Battery Charger Adapts to Multiple Chemistries

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A microcontroller-based mixed-signal design produces a programmable and adaptable battery charger for different rechargeable chemistries.

Many handheld-device designers struggle with the choice of battery chemistry for new product definitions. In some cases, design engineers are transitioning from lower-density nickel-based chemistries to more dense lithium-ion (Li-ion) solutions. In other applications, the exact opposite is happening — some applications are switching from Li-ion to nickel-metal hydride (NiMH) chemistries.

This selection significantly impacts both the user and the designer with regard to cost, portability, safety and product life. Obviously, the battery lives of all rechargeable handheld devices are not created equal. Improper charge profiles can take the life out of a device. The following is a method for developing battery chargers that are programmable and adaptable to all rechargeable battery chemistries. This approach can be adapted easily to new chemistries and charge methods as they emerge.

Different Charge Profiles

Fig. 1 shows a typical charge profile for a Li-ion battery, and Fig. 2 is a typical NiMH charge profile. For many applications, there is a need to modify or adapt the typical charge profile. In these cases, a microcontroller-based mixed-signal design can be used to develop programmable charge profiles.

Li-ion batteries are recharged using a constant-current, constant-voltage profile. Prior to charging the Li-ion battery, a charge-qualification process measures the battery's voltage to determine whether it is deeply discharged (typically, below 2.4 V to 3.2 V per cell). If the battery is deeply discharged, the charge cycle begins with a precondition charge current, typically 5% to 25% of the fast-charge, constant-current value.

Once the battery voltage is above the precondition threshold, the constant-current charge phase of the charge profile can begin (Fig. 1). During the constant-current phase of the profile, the battery's voltage rises. Once it reaches the desired constant voltage, the charger must transition from constant-current to constant-voltage mode.

Charge termination occurs when the charge current during the constant-voltage phase is reduced to a percentage of the fast-charge constant-current value. In this example, 20% is being used as the charge-termination current. Manufacturers recommend anywhere from 7% to 30% for optimal battery cycle and capacity performance. This completes a typical charge profile for Li-ion batteries.

Besides the development of the constant-current and constant-voltage phases of the charge cycle, battery charger designs also require safety features. One example is a safety timer limiting the amount of time a charger will spend in a particular portion of the charge cycle.

For instance, timers limit the amount of time a charger will attempt to condition a faulty battery in the precondition phase, or the amount of time the charger will spend in the high constant-current phase or constant-voltage phase. Limiting voltage during the constant-current phase and current during the constant-voltage phase are important safety features for all battery chargers.

As shown in Fig. 2, the charge profile for NiMH/nickel-cadmium (NiCd) batteries is significantly different from that of Li-ion batteries, even though they both begin with a small conditioning current for deeply discharged batteries.

NiMH and Li-ion batteries are different in how the end of charge is detected. For NiMH, the end of charge is detected by measuring a reduction of battery-pack voltage or an increase in battery-pack temperature. A decreasing pack voltage or an accelerated increase in temperature are indications that the fast-charge current phase of the charge cycle is over and the charger should transition to the top-off phase of the cycle.

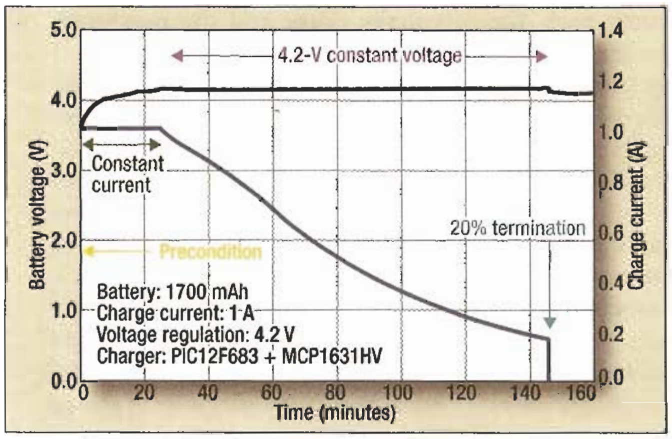


Fig. 1. *This typical single-cell Li-ion charge profile features a 1-A constant current and a 4.2-V constant voltage.*

