AN12536

Using MC33771 with less than 14 cells

Rev. 1 — 30 October 2019 Application note

1 Introduction

The document applies primarily to MC33771A, MC33771B, MC33771C, and MC33772B devices. These devices are SMARTMOS lithium-ion battery cell controller IC designed for automotive and industrial applications. Automotive application examples include hybrid electric vehicles (HEV) and electric vehicles (EV). Industrial application examples include energy storage systems (ESS) and uninterruptible power supply (UPS) systems.

MC33771A, MC33771B, and MC33771C devices can manage up to 14 cells. When fewer than 14 cells are connected to the cell controller IC, there are connection options for the unused cell controller inputs. This document describes the connection options and makes recommendations on the option selection for a given application.

The most relevant difference between the MC33771A, MC33771B, and MC33771C is the integrated averaging functionality available on the MC33771C. This functionality allows the cut-off frequency of the external anti-aliasing filter to be relaxed. A smaller, dominant time constant of the filter reduces the diagnostic times.

Similar to the MC33771B device, the MC33772B device manages up to 6 cells. When fewer than 6 cells are used with MC33772B devices, the same constraints for the MC33771B apply. For the MC33772B, cell terminals CT_3 to CT_5 must be used for not connected cell circuitry. For MC33771B, cell terminals CT_5 to CT_11 must be used for not connected cell circuitry.

2 Constraints

When defining the correct external circuit for the cell terminal input voltages, some constraints must be considered:

- **Anti-aliasing filter:** The ADC inputs are sampled with a certain frequency. Depending on communication constraints, and on usage of the internal averaging of the MC33771C, the sampling intervals can be between 520µs and 5 ms or even more. To avoid aliasing, some anti-aliasing filters are needed. The anti-aliasing filter is typically a one stage or two stage RC filter. Based on the sampling speed of the system, a minimum RC time constant is needed. The higher the RC constant, the lower the aliasing noise.
- **Diagnostic times:** For functional safety reasons, most BMS systems must perform some system integrity checks. These checks include the validation of the connectivity between the cell terminal pins and the IC pins. To execute the check, the voltage at the cell terminal must be manipulated. To allow a fast execution, a small external RC constant is better.
- **Leakage currents in the IC:** The way the internal circuit of the IC is designed results in some leakage currents at the cell terminal inputs. Together with the anti-aliasing filter, this leakage current may cause an error in the voltage measurement . The lower the filter resistance, the lower the voltage measurement error. See the parameter *Cell*

terminal input leakage current ($CTn_{(LEAKAGE)}$) in electrical characteristics section of the data sheet.

- **System cost:** For the cell input filter circuitry, typically the filter capacitors play an important role. The filter caps are cheaper when the capacitors are smaller.
- **Hot Plugging:** When the system is connected to the battery for the first time, all capacitors on the PCB must be charged. As the connection can happen in any order, there can be some stress to the pins of the IC. Larger resistors values are better. The larger the charge, the more likely that a component becomes overstressed.
- **Voltage constraints:** In case the system does not use all the 14 cells, some cell terminals are unused. Terminals CT_REF to CT_4 and CT_11 to CT_14 should always be used. The terminals CT_5 to CT_10 can be skipped.

Table 1. Constraints

Value of resistor or capacitor	Resistor	Capacitor
Higher value	Stronger anti-aliasing filtering Higher hot plugging robustness	Stronger anti-aliasing filtering Smaller hot plugging robustness
Lower value	Shorter diagnostic times Smaller impact of leakage currents in the IC	Shorter diagnostic times Lower system cost

Table 1 summarizes the impact the individual factors have on component choices. The constraints result in conflicting requirements and trade-offs must be made. Recommendations for the external components are provided in the specific device data sheets.

3 Connection options

Even with the constraints, numerous connection options are available. A short list of options is presented in this section.

3.1 Filter type A - Performance

Figure 1 is the schematic from the MC33771C data sheet. Filter type A uses a single input filter to connect unused terminals. The leakage currents of all unconnected cells are conducted into this filter and separated from the used terminals.

