# 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 Output for LED or System Interface Indicates Charge and Fault Conditions
- Battery Insertion and Removal Detection
- Available in DFN-12 (3mmx3mm) Package

## APPLICATIONS

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

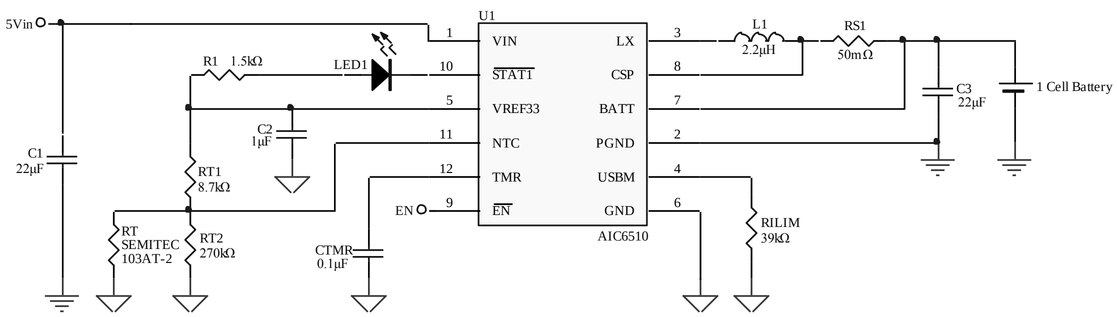
## GENERAL DESCRIPTION

The AIC6510 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 AIC6510 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, AIC6510 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**

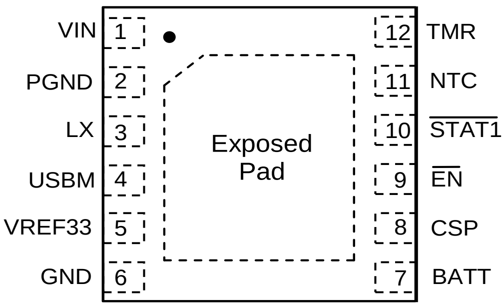
## ORDERING INFORMATION

AIC6510-XXXXXXXX

- PACKING TYPE
  TR: TAPE & REEL
  BG: BAG
- PACKAGE TYPE
  DBB: DFN-12 (3mmx3mm)
- G: Green Package
- Output Voltage
  Default: 4.2V
  -35: 4.35V

PIN CONFIGURATION

DFN-12 (3mmx3mm)
TOP VIEW




Note:
The exposed pad should be connected with GND.

Example: AIC6510GDBBTR
→ 4.2V Output Voltage, in DFN-12 (3mmx3mm)
Green Package and Tape & Reel Packing Type

AIC6510-35GDBBTR
→ 4.35V Output Voltage, in DFN-12 (3mmx3mm)
Green Package and Tape & Reel Packing Type

## ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage, VIN ........ 6.5V
LX Pin Switch Voltage ........ -0.3V to ($V_{IN}$ + 0.3V)
CSP Pin and BATT Pin Voltage ........ -0.3V to 6V
Other I/O Pin Voltage ........ -0.3V to 6V
Operating Maximum Junction Temperature $T_J$ ........ 150ºC
Storage Temperature Range $T_{STG}$ ........ -65ºC~150ºC
Lead Temperature (Soldering 10 Sec.) ........ 260ºC
Operating Ambient Temperature Range $T_A$ ........ -40ºC~85ºC
Thermal Resistance Junction to Case DFN-12 (3mmx3mm)* ........ 20°C/W
Thermal Resistance Junction to Ambient DFN-12 (3mmx3mm)* ........ 50°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 |
| **Current Regulation** | | | | | | |
| Output Current Range | RS1=50mΩ | $I_{O(OUT)}$ | 1800 | 2000 | 2200 | mA |
| Peak Inductor Current | | $I_{PK}$ | 3000 | 3800 | | mA |
| **Battery Charger** | | | | | | |
| Terminal Battery Voltage | For AIC6510GLT | $V_{BATT\_FULL}$ | 4.179 | 4.2 | 4.221 | V |
| | For AIC6510-35GLT | | 4.328 | 4.35 | 4.372 | |
| Battery Over-Voltage Threshold | For AIC6510GLT | $V_{BOVP}$ | 4.26 | 4.34 | 4.42 | V |
| | For AIC6510-35GLT | | 4.412 | 4.50 | 4.578 | |
| Recharge Threshold at $V_{BATT}$ | For AIC6510GLT | $V_{RECHG}$ | | 4.0 | | V |
| | For AIC6510-35GLT | | | 4.14 | | |
| Recharge Hysteresis | | | | 100 | | mV |
| Trickle-Charge Threshold | For AIC6510GLT | $V_{TC}$ | | 3 | | V |
| | For AIC6510-35GLT | | | 3.107 | | |
| Trickle-Charge Hysteresis | | | | 300 | | mV |
| Trickle-Charge Current | | $I_{TC}$ | | 10 | 15 | % $I_{CC}$ |
| Termination Charge Current | | $I_{BF}$ | 5 | 10 | 15 | % $I_{CC}$ |

## ELECTRICAL CHARACTERISTICS (Continued)

| PARAMETER | TEST CONDITIONS | SYMBOL | MIN. | TYP. | MAX. | UNIT |
|---|---|---|---|---|---|---|
| Maximum Current-Sense Voltage(CSP to BATT) | | | | 100 | | mV |
| $\overline{\text{STAT1}}$ Open-Drain Sink Current | $V_{DRAIN}$=0.3V, | | | 20 | | mA |
| VIN Min Head-room(Reverse Blocking) | $V_{IN}$- $V_{BATT}$ | | | 200 | | mV |
| CSP,BATT Current | Charging Disabled | $I_{CSP}$, $I_{BATT}$ | | | 1 | μA |
| **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 |
| | $\overline{\text{EN}}$=4V | | | 0.2 | | μA |
| VREF33 Output Voltage | | $V_{VREF33}$ | 3.23 | 3.3 | 3.37 | V |
| VREF33 Load Regulation | $I_{LOAD}$=0 to 20mA, | $\Delta V_{VREF33}$ | | 0.05 | | V |
| **Protection** | | | | | | |
| VIN Under Voltage Lockout Protection | $V_{IN}$ rising | | 3.55 | 3.75 | 3.95 | V |
| VIN UVLO Hysteresis | | | | 200 | | mV |
| 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