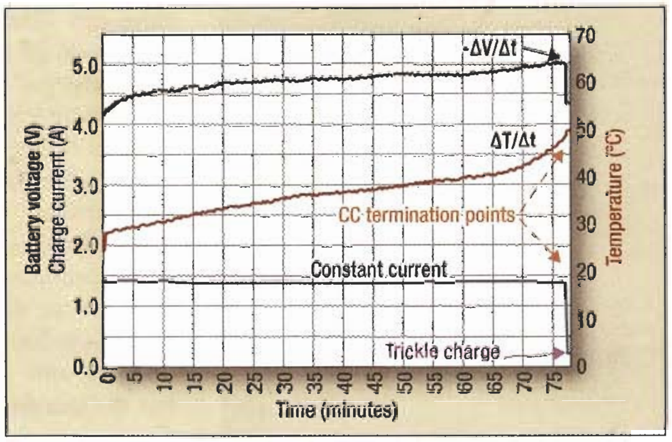


Fig. 2. *A NiMH or NiCd battery-charge profile for a three-cell battery-pack charging employs a constant 1.35-A charge current.*

The top-off portion of the charge cycle is a reduced constant-current phase for a defined length of time. Typically, the constant current can range from 5% to 20% of the fast-charge current value. For NiMH battery-safety timers, charge-current limit and output overvoltage protection are important features, as they are in Li-ion battery chargers.

Charger Concept

The task of designing a battery charger capable of developing a programmable charge profile for single or multiple cells, Li-ion or NiMH batteries can appear daunting. A starting point for this begins with the development of a concept.

The power management system for charging Li-ion and NiMH batteries could use a constant-current source for all phases of both charge profiles, with the exception of the constant-voltage phase for Li-ion batteries. During this phase, the charger output voltage regulates the Li-ion battery pack. A simple digital control loop, updated at a slow rate, could be used to program the battery current at a rate that keeps the voltage constant.

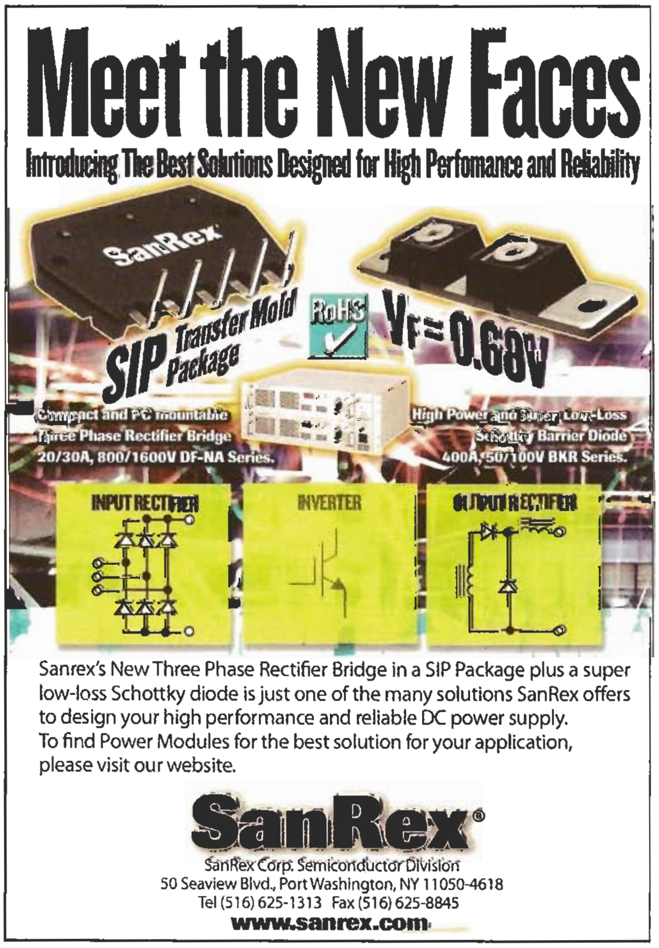
In Fig. 3, there are two main blocks that describe the mixed-mode analog/digital multi-chemistry battery charger. The programmable current-source block is an analog power train used to generate a constant-current source — the microcontroller block sets its output current.

