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AN-9721

Li-Ion Battery Charging Basics, Featuring the FAN5400 / FAN5420 Family of PWM Battery Chargers

Overview

Today's cell phones and other handheld devices provide ever increasing functionality and a richer user experience. As their functionality increases, the demand for battery power increases as well, which leads to adoption of higher-capacity batteries. These higher-capacity batteries require high-current charging solutions, which can best be served with efficient PWM chargers.

Lithium-Ion battery charging is simplified with modern IC charging solutions. This application note provides a guide for how to use the FAN5400 and FAN5420 family of PWM chargers for high-current, fast-charging solutions to minimize the charging time while providing full compliance to modern battery safety specifications.

Lithium-Ion Battery Charging Basics

A Li-Ion battery charger must provide a constant current to the battery until the battery voltage has reached its "float" voltage. The battery can be thought of as a very large capacitor in series with a small resistance that represents its ESR (equivalent series resistance). Inside every battery pack is a protection IC, which features two back-to-back MOSFETs and an analog control circuit that prevents overcharging and over-discharging by monitoring the cell voltage and discharge current. The protection circuit is referred to as "secondary protection" because the charging system must also ensure that the battery is not overcharged. The protection circuit provides a back-up safety circuit where overcharging is concerned.

Note:

- For functional clarity, Q1 and Q2 are shown as PMOS MOSFETs in series with the positive leg in Figure 1. Most protection circuits use NMOS MOSFETs in the return leg instead for lower cost.

The protection circuit's resistance should be considered to be part of the battery's total ESR.

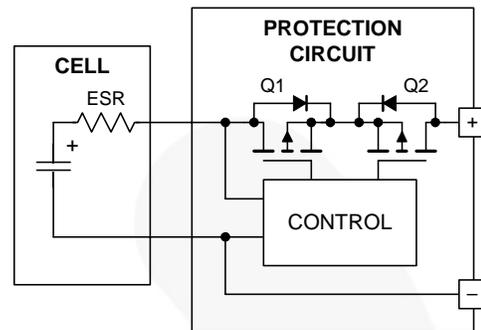


Figure 1. Li-Ion Battery Pack

During charging, assuming the battery was not too deeply discharged, a constant current I_{CHARGE} is provided until the battery's voltage has risen to V_{FLOAT} . The maximum float voltage is typically specified by the battery manufacturer and is programmed into the charger IC through the OREG register setting.

When V_{BAT} , the voltage at the battery terminals, reaches V_{FLOAT} , I_{CHARGE} is limited by the cell voltage, V_{CELL} :

$$I_{CHARGE} = \frac{V_{BAT} - V_{CELL}}{R_{ESR}} \quad (1)$$

As the internal cell voltage rises to approach V_{BAT} , the charge current continues to decrease until it reaches a termination current, which is commonly set for 10% of the full charge current.

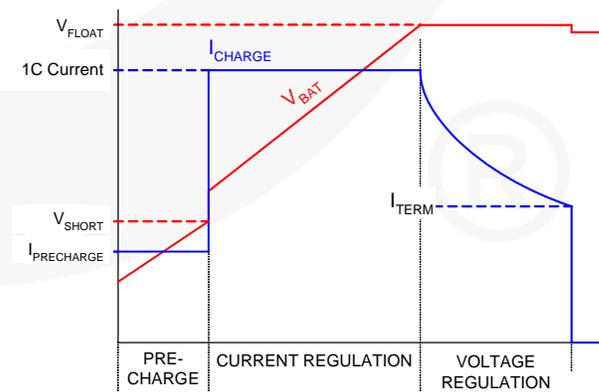


Figure 2. Li-Ion Charge Profile

Once the termination current is set (assuming charge termination has been enabled by setting the TE bit), the charger IC stops charging and waits for V_{BAT} to discharge to a recharge threshold. For the FAN540x family, this threshold is 120mV below the OREG setting.

Deeply Discharged Cells

Q2 in the protection circuit is open if the cell was deeply discharged ($V_{CELL} < 2.7V$). Charging is therefore still possible by driving current into the pack through Q2's body diode. When FAN540X determines that $V_{BAT} < 2.0V$, it uses a 30mA linear current source to charge the battery beyond 2.0V before applying the full I_{CHARGE} in PWM mode.

Avoid Over-Voltage

JEITA¹ standards require that the battery voltage not exceed 4.25V. While battery manufacturers may suggest that the cell should be charged to 4.20V, the charging IC's tolerance should be taken into account. With a V_{OREG} tolerance over temperature of $\pm 1\%$ (42mV), a setting of 4.20V would produce a worst-case V_{FLOAT} of 4.242V. This allows no room for temporary excursions above the OREG setting, which can occur during large system load transient events, such as a GSM pulse release.