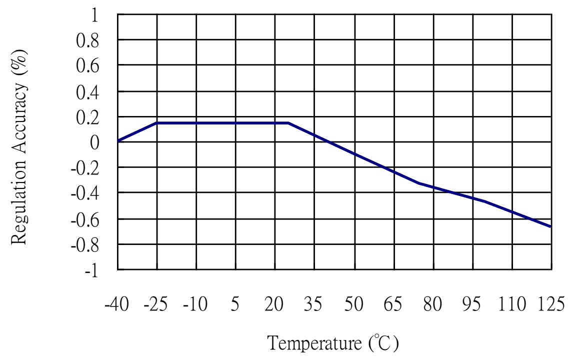



Fig. 1 $V_{BATT}$ Accuracy vs. Temperature

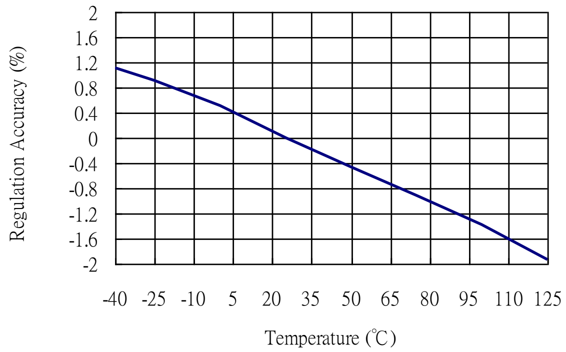



Fig. 2 Charge Current Accuracy vs. Temperature

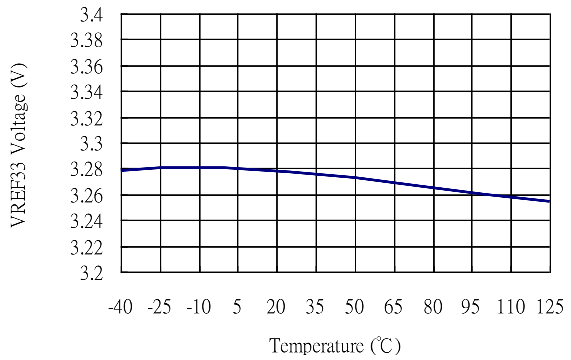



Fig. 3 VREF33 Voltage vs. Temperature

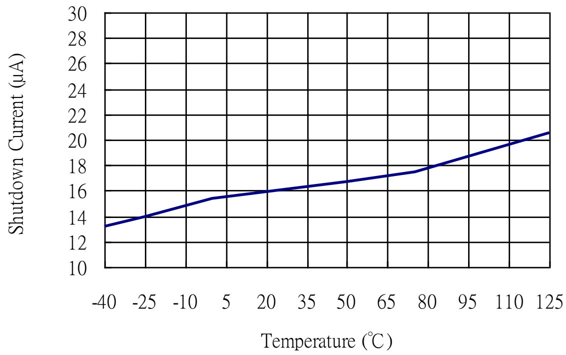



Fig. 4 Shutdown Current vs. Temperature

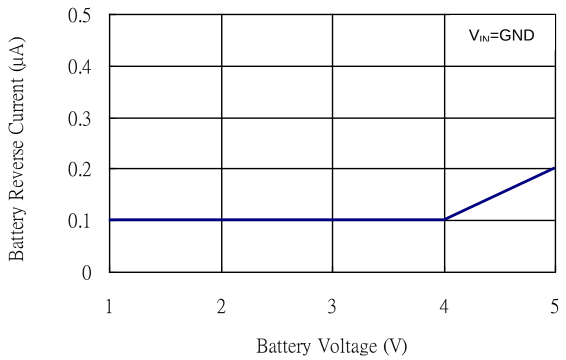



Fig. 5 Battery Reverse Current vs. Battery Voltage

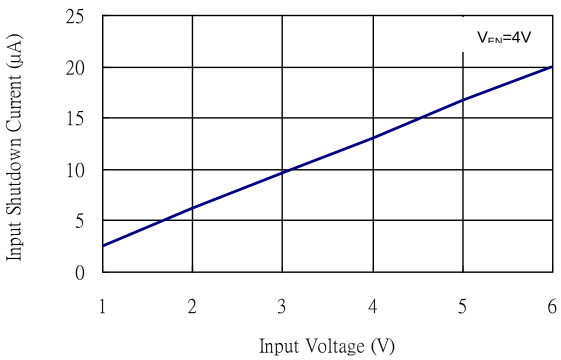



Fig. 6 Shutdown Current vs. Input Voltage

## TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

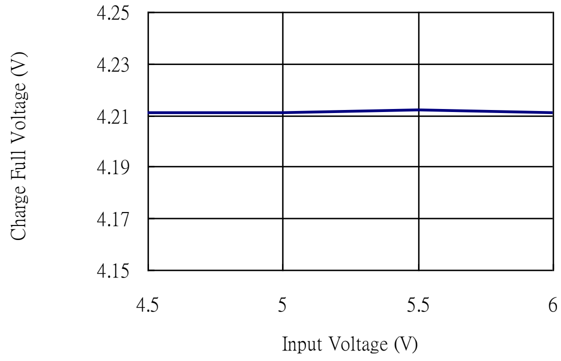



Fig. 7 Charge Full Voltage vs. Input Voltage

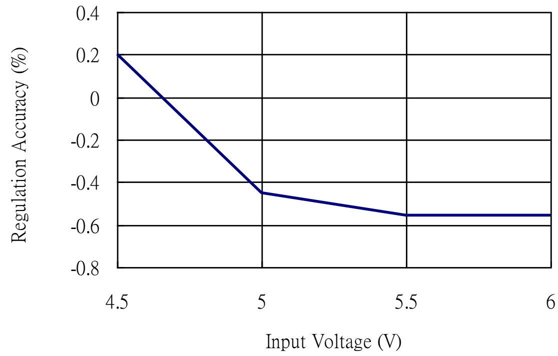



Fig. 8 Charge Current Accuracy vs. Input Voltage

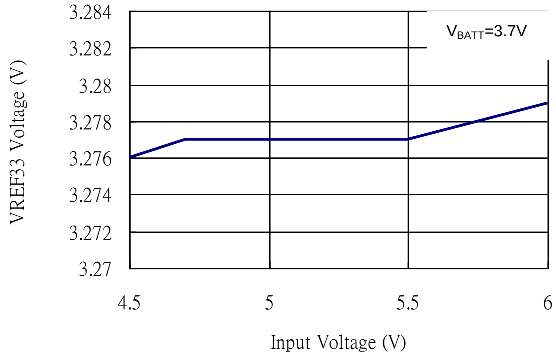



Fig. 9 VREF33 Voltage vs. Input Voltage

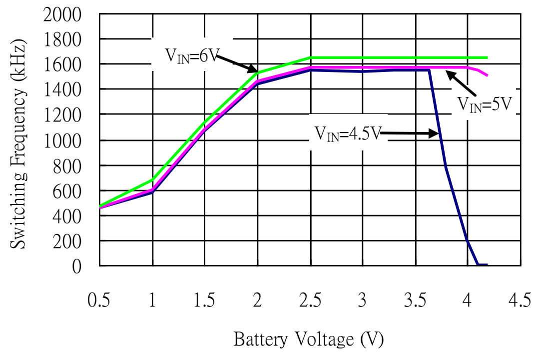



Fig. 10 Switching Frequency vs. Battery Voltage

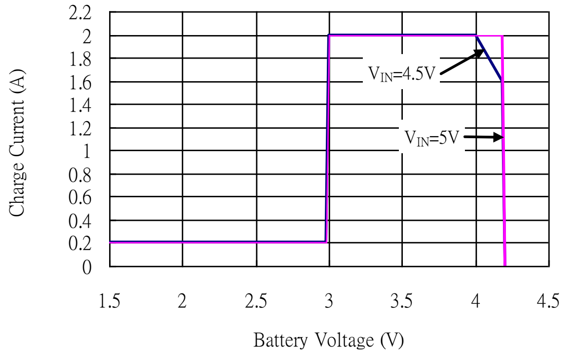



Fig. 11 Charge Current

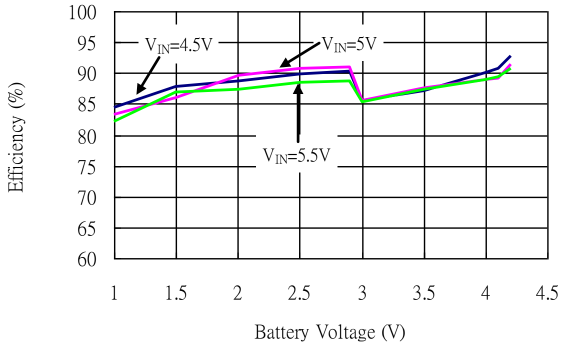



Fig. 12 Efficiency

## ■ TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

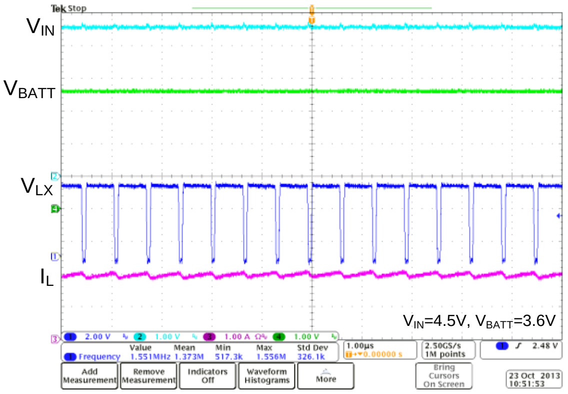