The microcontroller block consists of two analog-to-digital converter (ADC) inputs, as well as an output capable of setting the analog power train's current and charge-cycle timers. After the microcontroller samples the battery's voltage and temperature, it calculates a new current set point. This sample rate and calculation can be relatively slow, as the battery is being charged with a regulated constant-current source, so its voltage will not change very fast.

The analog power train's response provides current regulation during input-voltage transients, and any dynamic changes to the battery and load. The speed and magnitude of the input-voltage changes establish the power train's control-system performance.

Generating the programmable charge algorithm starts with the power system. The topology selected for this application is a single-ended primary inductive converter (SEPIC) power train. This power train can be used to step the input voltage up or down while regulating current into the battery.

The SEPIC power train has some unique features that are desirable for battery-charger applications. First, its ability to buck and boost voltage enables it to be used over a wide input-voltage range and with a wide selection of batteries. For example, if a USB or 5-V regulated input charges a



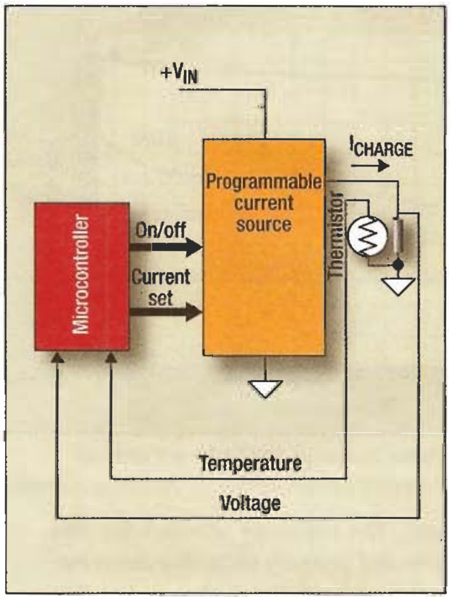


Fig. 3. *A concept diagram of a multichemistry programmable battery charger includes a microcontroller that drives a programmable current source and samples (via on-chip ADC) battery voltage and temperature.*

three-cell NiMH battery pack, the input voltage can be greater than the discharged battery pack's voltage (2.7 V at 0.9 V per cell), or lower than the final charge voltage of 5.2 V.

Other benefits to the SEPIC power train include:

- Continuous input current improves conducted input noise
- Output diode blocks battery reverse-discharge path
- Low-side current sense to protect the charger against output short circuits
- Charger current sense in series with a SEPIC secondary inductor.

By sensing current in the secondary SEPIC inductor, the sense resistance is not in the battery discharge path, which makes the discharge more efficient.

The design of the analog constant-current source topology is highly dependent on the input-voltage range, output-voltage range or battery-pack voltage range and the maximum fast-charge current. For a typical 1-A to 3-A fast-charge current and pack voltages up to 8.4 V, the converter's output power is limited to 24 W or less. Because the power is relatively low and, under some application conditions, the input voltage can be greater or less than the battery-pack voltage, a good choice for the converter would be a topology that could buck or step the voltage down, and boost or step the voltage up to charge the battery pack.