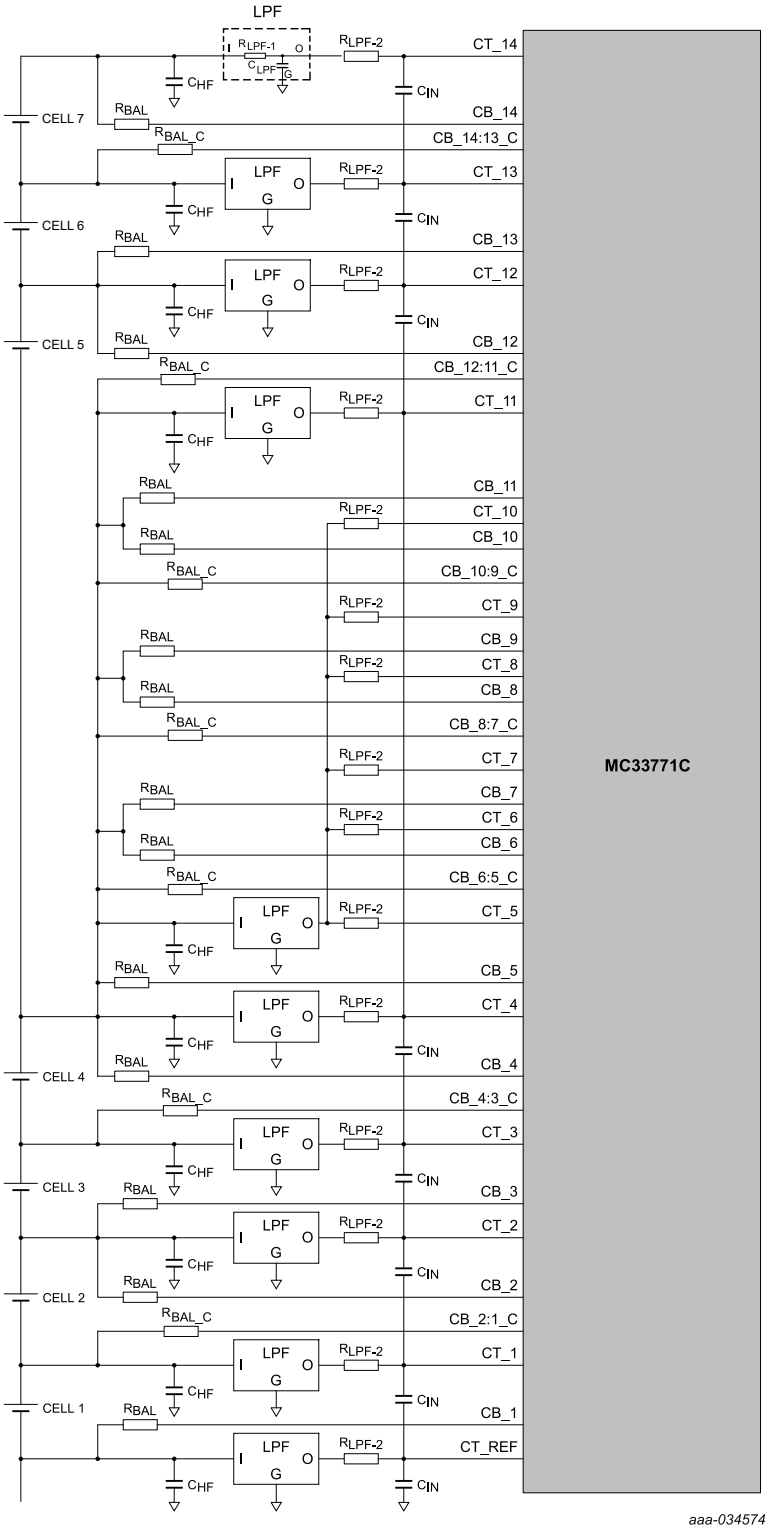

Figure 1. Filter type A configuration with seven cells

3.2 Filter type B - Cost optimized

Figure 2 is an alternative schematic to the one shown in the data sheet. Type B does not use a separate input filter but connects the *unused* cells to *used* cells. Compared with filter type A, two filter circuits are eliminated in filter type B. The leakage current from the unused cells generates some error in the voltage measurement. The schematic uses only one resistor for the R_{LPF-2} for the unused cells. Type B filter circuits result in lowest BOM costs of the system.

