AN3531

Simple LiPo Battery Management

Introduction

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Given the ubiquitous nature of battery-powered systems, battery management has become a required feature on most new designs. The purpose of battery management is threefold;

- Control of the battery charging
- Regulation of the battery output for use by the system circuitry
- Monitoring the charge input/output to approximate the amount of remaining charge

This application note will address all three areas; charging, load regulation and battery charge/health estimation. To simplify the design, an ASIC charger and ASIC switching regulator will be used to do the actual charging and load regulation in the design. Two high-side current mirrors will also be used to monitor both the battery charging and battery load currents.

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1. Design Specifications

A battery manager has several important functions in a system:

- Management of battery charging
- Management of power conversion between the battery and the load
- Tracking the battery state of charge
- Tracking the battery health

To do these functions, the system needs to be able to enable/disable both the charger and the output voltage regulator, monitor the various system voltages and currents, and be able to integrate both the charge and discharge current for coulomb counting (gas gauge function).

For this design, the battery used will be a dual cell, 1000 mAH Li-Poly battery, capable of a 20C discharge (20A). The charger ASIC will be an MCP73844 charge controller with an NDS8434 6.5A P channel MOSFET transistor. The load regulator will be an MCP16311 1A high-efficiency step-down regulator. To provide monitoring and control, a PIC16F15244 microcontroller with a 10-bit ADC and PWM will be used.

2. Hardware Theory of Operation

The system hardware is divided into several sections: voltage monitors, current monitors, the charger, the output regulator and the temperature sensor. The voltage monitors are voltage dividers that scale the measured voltage down to a range the ADC can handle. The current monitors are high-side current mirrors that measure and offset the charge/discharge current down to a range the ADC can measure. The charger handles the constant current/constant voltage charging curve for the 2-cell Lithium Polymer battery pack, and the output regulator converts the battery voltage efficiently down to 5V for the load. The temperature sensor is included to monitor the battery temperature to detect faults and to prevent hold/cold charging/discharging of the battery.

2.1 System Hardware Blocks

To implement the system, several hardware blocks will be required:

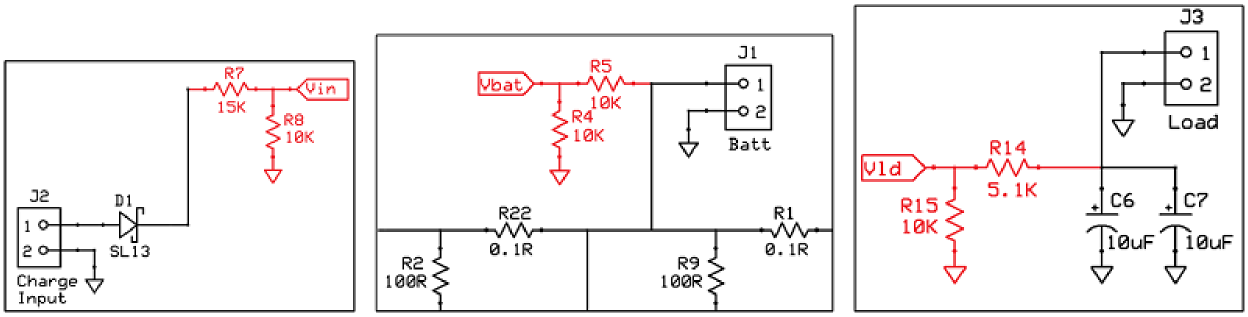
1. Voltage dividers for monitoring the input voltage, battery voltage and the load voltage.
2. An ASIC battery charger (MCP73844).
3. An ASIC switching regulator (MCP16311).
4. Digital outputs to enable/disable the charger and the output switching regulator.
5. An input to monitor the charger status.
6. A high side current mirror to monitor the battery charge and discharge currents.
7. A temperature sensor to monitor the battery temperature (MCP9700).

2.1.1 Voltage Monitors

The voltage monitors use resistor dividers to reduce the sense voltage down to the input range of the ADC.

1. The charger supply sensor uses a 15K/10K resistor divider to drop the 9V down to 3.6V.
2. The battery sensor uses a 12K/10K resistor divider to drop the 6.4V-8.4V to 2.9V-3.8V.
3. The output sensor uses a 5.1K/10K resistor divider to drop the 5.0V to 3.31V.

Figure 2-1. Voltage Sense Circuits



Battery Supply Voltage Sense   Battery Voltage Sense   Load Voltage Sense

Note: The maximum voltage range for all resistor dividers is below 4.0V, allowing the use of the fixed voltage regulator's 4.096V output as a reference for the ADC.

2.2 Load Voltage Regulator

The switching regulator that converts the 6.4V-8.4V battery voltage into the output 5V supply is an MCP16311 step-down regulator. It is rated for up to 1A of output current and employs a pulse frequency/pulse width modulation operating at 500 kHz. In addition to soft start and Undervoltage Lockout (UVLO), it has a low quiescent current of 44 µA and includes a digital enable input. The design of the regulator is taken directly from the device data sheet, and the enable input is connected to the PIC15224 for disabling the load when the battery is at its minimum charge voltage.