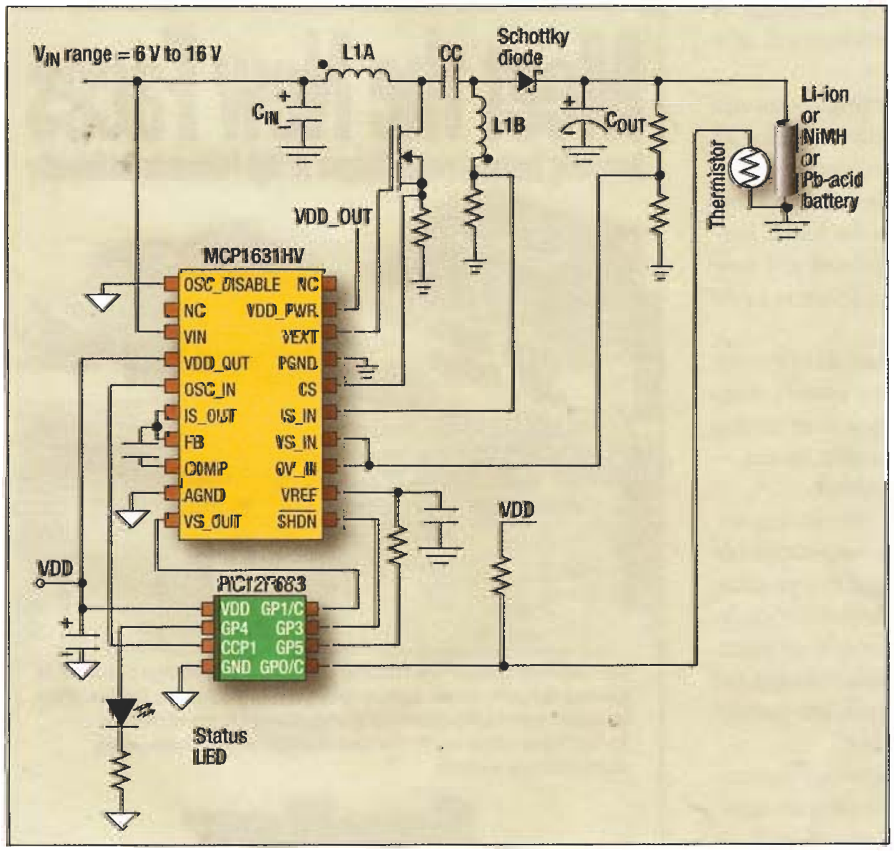


Fig. 4. *A battery charger based on the MCP1631HV PWM chip is configured as a SEPIC power source. (For the actual pinouts of the MCP1631HV and PIC12F683, see data sheets.)*

Fig. 4 shows the MCP1631HV high-speed pulse-width modulation (PWM) IC used in a programmable current-source SEPIC application. The MCP1631HV integrates:

- High-speed analog PWM
- Inverting current-sense amplifier with a 10x gain
- Low-quiescent current voltage-buffer amplifier
- High-speed overvoltage protection comparator
- Low-quiescent current linear regulator (used to power the microcontroller and the internal circuitry of the MCP1631)
- Low-quiescent current shutdown capability.

Changing the PWM reference voltage sets and adjusts the programmable current-source output. Increasing this reference voltage increases the pulse-width output, causing the output current to increase. The analog control loop, consisting of the PWM's internal amplifier, controls its duty cycle, which regulates the output current.

Developing the Charger

Fig. 5 is a simplified block diagram of the programmable constant-current-source regulator. By inspection, the average current flowing through L1B in the SEPIC converter is equivalent to the average current flowing into the connected battery load. By inserting a low-value power resistor in series with L1B, the battery current can be sensed as a voltage drop with the polarity shown.

To maximize efficiency, a low-value resistor should be used. The small voltage drop is negative with respect to ground, and an inverting 10x gain amplifier inverts and increases the signal level. By connecting the -10x I_{BATT} output to the FB pin or input of the error amplifier inverting input, and a programmable reference generated by the microcontroller to the noninverting input, the amplifier output will seek a value that makes the inputs equal. This forces the current into the battery to be proportional to the V_{REF} voltage generated by the microcontroller. Increasing the V_{REF} signal increases the battery-charge current.

