

Active Cell Balancing in Battery Packs

by: Stanislav Arendarik
Rožnov pod Radhoštěm, Czech Republic

1 Introduction

Batteries made of multiple cells connected in series are often used as a power source for common electronic devices. In multicell battery chains, small differences between the cells (due to production tolerances or operating conditions) tend to be magnified with each charge or discharge cycle. In these situations, weaker cells are overstressed during charging, causing them to become even weaker, until they eventually fail and cause a premature failure of the whole battery. Cell balancing is a way of compensating for these weaker cells by equalizing the charge on all the cells in the chain, thus extending the battery life.

The life of a rechargeable battery can be extended through the use of an intelligent charging system. The charging system must incorporate the proper charging method for the appropriate battery type (according to the battery chemistry) and overcharge protection to prevent battery damage. These circuits can be implemented in the charger or in the battery.

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Similar to the charging state, discharge control has to be implemented in the application or in the battery. One of the prime functions of this system is to provide the necessary monitoring and control to protect the cells from situations outside of normal operating conditions.

2 Balancing methods

There are two main methods for battery cell charge balancing: passive and active balancing.

The natural method of passive balancing a string of cells in series can be used only for lead-acid and nickel-based batteries. These types of batteries can be brought into light overcharge conditions without permanent cell damage. When the overcharge is small, the excess energy is released by increasing the cell body temperature. The excess energy can be released by the external circuit connection in parallel to each cell. This circuit consists of a power resistor connected in series with a control MOSFET transistor. This method can be used for all types of batteries, but is effective for a small number of cells in series.

The active balancing method is based on the active transport of the energy among the cells. This balancing method does not depend on the chemical characteristics of the cells, and can be used for most types of modern batteries. There are several types of active balancing methods based on the type of energy transfer. The energy transfer can be from one cell to the whole battery, from the whole battery to one cell, or from cell to cell. Each energy transfer is based on the type of dedicated DC-to-DC converter. The energy is transferred from the strongest cell to the whole battery or other cells, and from the battery or other cells to the weakest cell.

3 Selected solution

Each type of DC-to-DC converter used has its own characteristics. The final decision depends mainly on the electrical power sourced from the battery, on the battery capacity in ampere-hours (Ah), and on the final application requirements.

This example uses a charge transfer between individual cells. The block schematic is shown in [Figure 1](#).

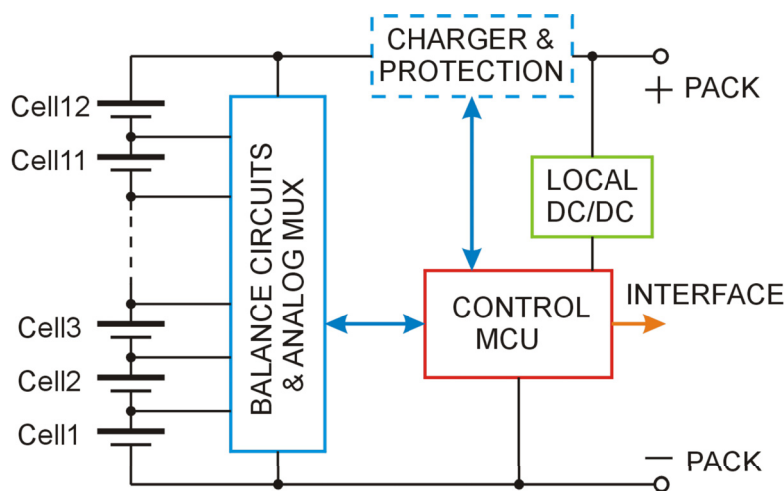


Figure 1. Block schematic

The energy transfer is based on the inductive storage element. The energy is accumulated into inductance by the MOSFET switch from the strong cell, and in the next cycle it is released into the closest weak cell. The amount of the transferred energy in one step depends mainly on the final application—it depends on the discharge current and the required cell-balancing speed. In accordance with these requirements, the inductor, its maximum current, and other circuit element parameters must be selected.

For this application, the battery pack consists of 12 NiMH cells with a nominal capacity of 1700 mAh. The maximum load current of the application is 500 mA. The balancing is active during the charging period, to maintain an equal state of charge (SOC) for each cell at the end of charge. The application is used daily, so that different discharges due to the different leakage currents of the cells are not important. The balancing is active in the discharge period too, so this circuit maintains an equal discharge for each cell, both strong and weak. The energy from the strong cells is transferred into the weak cells.

4 Description

A detailed schematic of the cell balancing circuitry in the center of the battery pack is shown in [Figure 2](#).