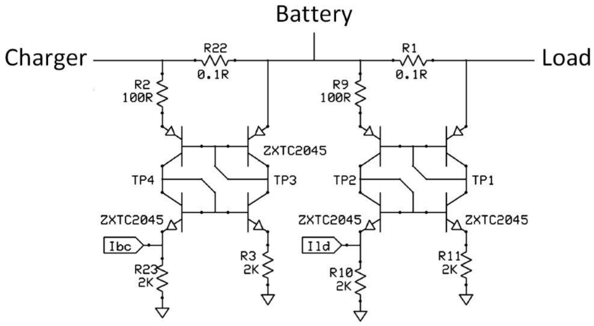
2.3 Battery Charger

The battery charger for the 2-cell lithium-polymer battery is an MCP73844 dual cell Lithium Polymer charge management controller. It uses an external pass transistor (NDA8434 P-channel enhancement MOSFET) to provide up to 6A of charging current, but the 100m Ω sense resistor R6 limits the charging current to 1.1A. The device also includes several safety times regulated by the 0.1 µF capacitor on pin 5. In addition to the constant current/constant voltage charging function, the device includes an enable input to disable the device, an Undervoltage Lockout and a charge status output. Both the enable and the status output will be connected to the microcontroller to manage the operation of the charger. The balance of the charger design is taken from the data sheet for the device.

2.4 Current Mirrors

The high-side current mirrors monitor charge and discharge voltages and use a dual NPN/PNP transistor pair (ZXTC2045) to implement the current sense circuits. See Figure 2-2 below. The left circuit monitors the charging current between the charger and the battery. The right circuit monitors the discharge current between the battery and the load.

Figure 2-2. Current Monitors



The charge current flowing through R22 generates a sensor voltage = I_{CHARGE} * R22. An identical voltage is generated across R2 due to the forced matching bias of the two PNP transistors of TP3 and TP4. The result is a current flowing from the PNP pair to the NPN pair = (I_{CHARGE} * R22)/R2 or (I_{CHARGE}/1000). So for a 1A charge current, 1 mA of current flows into both NPN collectors.

The current mirror action due to the forced matching bias of the two NPN transistors generates a matched current into R23 and R3, which in turn generates a matching output voltage across R23 and R3. The voltage is = (I_{CHARGE}/1000) * R23. So, for a 1A charge current, an output of 2V is generated across R23.

The current monitoring circuit for the load current operates in a similar manner generating an output voltage = (I_{CHARGE}/1000) * R10.

Both currents can be monitored by the microcontroller ADC, and the integration of total amp-hours both in and out is accomplished in software. Knowing the total charge in and out, as well as the batteries' capacity, allows for the calculation of the remaining charge in the battery. When combined with the current battery voltage, an estimate of the battery's health, or remaining life, can then be estimated.

2.5 Temperature Sensors

The battery temperature sensor is based on the MCP9700, an analog output temperature sensor. The outputs of the sensor are combined, plus the outputs of the voltage and current monitors are routed to the analog input pins on the microcontroller for sampling by the on-chip ADC. Table 2-1 shows which analog inputs are used to monitor the various values.

2.6 Analog Inputs

The analog port assignments cover the voltage, current and temperature monitors for the system. See Table 2-1.

Table 2-1. Analog Inputs

Analog Input	ADC Input Pins
V_{INPUT}	RB6
$V_{BATTERY}$	RB5
V_{LOAD}	RB7
I_{CHARGE}	RA4
I_{LOAD}	RA2
Temperature	RC5

2.7 Digital Inputs

The digital port assignments include enable and status pins for the charger and an enable control for the load regulator. See Table 2-2.

Table 2-2. Digital Inputs

Digital Input	ADC Input Pins
Function	GPIO
Charger Enable	RC7
Charger Status	RB4
Regulator Enable	RC6

3. Software Theory of Operation

The control software for the battery manager is a software state machine with four states of operation: Idle, Error, Charging and System-On.

The system will operate on one of three modes: Charging, Active Load and Idle. In Charging mode, the system will enable the charger ASIC and monitor its operation via the status line, the supply voltage to the charger, the battery voltage and the battery temperature. The charge current will also be tracked to estimate the current capacity of the battery.

In Active Load mode, the system will enable the switching regulator and monitor load operations via the battery voltage, battery temperature and the load voltage. The battery output current will also be monitored to estimate the remaining current capacity of the battery.

In Idle mode, the system will monitor the battery voltage, battery temperature and charger supply voltage. If the charger supply voltage is enough, the battery voltage is low, and the battery temperature is within the normal range, the system will switch to Charging mode. If the system requests power, and there is sufficient battery voltage, and the battery temperature is within the normal range, the system will switch to Active Load mode.

3.1 Idle State

In Idle mode, the system monitors the input voltage, battery voltage and temperature, as well as the communications port. If the battery voltage is below 8.4V, the input voltage is greater than 9V and less than 12V, and the battery temperature is greater than 0°C and less than 30°C, then the state machine will switch to Charge state.

