Application Report
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Li-Ion Battery Charger solution using the MSP430

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ABSTRACT

Rechargeable batteries are now widely used as the power supply source in many portable electronic equipments such as Laptops, cell phones and digital cameras. Charging circuits depend on the batterys chemistry and the most popular rechargeable batteries are Nickel-Cadmium (NiCd), Nickel-Metal-Hydride (NiMH), and Lithium-Ion (Li-Ion). This application report discusses the method to charge a Li-Ion battery using the MSP430 microcontroller.

1 Introduction

Li-Ion is rapidly becoming the chemistry of choice for portable applications because of its high capacity-to-size ratio and a low self discharge characteristic. There are a variety of battery charging solutions such as power management ICs, MCU controlled or even logic devices. The MCU controlled charging method offers its advantage as a safe charging, time efficient and low cost solution.

Battery capacity, C, expressed in mA hours, is a measure of battery life between charges. Battery current has the units of C-Rate. For example, a 500 mA-h battery has a C-Rate of 500mA. The current corresponding to 1C is 500 mA and for 0.1C is 50 mA.

A Li-Ion battery charging process consists of three stages:

- Slow Charge: Pre-charging stage using current of 0.1C
- Fast Charge: Constant current charging stage using current of 1C
- Constant voltage charging stage

During the slow charge stage, the battery is charged with a constant low charge current of 0.1C, if the battery voltage is below 2.5V. If some batteries like NiCd are recharged without fully discharging, they suffer from a phenomenon called memory effect, which causes a reduction in the battery capacity. Li-Ion batteries however do not suffer from memory effect and hence do not need to be fully discharged before recharging. The slow charge stage is rarely used during the charging process of a Li-Ion battery.

The fast charge (constant current) and constant voltage charging are the most important stages during a recharge process. Most Li-Ion batteries have a fully charged voltage of 4.1 or 4.2V. The battery is first charged with a constant current of 1C until a battery voltage reaches 4.1 or 4.2V. The firmware continuously checks the charging current by sensing the voltage at the current sense resistor (R_{sense}) and adjusts the duty cycle of PWM output from the MCU. The battery's voltage is checked frequently. Whenever found the battery's voltage reaches 4.1 or 4.2V, the charger will switch to constant voltage charging mode.

The battery is then charged with a constant voltage source at a fixed battery voltage of 4.1 or 4.2 V. The battery voltage is checked and maintained at 4.1V by controlling the duty cycle of the PWM output. During this process the charging current will start to fall due to internal cell resistance. When the charging current falls below 0.1C, the charging process must stop.

