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Selection of the MOSFET for Faster Cell Balancing of Li-Ion Batteries

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Table of contents

1 Introduction

In multi-cell battery packs, no two cells are identical. There is always a slight difference in the state of charge (SOC), capacity, impedance and temperature characteristics even with cells from the same manufacturer. These differences increase over the battery lifetime. By implementing cell balancing circuits these differences can be reduced significantly. This application note focuses on the selection of the MOSFETs for the cell balancing of Li-ion batteries.

2 Cell balancing

Cell balancing is considered when multiple cells in a battery pack are connected in series. Cell balancing is not needed in parallel connected Li-Ion cells since this configuration is self-balancing. In a battery pack, cells are balanced when all the cells in the pack have the same voltage per cell whilst in a fully charged or discharged state. If one or more of the cells in a pack are not matched then the battery pack is not balanced. In an unbalanced stack, the usable capacity is significantly lower compared to the nominal capacity.

The impact of cell imbalance on run-time performance and battery life in applications using series connected cells is certainly undesirable. The fundamental solution of cell balancing equalizes the voltage and SOC among the cells.

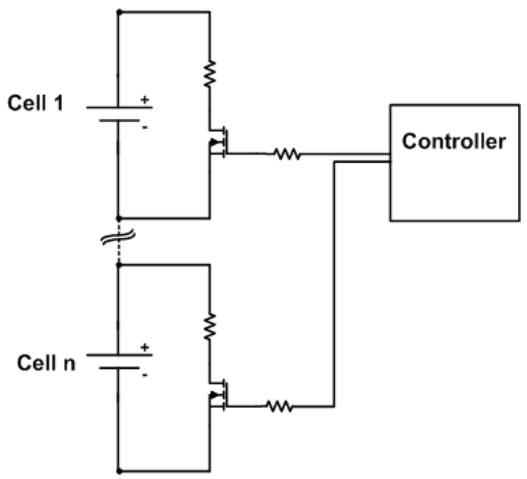

Figure1: Simplified cell balancing set up

A simple implementation of cell balancing is using a MOSFET and a resistor placed in parallel with each cell to discharge it or bypass a part of the charging current of the cells that are needed to be balanced. This method is also called “resistor bleeding balancing”. These circuits are controlled by a comparator for simple voltage based algorithms. Figure1 above illustrates a simplified cell balancing set up using bypass MOSFETs. The main task here is to select a MOSFET. The MOSFET should have as small a footprint as possible so that it occupies minimum space on the PCB. And it should have as low power dissipation as possible so that it bypasses sufficient current to balance the cell in reasonable time without heating up.

3 Implementation of cell balancing

Individual cell voltage must be monitored to allow cell balancing. When the cell-to-cell voltage variation is greater than a specific value, the cell balancing circuitry is enabled that gradually matches the voltages of the individual cells. As stated above, the MOSFET along with a series resistance bypasses a part of the current around the cell.

During charging of the battery pack when the MOSFET is turned on, it bypasses the current around the cell. This forces the cell to charge at a slower rate than the other cells in the pack. During discharge of the battery pack when the MOSFET is turned on, it acts as an extra load to the cell which forces the cell to discharge faster than the other cells in the pack. Figure2 illustrates an example of a cell balancing circuit for a single cell in the battery pack.

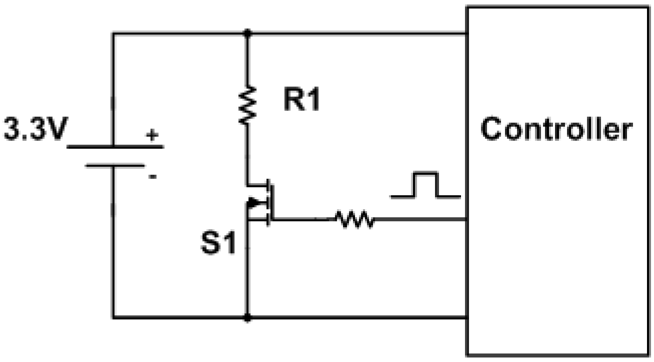

Figure2: Example of cell balancing module

There are three considerations which determine the bypass current used to balance the cell: the amount of cell imbalance, balance time and cell capacity. A reasonable amount of cell balancing is 10 % to 20% of capacity and a minimum time available for cell balance is one charge/discharge period and can be extended over multiple charge/discharge cycles.

For example, consider a cell of 2.3Ah capacity has an imbalance of 20% and has to be balanced in 1 hour then the bypass current can be calculated by:

$$I_{bypass} = \frac{\mathrm{Im}balance \times Capacity}{Balancingtime} = \frac{0.2 \times 2.3Ah}{1.0h} = 0.46A$$

To bypass this current at a nominal cell voltage of 3.3V, the loss in bypass path is around 1.5W. Even if the $R_{DS(on)}$ of the MOSFET (S1) is considered as negligible, the series resistance (R1) has to dissipate all of the energy. Thus the size of the resistor will be very big. So there is a trade-off between balancing time and the resistor size. Figure3 illustrates the relationship between R1, balancing time and bypass current of a 2.3Ah, 3.3V Li-Ion cell.