Fig. 13 Low Input Voltage Charge State

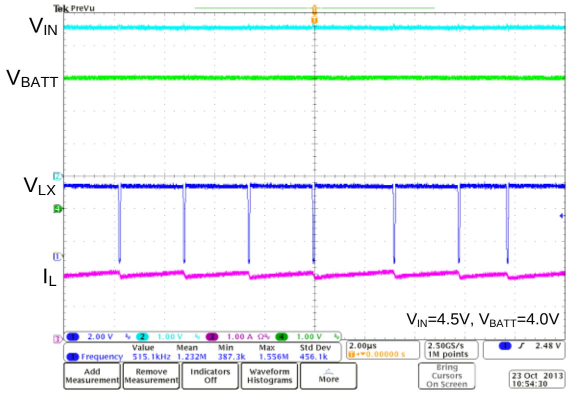



Fig. 14 Low Input Voltage Charge State

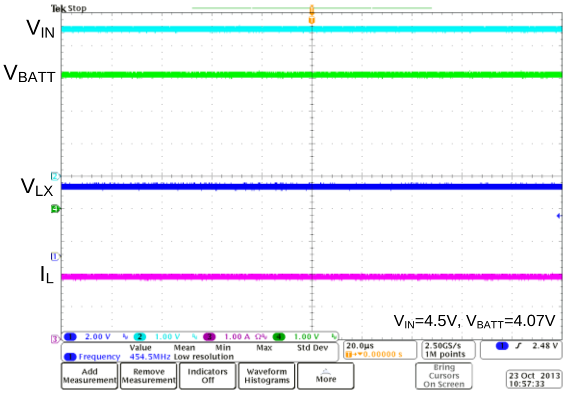



Fig. 15 Low Input Voltage Charge State

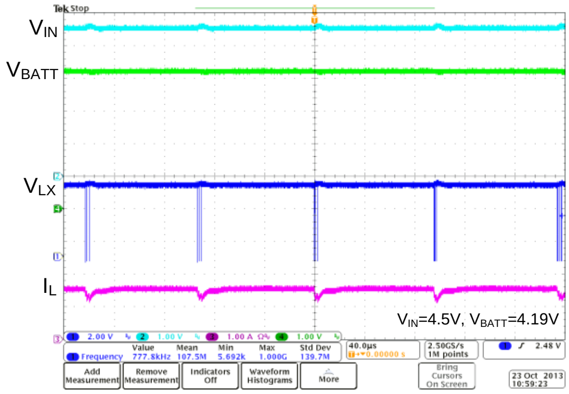



Fig. 16 Low Input Voltage Charge State

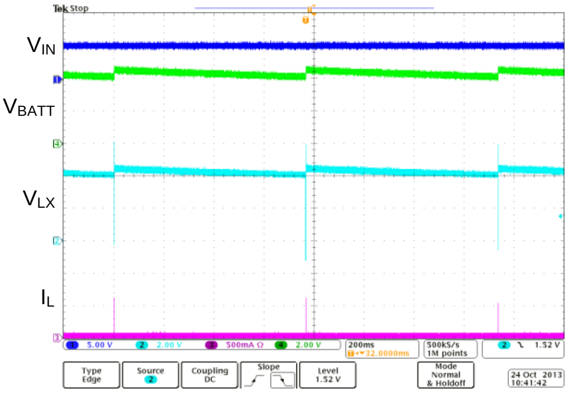



Fig. 17 BATT Float Waveform

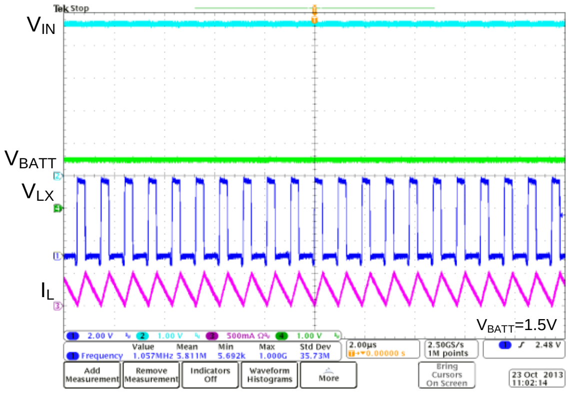



Fig. 18 TC Charge Steady State

## TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

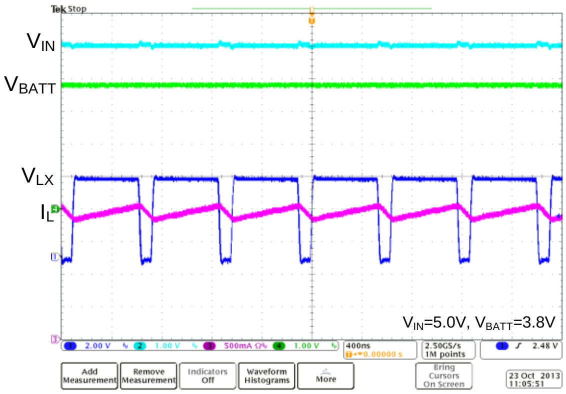