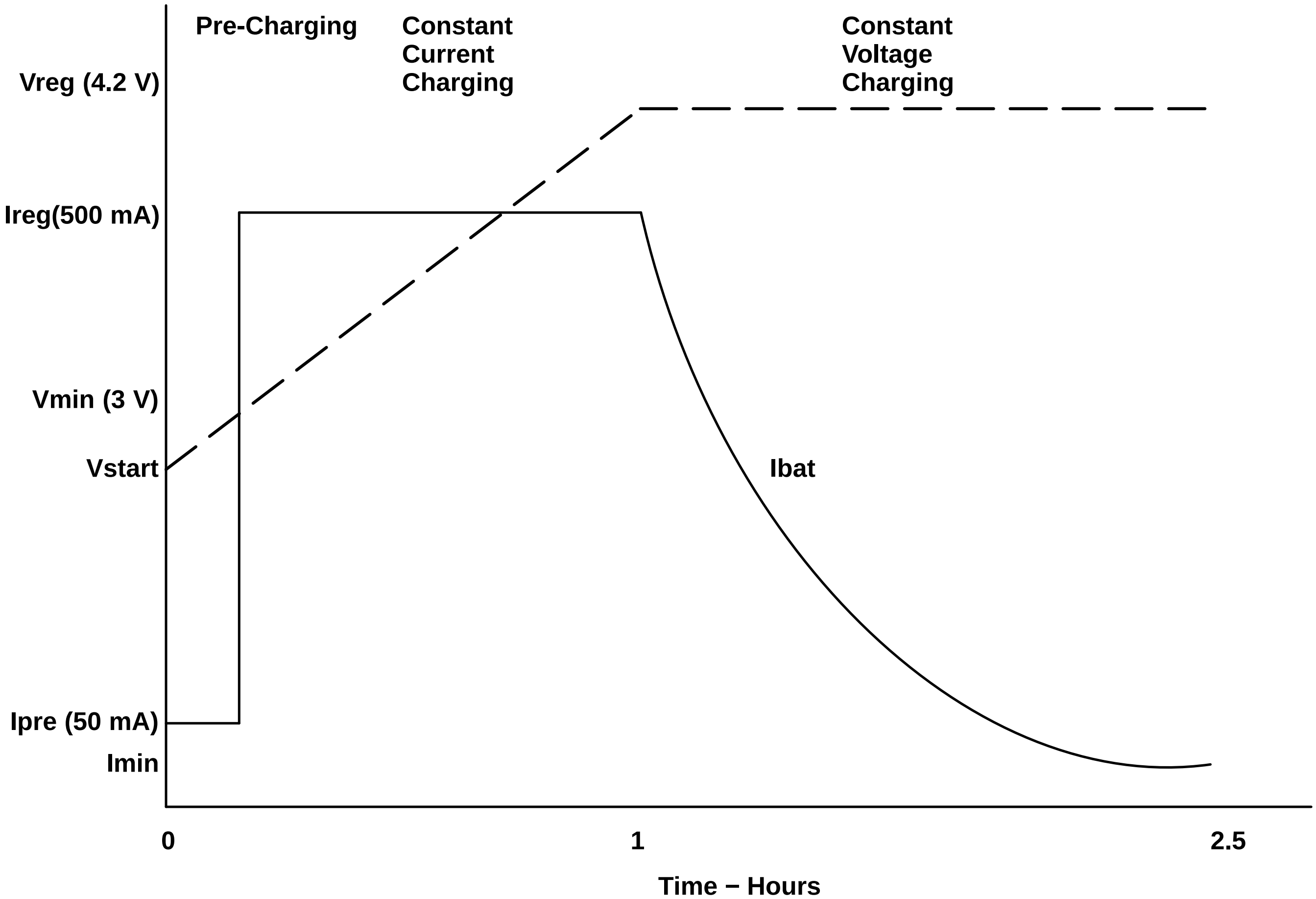

Figure 1. Current vs Voltage Curve for Li-Ion Battery Charging

When the battery is fully charged, most of the electrical energy is converted to thermal energy. Overcharging batteries can cause overheating, explosion due to outgassing of the electrolyte and severely reduce battery life. Li-Ion batteries are extremely sensitive to overcharging and hence it is critical that the final voltage be controlled to within ±50 mV of 4.1 or 4.2V. A battery charger design needs to be able to determine a fully charged battery to avoid overcharging. A few methods to determine a fully charged condition are:

- During the constant voltage charging stage, when the current drops to 0.1C, a fully charged condition is reached.
- Determine the battery temperature to avoid overheating
- Use a safe timing method: As long as the charging time is longer than a predetermined time, the battery can be considered as fully charged.

2 Measurement Circuit

A block level schematic of the charger is shown in Figure 2.