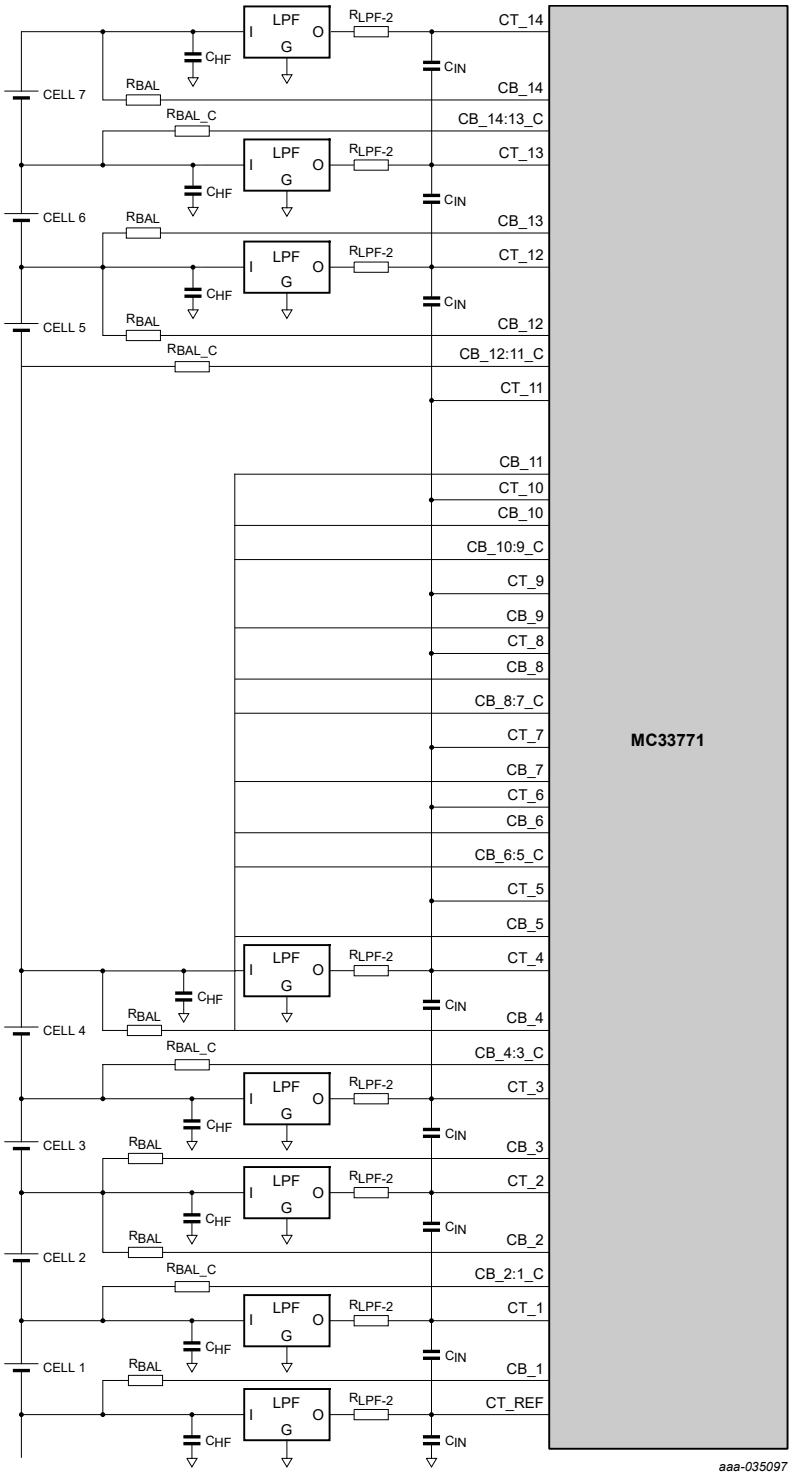

Figure 2. Filter type B for MC33771

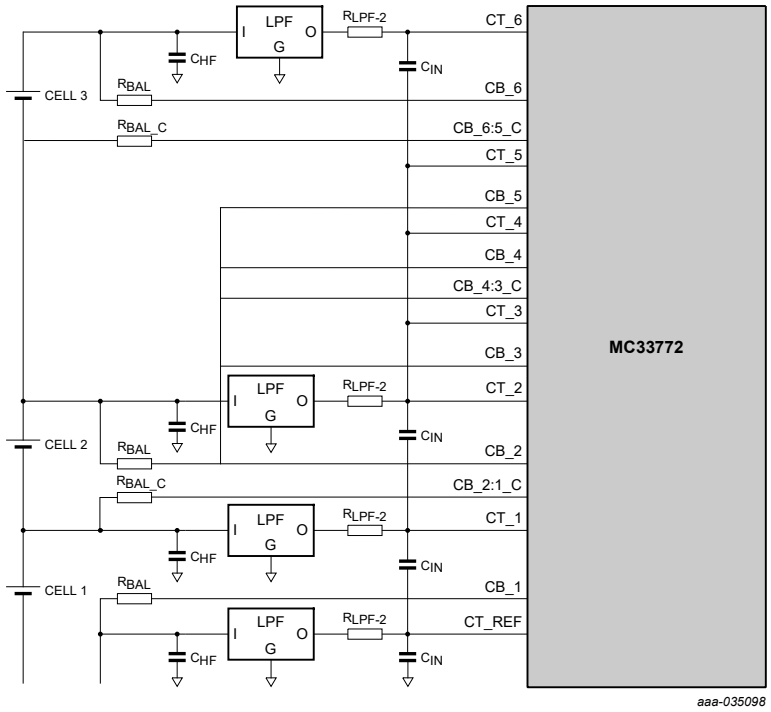

Figure 3. Filter type B - for MC3372B

3.3 Filter type C - Full population

Figure 4 utilizes the full population of all filters. This connection is very simple, but requires population of many components that are not needed. Each cell terminal has its own filter so there is no impact of leakage currents on the accuracy. However, around unused cells, several input filters are connected in parallel. The parallel filters lead to longer diagnostic times. This method does not produce performance or system costs benefits. The configuration still has an advantage; it is very flexible. By adapting the connector, it is possible to address several battery cell configurations with the same PCB.