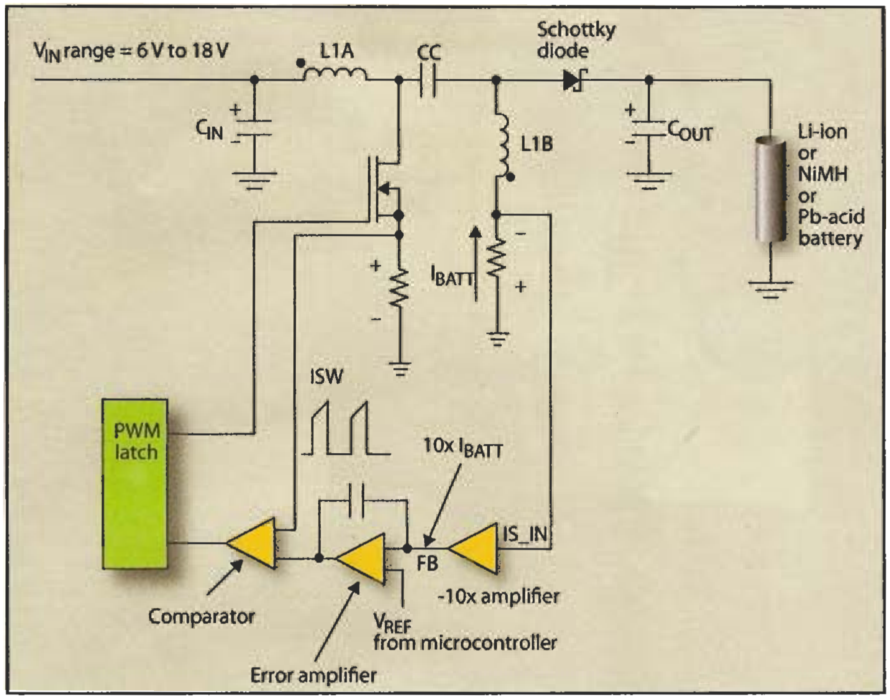


Fig. 5. *The analog power train's constant-current source uses a power MOSFET and three op amps that work in conjunction with a PWM IC.*

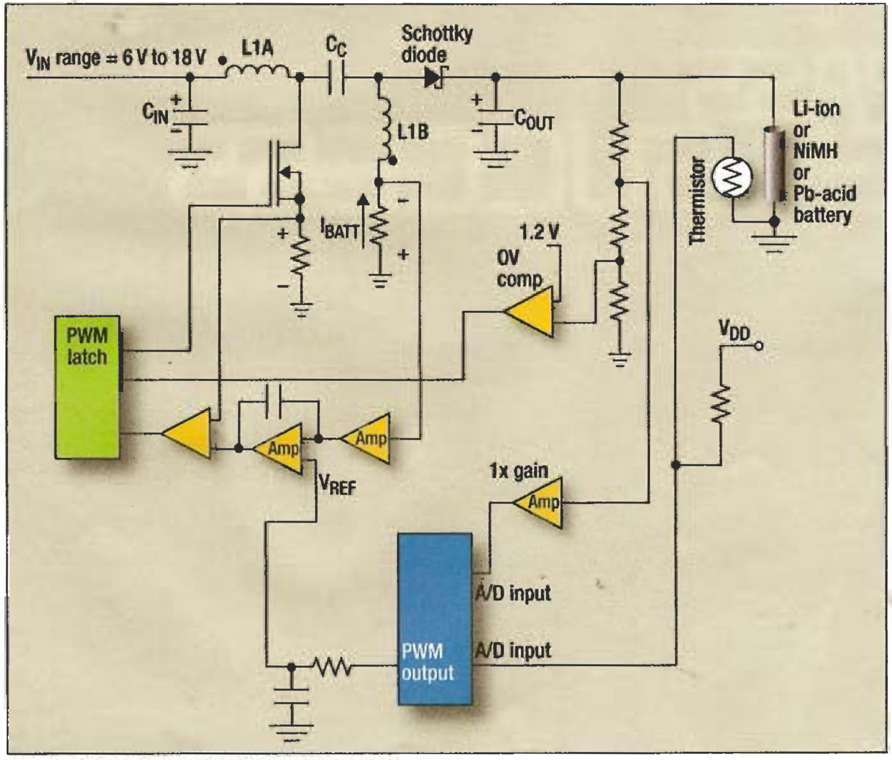


Fig. 6. *The voltage-regulation loop and charge-termination circuit for NiMH batteries employs the microcontroller's ADC to sample the battery's temperature and voltage.*

