Keywords: charger, lithium-ion, li+, battery

APPLICATION NOTE 3841

Improving Accuracy of the MAX1737 Lithium-Ion Battery Charger

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Jun 23, 2006

Abstract: This application note describes how to improve full-scale current-sense and charge-termination accuracy of the MAX1737 lithium-ion (Li+) battery charger. The MAX1737 current-sense is more accurate than stated in the data sheet, but different calculations are needed to realize the improvement. Examples are shown in the article.

Introduction

The current-sense on the MAX1737 **is more accurate than stated in the data sheet**. The data-sheet limits represent 6-sigma numbers and are very conservative. Sample test data suggests approximately a 4-sigma limit. The current-sense parameters that can be improved are the battery full-scale current, input full-scale current, and the full-charge termination threshold. These parameters are explained below, with new equations where needed.

CS-to-BATT Full-Scale Current Sense: 200mV ±4mV

Most of this error is offset error. Consequently, the ±4mV error remains constant as the CS voltage is reduced. The CS resistor value can be reduced as long as a 5mV error in the full-scale current-sense voltage is acceptable. The full-scale current error is $5mV/R_{CS}$.

CSSP-to-CSSN Full-Scale Current-Sense Voltage: 105mV ±4mV

The input current-sense error is the same as the battery-sense error, and is more accurate than the data-sheet spec. However, there are some filtering and noise-related errors at the CSSP and CSSN inputs because the current is not DC at this point. Because of these noise-related errors, **for best accuracy set the input current sense about 2% lower than the target**. The noise-related errors depend on input voltage, inductor, capacitors, but are repeatable from unit to unit. Once the board is designed, ISETIN or the input current-sense resistor (R12) can be slightly adjusted to remove the noise error. All later units will have the same input current setting.

Full-Charge Termination Threshold

The MAX1737's full-charge termination detector works differently from the full-scale current sense. **The full-charge termination threshold voltage does NOT change when ISETOUT is changed. It is only a function of R_{CS}.** So if the CS-to-BATT current-sense resistor is lowered from 0.1Ω to 0.05Ω, and ISETOUT is set to 0.5 REF (to maintain the same fast-charge current, but with a lower R_{CS}), the full-charge termination current increases. However, it may not double because the MAX1737 senses the peak inductor current for this function and not the average battery current (see **Figure 1**).
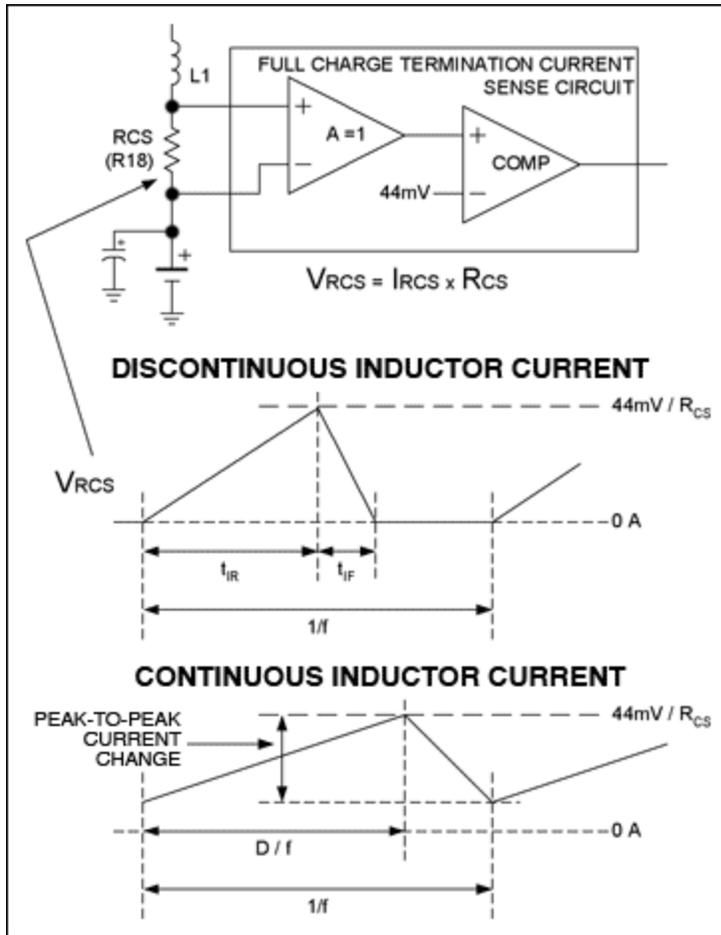
Figure 1. Full-charge termination detection circuit and inductor current waveforms. Full charge is indicated when peak inductor current falls below 44mV/R_{CS}. The battery charging current that corresponds to this peak current is a function of inductor value and input voltage, and can be calculated as described in the text.