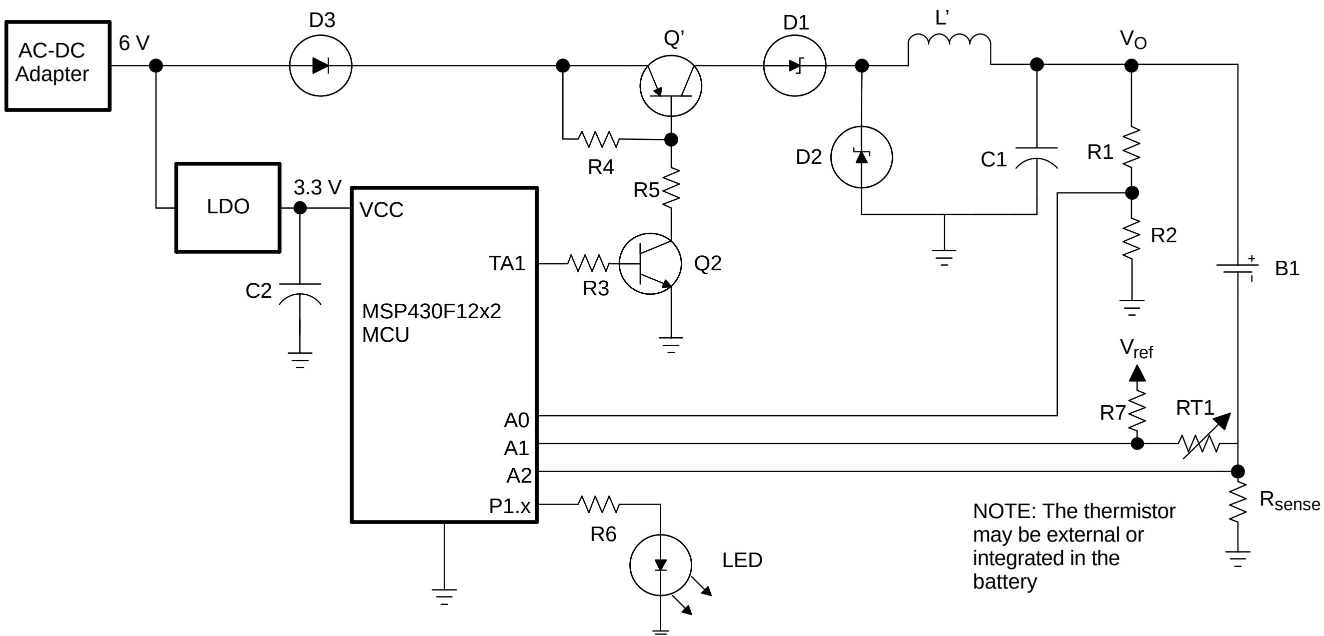

Figure 2. Block Level Schematic

A buck converter is used during the constant current and voltage charge stages. A buck converter is a step down voltage converter which uses the inductor as a current source to the output load impedance, which is the battery in this case. The PNP and NPN transistors form a switch that is controlled by a PWM signal. The Timer_A3 on the MSP430 can be used to control the current for charging the battery using the PWM feature. When this switch is on, current flows through the inductor and the capacitor is charged, as shown in Figure 3. When the switch is opened the inductor will try to maintain its current flow by inducing a voltage, because an inductor cannot have an instantaneous change in current. The current now flows through the diode and the inductor charges the capacitor, as shown in Figure 4. The LC network acts as a low-pass filter and if the PWM frequency is much higher than the cut-off frequency of the LC network, the capacitor voltage is constant and equal to the mean value of the input voltage to the buck converter.

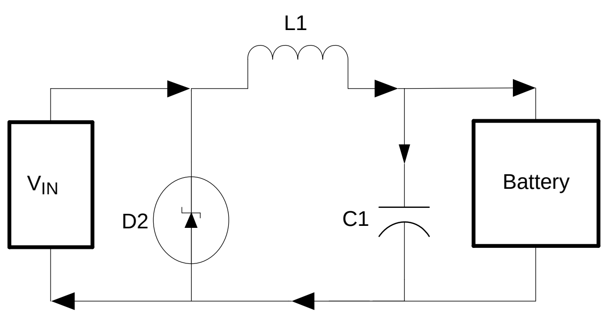

Figure 3. Buck Converter Switch On

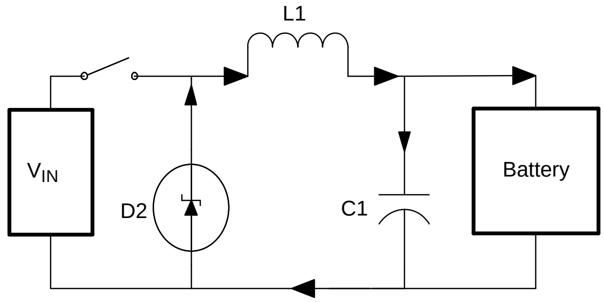

Figure 4. Buck Converter Switch Off

The value of the inductor can be calculated as follows:

$L = \text{Duty Cycle} \times T \times (V_I - V_{sat} - V_O) / 2I_O$

Duty Cycle = the duty cycle of the PWM

T = the period of the PWM

V_O = voltage output

V_{sat} = voltage loss on the switch

V_I = voltage input to the switch

I_O = current for constant current stage

Assuming V_I is 6V, V_{sat} is 0.5V, Io is 500mA, V_O is 4.575V, 1/T is 15 kHz, Duty cycle is 50%.

