RRC2xxx

Battery Design-In Guidelines

Rev. D

RRC

SETTING STANDARDS
IN POWER SOLUTIONS

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This document applies to the following RRC lithium-ion standard battery packs:

RRC PowerPAQs	Nominal Voltage (V)	Nominal Capacity (Ah)	Energy (Wh)	Discharge Current (A)
RRC2020	10.80	9.22	99.60	10.00
RRC2024	14.40	6.60	95.00	10.00
RRC2037	7.20	3.35	24.12	4.50
RRC2040	10.80	3.35	36.20	4.00
RRC2040-2	10.80	≥6.80	≥73.44	4.00

RRC PowerPAQs	Nominal Voltage (V)	Nominal Capacity (Ah)	Energy (Wh)	Discharge Current (A)
RRC2054	14.40	≥3.40	≥48.96	5.00
RRC2054-2	14.40	≥6.80	≥97.92	8.50
RRC2057	7.20	6.90	49.70	9.50
RRC FlatPAQs	**Nominal Voltage (V)**	**Nominal Capacity (Ah)**	**Energy (Wh)**	**Discharge Current (A)**
RRC2130	7.20	4.17	30.02	6.00
RRC2140	10.80	4.17	45.04	6.00

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Our 35 years of experience in designing portable power solutions, our high quality and reliability, as well as our knowledge of requirements in critical markets are incorporated into each of our lithium-ion battery packs and power management products. Each customer will benefit from this. We continuously challenge ourselves to set even higher standards not only regarding the housing's design but also in terms of quality and performance by striving to exceed our competition's products.

1 RRC standard battery packs

A standard battery pack is the key component for any portable device since the battery dramatically affects the run-time and performance. We offer

- standardized lithium-ion batteries in different housing shapes,
- with worldwide approvals,
- a variety of redundant safety features, and
- a communication interface for your application (SMBus).

Figure 1 – Smart Battery SMBus Communication

Thus, our smart standard batteries, battery chargers, and power solutions are suitable as power sources for all kinds of portable and mobile devices in demanding markets, such as medical, military, instrumentation, robotics, and drones.

1.1 Features of RRC standard battery packs

- Smart batteries with numerous features compliant to the SMBus specification
- Integrated LED State of Charge (SoC) indicator
- State-of-the-art lithium-ion cells with the market's highest energy density
- 21700 or 18650 battery cells (POWERPAQ), prismatic cells (FLATPAQ)
- Broad range of battery cell configurations from 1S1P to 7S1P
- High discharge performance
- JEITA charging profile optimization
- Numerous and redundant battery safety features, e.g.:
    - CUV (Cell Under Voltage): protection against deep discharge
    - COV (Cell Over Voltage): protection against overcharge
    - OTC (Over Temperature in Charge): Protection against overheating while charging
    - OTD (Over Temperature in Discharge): Protection against overheating during discharging
    - Medical-grade ESD protection up to 8kV contact discharge

1.2 Our benefits

Worldwide Approvals
Our products include all the approvals which are necessary to access the world market.

No Obsolescence
For our standard batteries, we guarantee product availability for 10+ years.

No NRE
No development costs for tools, approvals, or design.

Time-to-market
No development time required, immediate product availability.

Independent of quantity
Every order is possible. There is no minimum order required.

Highest performance
Our standard products offer the highest performance, capacity, and discharge capabilities.

Highest quality
Based on our ISO13485 certification, our batteries and chargers surpass the highest quality standards.

Maximum safety
Several levels of protection mechanisms guarantee the maximum safety of our products.

Design-In Support
Real-time design-in support, application notes, and tools are available.

Extensive Accessories
We offer a wide range of accessories for each battery.

Worldwide availability
With our locations in Europe, the USA, and Asia, we provide support and product availability worldwide.

Dual Sourcing Strategy
Identical components from different suppliers prevent supply shortages.

1.2.1 Worldwide Approvals

As a battery manufacturer and developer of reliable mobile power solutions, we provide you with key features that will equip your application with a competitive advantage over your competitors. Our batteries and chargers are delivered with all the approvals required for worldwide market entry.

Batteries are approved not only for safety but also for Material Compliance and Transport.

1.2.2 No Obsolescence

No Obsolescence

At RRC, we deliver batteries with the same main characteristics over years. If the currently used Li-Ion cells become obsolete, we replace them by new generation Li-Ion cells with similar characteristics. But with generation change, the charging voltage may change within a small range.

If you want to benefit from our no-obsolescence promise, ensure that you use a smart charger, which automatically adapts to the charging parameters communicated by the battery.

1.2.3 Highest Performance

All our products are qualified for the highest performance in our own test facility, not only regarding electrical performance but also mechanical endurance and environmental conditions.

1.2.4 Highest Quality

RRC is certified for both ISO9001 and ISO13485 quality management systems. We understand medical device manufacturer's quality needs.

1.2.5 Maximum Safety

For RRC power solutions, electricity is more than just an energy source. It is a base for creativity and innovation, inspiring us to create visions that can become tomorrow's reality.

We have the highest demands on the topic of safety and offer the right solutions.

Certification tests include single fault testing for mechanical stress and safety features. In addition, RRC batteries also comply with worldwide applicable country-specific battery safety certificates, which add several redundant safety tests.

2 Smart Battery

All RRC2xxx batteries are smart batteries. As such, they:

- Tell the charger how to charge optimally under the current circumstances.
- Tell the end application about its status & health.

2.1 Smart Charging

Smart Charging

To increase the battery's life expectancy, RRC smart batteries support smart charging. They communicate the optimum, temperature-dependent charging parameters to the charger, as defined in the JEITA profile. Smart Charging is also *crucial* for keeping the non-obsolescence promise.

2.1.1 JEITA profile

JEITA charging profile

The JEITA[1] profile defines a temperature-dependent charging current. With JEITA, the battery requests a charging current that adapts to the cell temperature, thus avoiding stress on the Li-Ion cells. Using a smart charger following the JEITA profile is essential to ensure battery performance over lifetime.

In the following figure, the "non-shadowed area" shows how the charging current derates over temperature:

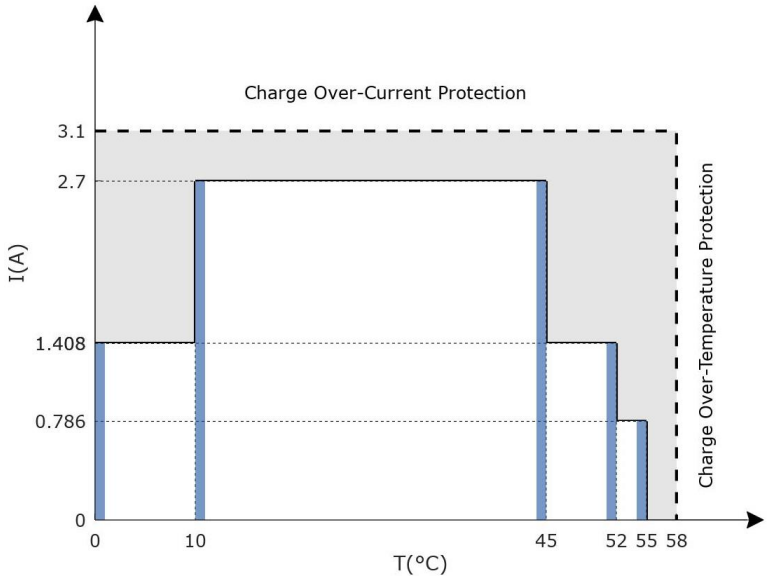


Figure 2 – JEITA profile example

The white area shows the allowed charging current. The "blue columns" represent a general hysteresis of 1°C.

[1] Japan Electronics and Information Technology Industries Association

2.2 Smart Discharging

RRC smart batteries use the standard SMBus protocol v1.1 to communicate with the charger and the end application. Chapters 9, SMBus Communication—Electronics, and 10, SMBus Communication—Software, provide detailed information about SMBus.

More concretely, RRC2xxx smart batteries provide:

- State of Charge
- Remaining Runtime
- State of Health
- Battery Temperature
- Actual Current & Voltage
- Average Current
- Full-Charge & Remaining Capacity
- Cycle Counter
- Battery Status
- Lifetime Data
- Device Name & Manufacturer Info
- Serial Number

3 Worldwide certifications

RRC's major benefit is that all standard battery packs come with worldwide certifications to enable market access practically everywhere. While some certificates focus on the battery safety, others focus on different other aspects.

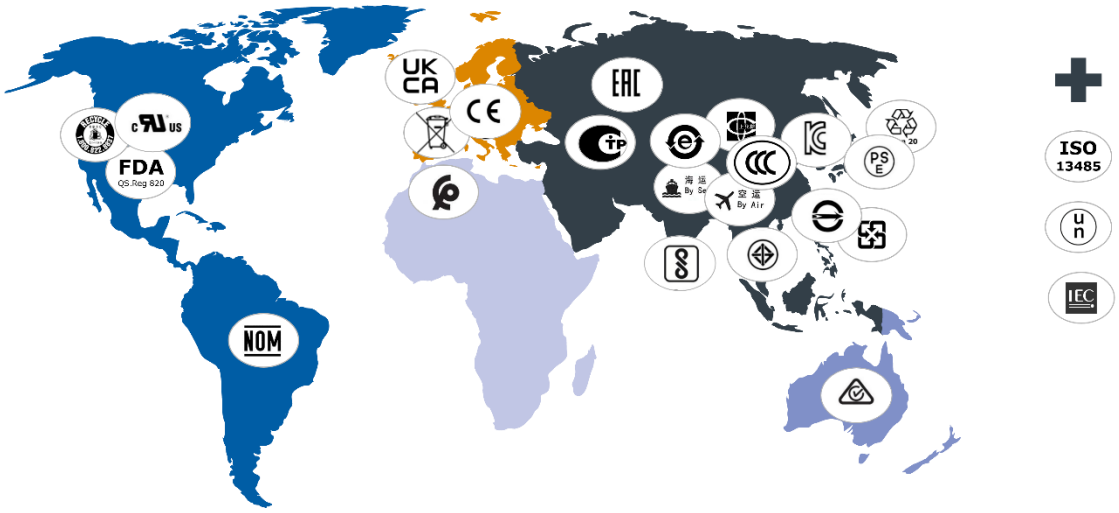


Figure 3 - Worldwide certificates

To access the list of certificates that each smart battery has please refer to the respective smart battery specification or the battery label. This table shows the correspondence between the certificates and the countries in which they are valid.