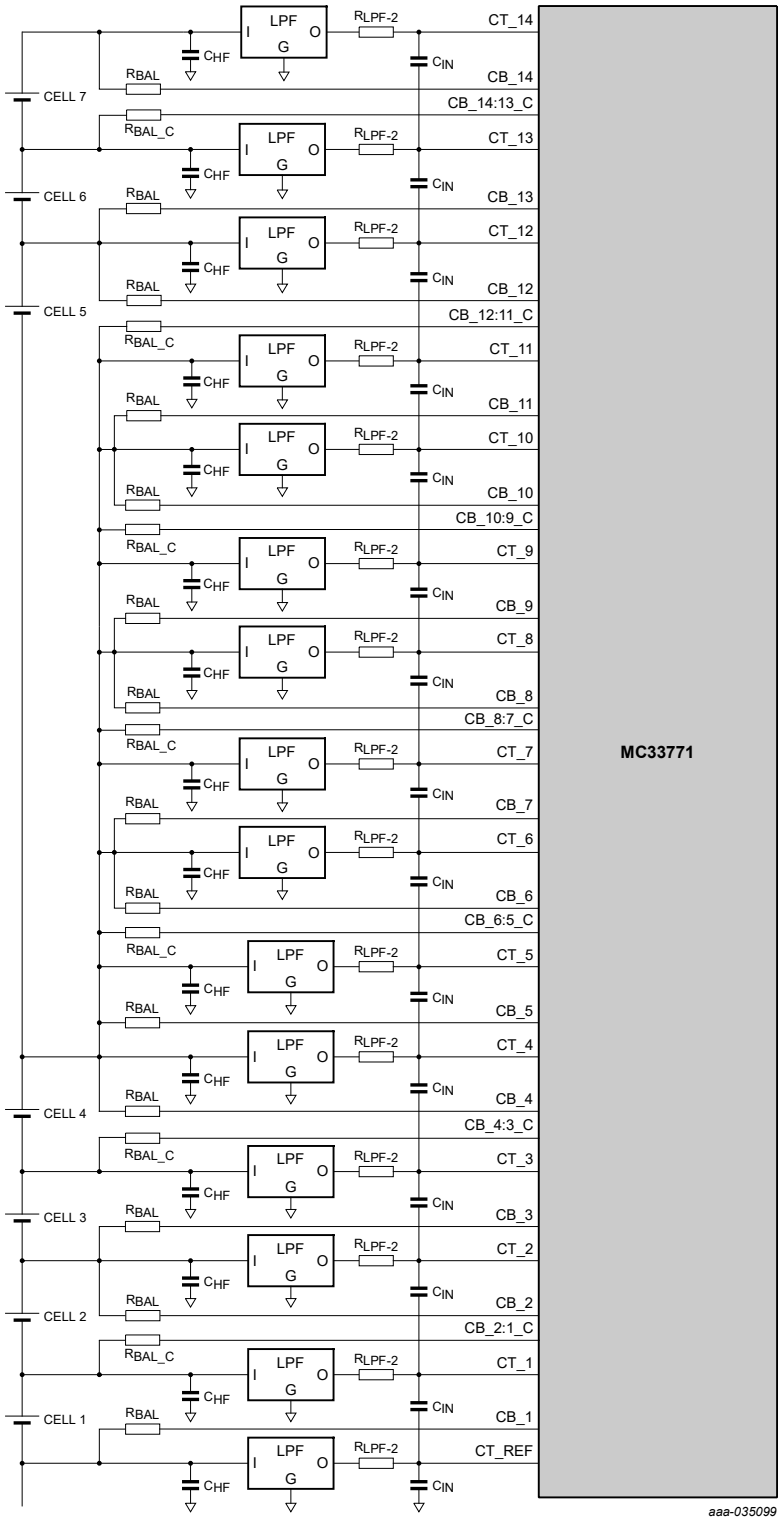

Figure 4. Filter type C - Full population

3.4 Comparison

The main impact of the three connection options on the system is listed in the following table. Values stated are rough estimations. A detailed calculation for the individual application must be done. For ease in performing the detailed calculations and examples, see Section 4.

Table 2. Circuit comparison

Difference	Type A	Type B	Type C
Diagnostic times	1.5 x Type B	reference	scales with number of skipped cells
Leakage impact on accuracy	none	yes	none
BOM cost	saves (#skipped cells - 2) filters	saves #skipped cells filters	full population required

Type A is not influenced by the leakage current of the unused cell terminal. Type B offers best system costs and best diagnostic times. Based on the project requirements, performance needs and cost pressure, type A and type B circuit can be the preferred choice.

4 Tools

To ease the calculation of the filter times, NXP provides a calculation tool. Request a prototype version of the calculation tool through the support channel. Four configuration examples with results are provided.

4.1 Example 1: MC33771B with 8 cells

Example 1 is a system with 8 cells using the standard external components as recommended for MC33771B. Table 3 presents sample input.

Table 3. Input for an MC33771B system using 8 cells

Component	Option
Device	MC33771B
Cells used	8
min(V_{CELL}) [mV]	2100
max(V_{CELL}) [mV]	4300
R_{LPF-1} [kΩ]	3
C_{LPF} [nF]	470
R_{LPF-2} [kΩ]	2
R_{LPF-1} tolerance [%]	5
R_{LPF-2} tolerance [%]	5
C_{IN} [nF]	47

Table 4 presents the following results.

Table 4. Results for an MC33771B system using 8 cells