When charging a battery that's already in CV (constant voltage) charge with a high current, a 2A GSM pulse loads the battery and drives V_{BAT} down by about 500mV. This causes the charger IC to change from CV to CC (constant current) control, providing about 1.2A of current at the highest setting (FAN540x). When the GSM pulse stops, the full 1.2A current flows into the battery briefly while the IC senses that V_{BAT} is rising and attempts to return to CV mode. Some overshoot can occur (about 50mV, worst-case) while the CV voltage loop regains control.

Without software mitigation, this overshoot should be subtracted from 4.25V to determine the maximum V_{FLOAT} voltage. The overshoot can, however, be mitigated in software, which is discussed later in this document.

System Startup

Typically, systems run from the battery. If the battery is missing or deeply discharged, the charger needs to be able to automatically and safely bring V_{BAT} up to a point where the system processor can wake up and manage battery charging. The FAN5403 and FAN5405 feature automatic charging.

When a charger is connected and a battery is present, the FAN5403 begins charging the battery without processor intervention with its default V_{FLOAT} of 3.54V for t_{15MIN} (nominally 12 minutes, 15 minutes maximum). If there is no battery when V_{BUS} first becomes valid, the FAN5403 detects

the battery's absence and shuts down, preventing the system from running without a battery. This is useful when the system does not have another method of determining battery absence, since the charger typically cannot support GSM pulses or other high-load current events without a battery.

Running without a Battery

The FAN5402 and FAN5405 continue charging after V_{BUS} POR with the default parameters, regulating the VBAT line to 3.54V until the host processor issues commands or the 15 minute timer expires. In this way, the FAN5402/05 can start the system without a battery.

The FAN5400 family's soft-start function can interfere with the system supply with battery absent. The soft-start activates whenever VOREG, IINLIM, or IOCHARGE are set from a lower to higher value. During soft-start, the I_{IN} limit drops to 100mA for about 1ms, unless I_{INLIM} is set to 11 (no limit). This could cause the system processor to fail to start. To avoid this behavior, use the following sequence:

1. Set the OTG pin HIGH. When VBUS is plugged in, I_{INLIM} is set to 500mA until the system processor powers up and can set parameters through I²C.
2. Program the Safety Register
3. Set I_{INLIM} to 11 (No Limit).
4. Set OREG to the desired value (typically 4.18).
5. Reset the IOLEVEL bit, then set IOCHARGE.
6. Set I_{INLIM} to 500mA if a USB source is connected or any other level that is preferred.

During the initial system startup, while the charger IC is being programmed, the system current is limited to 340mA for 1ms during steps 4 and 5. This is the value of the soft-start I_{CHARGE} current used when I_{INLIM} is set to No Limit.

If the system powers up without a battery present, the CV bit should be set. When a battery is inserted, the CV bit clears.

Programming Charge Parameters

The following recommendations are for general guidance only. For the correct charge parameter values, refer to the manufacturer's recommended charging conditions for the specific battery in use.

For the settings below, R_{SENSE} is assumed to be 68m Ω .

Watchdog Timer

Once the processor has powered up, charging continues under processor control. As soon as the processor writes to I²C, the t_{32S} timer (minimum of 18 seconds) begins counting. If t_{32S} expires without being reset, all registers reset and charging continues with default settings in t_{15MIN} mode. The processor should write a 1 to the TMR_RST bit at least every 15 seconds.

¹ A Guide to the Safe Use of Secondary Lithium Ion Batteries in Notebook-type Personal Computers, Japan Electronics and Information Technology Industries Association and Battery Association of Japan, April 20, 2007.

Safety First

The first register that should be programmed after the processor wakes up is the SAFETY register. The SAFETY register can only be programmed after either:

- Power is first applied to the IC by plugging in a battery with sufficient charge to run the processor

or

- V_{BUS} is plugged in, a battery is in place, and no I^2C writes occurred before writing to the SAFETY register.

If the battery is removed during charging with the TE bit set, the SAFETY register is continually reset every two seconds. Once a battery is inserted, the SAFETY register should be the first register programmed.

Input Power Source

The amount of power that can be drawn from a USB source is determined after a negotiation with the USB equipment. Until that negotiation takes place, 100mA is the maximum current allowed. The OTG pin allows the USB transceiver to set the maximum current during unattended charging. When OTG is HIGH, the input power source is limited to 500mA during unattended charging. When OTG is LOW, the FAN540X limits its input current to 100mA.

After the processor takes control, it can determine whether the power source is USB or a dedicated charger (“wall wart”). Typically the charger can supply more current than the 500mA allowed by USB. Set the $I_{INLIMIT}$ bits based on the connected power source:

Table 1. Input Current Limit

Power Source	$I_{INLIMIT}$	
USB 1.0	00	100mA
USB 2.0	01	500mA
USB 3.0 ⁽²⁾	10	800mA
Wall Wart	11	No Limit

Note:

2. The USB 3.0 maximum available configured current is 900mA.

Some wall warts have limited power. The processor is typically unable to determine this until after charging starts. If the wall wart is unable to support the charging current, V_{BUS} begins to drop. The special charger loop scales back the charging current to prevent V_{BUS} from dropping lower than 4.53V, which draws as much current as the wall-wart is capable of producing, if required.