3.1 Safety related certificates

Safety

The following map of the world shows all certificates, which perform lithium battery safety testing. Although similar in the approach, some countries have substantially different test which must be considered in the design process of a battery.

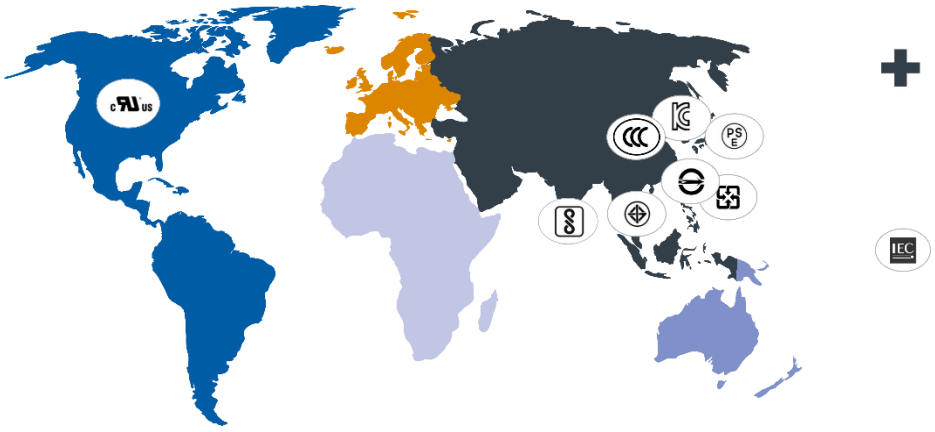


Figure 4 – Safety related certificates

The regions, corresponding standards, and certifications are listed in the table below.

Region	Certificate	Mark
International	**CB/IEC62133-2**	-/-
USA / Canada	**UR /cURus**	
Japan	**PSE**	
China	**CCC**	
India	**BIS**	
Taiwan	**BSMI**	
South Korea	**KC**	
Thailand	**TISI**	

Table 1 Safety related certifications

3.2 Transport related certificates

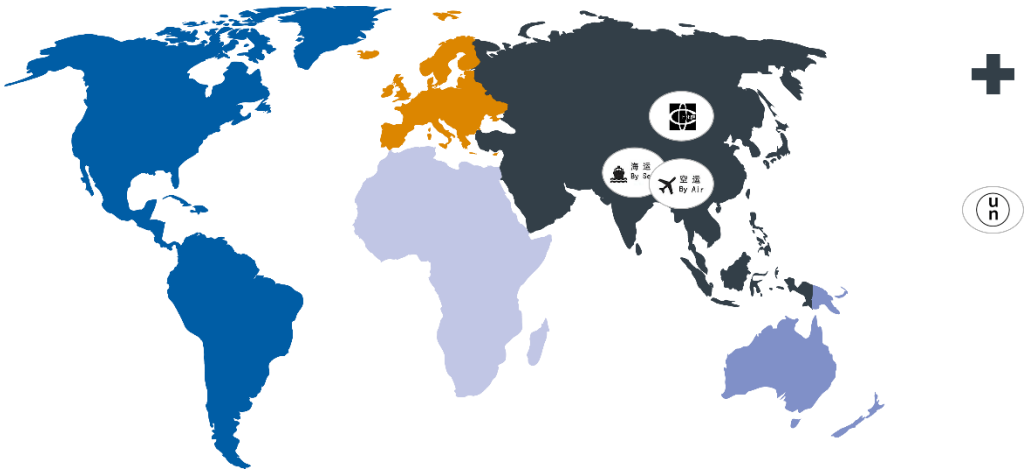


Figure 5 – Transport related certificates

For international shipping of batteries, certificates showing that the batteries can safely be transported are necessary. While "UN38.3" is most common, many shippers also rely on more country-specific transport certificates. The safety

SDS

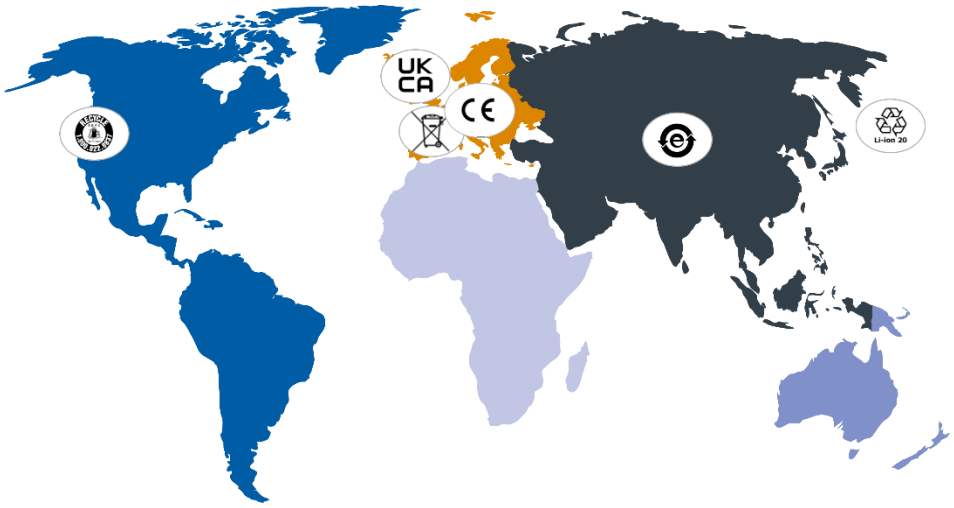
datasheet is a well-established document – the latest version is available on RRC's homepage.

Region	Certificate	Mark
International	**UN38.3**	un
China	**SICIT**	-/-

Table 2 Transport related certifications

3.3 Material compliance related certificates

Material compliance is another topic of concern – batteries are products which could generate toxic waste. In many countries, batteries are required to be collected in a recycling system.

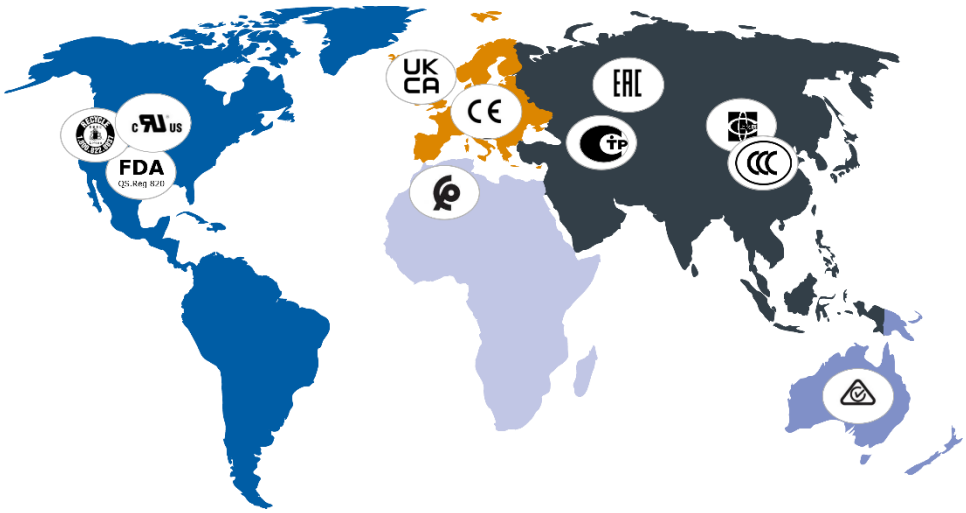


The following table lists the regions and the corresponding marks.

Region	Mark
USA	Recycle Mark
Japan	Li-Ion 20
China	e.g. EFUP 10 yrs
Europe („EU")	CE + BattDir
UK	UK CA
Turkey	

3.4 EMC related certificates

Some countries focus on electromagnetic compatibility, as batteries are treated as electronic devices. Typically, the battery is not a device that causes emissions, but in certain environments, batteries might be subject to noise, either caused by the connection to the application, a radiating mobile device, or a user swapping the batteries, which causes electrostatic discharge.

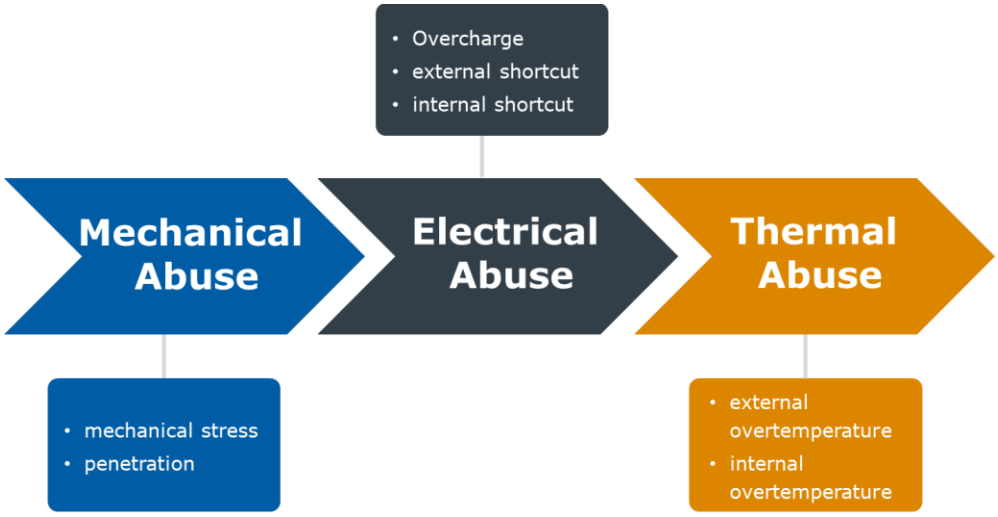


The following table lists the regions and the corresponding certificates and marks for EMC related certificates.