The data-sheet spec for the BATT charge current full-charge termination threshold is 44mV +11mV/-10mV. This is a very conservative specification. A reliable limit can be 44mV ±4mV. But this threshold senses when the **peak** inductor current (not average DC charging current) falls below this point. With a 0.1Ω R_{CS}, the peak inductor current must fall to 440mA to reach the threshold. At low current in voltage mode, the average charging current is much less than the 440mA peak inductor current, but can be calculated as shown in the ***Calculating Full-Charge Termination Threshold*** section below.

If the current-sense resistor is lowered to 0.05Ω, the full-charge termination threshold is still 44mV (and does not change with ISETOUT). The inductor peak current must then fall below 880mA to trigger the comparator. This means that the average current that trips the full-charge termination threshold will be higher with 0.05Ω than with 0.1Ω, even if ISETOUT is used to set the same 2A fast-charge current in both cases.

The ratio between the peak inductor current and the average charge current depends on the inductor value, output voltage, and input voltage. Fortunately, the input voltage is usually a regulated supply and is known. The output voltage is also known because the charger is in voltage mode when the full-charge termination occurs, so it will be 4.2V times the number of cells. Since the inductor value is also fixed, **the full-charge termination threshold will be quite consistent from board to board**.

Note: *the term "BATT charge current full-charge termination threshold" used in the MAX1737 data sheet is somewhat misleading* because charging does not actually stop when the battery current falls to this level. The FULLCHG-bar and FASTCHG-bar are both high in this state, indicating that the battery is full (see **Figure 2**), but charging still continues in top-off mode until the top-off timer times out.
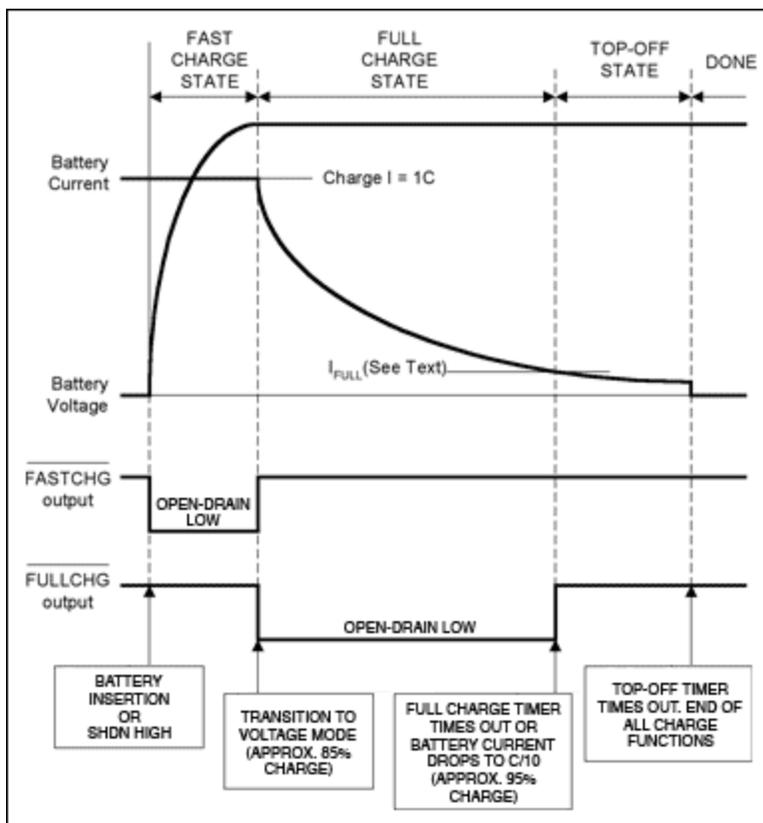
Figure 2. Charge state and indicator timing for a typical charging sequence. Full battery is indicated when FULLCHG-bar goes high with FASTCHG-bar already high. This occurs when battery charging current falls to I_{FULL}, as described in the text.