The processor can determine if special charger loop is active by reading the SP bit.

Programming the Float Voltage (OREG)

Program V_{FLOAT} by setting OREG, following the battery manufacturer’s recommended maximum float voltage, but subtracting 40mV for the charger IC’s OREG tolerance. Ensure that the overshoot does not exceed the 4.25V level specified in the JEITA standard. Typically, programming OREG to 4.16V should suffice.

Setting the Charge Current (I_{CHARGE})

Most battery manufacturers recommend the battery be charged at a rate not to exceed 1C. For example, an 800mA-Hr battery can be charged with up to 800mA of current, which allows it to charge in about one hour.

The FAN540X limits the charging current for unattended charging to 340mA (23.1mV across R_{SENSE}). To achieve the desired charge current, set IOCHARGE (Reg4[6:4]) for the desired charging current, then reset the IO_LEVEL bit (Reg5[4]).

Termination Settings

The termination current is typically set for ~10% of the charge current. If the system load is connected at VBAT, nominal system load current should be added to the battery termination current. If the TE bit is set, when the voltage across R_{SENSE} remains below the ITERM setting for 32ms, charging stops. For example, with an 800mA-Hr battery and a 200mA maximum system load, ITERM should be set for 300mA.

Preventing Charging at Temperature Extremes

The JEITA specification prohibits charging below a minimum temperature (typically 0°C) and above a maximum temperature (typically 60°C). Full current and rated V_{FLOAT} charging is only allowed inside an even more narrow range (typically above +10°C and below 45°C). The allowable temperature, V_{FLOAT} , and charge currents should be specified by the battery manufacturer.

The FAN540X IC’s can automatically charge when V_{BUS} comes up. The default charge current is limited to 340mA and default V_{FLOAT} is limited to 3.54V, which is within the boundaries of the reduced I_{CHARGE} and V_{FLOAT} for batteries that are inside the wider temperature range of 0°C to 60°C.

If the battery temperature is outside the 0°C to 60°C, charging can be inhibited by using the DISABLE pin with a low-cost temperature switch IC.

The temperature sensing IC can be powered from either PMID (which is protected from high-voltage excursions) or from V_{REG} , if the IC can run from a 1.8V supply.

[Seiko Instrument's](#) S-5842ADAAQ-I6T1G temperature sensor provides a logic 1 on its open-drain DETL pin which, when connected to the FAN54xx's DISABLE pin with a pull-up resistor to VREG, inhibits charging when outside the allowable temperature range.

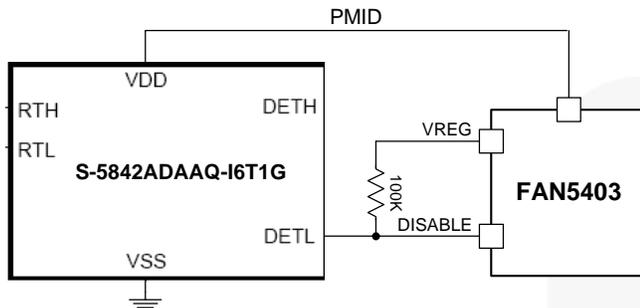


Figure 3. Temperature Limit IC Inhibits Charging Below 0°C and Above 60°C

If a thermistor is provided inside the battery pack, the circuit in Figure 4 raises the DISABLE when battery temperature is outside the 0°C to 60°C.

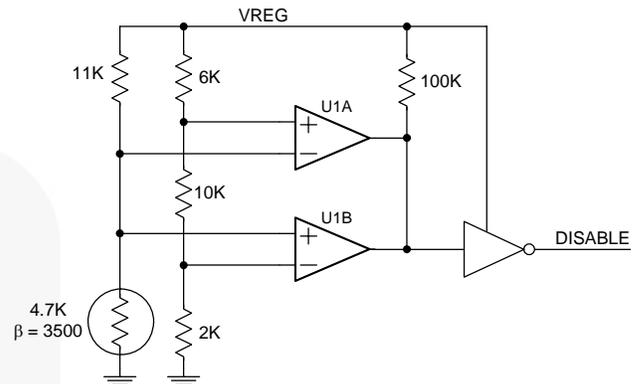


Figure 4. Disabling Charge at Temperature Extremes Using a Thermistor

Some battery vendors allow some charging outside the JEITA-recommended temperature range if charge current, time, and voltage are restricted. Consult the battery vendor for safe charging recommendations.

Related Datasheets

[FAN5400 Family](#)

[FAN5420 Family](#)

S-5842A series datasheet, Seiko Instruments: <http://www.sii-ic.com>

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