Region	Certificate	Mark
USA	**FCC**	
Canada	**ICES-007**	
Europe („EU")	**CE**	
UK	**UKCA**	
Australia / New Zealand	**RCM**	
Russia	**GOST-R**	
Belarus / Kazakhstan / Kyrgyzstan	**EAC**	
Morocco	**CMIM**	

4 Battery Safety

Lithium-ion batteries need to be protected against various types of abuse. If the battery is not well protected, many kinds of abuse can lead to thermal events.



For reliable protection, it is required that it guarantees safety even if a protection device fails to act. All RRC2xxx smart batteries are composed of even 3 independent safety levels:

Three independent safety levels

1st level protection

MOSFETs protect the battery cells against

- over-voltage,
- over-current,
- over-temperature,
- short circuit and
- under-voltage.

2nd level protection

A fuse is actively triggered:

- if an over-current or over-voltage situation occurs, which has not been interrupted by the 1st level protection.
- if the 1st level protection fails to switch off the charge or discharge FET.
- if a voltage imbalance among the individual cells beyond predefined limits is detected.

3rd level, cell-level protection

If both the first and second level protection fail to trigger, the cell's internal pressure considerably increases, resulting in activation of the CID (current interrupt device), which cuts open the cell's internal electrical path.

On top of that, RRC2xxx batteries have active battery life management, which further reduces the risk for aged batteries.

4.1.1 RRC2xxx battery solutions

Here you can find out how our RRC2xxx batteries manage each of these single faults:

Overcharging

Safety circuit

A safety circuit protects the battery if a charger applies a higher charging voltage than the battery's allowed maximum.

- This safety circuit withstands up to 24 V continuously.

Over-discharging

Shut down option

If you force the battery to discharge below its 0% State of Charge (SOC), the protection circuit activates the safety protection and shuts down the battery, preventing further discharge.

- RRC smart batteries ensure safety in over-discharge situations.

Over-current / Short Circuit

Over-current overload and short-circuit protection

Suppose you would try to discharge the battery with higher currents than specified. In that case, the battery activates its over-current, over-load, or short-circuit protection depending on the magnitude of the discharge current, as shown in Figure 1. These current and time thresholds can be found in the respective battery specification.

- RRC batteries always remains safe in any short-circuit situation by interrupting the current flow.

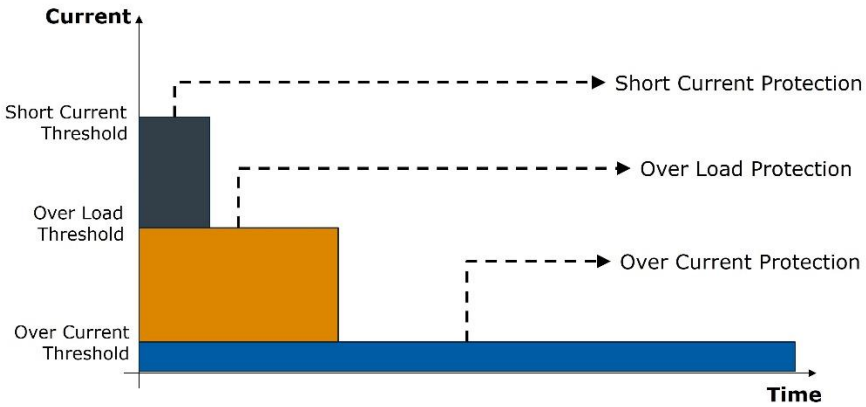


Figure 6 – Discharge current protections

Circuit protection limits heat production

Over-temperature

Above a specific temperature, the protection circuit interrupts the current flow, limiting the heat produced by charging or discharging the battery. However, you must manage external heat sources, as the battery protection system cannot influence these.

Decrease of available capacity

Battery Life Management

Over time, the Available Capacity of a battery decreases.

Figure 3 illustrates the relation between Available Capacity (or FullChargeCapacity()) and the original Rated Capacity (or DesignCapacity()). This relation is called State of Health (SOH). A brand-new Li-Ion battery has an SOH of approximately 100%.

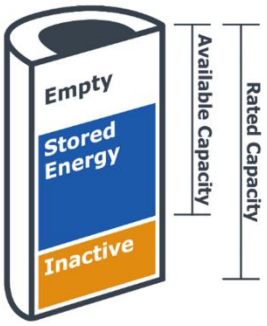


Figure 7 – State of Health definition

The SOH is an indication of the age of the battery and is calculated as below:

SOH(%) = FullChargeCapacity() / DesignCapacity() · 100

Figure 4 shows the internal structure of a Li-Ion cell. It contains a positive and a negative electrode. Between them, there is a separator that ensures electrical isolation, therefore avoiding short circuits.

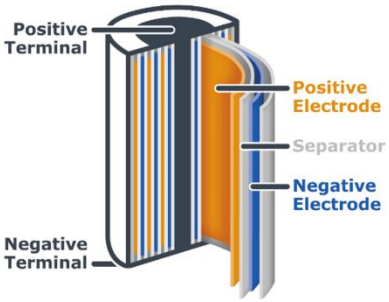


Figure 8 – Lithium Ion Cell

Compression of the separator increases the risk of internal short circuit

As Li-Ion cells age, the following may occur:

- An overall increase in internal cell pressure.
- An expansion of both the positive and the negative electrode.

These two factors lead to a compression of the separator between the electrodes. This compression then increases the risk of an internal short circuit.

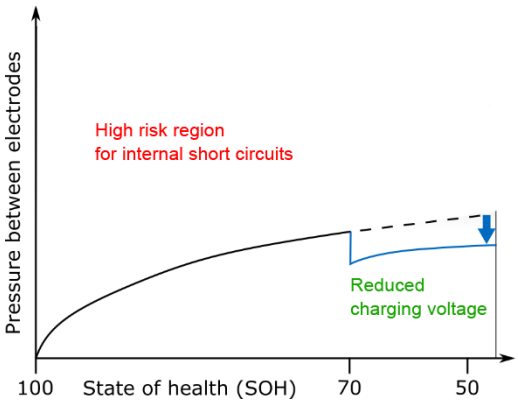


Figure 9 – Battery Life Management

Lower charging voltage with battery age

Since the Li-Ion cell's internal pressure increases with charging voltage, RRC developed the "Battery Life Management" protection mechanism, which lowers the charging voltage with battery age. Figure 4 illustrates how this protection feature works.

- The BMS reduces the charging voltage requested by the battery once its SOH reaches 70%. Thus, the Li-Ion cells' internal pressure stays low.
- The risk of an internal short circuit is reduced. This protection feature is only available when using a smart charger as communication between the battery and charger is necessary for the battery BMS to reduce the charge voltage requested.

Mechanical Stress

RRC batteries are built into a rigid housing that protects the Lithium-ion cells and the protection circuitry from physical damage.

Drop test

Comply with drop test require-ments

Each battery pack complies with the drop test requirements defined in UL2054 and IEC62133. These tests consist of three samples, each dropped from a height of 1 meter so that it strikes a concrete surface in the position where the housing is most vulnerable. Each sample is dropped three times in the same position. To pass the test, each sample:

- shall not explode or catch fire.
- must be examined 6 hours after the test and it shall not vent or leak. The integrity of the protection circuitry must be maintained.
- The outer battery enclosure shall not crack to the extent that cells or any protective circuitry are exposed.

You want some more information?

RRC power solutions - this name stands for the highest reliability and innovative technologies in the field of mobile power supply. Convince yourself of our RRC battery solutions and get more information on social media or our website.

Scan me

Get to know our product configurator

You want to know which RRC standard product fits your application? Then use our product configurator now. Simply select a category, click on the setting variables, and display the appropriate products. If you don't find what you are looking for, we look forward to receiving your inquiry regarding a customer-specific solution. Just scan the QR code below.

4.2 Architectural Details

4.2.1 Battery Management and Safety Unit

Figure 10 shows the block diagram of an exemplary RRC2xxx smart battery. You see the "Battery Management and Safety Unit" (BMS) in its center. It performs all measurements and controls. This is where we find the "smarts" of the battery. You can communicate with the BMS using SMBus and request the data described above. The red block in the block diagram is the ESD protection, protecting the SMBus lines.

The "Fuel Gauge Display" shows the state of charge in the form of four LEDs.

