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USB charging solution for 2-cell (2S) discrete using BQ25887 with cell-balancing function

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ABSTRACT

As the market continues to demand higher-performance electronics, the need for increased system power rises as well. A two-cells-in-series (2S) battery configuration is a good solution to this problem. Using a 5-V USB adapter to charge a 2S battery enables you to use the same adapter across products and increases cost savings. However, in order to maximize the benefits of a 5-V USB and 2S configuration, cell balancing is required.

Cell-balancing is essential due to the potential differences in cell voltage; this is especially true in applications with replaceable individual battery cells. In such cases, the higher-voltage cell is at risk of overcharging and the lower-voltage cell is underutilized.

This application report introduces the BQ25887, an I2C-controlled 2-cell 2-A boost-mode battery charger with a novel cell-balancing function. This report also provides a design example illustrating an implementation of the cell-balancing function.

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1 Introduction

In 2S battery applications with one or two replaceable cells, the battery cells can have very different voltages because replacement batteries can come from anywhere, at any state of charge. Traditional multi-cell chargers only monitor the total voltage of series-connected cells; the charger does not measure each individual cell voltage. Consequently, even though the total voltage of series-connected cells does not reach the regulation voltage, the cell with the higher voltage may overcharge due to unbalancing of the cells. Overcharging battery cells not only shortens battery life but can also cause serious safety concerns. On the other hand, the cell at the lower voltage cannot fully charge, which means that its full capacity is not completely utilized. Therefore, cell-balancing becomes essential during battery charging in this type of 2S battery application.

The BQ25887 boost charger has a cell-balancing function that charges 2S battery cells from a 5-V USB adapter. Unlike traditional pack-side cell-balancing, an integrated cell-balancing function enables the charger to balance the voltage of the two cells during charging within one charge cycle. With the integration of input current- and voltage-limiting functionality, along with an input current limit optimizer, the BQ25887 can detect the current capability of unknown adapters, enabling the device to universally charge with any 5-V adapter.

2 The BQ25887 Cell-Balancing Algorithm

The BQ25887 balances cells during charging. Charge current to the cell with the higher voltage is reduced while the charge current to the cell with the lower voltage is kept at the full charge current setting. With this architecture, the lower voltage cell can charge up without waiting for the cell with the higher voltage to discharge.

Figure 1 illustrates the implementation of two field-effect transistors (FETs) to switch the current bypass on and off to each cell. The circuit shown in Figure 1a illustrates the case where VCELL1 > VCELL2, while the circuit in Figure 1b shows VCELL1 < VCELL2.

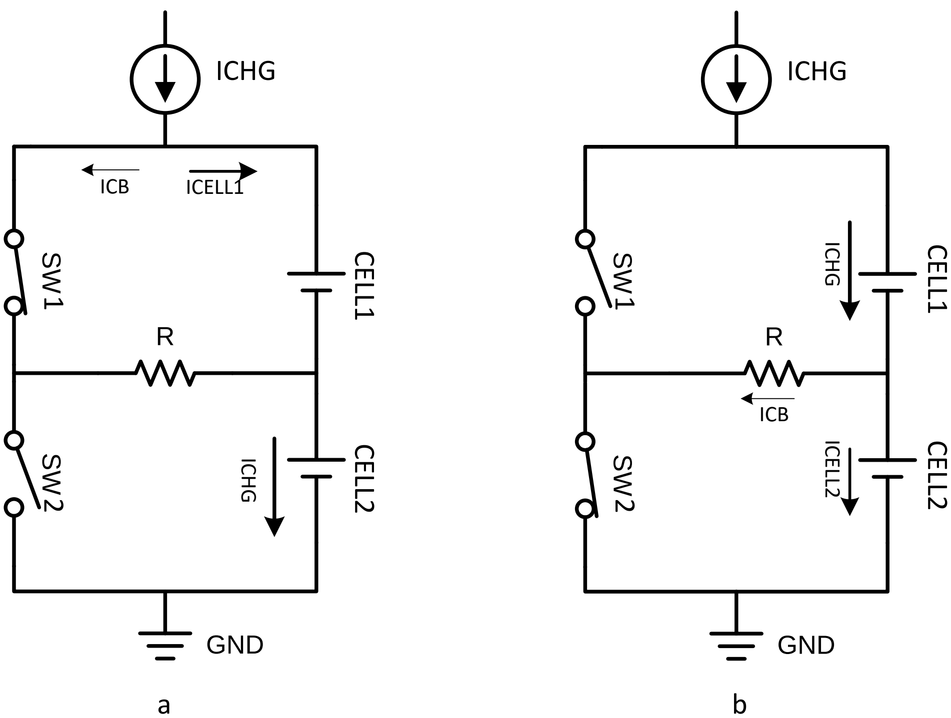


Figure 1. Simplified Cell-Balancing Diagram and Current Illustration Where VCELL1 > VCELL2 (a); and VCELL1 < VCELL2 (b)