Circuit	Analog cut-off frequency	SM02 diag time const	Kwait	SM02 Twait	SM02 Trecv	SM02 Tdet	SM02 comm time	SM02 IC time	SM02 threshold
	[Hz]	[ms]		[ms]	[ms]	[ms]	[ms]	[ms]	[mV]
Type A	113	12.13	2.38	28.83	10.0	39.3	0.74	40.1	142
Type B	113	5.84	2.21	12.94	10.0	23.5	0.74	24.2	142
Type C	113	34.96	2.38	83.04	10.0	93.6	0.74	94.3	142

As expected, the tool is showing very long diagnostic times for type C and confirms that this type of circuit is not suitable for this application. With 8 used cells, the effect of leakage currents starts to impact the overall accuracy of the measurement. As a result, the type A filter is recommended here.

4.2 Example 2: MC33771B with 12 cells

Example 2 is a system with 12 cells using the standard external components as recommended for MC33771B. Table 5 presents sample input.

Table 5. Input for an MC33771B system using 12 cells

Component	Option
Device	MC33771B
Cells used	12
min(V_{CELL}) [mV]	2100
max(V_{CELL}) [mV]	4300
R_{LPF-1} [kΩ]	3
C_{LPF} [nF]	470
R_{LPF-2} [kΩ]	2
R_{LPF-1} tolerance [%]	5
R_{LPF-2} tolerance [%]	5
C_{IN} [nF]	47

Table 6 presents the following results.

Table 6. Results for an MC33771B system using 12 cells

Circuit	Analog cut-off frequenc	SM02 diag time const	Kwait	SM02 Twait	SM02 Trecv	SM02 Tdet	SM02 comm time	SM02 IC time	SM02 threshold
	[Hz]	[ms]		[ms]	[ms]	[ms]	[ms]	[ms]	[mV]
Type A	113	12.13	2.38	28.83	10	39.3	0.74	40.1	142
Type B	113	5.38	2.21	11.9	10	22.4	0.74	23.2	142
Type C	113	14.96	2.38	35.59	10	46.1	0.74	46.8	142

With 12 used cells, the effect of leakage current is not very significant. Filter type B is cheaper and has faster timings. The type B filter is recommended here.