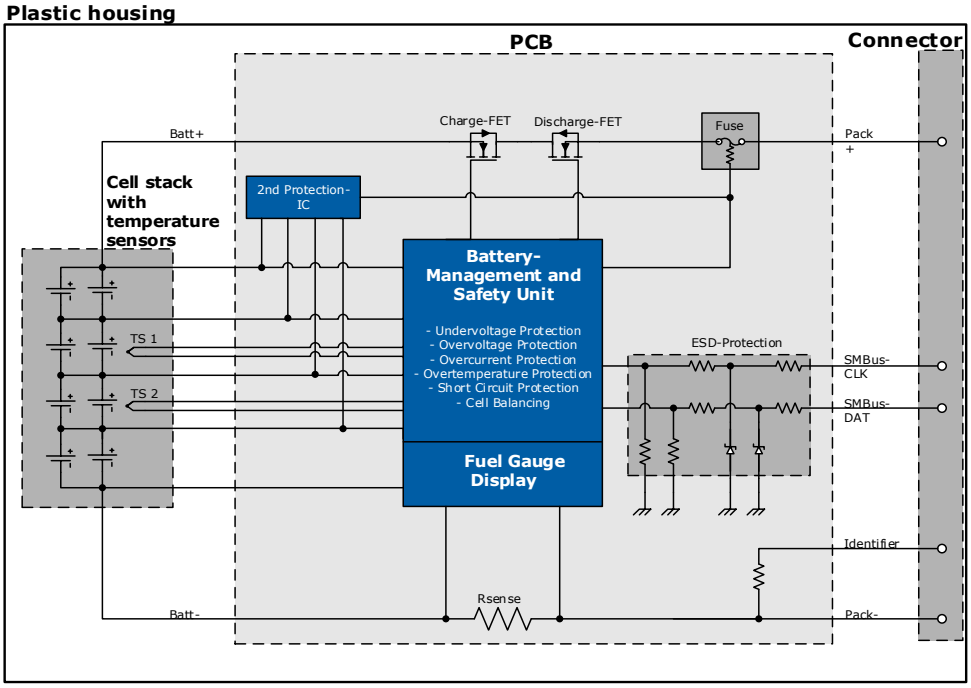


Figure 10 – Block diagram of the battery pack

4.2.2 Levels of Safety

1st level protection

In the path of the electrical current, you see the *Charge FET* and the *Discharge FET*, which serve as switches. The BMS can open those FETs to interrupt the current flow and protect the battery cell from threshold-exceeding voltages, currents, or temperatures. When the situation is cleared, the BMS closes the FETs again. This protection is reversible and is called: 1st level protection.

2nd level protection

For redundancy, there is a 2nd level of protection. It consists of a thermal fuse that breaks the output upon exceeding a specific current. In addition, if ever the FETs would fail to shut off the current flow, either the BMS or (for additional redundancy) the so-called "2nd protection IC" can heat, and thereby break, the fuse intentionally. This 2nd level protection is non-reversible.

The current shunt R_{sense} serves to measure the current in and out of the battery. At the same time, the BMS measures the voltage of each battery cell. The current and voltage information is used for the respective protections as well as for the state of charge, runtime, and state of health calculations. You can retrieve this information at any time via SMBus.

Two NTCs measure the temperature of the battery cells. It is used for the over-temperature protection, and you can retrieve the temperature information anytime via SMBus.

4.2.3 Additional Safety on Cell Level

3rd level protection

RRC20xx batteries are composed of 18650 cells. Each cell has a CID (Current Interruption Device) that interrupts the current flow before the internal pressure of the battery cells becomes dangerously high. The CID provides an additional, 3rd level protection on severe over-temperature and overcharge events for even more redundancy.

RRC21xx batteries are composed of prismatic cells. As they do not provide a CID protection, we've added temperature switches. If the cell temperature becomes too high, those switches will interrupt any current flow and act like a 3rd level protection for the battery for even more redundancy.

5 Removable or Non-Removable Battery

When starting a new design, you decide what battery access your users will have: will your battery be charged internally (not removable) or externally (removable)?

5.1 Removable Battery

Complete flexibility in application

Removable batteries have some advantages:

- Swap-ability when they are fully discharged.
- The device remains mobile and continues to run on another battery.
- Devices with removable batteries also don't require an internal charger.

RRC has several external chargers, including the RRC-SMB-UBC, RRC-SMB-MBC, and the RRC-SMB-DBC, which can charge two batteries at once.

Sometimes, you want to combine the cavity design with added parts on the battery, as shown in the picture below.

Figure 11 – Example of a removable battery with added parts by a customer.

5.2 Non-Removable Battery

Perfect for medical devices that need to be sterile

Non-removable batteries make it easier to build sealed and dust or water-resistant devices, particularly important for medical devices requiring frequent cleaning or sterilization.

Or suppose you work in an environment with flammable gases. In that case, ATEX requirements dictate fireproof housings, making it necessary to use a non-removable battery.

But then, the end-of-life of the battery often means the end-of-life of the device itself, unless a technician is instructed how to change the internal battery.

If your system requires internal charging and you don't want to design it yourself, you can use our RRC-PMM20 or RRC-PMM35 module.

Which design is better?

Often, your application is just weight, space, and cost-driven. In that case, there is no simple answer to which is better: While a removable battery design saves you the need for an internal charger, it also adds to the cavity lid's complexity.

6 Choosing a Battery

6.1 Battery Voltage

Batteries do not output a constant voltage. Instead, every battery has a voltage *curve*, as shown in Figure 12. The often used "nominal voltage" is, in contrast, nothing but the *average* output voltage. Figure 12 shows the typical voltage curves of 1S to 4S batteries.

Voltage curve

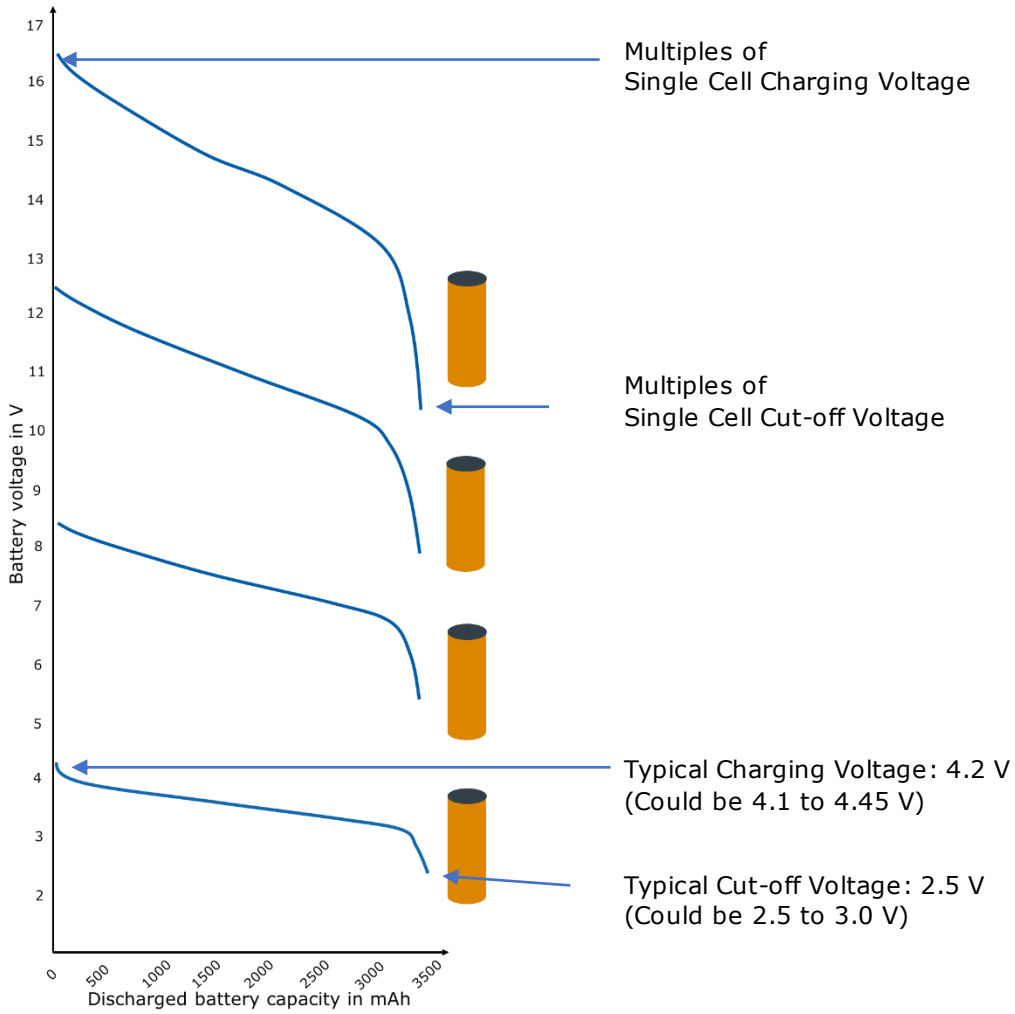


Figure 12 – Typical output voltages of 1S to 4S batteries

Because charging voltages can change over time, you should design your circuit to work with and withstand the highest possible charging voltage, i.e., 4.45 V per cell.

Charging voltages

Symbol	Typical Charging Voltage	Design for Charging Voltage
1S	4.2 V	4.45 V
2S	8.4 V	8.90 V
3S	12.6 V	13.35 V
4S	16.8 V	17.80 V

Table 3 - Charging Voltages

Most batteries have a charging voltage of 4.2 V. But that can change in the future, as today's components may become obsolete. RRC smart batteries can communicate their charging voltage, and the smart charger adapts.

6.2 Energy-Efficiency of the Battery

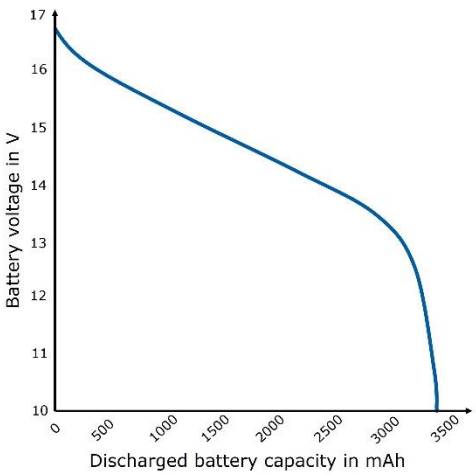


Figure 13 - Voltage vs. Discharged Capacity in mAh.

Suitable for LDO input stages.

