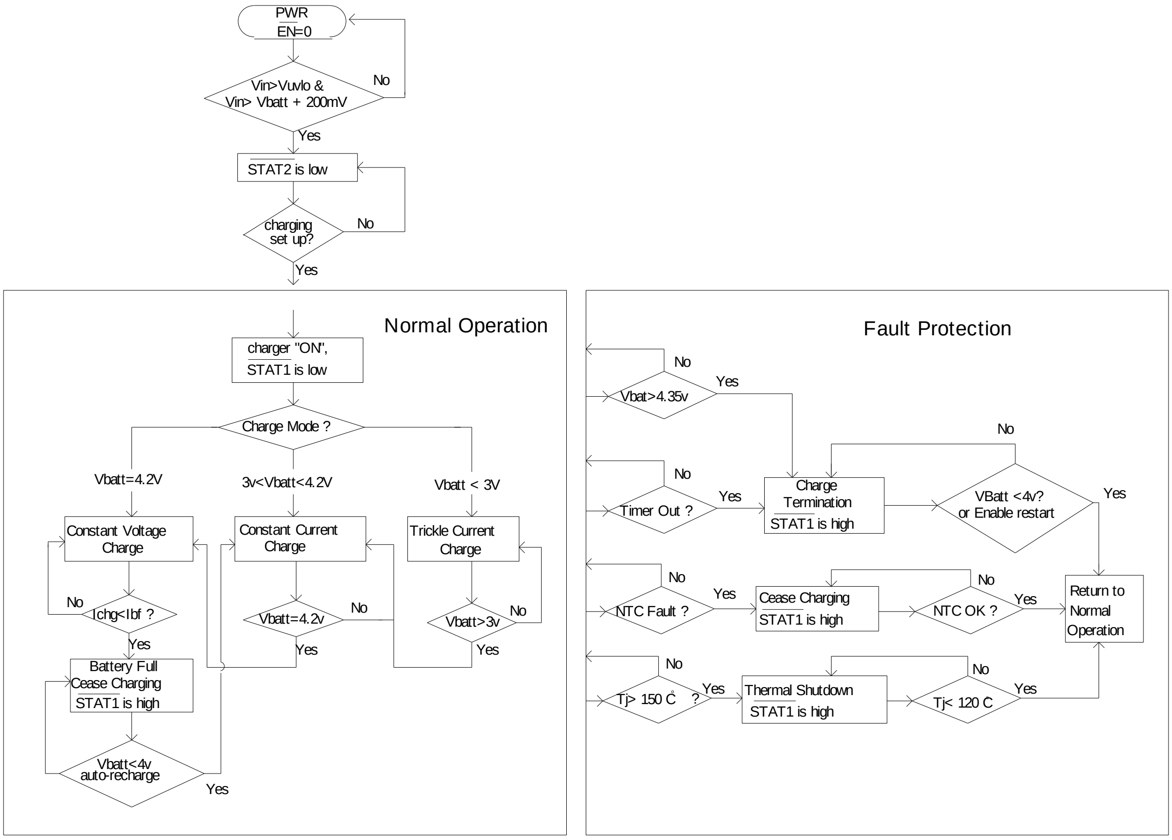
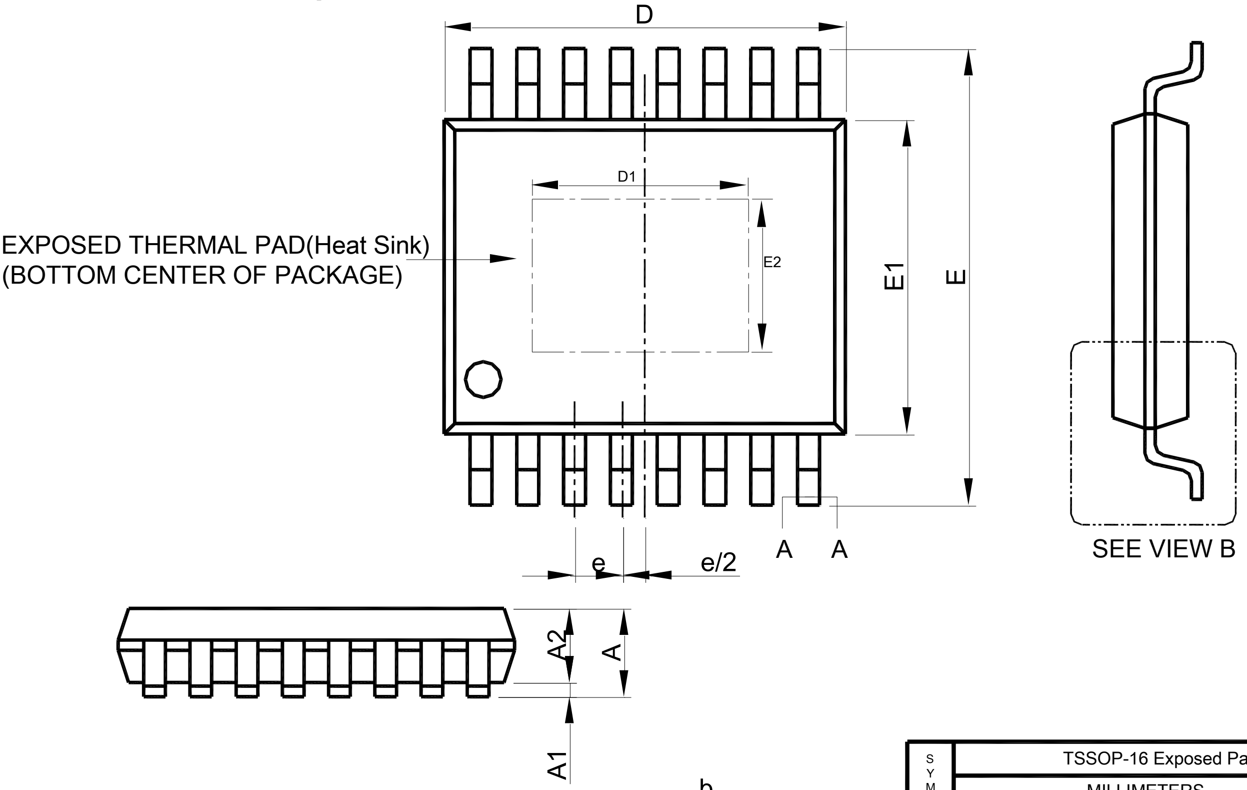
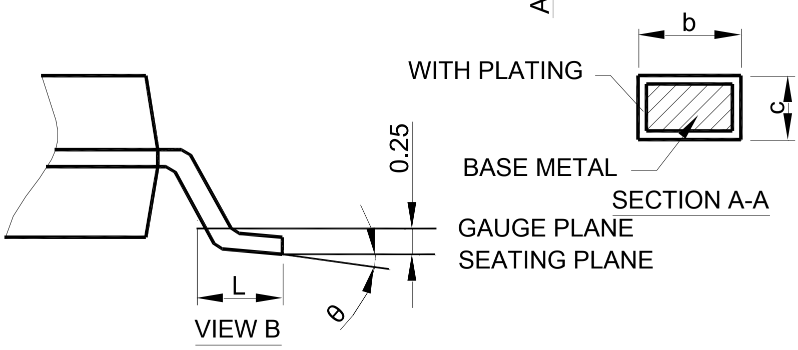


Fig. 40 Operation Flow Chart

PHYSICAL DIMENSIONS

- **TSSOP-16 Exposed Pad**





SYMBOL	TSSOP-16 Exposed Pad	
	MILLIMETERS	
	MIN.	MAX.
A		1.20
A1	0.00	0.15
A2	0.80	1.05
b	0.19	0.30
c	0.09	0.20
D	4.90	5.10
E	6.40 BSC	
E1	4.30	4.50
e	0.65 BSC	
L	0.45	0.75
θ	0°	8°
D1	2.00	4.00
E2	1.80	3.40

Note: 1. Refer to JEDEC MO-153AB.
2. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion or gate burrs shall not exceed 6 mil per side.
3. Dimension "E1" does not include inter-lead flash or protrusions.
4. Controlling dimension is millimeter, converted inch dimensions are not necessarily exact.