INTRODUCTION

Batteries often serve as the main energy source for portable electronic devices. Although they depend on batteries, portable consumer electronic products, such as GPS and multi-media players, often consume energy directly from ac-dc wall adapter or accessory power adapter (or "Auto Adapter") when the battery is low or the device is in a stationary mode.

Relatively high energy density and maintenance free make Lithium-Ion (Li-Ion) batteries popular in the portable consumer electronic products. Li-Ion batteries are the example of the portable power source in this applications note.

Depending on the product design or local government regulations, rechargeable batteries are often charged inside the handheld devices or from battery charger cradles. Due to the safety concerns or design concepts in some products, the batteries are required to be removed from the portable device and charge directly from the battery charger cradle.

However, most of time, batteries are designed to be recharged inside the devices while the devices are still in the operational mode. An end-user can extend run time while refilling the energy back to the battery for the next mobile action. The adapter now has to power up the device while charging the battery. The battery can deliver energy to the system load when the power source is absent as depicted in Figure 1.

Portable electronic devices play an important role in a person’s daily life from grocery shopping to personal data assistant and have dramatically changed the way people live and work. With the emerging technologies that are available today, portable electronic designers are trying to integrate more features into smaller and lighter form-factors while extending the system run times.

This application note is intended to assist product designers by taking advantage of using Microchip’s fully integrated simple Li-Ion battery charge management controllers with common directional control to build a system and battery load sharing circuitry. The solutions are ideal for use in cost-sensitive applications that can also accelerate the product time-to-market rate.

FIGURE 1: Typical Portable Power Source.
DESCRIPTION

This applications note shows how to design a simple system load sharing with Microchip’s popular “Advanced Stand-Alone Li-Ion / Li-Polymer Battery Charge Management Controller with Autonomous AC-Adapter or USB-Port Source Selection” for cost-sensitive applications.

References to documents that treat these subjects in more depth and breadth have been included in the “Reference” section.

BATTERY CHARGER AND SYSTEM LOAD DESIGN SPECIFICATIONS AND APPLICATION DESCRIPTION

The example system load consumes a maximum 500 mA when all applications are running at the same time. A 950 mAh rated Li-Ion battery is required to operate the example portable system for approximately two hours during intensive load operations.

The input power should supply the system load and charge battery when a battery is present in the system. When input power source is removed, the system is supported by the battery. When the system load and the battery draw more energy that the supply current can offer, the system load has priority over the battery charger.

Design Specifications

- Input Voltage Range:
  - 4.5V - 6.5V from ac-dc adapter (1A)
  - 5V from USB port (100 mA/500 mA)
  - 3V - 4.2V from 1-cell Li-Ion battery (950 mAh)
- Constant Charge Current:
  - 0.5C (The battery manufacturer recommended value)
  - 100 mA / 500 mA (Charge from USB port)
- Precondition Current:
  - 0.1C or recommend value
- Termination Current:
  - 0.07C
- Charge Status and Power Good Indicators
- Safety Timer: Turn charger off after 6 Hours before termination
LI-ION (LITHIUM-ION) / LI-POLYMER (LITHIUM POLYMER) BATTERIES

There are some important attributes when selecting a battery for an application:
1. Internal Resistance,
2. Operational Load Current,
3. Energy Density (Size & Weight),
4. Charge/Discharge Cycles (Life Cycle),
5. Capacity (dominates the operational duration without external power source present).

Like most engineering work, these key attributes do not exist in the same technology. There is always a trade-off between them when selecting the battery chemistry for a portable application. Refer to Microchip's AN1088 “Selecting the Right Battery System for Cost-Sensitive Portable Applications While Maintaining Excellent Quality” for the details of battery chemistry comparisons.

Li-Ion batteries have played an important role in today's portable world because of the advantages in high energy density, low maintenance requirement, relatively low self discharge rate and higher cell voltages. 1-cell Li-Ion batteries especially enjoy the largest share of the Li-Ion battery market while 1-cell and 2-cell applications are available in more than 70% of total available market. An example of the single-cell Li-Ion battery charger and system load sharing power path circuit is demonstrated in this application note.

Li-Polymer batteries which are also recognized as Li-Ion Polymer batteries are similar in terms of chemistry with Li-Ion batteries. Li-Polymer can be charged as same algorithm as Li-Ion batteries because of the similar characteristics. The flexible form-factors and very low profile to fit inside the compact applications make it an ideal candidates for MP3 Players and Mobile Phones.

SELECT BATTERY CHARGE MANAGEMENT CONTROL CIRCUIT

The emerging semiconductor technologies shorten the design cycles and simplify design methods for the consumer product designers by integrating circuits into a single chip. The first step is to decide to design a custom charge control management circuit or adapt a standalone charge IC.