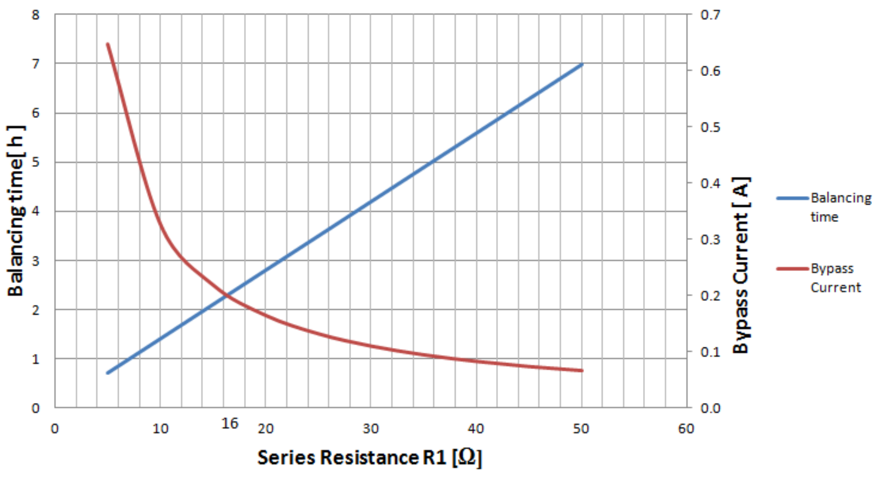

Figure3: Series resistance vs. balancing time of a 2.3Ah, 3.3V Li-Ion cell

4 Selection of the MOSFET

The important factor that has to be considered in selecting a MOSFET for cell balancing is space occupied. The MOSFET has to occupy minimum space on the board as most of the time the balancing circuit is mounted on the battery pack itself.

In the above section, it is considered that the $R_{DS(on)}$ of the MOSFET is negligible. This is not the case in practice; there will be a significant amount of on-resistance. Thus there will be losses in the MOSFET. Due to this power dissipation in MOSFETs with small footprints, the chip temperature can increase to dangerous levels. Thus the selected MOSFET for the circuit should have low on-resistance so that it has low power dissipation which in turn has a low temperature rise at the junction. Therefore, a low ohmic part with a small footprint is desirable.

Infineon's new 60V, 60mΩ Small Signal OptiMOS™ 606 family is Best-in-class $R_{DS(on)}$ for the given footprint - available in space saving TSOP-6, SOT-89 and SC59 packages. The low $R_{DS(on)}$ makes the OptiMOS™ 606 family suitable for cell balancing in Battery Energy Control Modules (BECM). Also the 4.5V Logic Level gate enables it to be easily interfaced directly with MCUs/Digital circuits.

As all the products are qualified to AEC Q101, they are ideally suitable for automotive and high quality demanding applications.

Table1 below illustrates the Small Signal OptiMOS™ 606 product portfolio.

	Package	V_{DS} [V]	$R_{DS(on)\ max}$ [mΩ] (V_{GS}=10V)	$R_{DS(on)\ max}$ [mΩ] (V_{GS}=4.5V)	$I_{D(max)}$ [A]	$V_{GS(th)\ max}$ [V]	$Q_{g(max)}$ [nC]
BSS606N	SOT-89	60	60	90	3.2	2.3	6.1
BSL606SN	TSOP-6	60	60	95	4.5		
BSR606N	SC59	60	60	90	2.4		

Table1: Small Signal OptiMOS™ 606 product portfolio

In order to understand the benefits of an OptiMOS™ 606 MOSFET in cell balancing the losses in the circuit are calculated and shown below.

Consider a series resistance R1=3.3 Ω is used to balance a 2.3Ah cell with a nominal voltage of 3.3V. It is also assumed that BSL606SN is used in the circuit and is driven by a 4.5V gate drive power supply. Thus the bypass current I_{bypass} in the balancing circuit is given by:

$$I_{bypass} \approx \frac{V_{batt,nom}}{R1 + R_{DS(on)}} = \frac{3.3V}{3.3\Omega + 0.095\Omega} \approx 1A$$

Thus the losses in the MOSFET S1 are:

$$P_{Losses,S1} = I_{bypass}{}^{2} \cdot R_{DS(on)}$$

$$P_{Losses,S1} = 1^{2} \times 95 \times 10^{-3} \approx 95mW$$

Assume, the ambient temperature is 85°C and the MOSFET is assembled on epoxy PCB FR4 with minimal footprint. The temperature rise at the junction of the MOSFET S1 is:

$$\Delta T = (P_{Losses,S1} * R_{thJA})$$

$$\Delta T = 95 \times 10^{-3} W \times 230 K/W \approx 22K$$

With this temperature rise, the junction temperature of the MOSFET at 85°C of ambient will be around 107°C.

5 Summary & conclusion

It is clear from the calculations above, that even with very fast cell balancing the temperature rise is still within the limits thanks to the lower power dissipation of BSL606SN.
By using any of the OptiMOS™ 606 family for this application typically 20% of the board space can be saved in comparison to existing solutions. This gives the flexibility to reduce the series resistance and in turn decrease the balancing time within the existing board space.