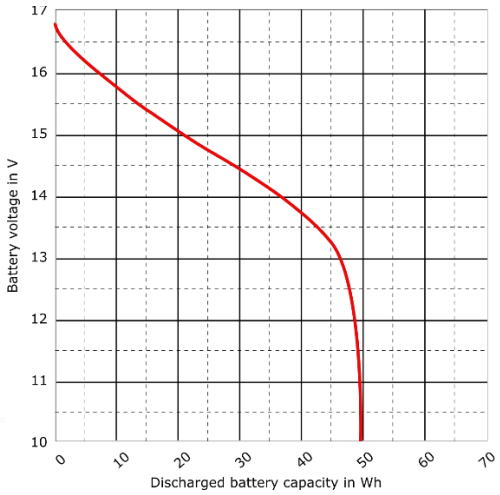


Figure 14 - Voltage vs. Discharged Capacity in Wh.

Suitable for DC-DC converter input stages.

DC-DC converter inputs for more efficiency

Efficiency plays an important role in battery-powered devices. The more energy-efficient the device, the longer it can run on battery power. This is why most battery-powered devices have DC-DC converter inputs, instead of LDO's.

Giving a constant load,

- With a DC-DC converter input, the device consumes a *constant power* over the whole battery input voltage range.
- With an LDO converter input, the device consumes a *constant current* over the whole battery input voltage range.

Accordingly, you select the graph to look at when choosing a battery. Figures 9 and 10 show the characteristics of the same battery. The left graph shows the battery voltage vs the discharged capacity in mAh, the right graph in Wh. Having only one of those graphs at hand, you can convert one into the other.

Also, we suggest setting the BatteryMode() register accordingly so that the State of Charge (SOC) refers to the capacity in mAh or in.

6.3 Total Runtime and Battery Capacity

The battery capacity is only an approximate selection criterion. What really matters is the runtime that you can achieve.

For example, imagine you have a circuit with an average power consumption of 5W. According to Figure 9, the battery offers a capacity of 50 Wh. Hence, your circuit could run for 50 Wh / 5 W = 10 hours.

6.4 Influences on the Runtime

6.4.1 Charging Voltage

If you charge the battery to a voltage inferior to the nominal charging voltage, the runtime will decrease accordingly. Every 100 mV per cell corresponds to approximately 14% less SOC.

This can make perfect sense if you want to prolong the battery life. See Appendix X for details.

Typical voltages at different SOC%

Symbol	100% SOC (typ.)	90% SOC	80% SOC
1S	4.2 V	4.13 V	4.06 V
2S	8.4 V	8.26 V	8.12 V
3S	12.6 V	12.39 V	12.18 V
4S	16.8 V	16.52 V	16.24 V

Table 4 – Typical voltages at different SOC%

For proper end-of-charge recognition, you should apply at least [cell charge voltage – 0.2 V], and the charging current must fall below the taper current threshold defined in the respective battery specification.

6.4.2 Cut-off Voltage

Let's get back to our example in section 6.3 Total Runtime and Battery Capacity: What would happen if your application requires a minimum input voltage of 12.5 V? Figure 15 demonstrates how the available capacity drops to 48 Wh, resulting in a runtime of 48 Wh / 5 W = 9.6 hours, i.e. 9 hours and 36 minutes.

Voltage vs capacity

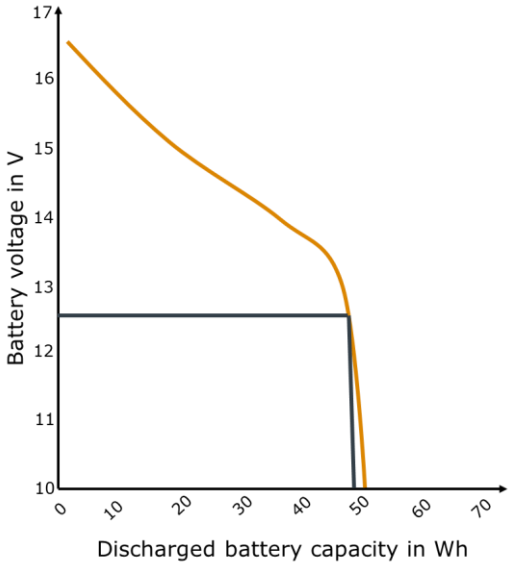


Figure 15 – In this example, if the cut-off voltage would be 12.5 V, the available capacity drops to 48 Wh.

Important notice!

If the battery cell becomes obsolete and is replaced by a more modern one with similar capacity, the voltage characteristics may change! The voltage curve may be flatter or steeper, eventually resulting in less available capacity and a non-expected premature shut-down of your application. If possible, ensure that your application can work down to the battery cut-off voltage.

If that's not possible, consider implementing an intelligent algorithm that takes the battery voltage into account and "learns" the SOC before shut-down. That way, you stay able to inform the user about the remaining runtime.

Even if your circuit supports working down to the battery cut-off voltage, we generally recommend switching off at a remaining capacity of 5 to 10% (see Appendix B for details).

6.4.3 Discharge Current

Take care with pulsed loads

Just like any power source, the battery has an internal impedance. On discharge, there is an equivalent voltage drop over that impedance. This will cause reaching the cut-off voltage earlier. Take special care with pulsed loads, which may suddenly shut your system down even though the battery is not yet depleted.

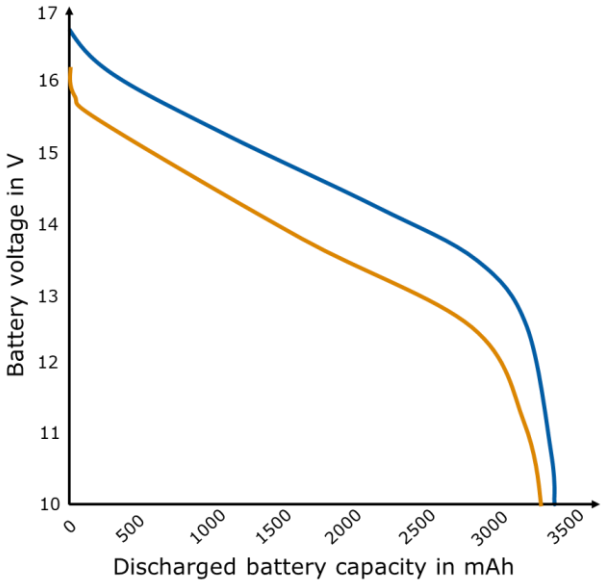


Figure 16 – Battery voltage vs discharged battery capacity

Due to the battery impedance, the battery voltage depends on the current flow, which may lead to an early shutdown.

6.4.4 Temperature

Influence of temperature on the capacity

As the battery is a chemical energy storage, the temperature has an important influence on the capacity.

Cold temperature losses are approximate:

- 0% at 25 °C and above
- -15% at 0 °C
- -30% at -10 °C
- -45% at -20 °C

During use, the battery warms up because of the dissipated power across the internal impedance. Thus, the capacity loss is generally less than indicated above. We provide test data for every battery upon request.

6.4.5 Battery Age

Battery capacity drop

Over time and usage, the total battery capacity slowly drops. If you have a particular runtime requirement, you should design conservatively if you do not want to replace the battery early.

The graph in Figure 17 illustrates the decline in performance of the RRC2054-2 battery when using the specified testing parameters. It's important not to overlook these parameters, as variations in charging and discharging currents or depth of discharge can affect your results. Refer to Appendix X for more information on maximizing battery lifespan.

Stay conservative in your approach. Additional influences, like aging and temperature cycling, may affect your battery in real life, while the laboratory tests are done within a couple of months and at room temperature.

The load signature also plays a role, as all batteries were discharged with a DC load. Batteries tend to have a lower cycle life if discharged with pulses. Do not overstress a battery, as this will shorten its life span. If a battery must repeatedly be loaded at high peak currents, choose a battery with an increased output current capability.[2]

For applications focusing on safety, especially medical instruments, we recommend replacing batteries after two years of use or after 300 cycles, whatever first comes. You should do this regardless of the remaining capacity. Most of our medical customers consider this a good practice.

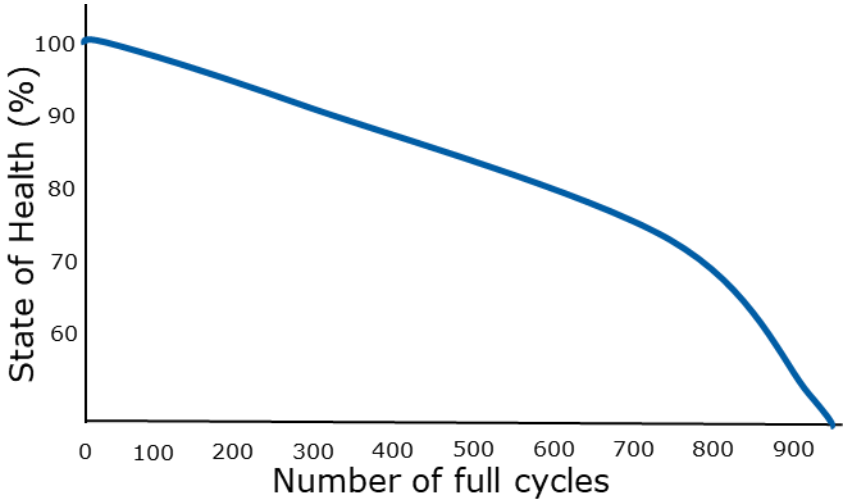


Figure 17 – Cycle life of a Lithium-Ion battery

6.4.6 Self-Discharge

Low Self-Discharge

The Self-Discharge of the Li-Ion Technology is generally low and is governed by the current consumption of the Battery Management System inside of the battery, or your application if it's attached. Chapter When to change the battery gives you more details on that subject.

Be aware that the self-discharge rate can increase if the battery is exposed to misuse or deep discharges. That can also affect cell balancing: if one cell self-discharges much quicker than the others, the battery must protect itself and can eventually shut down irreversibly.

2 Even if short pulses does not necessarily lead to increased heat, the cathode is speed-limited in stocking Li-Ions, and the separator also has its limits when it comes to transporting them from anode to cathode.