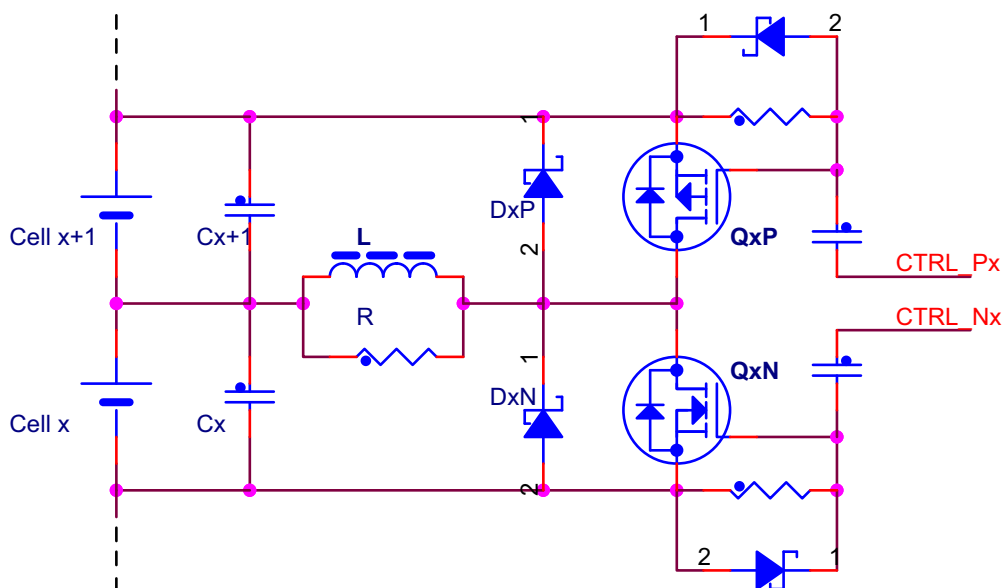


Figure 2. Balancing circuitry

The selected power inductor, L, is 33 uH / 1.4 A max, and the power MOSFETs are P + N type in one SOIC-8 package with a max current of 7 A. The max charged NiMH cell's voltage is 1.38 V. These values give us the max switch time for the inductor charge:

$$dt = (L * dl) / dU = (33 \mu H * 1.4 A) / 1.33 V = 35 \mu sec \quad \text{Eqn. 1}$$

The voltage drop on the switched-on MOSFET is about 50 mV. In the next cycle, the inductor discharges through the Schottky diode, connected in parallel to the body diode of the MOSFET and to the upper cell of the battery. The discharge time is a bit shorter due to the higher voltage drop on the Schottky diode.

$$dt = (L * dl) / dU = (33 \mu\text{H} * 1.4 \text{ A}) / (1.38 \text{ V} + 0.4 \text{ V}) = 26 \mu\text{sec} \quad \text{Eqn. 2}$$

To improve the energy transfer efficiency, the power MOSFET in parallel to the opened Schottky diode is switched on for 25 μsec . This action eliminates the voltage drop on the Schottky diode and the efficiency is higher—about 92%. A higher efficiency can be reached when the lithium-based cells are balanced.

The whole designed balancer uses a dedicated integrated circuit for the cells' voltage measurements, simple on/off switches for the MOSFET's gates driven by a 5-V voltage level, and the Freescale ColdFire V1 MCF51JM128 microcontroller for overall control. The nominal battery voltage is 14.5 V and all the control circuits are powered by the small DC-to-DC converter with a 5-V output voltage level.

The MCF51JM128 MCU was selected for this design because of the external peripherals that it offers: serial or USB, good ADC properties for the temperature measurement of each cell, good PWM module properties for the charger control implementation, and high computing power to manage all these tasks. The serial interface can be used for connection at a higher system level.

The MCF51JM128 features the following functional units:

- V1 ColdFire core with background debug module
- Up to 128 KB of flash memory
- Up to 16 KB of static RAM (SRAM)
- Multipurpose clock generator (MCG)
- Dual-role Universal Serial Bus On-The-Go device (USBOTG)
- Controller-area network (MSCAN)
- Cryptographic acceleration unit (CAU)
- Random number generator accelerator (RNGA)
- Analog comparators (ACMP)
- Analog-to-digital converter (ADC) with up to 12 channels
- Two Inter-integrated circuit (IIC) modules
- Two serial peripheral interfaces (SPI)
- Two serial communications interfaces (SCI)
- Carrier modulation timer (CMT)
- Eight-channel timer/pulse-width modulators (TPM)
- Real-time counter (RTC)
- 66 general-purpose input/output (GPIO) modules plus interrupt request input
- Eight keyboard interrupts (KBI)
- 16-bit rapid GPIO

5 Summary of requirements for control

The requirements for control are split into two main sections:

1. Requirements for the charging state:
 - a) Control the charging process

- b) Avoid overcharging any cell
 - c) Balance the cells during the charge state
 - d) Check the battery temperature
2. Requirements for the discharging state:
- a) Limit the max output current of the battery pack
 - b) Avoid deeply discharging any cell
 - c) Balance the cells during discharge
 - d) Check the battery temperature

The battery charger and protection circuitry are not implemented in this design example. The control MCU provides a sufficient amount of resources for control in this area.