4.3 Example 3: MC33771C with 12 cells

Example 3 is a system with 12 cells using the standard external components as recommended for MC33771. Table 7 presents sample input.

Table 7. Input for an MC33771C system using 12 cells

Component	Option
Device	MC33771C
Cells used	12
min(V_{CELL}) [mV]	2100
max(V_{CELL}) [mV]	4300
R_{LPF-1} [kΩ]	3
C_{LPF} [nF]	100
R_{LPF-2} [kΩ]	2
R_{LPF-1} tolerance [%]	5
R_{LPF-2} tolerance [%]	5
C_{IN} [nF]	10

Table 8 presents the following results.

Table 8. Results for an MC33771C system using 12 cells

Circuit	Analog cut-off frequency	SM02 diag time const	Kwait	SM02 Twait	SM02 Trecv	SM02 Tdet	SM02 comm time	SM02 IC time	SM02 threshold
	[Hz]	[ms]		[ms]	[ms]	[ms]	[ms]	[ms]	[mV]
Type A	530	2.88	2.38	6.84	2.1	9.5	0.74	10.2	142
Type B	530	1.56	2.21	3.45	2.1	6.1	0.74	6.8	142
Type C	530	4.44	2.38	10.54	2.1	13.2	0.74	13.9	142

MC33771C requires less filtering on the inputs. With less filtering, smaller capacitors can be used. Smaller time constants for the diagnostic times are a result. In this example, the difference in the diagnostic times for type A and type B circuits is 4.6 ms. Since input filters now use 100 nF capacitors for C_{LPF}, the cost delta between type A and type B circuits is also smaller compared to example 1. As the cost impact is not that high, and the impact on diagnostic times is manageable, type A is a good choice for this application.

4.4 Example 4: MC33772B with 3 cells

Example 4 is for a system with 3 cells using the standard external components as recommended for MC33772B. Table 9 presents sample inputs.

Table 9. Input for an MC33772B system using 3 cells

Component	Option
Device	MC33772B
Cells used	3

Component	Option
min(V_{CELL}) [mV]	2100
max(V_{CELL}) [mV]	4300
R_{LPF-1} [kΩ]	3
C_{LPF} [nF]	470
R_{LPF-2} [kΩ]	2
R_{LPF-1} tolerance [%]	5
R_{LPF-2} tolerance [%]	5
C_{IN} [nF]	47

The calculation tool does not currently support the MC33772B, timing results are not included.

A system monitoring only 3 cells is unlikely for automotive applications that are the target of this application note. However, the MC33772B could be used with 3 cells as an add-on to a MC33771B or an additional MC33772B. In such a mixed application case, it is desirable to have similar timings for SM02 everywhere. If a mixed system is using filter type B, or has ICs with less than three cells not connected, a filter type B will be required to match the timings of the other ICs.

5 Validation

With the large number of possible system combinations, NXP is not able to verify each filter type for all possible configurations. The basic filter types A, B, and C have been tested at NXP with the standard BOM for 12- and 8-cell applications. No issues where found.

The calculation tool results were compared to spice simulations with a good matching. Good matching was also achieved between the spice simulations and measurements with the basic filter types with the standard BOM.

Even though NXP has performed extensive validation, the user is responsible to ensure that the system is operating as intended. Table 10 lists some essential tests that must be done to ensure proper operation.

Table 10. Checks for unconnected cells

Check	What to check
Filter characteristics	Check influence of not connected cells circuitry on the filter characteristics of the external low pass filter.
Diagnostic timings	Circuit of not connected cells may cause longer diagnostic times. Check diagnostic timings for open cell terminal test (SM02) are long enough so that measurements are only taken when circuit has settled to the final values.
Diagnostic thresholds	A change of the external components, can impact diagnostic thresholds. Checking of the correct detection of errors is needed.
Accuracy	Check influence of not connected cells circuitry on the accuracy of the cell voltage measurement.
Hot plug	Check hot plug performance of system with not connected cells circuitry.

The checks can be done in various ways. For early development stages, simulations are the most appropriate way of checking. To ensure that all effects of the real application are covered, NXP recommends executing the checks as early as possible in the development process. A confirmation of the checks with the final HW and SW is recommended.

6 Revision history

Table 11. Revision history

Rev	Date	Description
v.1	20191030	Initial version

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Date of release: 30 October 2019
Document identifier: AN12536