$V_O = V_{bat} + I_{bat} \times R_{sense} = 4.2 + 500mA \times 0.75 = 4.575V$

The inductor should be at least 62 µH. For this implementation a value of 75 µH is used. When the timer is clocked from the DCO whose frequency is set to 3.84 MHz, the TACCR0 value needs to be 255 to achieve a PWM frequency of 15 kHz (3.84 MHz/256). The timer runs in up mode and the timer output switches in toggle/set mode. The duty cycle of the timer output (TA1) can be controlled by adjusting the value of TACCR1. A PWM resolution of 8-bits is enough to control the constant current flow in the battery during the constant current charging stage and maintain a constant voltage on the battery during the constant voltage charging stage. If the capacitor is 220 µF and the inductor is 75 µH, the cutoff frequency of the LC network is 1.2 kHz ($1 \div (2 \times \pi \times (\sqrt{(L \times C)})))$, which is much lower than the PWM frequency. This helps the capacitor to effectively reduce the output voltage ripple and maintain a DC voltage level.

Three channels (A0, A1, A2) on the 10-bit A/D converter on the MSP430 can be used to monitor the battery voltage, battery temperature and battery current. 1 LSB is equal to $V_{ref}/(N - 1)$, where V_{ref} is the reference voltage and N is the resolution in bits of the A/D converter. With a 1.5V on chip reference, 1 LSB is 1.5/1023 =1.47 mV

The range of voltages that the ADC10 needs to detect can be calculated as follows:

The highest voltage, V_O, during the constant current charging stage is 4.575V. The voltage seen by the ADC10 input due to the voltage divider (R1 = 2.1 × R2) is 4.575/3.1 = 1.5V. This is within V_{ref} and hence can be resolved by the ADC10.

The smallest voltage that the ADC10 needs to detect is during the constant voltage stage to monitor the battery current and stop the charging process. ADC10 needs to detect the voltage drop created by a 0.1C current through the battery. In this case it is 50mA × 0.75 = 37.5 mV. This is about 25 LSB of resolution and can be resolved with the ADC10.

For this application, a thermistor (RT1) was connected to the negative pole of the battery. The thermistor resistance decreases with temperature and so does the thermistor voltage. The thermistor chosen is a 10 k part. The thermistor characteristics can be found at:

http://rocky.digikey.com/WebLib/BC%20Components/Web%20Data/2322%20640%205%20NTC%20Thermistors.pdf

An abnormally low voltage indicates overheating and the charging process must stop. This voltage can be detected by the ADC10 input.

3 Software

The software provided with this firmware is supported in both C and assembly languages (IAR and CCE). The software is divided into a main routine and two ISRs, which are explained as follows:

3.1 Main

This routine sets up DCO to run SMCLK at 3.84 MHz. The Timer_A3 registers are setup to output a PWM on TA1. The timer is also setup to trigger ADC10 conversions. The ADC10 is setup in repeat sequence of channels mode along with the DTC, which is setup to continuously transfer data from channels A2, A1 and A0 to a RAM array.

Channel A2 samples the thermistor voltage (Battery temperature), A1 monitors the voltage on R_{sense} (Battery current) and A0 monitors the voltage on R2 (Battery voltage).

The 1.5V reference is also output on V_{ref}+ pin on the chip to be used as a reference for thermistor voltage measurements.

3.2 ADC10 ISR

The ADC10 ISR is triggered when the DTC completes the transfer of one block (3 words of data) to the ADC10SA which is a RAM array that stores conversion results from channel A2, A1 and A0.

If the Battery temperature exceeds 40 C, the charging process is stopped. The timer, ADC10 and the Watchdog timer (interval timer mode) are halted.

In the beginning of the charge cycle, if the battery voltage is less than 1V or greater than 4.3V, a LED is set to indicate a short circuit or battery not detected status.

During the constant current and constant voltage charging stages, TACCR1 controls the duty cycle of PWM output on TA1 to maintain constant current/voltage respectively.

3.3 Watchdog Timer ISR

When the charge current drops to 0.1C during the constant voltage charging stage, the watchdog timer is setup as an interval timer clocked from ACLK/8. The watchdog timer ISR is entered every 8 seconds to create a 15 minute delay before ending the charging process.

The MSP430 microcontroller sits in LPM0 during the entire charging process and is only woken up by the interrupt service routines.