7 Choosing a Charger

We highly recommend that you use a smart charger. As stated before, smart charging is a crucial prerequisite for RRC's non-obsolescence promise.

7.1 Advantages of Charging Smart

Each smart battery label shows: "Charge only with a SMBus compliant level 2 or 3 charger". These kinds of chargers exchange essential real-time data with the battery, such as:

- The desired battery charging voltage and current, which are adjusted depending on battery temperature and age.
- Alarms and warnings that inform the charger to stop charging if necessary (e.g., temperature too high).

Advantages of using a smart charger

Advantages of using a smart charger are:

- Optimized charge process depending on battery temperature, health, and age.
- Fast reaction to any alarm set in the AlarmWarning() register.
- It provides the highest battery performance and increased battery lifetime.
- Full compatibility with future revisions of each battery model. RRC smart batteries are available on the market for 10+ years. Throughout the lifetime of each model, the battery pack will be modified to keep up with current technology. New generations of Lithium-ion cells have increased performance (e.g., higher capacity) and may have different charging voltages. A smart charger communicates with the battery, therefore charging the battery with the correct voltage. Not using a smart charger could lead to future incompatibility issues.

7.2 Charging a Single Battery

There are a variety of smart charger options that users can choose from :

Single battery smart chargers

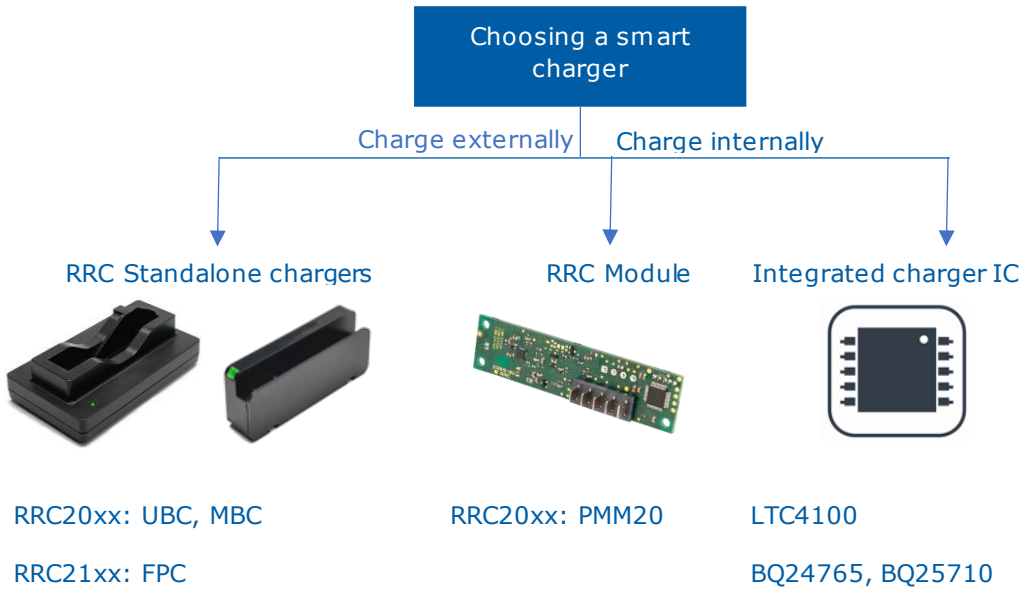


Figure 18 – Single battery smart chargers

Stand-alone charger

The easiest way might be to use a stand-alone charger offered by RRC:

- UBC for RRC20xx batteries
- FPC for RRC21xx batteries
- MBC as a smaller budget solution for RRC20xx batteries except the **RRC2020** and **RRC2024**.
- SBC2037 as a very small solution for **RRC2037** only.

Module solution

If you need to charge internally, the easiest way is to use the **PMM20** module. It is available for RRC20xx batteries only.

Build a charger on your own

RRC gives support and feedback

For internally charging RRC2xxx batteries, or if you want to design to your form factor, you can choose from a wide variety of charging IC's. Generally, IC manufacturers offer reference designs, serving as a good starting point.

Probably, you are already using a microcontroller in your system. If you imply that microcontroller, you can very freely choose a charger IC on the market, as long as its output is controllable via I2C or SMBus. If unsure, you can ask **applicationsupport@rrc-ps.com** and we give you feedback on your selection.

The microcontroller communicates with the battery, retrieving e.g., the charging parameters. Over another bus (SMBus or I2C), the microcontroller controls the charger IC you've chosen.

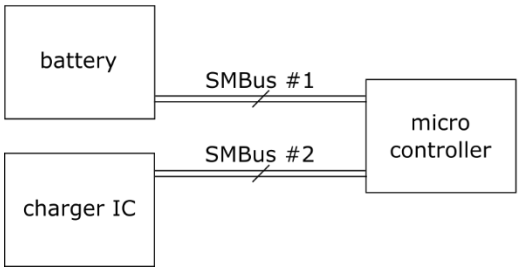


Figure 19 - Use a microcontroller on the charger board to control messages the charger IC.

If you don't want to imply a microcontroller, most SMBus charger ICs can directly support charging the battery, but with less control. Make sure to read the next section about dealing with PEC.

Packet Error Checking (PEC)

Dealing with Packet Error Checking (PEC)

The following batteries broadcast their charging parameters using a Packet Error Checking (PEC) byte as defined in the **[SMBS]**[3]. This byte is appended to each SMBus frame and corresponds to the CRC-8 checksum over the broadcast message. When designing a charger on your own, you must consider that not every charger IC supports the PEC byte. We have only found the charger IC's LTC4100, BQ24765, and BQ25710 to be PEC compliant.

If you want to use any other charger IC, you either must disable broadcast messages (see section X for more details) and let the charger IC actively poll the charging parameters:

1. Poll the ChargingVoltage() and ChargingCurrent() registers once every 60 s.
2. Poll the BatteryStatus() register once every 10 s.

Or you must use a microcontroller-supported scheme as in Figure 19 to tunnel the broadcast messages. The microcontroller uses one I2C port to communicate with the battery and another I2C port to communicate with the charger IC. Next, it translates the messages from one port to the other by cutting the PEC byte away.

The following RRC batteries use the PEC byte:

- **RRC2020**,
- **RRC2024**,
- **RRC2040**,
- **RRC2040-2**,
- **RRC2054**, and
- **RRC2057**

All other RRC smart batteries (e.g., **RRC2054-2**, **RRC2130**, **RRC2140** …) do not use PEC, and any SMBus charger IC works properly.

[3] Smart Battery Data Specification Revision 1.1, see http://sbs-forum.org/specs/sbdat110.pdf.

7.3 Charging Multiple Batteries

For charging multiple batteries, the same exact principles apply as for charging single batteries.

If you charge externally with a dedicated charger, RRC offers a two-bay solution with the **DBC** charger.

For charging internally, use a dedicated charger module[4] or circuit for every battery. With the LTC1760, there is also a charger IC that supports charging two batteries simultaneously.

[4] For instructions on how to combine two RRC-PMM20, please refer to the PMM20 application note.

8 Using Multiple Batteries in Parallel or Serial Configuration

When multiple batteries are connected in parallel, their positive terminals are connected, and their negative terminals are connected, increasing the overall capacity of the battery bank.

In a serial configuration, the positive terminal of one battery is connected to the negative terminal of the next battery, increasing the overall voltage output of the battery bank.

By combining batteries in parallel or serial configurations, users can customize their power supply.

8.1 Charging Multiple Batteries

Extensive Accessories

For charging multiple batteries, the same exact principles apply as for charging single batteries. If you charge externally with a dedicated charger, RRC offers a two-bay solution with the **DBC** charger.

For charging internally, use a dedicated charger module[5] or circuit for every battery. With the LTC1760, there is also a charger IC that supports charging two batteries simultaneously.

8.2 Communicating with Multiple Batteries

All smart batteries share the same SMBus address. Hence, two batteries cannot connect simultaneously to the same bus. If separate buses are not possible, a multiplexer is necessary.

8.3 Discharging in Parallel Configuration

How to discharge multiple batteries in parallel

It is possible to combine multiple batteries to discharge in parallel, as shown in Figure 20. The following design considerations should be taken into account:

- Use "ideal diodes" (e.g., LM5050 from Texas Instruments) to avoid back-driving currents from one battery into another.
- If more than one battery must discharge simultaneously to support the load, ensure that the batteries are approximately at the same SOC (State of Charge) for balanced discharge rates between the batteries.
- Do not attach batteries with considerable "different age" to the same host. "Different age" means a combination of cycle count and/or production date.
- Control inrush currents as these might not be equally distributed among all batteries.

[5] For instructions on how to combine two PMM20, please refer to the PMM20 application note.

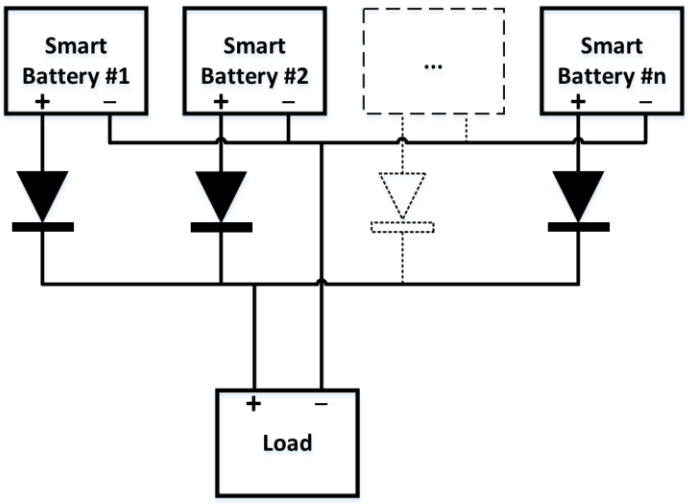


Figure 20 – Discharging multiple batteries in parallel

8.4 Discharging in Series Configuration

We offer an application note for serial connection

We generally don't recommend using smart batteries in series, because of a more demanding circuitry. However, we offer an application note on that subject if you are willing to do so. Ask your local salesperson for that document or write to **applicationsupport@rrc-ps.com**

9 Using Batteries as Backup Power Source (UPS)

Please read this chapter carefully if you intend to use the battery as a backup power source, with the power supply plugged in most of the time.