1. If the battery voltage is greater than 6.4V, the battery temperature is greater than 0°C and less than 30°C, and a turn-on request is received from the communications port, then the state machine will switch to System-On state.
2. If a charging error condition is detected or the input voltage is outside its operating range, the system will switch to Error state.
3. If a status request is received from the communications port, then the status will be returned.

3.2 Charge State

In Charge mode, the battery charger is enabled while the system monitors the input voltage, battery voltage, battery temperature, charger status and the communications port.

1. If the charge is complete, the state machine will switch to the Idle state.
2. If the charger reports an error, the charger is disabled, and the state machine will switch to the Error state.
3. If the input voltage is not greater than 9V or less than 12V, the charger is disabled and the state machine will switch to the Error Sate.
4. If a status request is received from the communications port, then the status will be returned.

In addition to the periodic Round Robin monitoring the system, the ADC also accumulates periodic readings of the charge current to estimate the total charge injected into the battery. By comparing the total charge current and the starting/ending voltage of the battery against the original specifications for the battery, an estimate of the battery health can also be calculated.

Note: Because the charge current for the battery is reasonably constant, the polling of the charge current can be relatively slow, which allows the polling of the other parameters.

3.3 System-On State

In the System-On state, the switching regulator is enabled while the system monitors the output voltage, battery voltage, battery temperature and communications port.

1. If a turn-off request is received from the communications port, the switching regulator is disabled and the state machine will switch to the Idle state.
2. If the output is not greater than 4.8V after 2 seconds after the start-up, the switching regulator is disabled and the state machine will switch to the Error state.

3. If the battery temperature is below 0°C or greater than 30°C, the switching regulator is disabled and the state machine will switch to the Error state.
4. If the battery voltage drops below 6.4V, the switching regulator is disabled and the state machine will switch to the Error state.
5. If the battery current is greater than 1A, the switching regulator is disabled and the state machine will switch to the Error state.
6. If a status request is received from the communications port, then the status will be returned.

The System-On state also uses accumulated periodic readings of the discharge current to estimate the total charge remaining in the battery. However, while the charge current is reasonably constant, the discharge current can fluctuate more, requiring the system to poll more frequently to generate an accurate reading of the discharge. As a result, the other parameters are polled less frequently.

3.4 Error State

In the Error state, the charger and switching regulators are disabled, and the communications port and battery temperature are monitored.

1. If a status request is received from the communications port, then the status will be returned.
2. If a clear status request is received from the communications port, then the state machine will clear the error flags and switch to the Idle state.
   Note: If the error persists (high battery temperature or low input voltage), then the state machine will immediately return to the Error state.

3.5 Coulomb Counting

One of the challenges with integrating the current flow is capturing a good average, without spending all available bandwidth managing the ADC. Charging is reasonably easy, with a constant current charge and a ramp down during the constant voltage. Discharge is more of a challenge, although having an ADCC helps, as it has an accumulated post conversion function. In this example, we have a regular ADC, so the firmware has to accumulate the current flow through multiple conversions. To provide a consistent sample rate, the ADC is triggered by TMR0.

Note: The accuracy of the discharge coulomb counting will be affected by fast transients in the load current. The micro can either sample faster, or put a low-pass on the output of the current mirror to average out the ADC current draw.

3.6 Interrupts

In every state of the state machine, the analog input channels are polled and stored in the system status memory. In the Charge state, the charge current measurement is polled faster and accumulated as a coulomb counter for measurement of the battery charge. In the System-On state, the discharge current measurement is polled faster and accumulated as a coulomb counter for measurement of the battery state of change (percent capacity remaining). The remaining charge is also estimated using the battery voltage. By combining the coulomb count and the estimated battery charge, an estimate of the battery health is calculated.

4. Conclusion

The system described works well. It manages both the charge and the discharge of the battery using the ADC for monitoring and a collection of GPIO for control. Based on these requirements, the system can be implemented on a variety of PIC16F or PIC18F microcontroller families with the requisite peripherals. In fact, the system is sufficiently stand-alone in its operation. It can be combined with a variety of supervisory functions such as fan speed control, Real Time Clock, Watchdog Timer and/or serial EEPROM, all within a common microcontroller.

The design is limited in that it precludes running the load during battery charging. There are two reasons for this. First, it puts a significant load on the charger and can confuse its control state machine if load current transients occur during the change over from constant current to constant voltage. Second, cycling charge in and out of the battery reduces battery life. To minimize this effect, it is best if the load draws power directly from the supply rather than through the charger.

4.1 Enhancements

It would be relatively easy to implement a power bypass by adding a bypass power switch between the input voltage and the supply to the load switching regulator. All that is needed is a common cathode Schottky diode pair. The common cathode supplies the switching regulator input. One anode goes to the battery and the other anode to the input voltage. When the input voltage is present, the diode from the battery is reverse biased and the switch pulls power from the input voltage. When the input voltage is not present, the diode from the battery forward biases, the input voltage reverse biases and the output switcher pulls power from the battery. The only downside is the slight reduction in efficiency due to the power loss in the diodes.

Another potential enhancement would be to offload the load current conversion to an external delta-sigma ADC for greater resolution in the coulomb counting function. Several good application notes are available on Microchip’s website that cover this option.

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