The error amplifier's output is compared with the peak current in the main SEPIC switch. By limiting the output of the error amplifier to 2.7 V/3, or 0.9 V, the peak current in the switch protects the charger from a shorted battery or output. The delay from sensing the peak current limit to turning off the main SEPIC switch is critical in protecting the power train.

For constant voltage and charge termination, one input of the microcontroller's ADC senses the battery's output voltage. Fig. 6 shows a simplified block diagram of the voltage regulation loop and charge termination for NiMH batteries.

For Li-ion batteries, sensing the battery-pack voltage with the ADC voltage input regulates the charger's output voltage. A buffer amplifier buffers the battery-divider resistor sensing, so that very high-value resistors can minimize any unnecessary drain on the battery.

The voltage regulation algorithm consists of measuring the battery's voltage and averaging the measured value. If the value is greater than 4.2 V, decrement the V_{REF} PWM by 1 bit to reduce the charge current. The reduction in current will drop the battery's voltage. As the battery continues to charge, the sensed voltage will rise above 4.2 V, forcing another decrement in current. Once the current reaches the termination value preset in the microcontroller's firmware, the charge cycle terminates. Temperature monitoring prevents charging batteries that are outside the specified operation range.

Because the voltage-regulation tolerance for Li-ion batteries is critical to capacity and safety, calibrate the circuit to remove initial errors in tolerance, offset voltage and bias current. Obtain this calibration by applying a precise 4.2-V source to the charger's output.

When in calibration mode, the ADC will read the applied voltage and store the value in EE memory. This stored value allows a comparison between the battery pack's ADC reading while in the CV phase of the charge cycle. Updating the programmable current keeps the charger's output the same value as the stored calibration value.

For NiMH batteries, set the fast-charge current while sensing the battery pack's voltage and temperature. Fast rising temperature or falling voltage during fast current charge indicate that the batteries have reached their capacity and that the fast-charge cycle should be terminated, as shown in Fig. 2.

Typically, the charge cycle is completed by a timed top-off charge that is 5% to 20% of the fast-charge current. This can be achieved by reducing the V_{REF} input to the error amplifier. If the batteries are removed or disconnected from the output during the charge cycle, the SEPIC constant-current source will pump the output voltage of the charger up to damaging voltage levels. To prevent this, a comparator senses the voltage and terminates the PWM input to the SEPIC switch. This shuts the charger off until the voltage is below the comparator's hysteresis point, thus regulating the open-circuit output voltage to a safe value.

There are many ways to generate a programmable reference to set current. Popular methods include those that use digital-to-analog converters, digital potentiometers and filtered PWM circuits. For this application, a 10-bit firmware generated PWM approach was used.

By pulsing the PWM pin and filtering with an RC circuit, the reference voltage is an analog representation of the PWM duty cycle, or on-time versus period. Increasing the PWM duty cycle increases the analog voltage level, which increases the battery-pack charge current. Likewise, lowering the duty cycle decreases the battery-pack charge current.

Designers can differentiate their demanding portable-power applications by increasing battery life, allowing multiple chemistry sources, improving cycle life and increasing reliability of the portable-power system.

The multichemistry charger method described here provides designers and consumers the flexibility to choose what is most important for their application. By lowering the fast-charge rate for NiMH batteries, or the constant-voltage regulation point for Li-ion batteries, the number of charge cycles and the reliability of the system increase at the expense of longer charge cycles and less device run time.

In some instances, it would be beneficial if designers could select battery-pack chemistries to better optimize their devices for particular applications. Having this flexibility to develop proprietary charge profiles allows designers to differentiate their products in the marketplace. **PETech**