Keeping the battery close to 100% SOC most of the time leads to voltage-related stress on the electrodes. For a longer battery life, consider using the battery at a lower SOC. Read the appendix, section How to prolong battery life for more information. We generally recommend charging a backup battery to 80% only.

Generally, Li-Ion batteries cannot absorb overcharge. The charge current must be cut off when the battery is fully charged. A continuous trickle charge would cause the plating of metallic lithium at the anode and compromise safety.

Battery protects itself

The battery can protect itself: A timer counts the total charging time. Once that timer reaches 18 hours, the battery refuses any further charge until it is discharged. Using the battery as a backup power source, with an internal charger in your device, be prepared for the following scenario:

1. Upon first use, the battery must be charged to 100%, which may take 2 to 3 hours.
2. While the device continues to run on mains power, the battery slowly drains due to self-discharge into the battery management unit. We usually see a self-discharge rate of 2 to 5% per month.
3. Once the SOC has dropped to 95%, the battery requests recharging. That may take about 40 minutes because the last few percent always take the longest. That time adds to the charge counter.
4. The cycle "100% → 95% → 100% …" repeats until the charge counter arrives at 18 hours. This mostly happens after 1 to 3 years.
5. After that, the battery refuses any charge. If the mains stays plugged in, the battery will never discharge, and the counter does not get reset. After another 1 to 2 years, the battery becomes completely discharged, with consequences:
    - The battery won't act as a backup power supply if needed
    - The battery rejects any wake-up charge – you cannot charge it anymore.

How to extend battery life

How can you prevent this issue from happening? There are three solutions:

1. Either you can reset the timer by setting the battery into shipping mode once it is fully charged and wake it up immediately. For information on how to use the shipping mode, see section X.
2. Or you can let your device run on battery from time to time, at least for a short moment.
3. Or you use a dedicated discharge circuit to discharge the battery even if your device stays connected to the mains.

The battery itself resets the timer once it detects discharging. That happens

- Either by discharging by at least 30 mA for at least 20 s,
- Or by discharging by at least 320 mA for some milliseconds.

You can check whether the Charge Timer has run into a timeout by requesting the CTO bit in register SafetyAlert(). See section X for details about how to access that register. However, please note that the SafetyAlert() register is not part of the SMBus standard and may be subject to change in future battery generations.

10 Battery Mechanical Design

This section focuses on the battery's mechanical features, such as the LED push button, insertion key features, designing a cavity to insert the battery, and using the mating connectors.

10.1 LED Push Button

State of Charge (SOC)

RRC20xx batteries have an LED that indicates the battery's State of Charge (SOC). The LEDs are activated by pressing the push button. Each LED that lights up represents 25% capacity, as shown in Table 1. While charging, the last LED blinks. For example, if the SOC is 45% and the battery is charging, then 1 LED lights up, and the 2nd LED segment blinks.

Capacity	LED Indicators				Note
	1	2	3	4	
Undervoltage					No LED
0% - 10%	X				Blinks
10% - 25%	X				Lit for 4 seconds
26% - 50%	X	X			Lit for 4 seconds
51% - 75%	X	X	X		Lit for 4 seconds
76% - 100%	X	X	X	X	Lit for 4 seconds

Table 5 – LED indicator

10.2 3D Models and Mechanical Drawings

Contact RRC for 3D models

For every battery model, RRC can provide a 3D model as a STEP file. Please reach out to your local RRC salesperson to get this information.

The mechanical drawing is part of the specification document. Your local RRC salesperson can also provide you with that document.

Please email us with any questions to **sales@rrc-ps.com** or https://www.rrc-ps.com/kontakt.

10.3 Mechanical Guides

Most RRC smart batteries have two notches left and right next to the connector. They serve as *keys* and provide protection against reverse polarity insertion.

In addition, some RRC smart batteries feature two notches across the entire length of the battery.

You can design the corresponding elevation in your battery slot or bay, which we call a *mechanical guide.* If the guide and key match, the battery will fit correctly.

The *middle notch* is used on most batteries of this kind. Because it is slightly off-center, it ensures that you can insert the battery into the slot or bay only in one direction. Additionally, this mechanical guide adds some mechanical stability to the system. We strongly suggest that you implement this mechanical guide if the battery in question offers this feature.

The *second notch* feature is only present on RRC batteries. If you want to ensure that only RRC batteries will be used (instead of a third-party battery that may not have all the approvals or safety features), you can design the matching mechanical guide into your cavity.

Smart battery key features

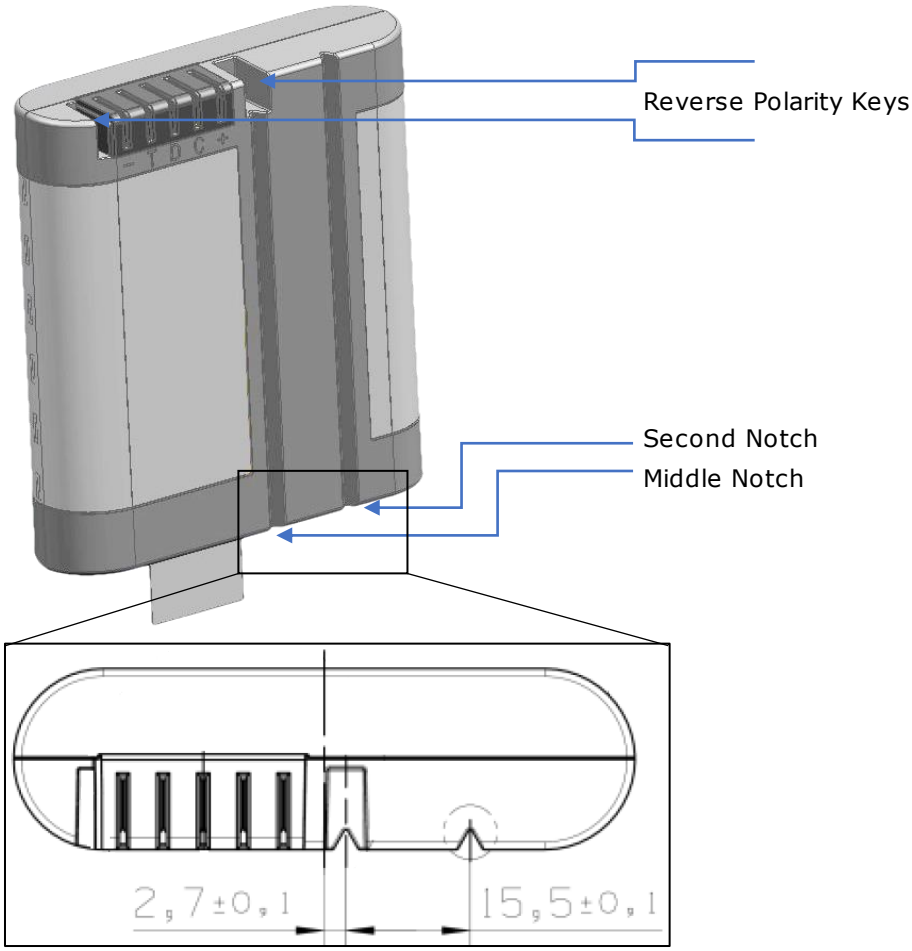


Figure 21 – Smart battery "key" features for mechanical guides

10.4 Slot or Bay

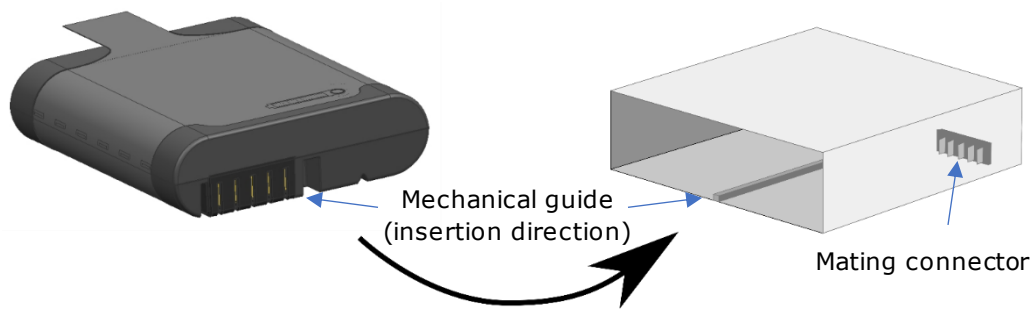
Comparison between battery slot and battery bay

In this section, we compare a battery slot (where the battery is inserted from the side) to a battery bay (where the battery is inserted from above).

Slot

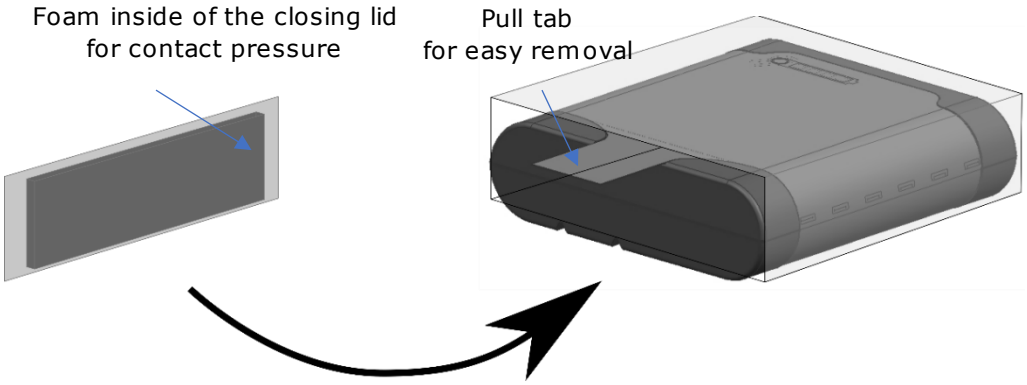
A battery slot allows you to slide the battery into the application. The opening is small compared to the bay solution.