The analog multiplexer performs the voltage measurement of each cell and provides this information to the control MCU. The MCU runs a dedicated algorithm for correctly selecting a strong and weak cell, and determines which cell must be charged to equalize the SOC of all the cells. The maximum and the minimum cell voltages are checked simultaneously. If all the cells are fully charged, the control MCU switches off the charging state.

For the discharge state, the MCU periodically checks the voltage of each cell and the temperature of the whole battery. The current sourced from the battery is checked only if the protection module is included. This protection avoids a short circuit or an overcurrent condition of the whole battery pack. As in the charging state, the individual cell voltages are checked periodically. All values are compared and the weaker cells are charged. This algorithm equalizes the discharge state of all the cells to provide the most available power from the battery pack. If most of the battery cells are at the low voltage limit, the MCU sends a warning signal through the external interface.

This type of control of the charge distribution between all battery cells maintains the longest lifetime of the whole battery, maintains that the battery is charged with the highest amount of energy, and ensures that the battery can release the full energy to the appliance.

6 Design example

The hardware and software design example was made to check the properties of this battery balancing solution (see [Figure 3](#)). With the aforementioned value of the transfer inductance, $L = 33 \mu\text{H}$, the energy transfer runs at about 16 kHz. This design is able to equalize a 5% difference of one cell within 15 minutes. This is the result of the simplest charge transfer—from one strong cell to one adjacent weak cell. It is very simple to improve the balancing speed by using a higher power inductance. The switching capability of the MOSFETs is sufficient. It is possible to improve the balancing speed further by using control software that balances more than one cell simultaneously.

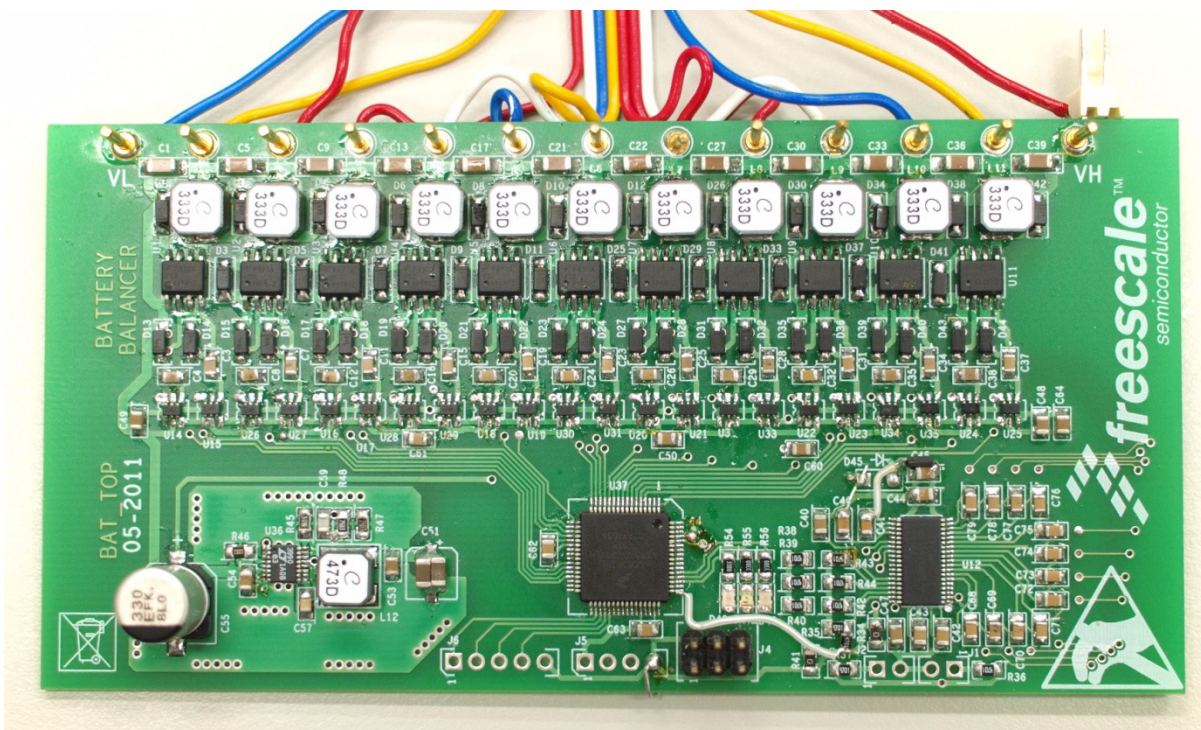


Figure 3. Balancer

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