In Figure 1:

- ICHG is the charge current source.
- ICB is the bypassing current to the higher voltage cell which is limited by resistor R. The bypassing current is a function of the corresponding cell voltage. For instance, if VCELL1 is greater than VCELL2, ICB = VCELL1/R. The maximum bypassing current limit is reached when VCELL1 reaches its regulation voltage.
- ICELLx is the reduced charge current to the cell with the higher voltage. ICELLx = ICHG - ICB. Therefore, ICELLx is also a function of cell voltage, but inversely. As the cell voltage increases, ICELLx reduces.

Based on the architecture described above, the BQ25887 enables antonymous cell-balancing by default. The device incorporates a cell-balancing algorithm illustrated in Figure 2.

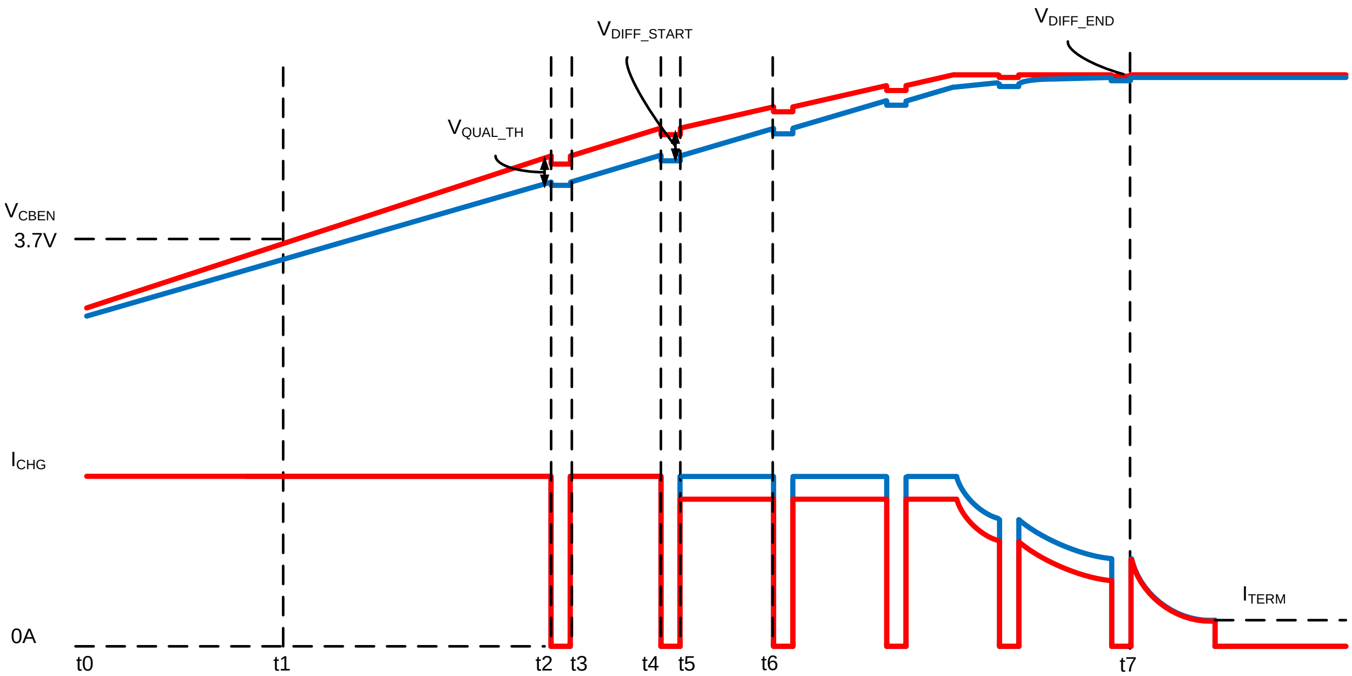


Figure 2. BQ25887 Cell-Balancing Timing Diagram – Entering Pre-Qualification and Qualification Modes

In Figure 2:

- [t0:t1] – Cell-balancing circuitry is off.
- [t1:t2] – Pre-qualification mode. Charge is continuous during cell-balancing measurements.
- [t2:t5] – Qualification mode. Charge is suspended during cell-balancing measurements.
- [t2:t3] – Total time of battery voltage settlement time and cell voltage measurement time.
- [t3:t4] – Internal time between cell voltage measurements in pre-qualification and qualification modes.
- [t4:t5] – Total time of battery voltage settlement time and cell voltage measurement time.
- [t5:t6] – Internal time between cell voltage measurements in cell-balancing active mode.
- [t5:t7] – Cell-balancing active mode where charge current to higher-voltage cell is reduced.