Fig. 19 CC Charge Steady State

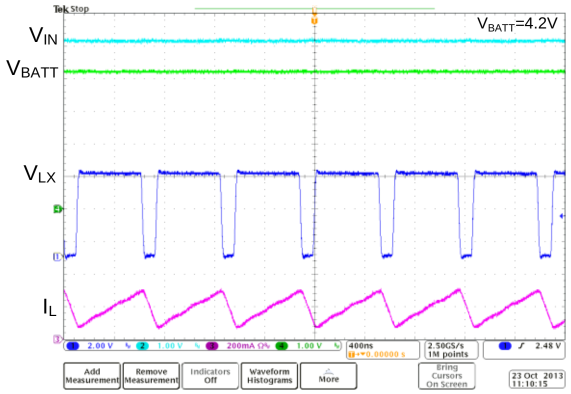



Fig. 20 CV Charge Steady State

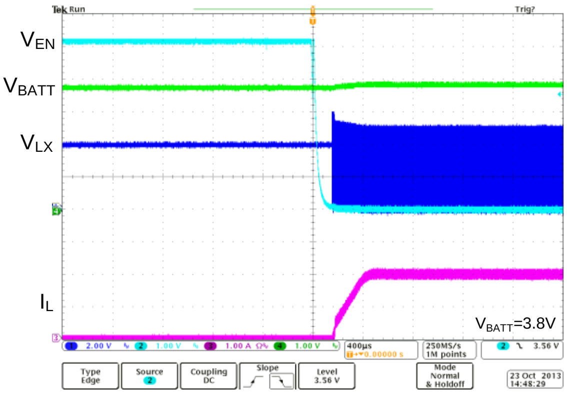



Fig. 21 Enable On

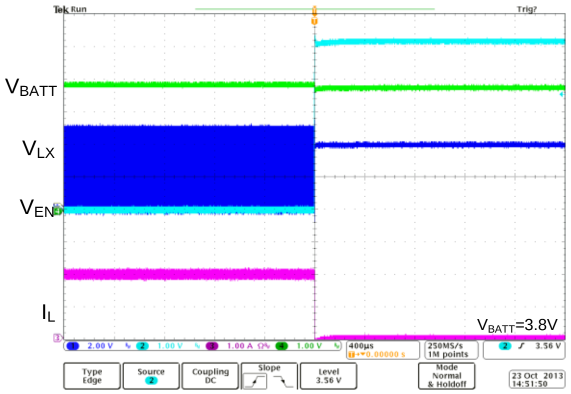



Fig. 22 Enable Off

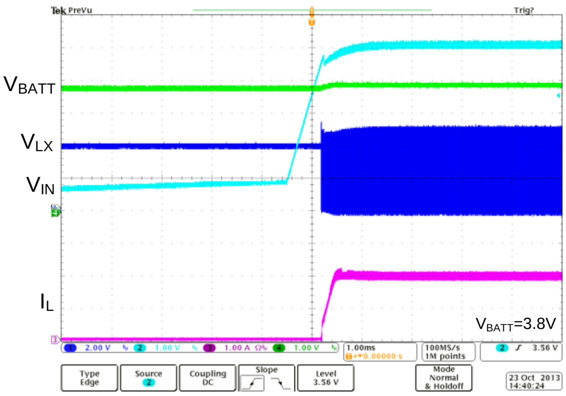



Fig. 23 Power On

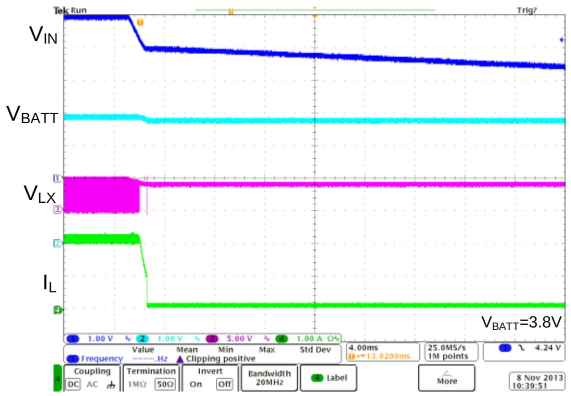



Fig. 24 Power Off

## TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

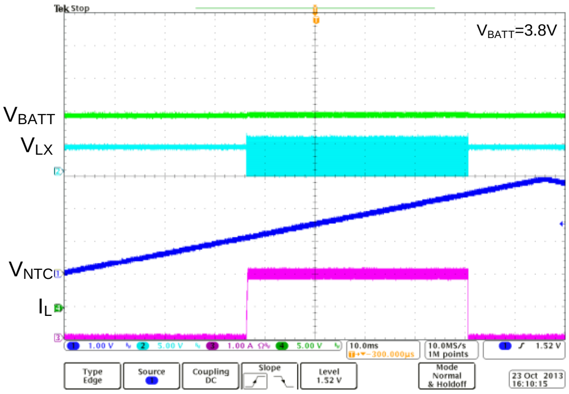



Fig. 25 NTC Control

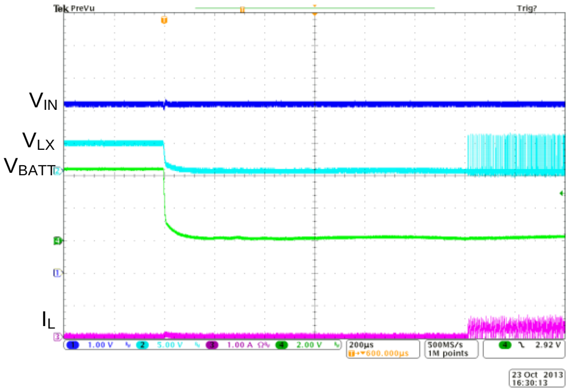
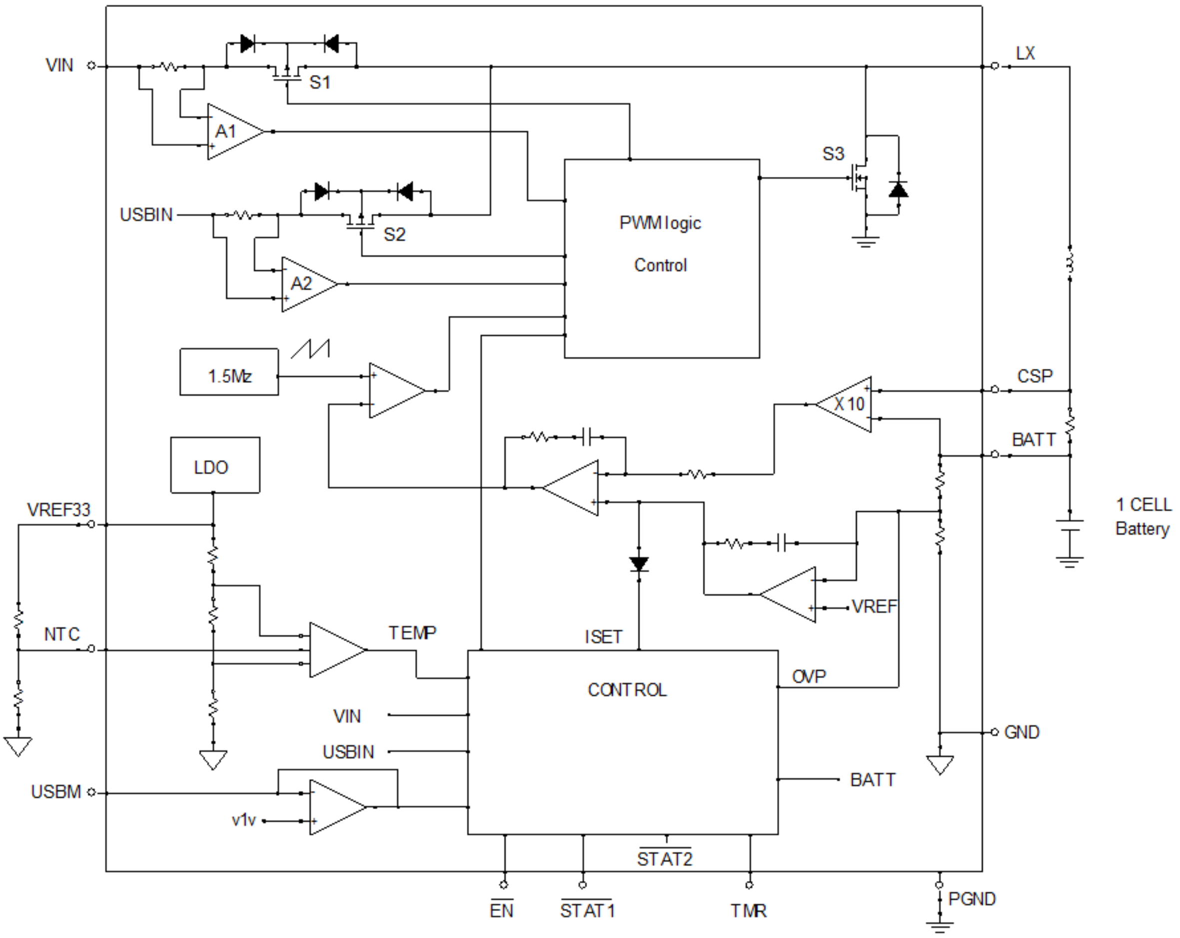