3.4 Software Flowchart

A software flowchart is shown below to illustrate the charging algorithm:

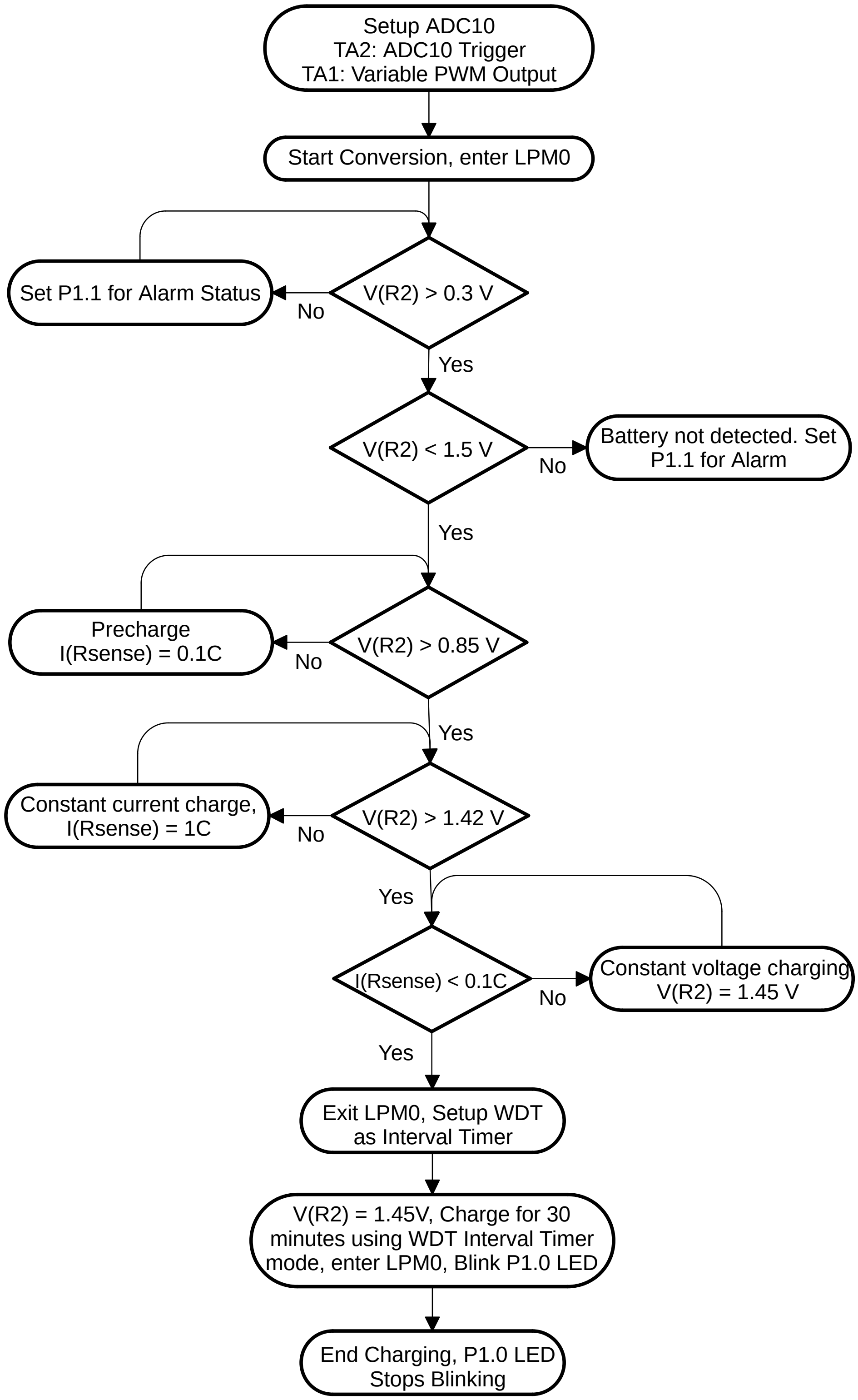

Figure 5. Software Flowchart

4 Conclusion

MSP430 microcontroller is a good fit for Li-Ion battery charger solution because of integrated peripherals like the high resolution ADC10 and a watchdog timer. The example application for this report has been implemented and tested to be functional for the operations described.

5 References

1. *MSP430x1xx Family User's Guide*, SLAU049
2. *MSP430F11x2, MSP430F12x2 Mixed Signal Microcontroller* datasheet, SLAS361

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

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