The cell-balancing circuitry turns on when one of the cell voltages reaches 3.7 V. The BQ25887 starts to compare voltage measurements of the two cells, putting the device into pre-qualification mode.

The cell voltage measurements are taken in a time interval at the same value as [t3:t4], while the charge current remains continuous. The device compares the cell voltage difference with V_{QUAL_TH}. If the cell's voltage difference is greater than V_{QUAL_TH}, then the device enters qualification mode. In qualification mode, the integrated circuit (IC) suspends charging in the next measurement interval in order to take a more accurate cell voltage measurement. Due to the characteristics of lithium-based batteries, a settlement time is implemented to stabilize the battery voltage after suspending charging for cell voltage measurements. The measurement time interval is kept at $T_{CB\_QUAL\_INTERVAL}$.

Once the measured voltage difference between the two cells exceeds the V_{DIFF_START} threshold in qualification mode, cell-balancing is active. The corresponding FET switch turns on to bypass charge current to the cell with the higher voltage. During cell-balancing active mode, the cell voltage measurement is taken in time interval [t5:t6]. Both charge and cell-balancing are turned on for the time period of [t5:t6] and then turned off for cell voltage measurement. Implementing the battery settlement time in cell-balancing active mode obtains a more accurate cell voltage measurement result. When the measured voltage difference between the two cells is less than V_{DIFF_END}, cell-balancing is complete and the device exits cell-balancing active mode.

In addition to the antonymous cell-balancing routine, the BQ25887 also integrates a 16-bit analog-to-digital converter (ADC); I2C can enable and read both which both top-cell and bottom-cell voltage ADC conversion can be enabled and read through I2C. You can use the cell voltage information for simple estimations of battery capacity.

To enable the ADC, set the ADC_EN bit to 1 in REG0x15[7] and set VCELL_ADC_DIS to 0 in REG0x16[1]. The ADC value of the top cell voltage is reported in REG0x1F to REG0x20 and the bottom cell voltage is reported in REG0x26 to REG0x27.

Charge can be enabled during cell-balancing measurements for faster charging times. In this case, setting CB_CHG_DIS in REG0x2A[7] to 1 achieves continuous charging during cell-balancing active mode.

The BQ25887 also implements a manual cell-balancing mode where you can build an even more customized cell-balancing program according to your application requirements. In manual cell-balancing mode, the cell-balancing discharging FETs, Q_{CBH} and $Q_{CBL,}$ can be enabled through the Q_{CBH_EN} and Q_{CBL_EN} bits. Only one of these bits can be selected at a time. Q_{CBH} and Q_{CBL} can only be enabled when charge is enabled and CB_EN is set to 0.

Cell-balancing status is reported in the CB_STAT register to indicate whether the device is in cell-balancing active mode. HS_CV_STAT and LS_CV_STAT report if the top cell or bottom cell is in a constant voltage phase. For fault conditions, HS_OV_STAT and LS_OV_STAT show overvoltage conditions, and CB_OC_STAT reports the detection of an overcurrent condition at Q_{CBH} or Q_{CBL}.

3 Design example

For a BQ25887 cell-balancing design example, see the parameters shown in Table 1. The charge current is set to 800 mA and the cell regulation voltage is set to 4.2 V. For examples of other charge-related design parameters, see the *Typical Application* section in the BQ25887 data sheet (SLUSD89).