Calculating the Full-Charge Termination Threshold

The "BATT charge current full-charge termination threshold" is triggered when peak inductor current falls

to:

$$I_{PKTERM} = 44mV/R_{CS}$$

Note again that I_{PKTERM} is only a function of R_{CS} and does not change with ISETOUT.

The battery current, I_{FULL}, is the average value of the inductor current. I_{FULL} is a function of R_{CS}, input voltage (V_{IN}), battery voltage (V_{BATT}), and inductor value (L). It can be calculated as follows for the two cases where inductor current is discontinuous ($I_{>FULL(DISC)}$) or continuous ($I_{FULL(CONT)}$).

Most MAX1737 charger designs have discontinuous inductor current near the end of charging when the battery current is small. Assuming discontinuous current, the average current is:

$$I_{FULL(DISC)} = I_{PKTERM} (t_{IU} + t_{ID})/2 \ t_{PER}$$

Where $I_{PKTERM} = 44mV/R_{CS}$, t_{PER} is the period of the switching frequency (1/300kHz = 3.33µs), and t_{IU} and t_{ID} are the inductor-current ramp-up and ramp-downtimes. These are:

$$t_{IU} = I_{PKTERM} \ L/(V_{IN} - V_{BATT})$$

$$t_{ID} = I_{PKTERM} \ L/(V_{BATT})$$

Since the charger is in voltage mode when calculating I_{FULL}, V_{BATT} is the lithium-ion (Li+) termination voltage (usually 4.2V per cell).

As an example, when charging a 2-cell Li+ battery from a 12V input with $R_{CS} = 0.1\Omega$ and L = 10µH:

$$t_{IU} = 0.44 \times 10 \times 10^{-6}/(12 - 8.4) = 1.22µs$$

$$t_{ID} = 0.44 \times 10 \times 10^{-6}/(8.4) = 0.52µs$$

$$I_{FULL(DISC)} = 0.44 \times 1.74µs/(2 \times 3.33µs) = 115mA$$

If $((t_{IU} + t_{ID})/t_P)$ is 1 or greater, this indicates that the inductor is still continuous when its peak current is I_{PKTERM}. This can occur with larger inductor values. The battery charging current is then:

$$I_{FULL(CONT)} = I_{PKTERM} - \text{half of the peak-to-peak inductor current change} = I_{PKTERM} - [(V_{IN} - V_{BATT}) \ D \ t_{PER}/(2L)]$$

Where D is the switch duty factor, which for a step-down switching regulator is V_{OUT}/V_{IN}, or for the MAX1737, $D = V_{BATT}/V_{IN}$.

If 22µH is used instead of 10µH in the above example, you get:

$$t_{IU} = 2.69µs \text{ and } t_{ID} = 1.15µs, \text{ so } (t_{IU} + t_{ID})/t_P = 1.16µs, \text{ indicating continuous current.}$$

The charge current is then:

$I_{FULL(CONT)}$ = 0.44 - [(12 - 8.4) (8.4/12) 3.33µs/(2 × 22µH)] = 249mA

Related Parts		
MAX1737	Stand-Alone Switch-Mode Lithium-Ion Battery-Charger Controller	Free Samples

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