Fig. 26 Short-Circuit Protection

## BLOCK DIAGRAM




Functional Block Diagram of AIC6510

## PIN DESCRIPTIONS

| Pin Number | Pin name | Pin Function |
|---|---|---|
| 1 | VIN | Power Supply Input. Decouple this pin to PGND with a capacitor. |
| 2 | PGND | Power Ground. Connect this pin to the negative terminal of input capacitor and output capacitor. |
| 3 | LX | Internal Power MOSFET Switches Output. Connect this pin to the inductor. |
| 4 | USBM | USB Input Current-Limit Set. |
| 5 | VREF33 | Reference Voltage Output. |
| 6 | GND | Signal Ground. All small-signal components should connect to this ground, which in turn connects to PGND at one point. |
| 7 | BATT | Positive Battery Terminal. |
| 8 | CSP | Charge Current Sense Positive Terminal. |
| 9 | $\overline{\text{EN}}$ | Enable Pin. |
| 10 | $\overline{\text{STAT1}}$ | Charge Status Indicator: 1.Charging; 2. End of charge; 3. Charging Suspended; 4. Fault; 5. Invalid Input Supply. |
| 11 | NTC | Temperature Sense Input |
| 12 | TMR | Internal Safety Timer Set. |

## APPLICATION INFORMATIONS

The AIC6510 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 AIC6510 integrates an internal synchronous rectifier, which eliminates the external Schottky diode and increases efficiency. During normal operation, the AIC6510 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 AIC6510 smoothly transits to 100% duty cycle operation. This allows AIC6510 to regulate the charge current and battery voltage until AIC6510 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.

### Trickle Charge

Figure 28 is the typical charging profile. During a charge cycle, the AIC6510 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 AIC6510 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 AIC6510 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 AIC6510 monitors the battery voltage through the BATT pin. When the battery voltage rises to CV charge threshold, the AIC6510 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 AIC6510 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 AIC6510 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 AIC6510 can restart the charge action once the voltage on the BATT pin falls below the recharge threshold $V_{RECHG}$, as shown in Figure 29.

### Timer Fault Recovery

As shown in the figure 30, the AIC6510 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 AIC6510 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 27. The AIC6510 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 AIC6510 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.

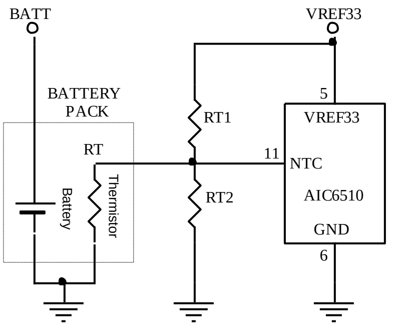



Fig. 27 Battery Temperature Sense Circuit

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 AIC6510 includes an under voltage lockout circuit, which monitors the input power source and keeps the charger in shutdown mode until VIN rises above the under voltage lockout threshold. In addition, in order to prevent battery drainage, the AIC6510 can enter sleep mode if the VIN falls below the sleep mode entry threshold.

## Short Circuit Protection

The AIC6510 provides battery short circuit protection function. While the battery voltage is lower than 1.5V, the AIC6510 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 AIC6510 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 Output

The AIC6510 provides one open-drained output: $\overline{\text{STAT1}}$. The $\overline{\text{STAT1}}$ can indicate the charging status of the charger, as shown in the following table. The status pin can be used to drive an LED or communicate to the host processor.

Table 1. Status Pin Summary

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

$$I_{CINRMS} \approx \sqrt{I_{CC(MAX)}^2 \times \frac{V_{BATT}\left(V_{IN}-V_{BATT}\right)}{V_{IN}^2} + \frac{\Delta I_L^2}{12}}$$

For most AIC6510 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 AIC6510, the following points should be managed comprehensively.