Table 1. Cell-Balancing Design Parameters

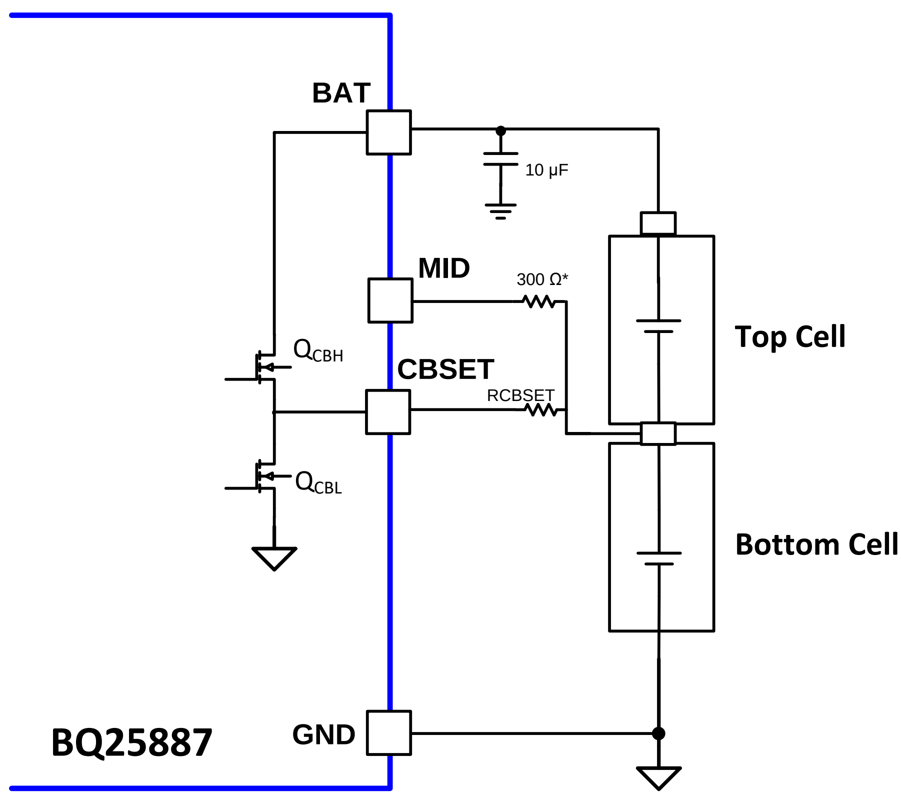
Parameter	Value
Maximum cell-balancing current	300 mA
Voltage difference in pre-qualification mode where charge is continuous	100 mV
Time interval for voltage measurement in pre-qualification mode	2 min
Voltage difference to turn on Q_{CBX} starting cell-balancing	80 mV
Voltage difference to exit cell-balancing	10 mV
Time interval for voltage measurement in cell-balancing active mode	2 min
Battery voltage settlement time before voltage measurement	1 s

3.1 Cell-Balancing Current Limit Resistor Selection

The BQ25887 implements the cell-balancing architecture with a recommended maximum bypassing current of 400 mA. In addition, the device also implements a remote sense point for more accurate cell voltage sensing. The high-side cell voltage is sensed between the BAT and MID pins, and the low-side cell voltage is sensed between the MID pin and GND. Bypassing the charge current through the external balancing resistor, RCBSET, reduces the charge current to the higher-voltage cell.

Equation 1 calculates the value of R_{CBSET}, where VREG is the cell regulation voltage and ICB_MAX is the maximum cell-balancing current.

$$RCBSET = \frac{VCELLREG}{ICB\_MAX} - RDSON\_QCBX \quad (1)$$



*Note: The 300-Ω resistor on the MID pin is used to limit the current in cases where the bottom cell is plugged in reversely

Figure 3. BQ25887 Application Diagram

Using Equation 1, R_{CBSET} can be calculated as:

$$RCBSET = \frac{4.2V}{300mA} - 1\Omega = 13\Omega \quad (2)$$

The cell-balancing current is limited by the external R_{CBSET}. Select R_{CBSET} with power rating in mind to ensure that it is sufficient for the maximum cell-balancing current. For a 300-mA cell-balancing current, consider connecting multiple power resistors in parallel, such as six 82-Ω resistors (1205, 0.25 W).

3.2 Cell-Balancing Register Setup

Set up cell-balancing registers REG0x28 to REB0X2C to follow Table 2 through Table 6 and the design specifications in Table 1.