Stand-Alone Charge Management Controller

Microchip's MCP73837 “Advanced Stand-Alone Li-Ion / Li-Polymer Battery Charge Management Controller with Autonomous AC-Adapter or USB-Port Source Selection” is selected to complete the design because it dramatically reduces the software/hardware design time and simplify the PCB layout. The selected MCP73837 is regulated at 4.20V and programmed at 500 mA for ac-dc wall adapter. The general features of MCP73837/8 are listed below:

- High Accuracy Preset Voltage Regulation: ± 0.5%
- Available Voltage Regulation Options:
  - 4.20V, 4.35V, 4.4V or 4.5V
- Complete Linear Charge Management Controller
  - Autonomous Power Source Selection
  - Integrated Pass Transistors
  - Integrated Current Sense
  - Integrated Reverse Discharge Protection
- Constant Current / Constant Voltage Operation with Thermal Regulation
- Selectable USB-Port Charge Current:
  - 100 mA maximum (Logic Low) / 500 mA maximum (Logic High)
- Programmable AC-Adapter Charge Current:
  - 15 mA - 1000 mA
- Two Charge Status Outputs
- Power-Good Monitor:
  - MCP73837
- Timer Enable:
  - MCP73838
- Automatic Recharge
- Automatic End-of-Charge Control
  - Selectable Charge Termination Current Ratio
  - Selectable Safety Timer Period
- Preconditioning of Deeply Depleted Cells
- Battery Cell Temperature Monitor
- UVLO (Under Voltage Lockout)
- Automatic Power-Down when Input Power Removed
- LDO (Low-Dropout) Linear Regulator Mode
- Minimum External Components Required

Note: The major drawbacks of Li-Ion batteries are higher initial cost and aging effect. Li-Ion batteries age over time regardless the number of cycles that have been reached. A Protection circuit is required for Li-Ion batteries to prevent over voltage during charge cycle and under voltage during discharge cycle; overcurrent as well in both directions.

Batteries usually occupy a considerable amount of space and weight in today's portable devices. The energy density for each chemistry dominates the size and weight for the battery pack. Li-Ion has advantages in both energy density weight and energy density volume among other available battery technologies.
Common Cathode Diode

A common cathode diode is applied here to drive LEDs and supply system load when either source from ac-dc adapter or USB-port. It prevents reverse current feeding into the other source.

A common cathode diode can be left out of the design if an automatic switch between ac-dc adapter and USB port feature is not required or a different charge IC which does not have autonomous dual power source selection is adapted to the design. Figure 3 depicted a closer look of the common cathode diode that is used in the design.

FIGURE 3: Common Cathode.

SELECT THE SYSTEM LOAD SUPPLY CIRCUIT

Some designers may think an additional circuit is not required and simply connect a system load to the battery cell. The current flows to system when the sources are removed and randomly dump current into battery pack when the extra current is available.

Here are few reasons that the system load is not recommended to be directly connected to the battery terminals:

1. The charge may never end - Most Li-Ion battery chargers are based on CC-CV (Constant Current and Constant Voltage) mode. The termination is based on the ratio of output current and constant current. If the system constant draw current from the charger, the charge current never will meet the termination value.

Note: MCP73811/2 Li-Ion battery charge management controllers with no auto-termination may be a good solution for the type of applications that are designed to simply tie system load to Li-Ion battery.

2. The total system current is limited by charge current because the charger will deliver total system and battery charging current through the output pin. This problem may be feasible for some applications that run on constant current, but not recommended.

FIGURE 4: Do not just connect the load to battery.

Select The Pull Down Resistor

The $R_{\text{PULL}}$ in Figure 5 represents pull down resistor to make sure that the P-Ch MOSFET (Q1) turns on when input sources are removed. When the input sources are absent, the $R_{\text{PULL}}$ pulls the gate to zero allowing current to flow out of the battery.

$R_{\text{PULL}}$ value can be any reasonable resistor. However, $R_{\text{PULL}}$ value should not be too small. The small $R_{\text{PULL}}$ wastes unnecessary current when input sources are present. 100 k$\Omega$ $R_{\text{PULL}}$ is recommended in this design which consumes about 50 $\mu$A when $V_{\text{IN}} = 5V$.

FIGURE 5: Current Directional Control Circuit.
Select The MOSFET

The nature of the MOSFET makes it the best candidate for current direction control. A P-Channel MOSFET is selected to complete this circuit. Figure 6 depicts when \( V_{IN} \) is available, the gate of Q1 is High. Q1, which blocks the current from Li-Ion battery is turned off and allows current to support the system load from \( V_{IN} \) when charging the battery from \( V_{BAT} \) pin. When the gate of Q1 is Low, Q1 turns on and allows the Li-Ion battery to supply the system as shown in Figure 7. The MCP73837 VBAT pin also is disabled when \( V_{IN} \) is absent.