1. The input capacitors and VIN pin 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.

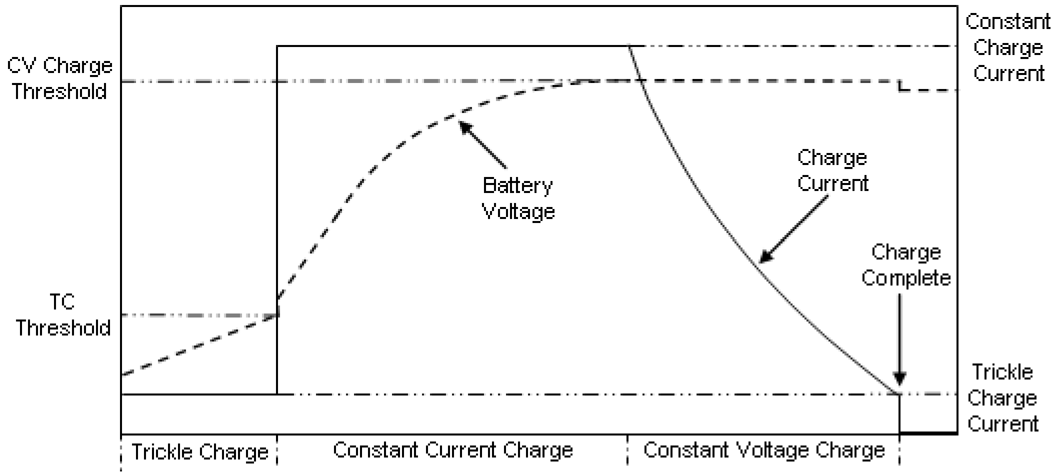



Fig. 28 Typical Charging Profile

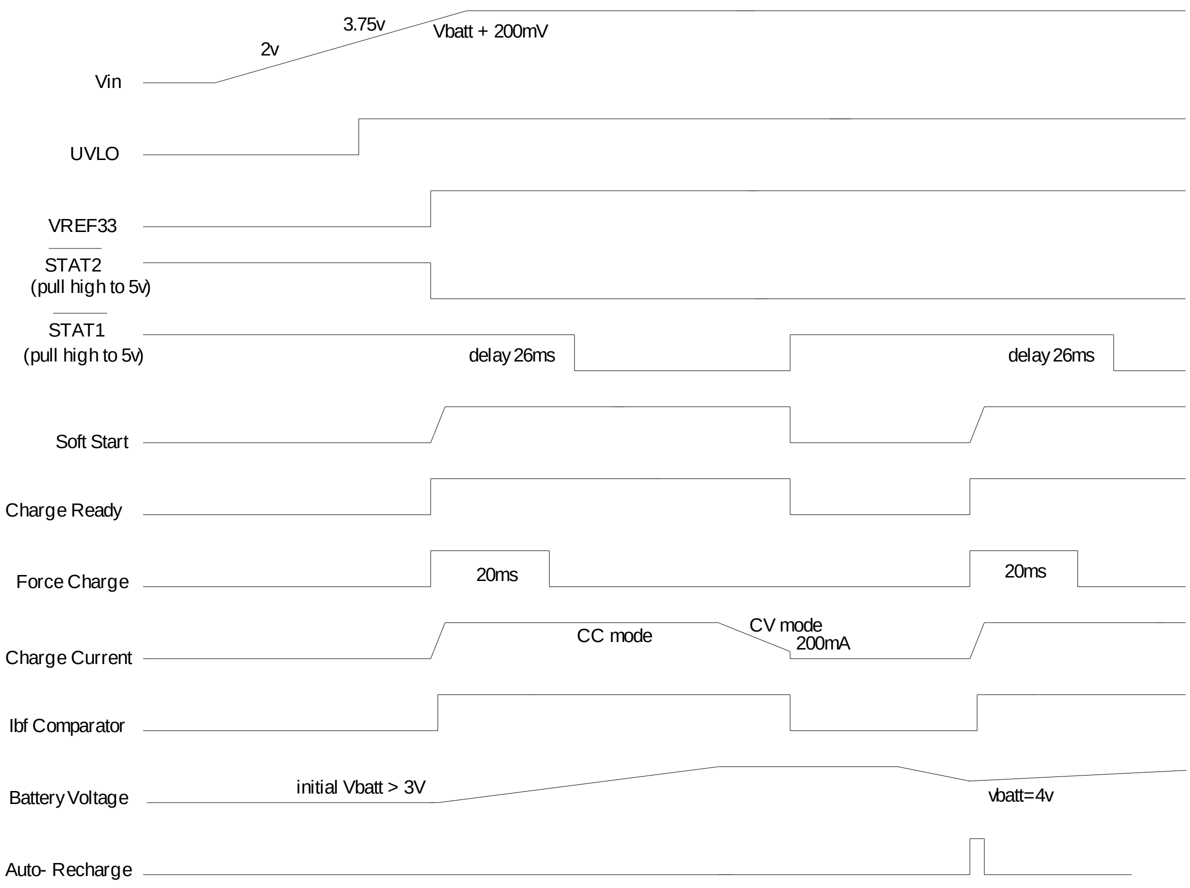



Fig. 29 Battery Charge Timing Diagram

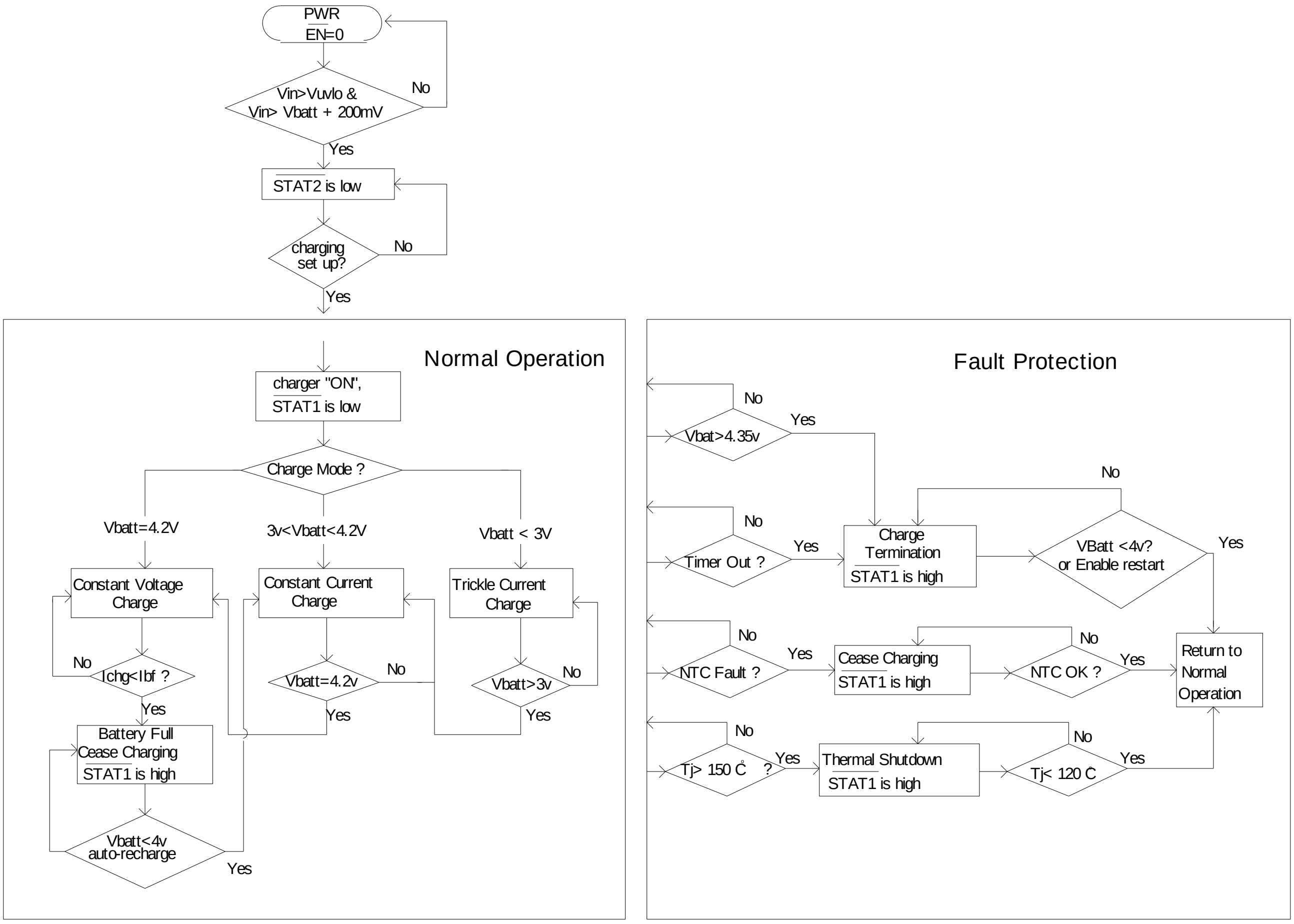
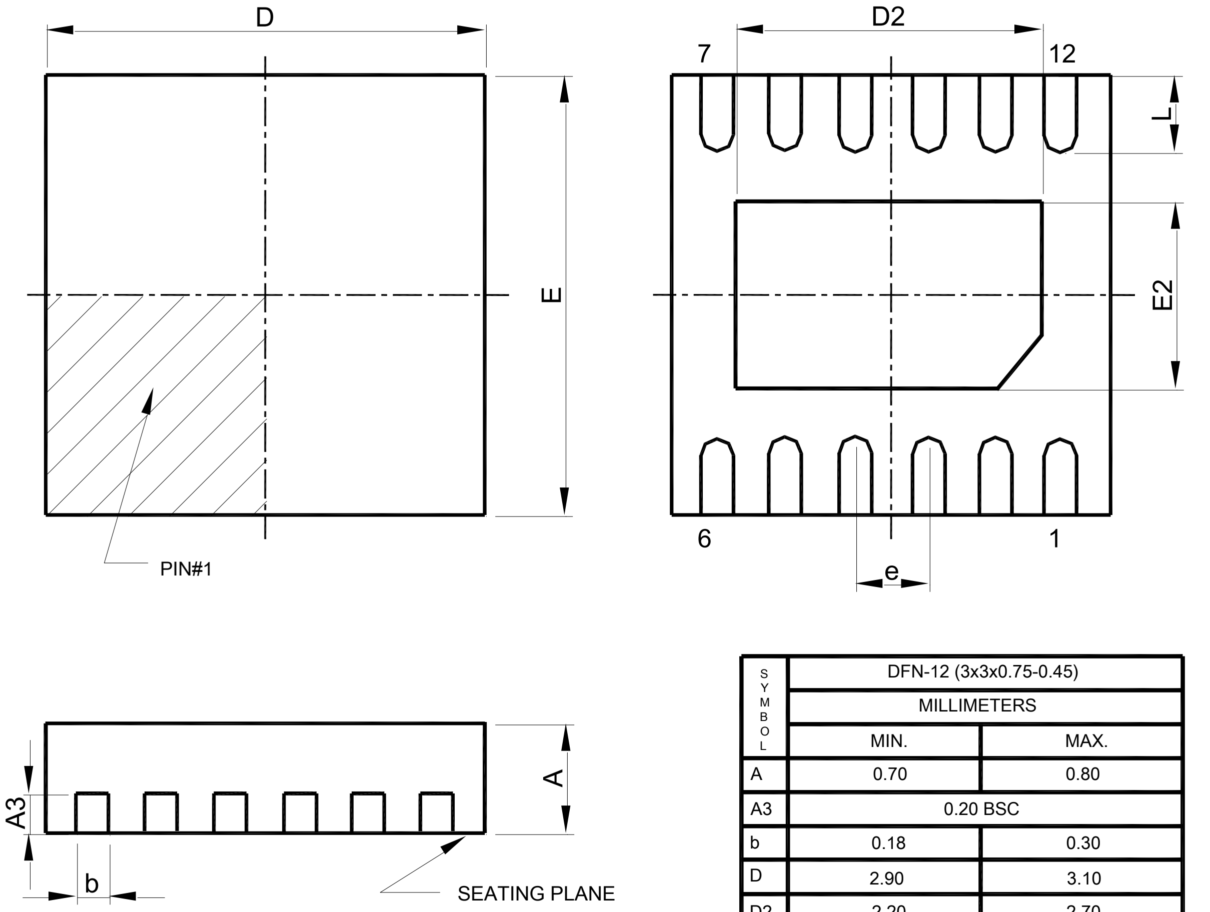



Fig. 30 Operation Flow Chart

## PHYSICAL DIMENSIONS

- **DFN-12 (3x3x0.75-0.45)**




| SYMBOL | DFN-12 (3x3x0.75-0.45) | |
|---|---|---|
| | MILLIMETERS | |
| | MIN. | MAX. |
| A | 0.70 | 0.80 |
| A3 | 0.20 BSC | |
| b | 0.18 | 0.30 |
| D | 2.90 | 3.10 |
| D2 | 2.20 | 2.70 |
| E | 2.90 | 3.10 |
| E2 | 1.40 | 1.80 |
| e | 0.45 BSC | |
| L | 0.30 | 0.50 |

Note : 1. DIMENSION AND TOLERANCING CONFORM TO ASME Y14.5M-1994.
2.CONTROLLING DIMENSIONS：MILLIMETER，CONVERTED INCH DIMENSION ARE NOT NECESSARILY EXACT.