Table 2. REG28 Register

Bit	Value	Field
7	VDIFF_END_OFFSET[2:0] = 100	Voltage difference to exit cell-balancing = VDIFF_START - VDIFF_END_OFFSET
6		
5		
4	TCB_QAUL_INTERVAL = 0	Time interval for voltage measurement in pre-qualification mode
3	TCB_ACTIVE[1:0] = 10	Time interval for voltage measurement in cell-balancing active mode
2		
1	TSETTLE[1:0] = 10	Battery voltage settlement time before voltage measurement
0		

Table 3. REG29 Register

Bit	Value	Field
7	VQUAL_TH[3:0] = 0110	Voltage difference in pre-qualification mode where charge is continuous
6		
5		
4		
3	VDIFF_START[3:0] = 0100	Voltage difference to turn on $Q_{CBX,}$ starting cell-balancing
2		
1		
0		

Table 4. REG2A Register

Bit	Value	Field
7	CB_CHG_DIS = 1	Disable charging for cell voltage measurement
6	CB_AUTO_EN = 1	Enable automatic cell-balancing
5:0	Status registers = read only	Status register indicates cell-balancing status

Table 5. REG2B Register

Bit	Value	Field
7	QCBH_EN = 0	Enables Q_{CBH} in manual mode
6	QCBL_EN = 0	Enables Q_{CBL} in manual mode
5:0	FLAG registers = read only	LAG register bit is cleared upon read.

Table 6. REG2C Register

Bit	Value	Field
7:6	Reserved = 0	Reserved bit always reads 0h
5	CB_MASK = 0	Device sends out INT pulse when entering cell-balancing active mode
4	HS_CV_MASK = 0	Device sends out INT pulse when the top cell enters CV mode
3	LS_CV_MASK = 0	Device sends out INT pulse when the bottom cell enters CV mode
2	HS_OV_MASK = 0	Device sends out INT pulse when a top cell over-voltage fault occurs
1	LS_CV_MASK = 0	Device sends out INT pulse when a bottom cell over-voltage fault occurs
0	CB_OC_MASK = 0	Device sends out INT pulse when a Q_{CBX} over-current fault occurs.

3.3 Test results

Figure 4 and Figure 5 show the test results.

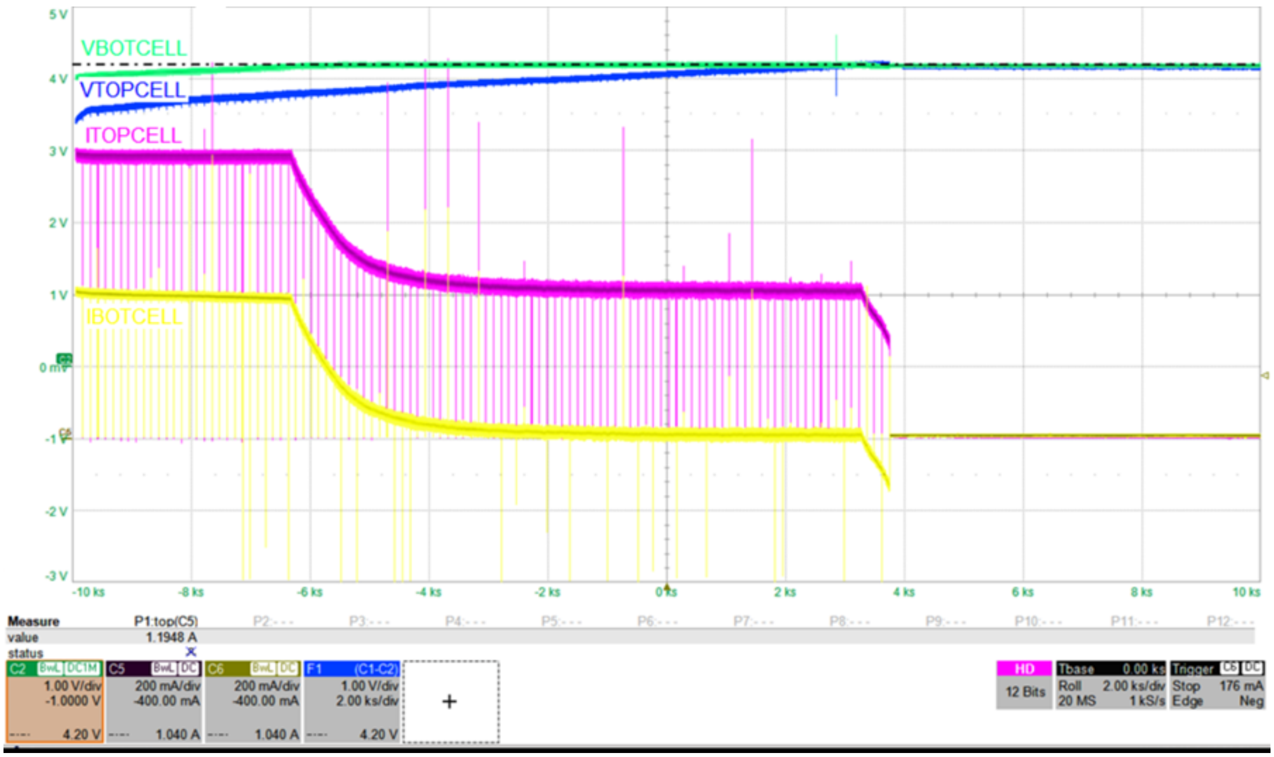


Figure 4. Charge Cycle with the Bottom Cell Voltage Higher Than the Top Cell Voltage