Note: It is important to select proper gate threshold voltage range, so the MOSFET will be turned on.

Select The Diode

A diode is required to prevent reverse current to the power source as depicted in Figure 6 and Figure 7. Selecting the right diode can minimize the leakage current and forward voltage drop from power source to the system load. A schottky diode, which has lower forward voltage drop is recommended.

Note: Average Forward Current has to be rated greater than the maximum system load current for the application.

Co-packaged MOSFET + Schottky Diode

Semiconductor manufacturers provide MOSFET and Schottky Diode in one small package to save board space and cost. A typical SO-8 packaged low forward voltage drop schottky diode and power P-Ch MOSFET was used for demonstration in this application note.

CHARGE PROFILE WITH SYSTEM LOAD

A complete system load and battery power path management circuit, which depicted in Figure 2 was designed for demonstration purpose in this application note. The system load was setup at a constant 500 mA rate. A deeply depleted 950 mAh Li-Ion battery was used and charged by Microchip’s MCP73837 “Advanced Stand-Alone Li-Ion / Li-Polymer Battery Charge Management Controller with Autonomous AC-Adapter or USB-Port Source Selection”. A fast charge current of USBHigh was selected to charge 450 mA in Constant Current Mode. The MCP73837/8 was designed to charge at a typical 450 mA constant current when USBHigh is selected and guaranteed not exceed 500 mA limit when high-power USB port is available.

Note: The USB (Universal Serial Bus) Specification clearly defined that a device may be either low-power at 100 mA loads or high-power, consuming up to 500 mA loads. All devices default to low-power. The transition to high-power is under software control. It is the responsibility of software to ensure adequate power is available before allowing devices to consume high-power. The number of unit loads a device can draw is an absolute maximum, not an average over time. (Designers should obtain the latest design guide line and detail information from the USB-IF if USB peripherals is going to be implemented in a project.)
FIGURE 8: 450 mA Constant Charge Current Li-Ion Battery Charge Profile With Constant 500 mA System Load.

Stage 1: Preconditioning - Preconditioning is employed to restore charge to deeply depleted cells. When the cell voltage is below designed threshold voltage, the cell is charged with a constant current of 0.1C maximum. This period is hard to see from Figure 8 because the VBAT rises above 3V in very short period of time and enters the Constant Current (Fast Charge) mode.

Stage 2: Constant Current - Once the cell voltage has risen above the preconditioning threshold, the charge current is increased to perform fast charging. The fast charge current should not be more than 1C. A fast charge current of 450 mA (~ 0.5C) is used in this example. The thermal foldback period demonstrates temperature regulation by limiting current during Fast Charge Period which also improve the reliability and prolong the life of charger IC.

Stage 3: Constant Voltage - Fast charge ends, and the Constant Voltage mode is initiated when the cell voltage reaches 4.2V (Or the desired available option, which is available to order via Microchip for MCP73837/8). In order to maximize capacity, the voltage regulation tolerance should be better than ±1%. MCP73837/8 provides a ±0.5% superior voltage regulation tolerance to deliver maximum battery runtime after each completed charge cycle.

Stage 4: Termination

Charging in this manner replenishes a deeply depleted battery in roughly 140 minutes at 0.5C mA. Advanced chargers employ additional safety features. For example, charge is suspended if the cell temperature is outside a specified window, typically 0°C to 45°C.

After 140 minutes, Figure 8 demonstrates that the power supply still supports a solid 500 mA system load when charge termination occurs and the battery charger went into standby mode. During this standby mode, the MCP73837 continues to monitor the VBAT and will recharge the Li-Ion battery once it drops 150 mV below regulated VBAT voltage.

DISCHARGE THE LI-ION BATTERY

The input power source was removed when a full charge cycle was completed. The P-Ch MOSFET was turned on to supply the system load with 0.53C and discharged the 950 mA Li-Ion battery as depicted in Figure 9. The termination duration is load dependent and the Figure 9 also shows the Li-ion battery was not able to deliver 500 mA after 105 minutes. With approximately 0.5C discharge rate, the time should last about 2 hours. The main reason that the remain 15 minutes are not available from this experiment is because the remaining capacity level is not enough to support 500 mA.

FIGURE 9: 500 mA Discharge Profile when V_IN is removed.

Note: Fully depleted a Li-ion battery may degrade its life cycles and should be avoided.

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CONCLUSION
System and battery load sharing power path management circuits are very common in portable applications. Adapting this simple design wisely can dramatically reduce the total system cost and product developing time in order to take advantages of using a fully integrated battery charge management controller.

REFERENCES
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