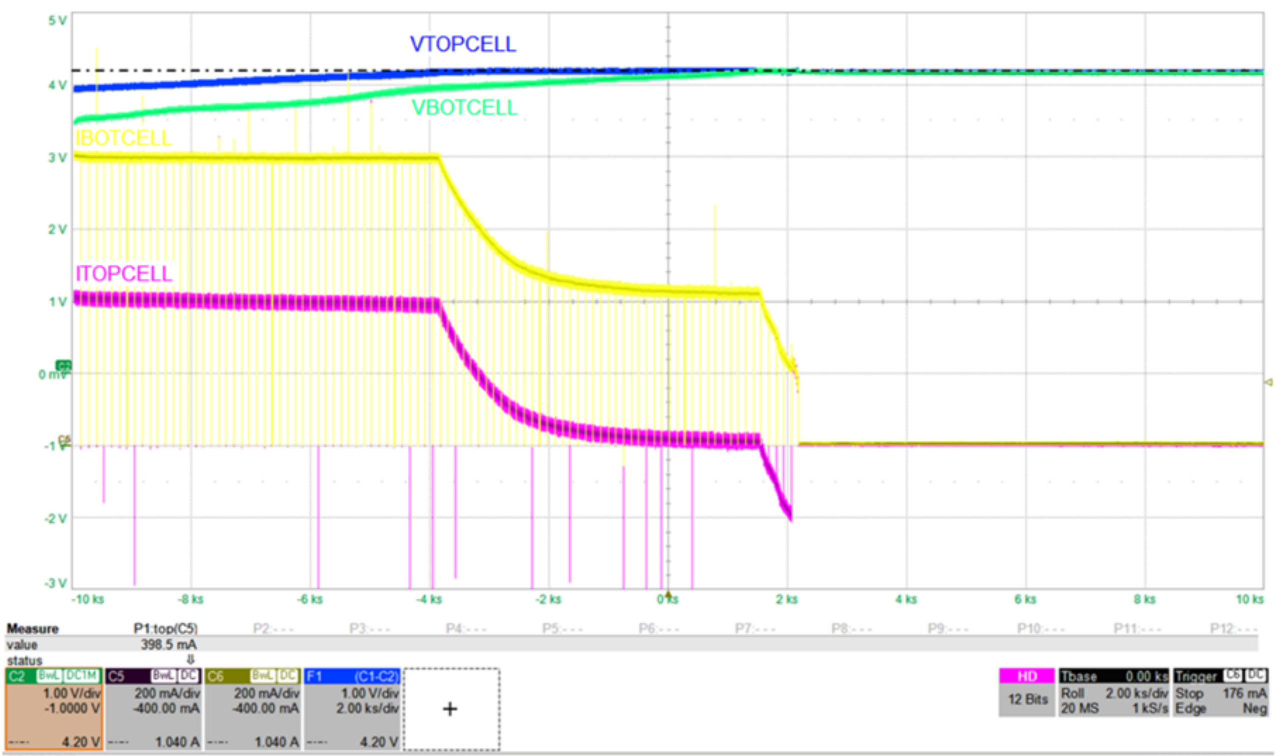


Figure 5. Charge Cycle with the Top Cell Voltage Higher Than the Bottom Cell Voltage

4 Summary

The BQ25887 integrates a cell-balancing algorithm that automatically starts and completes cell-balancing when cell voltage conditions are met. The cell-balancing circuit is easy to design; parameters can be programmed through user registers, enabling the cell-balancing feature to be more flexible for different application needs.

The 400-mA maximum cell-balancing current enables fast balancing time between two unmatched cells with integrated metal-oxide semiconductor field-effect transistors. The integrated ADC monitoring each cell voltage can also be used for simple voltage-based cell capacity estimation. The BQ25887's cell-balancing function is powerful yet easy to use for applications with discrete 2S battery cells.

5 References

- BQ25887 Data sheet SLUSD89