Utilize the mechanical guides: That leaves only one way – the correct way – to insert the battery.



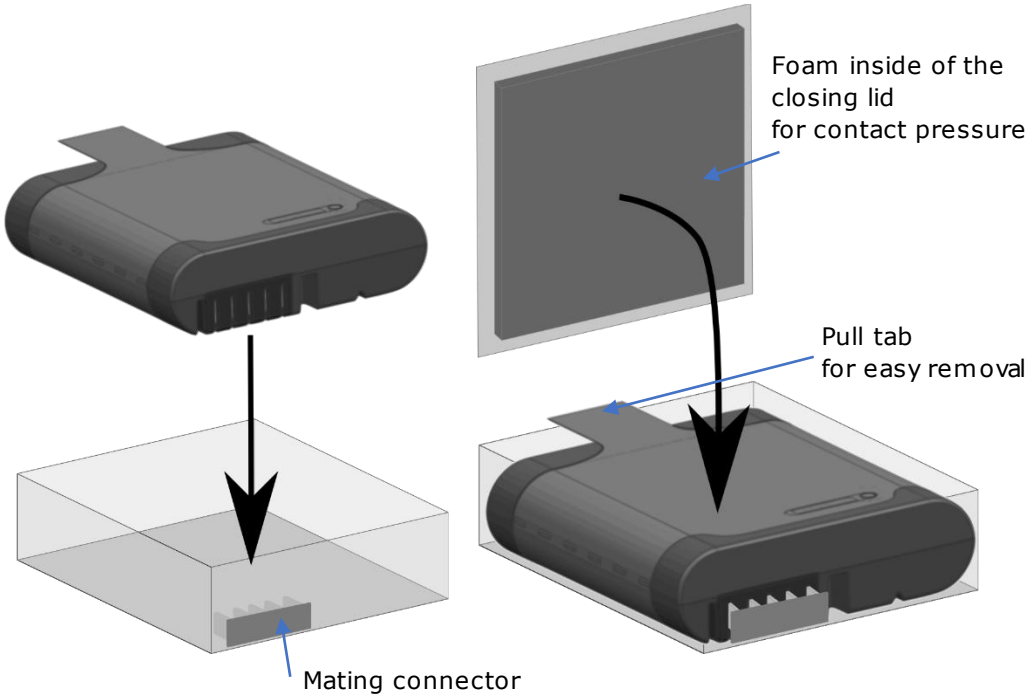
Once the battery is inside the slot, you can remove it using the battery pull tab. The pull tab is made of soft material and folds into the battery bay when you close the lid. Every RRC20xx battery offers this pull tab, while RRC21xx batteries don't.

In most designs, when using a battery slot if there is vibration or the device is turned upside-down, the battery should remain in its position. We suggest closing the battery slot with a lid that gently pushes the battery inside, using foam or a spring.



Bay

If you want your application to have a non-removable battery, the bay may be your better choice, as it makes it relatively easy to put the battery into the device before closing the enclosure. Consider using some foam or a spring to push the battery down onto the mating connector gently. Although not drawn here, mechanical guides would give additional stability.



10.5 Battery Temperature

High Temperatures

RRC batteries can be used safely at higher temperatures up to the switch-off threshold of 78°C. This threshold was selected to treat the battery with care and achieve a minimum service life. The battery is still safe; but you must ensure that the battery does not see temperatures above 100°C.

Lower Temperature Aids in Longer Battery Life

A battery ages with temperature. Generally, the lower the temperature, the longer the battery cycle life.

Why does this happen? Chemical reactions occur inside the battery cells, producing the voltage and the current. Additionally, some unwanted chemical reactions lead to a lower battery capacity, which can shorten the battery's lifespan. These unwanted chemical reactions occur naturally, even when the battery is not used. According to the Arrhenius equation, the reaction speed roughly doubles every 10°C temperature increase.

If the battery is good for up to 800 cycles at 25°C in your application, it may only last 400 cycles at 35°C or 200 cycles at 45°C ambient temperature for the same decline in remaining battery capacity.

Can the temperature be too low? Yes. Below 0°C, the battery current rating drops because the current production also relies on chemical reactions. Below roughly -20°C (for more exact values, review the specification or ask applicationsupport@rrc-ps.com), the electrolyte inside the battery cells can freeze, which may cause permanent damage to the battery.

Get further information

Move the battery away from external heat sources

Shield the Battery from External Heat Sources

Because of the effects described above, you should move the battery away from external heat sources, for example: direct sunlight or hot components on your PCB.

The latter may radically shorten the battery lifetime. To understand this, the diagram below is representative of a Li-Ion battery:

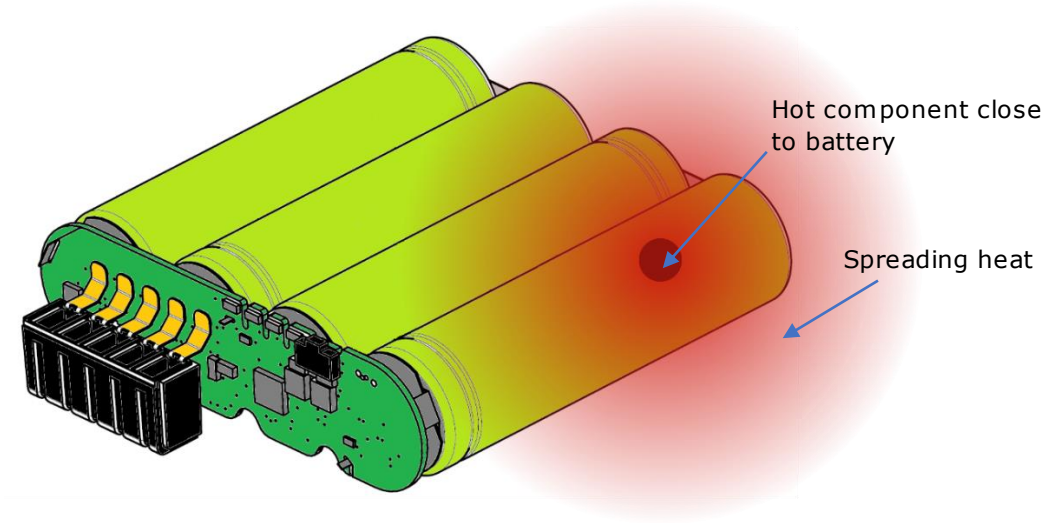


Figure 22 – Heat Sources vs battery lifetime

The battery is composed of several individual cells. Each cell delivers a part of the total voltage and current, and the parallel and series configuration determines the battery characteristics.

Because of a small external heat source, one cell might degrade faster than the others. The battery is like a chain; it's only as strong as its weakest link, and the entire battery would age much faster. If the imbalance becomes too great, eventually the safety circuit will activate and detach the battery from the circuit. When that happens, the battery won't charge or discharge any longer but will be in a safe state.

To prevent this, consider using a thin metal sheet between the hot components and the battery. The shield would spread the heat evenly over a larger surface, protecting the entire battery. However, in many cases, an air gap between the PCB and the battery would provide enough thermic isolation.

Make Convection Possible

In addition to external heat sources, the battery itself becomes warm while discharging (see graph below) and charging. This contributes to the overall battery cell temperature. The self-heating is proportional to the current and to the thermal isolation of your battery compartment.

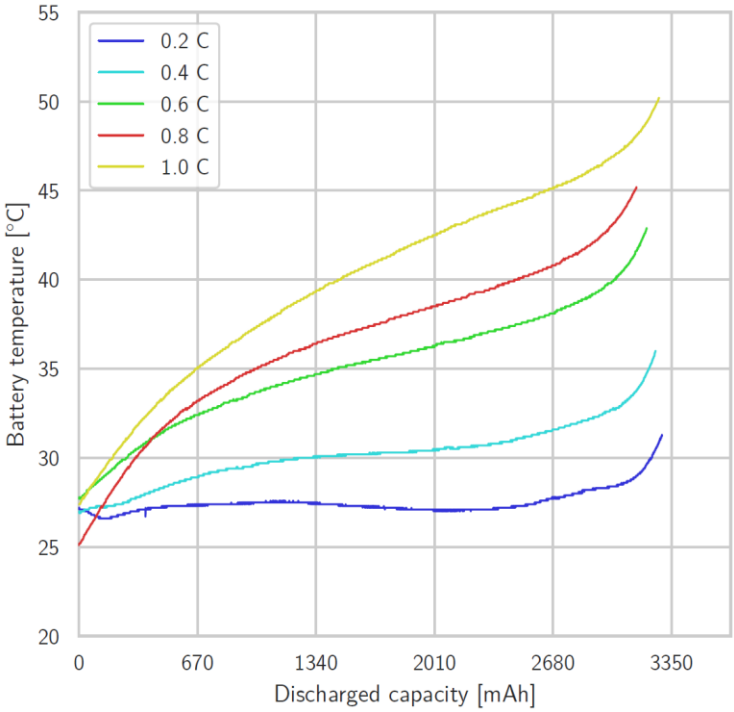


Figure 23 – Battery temperature vs discharged capacity

Keep the battery temperature low

Because of the "the cooler, the longer" mechanism described above, it's always a good idea to keep the battery temperature low. Were the battery to become too hot depending on your ambient temperature, the safety circuit would protect the battery from permanent damage by temporarily disconnecting the battery from your circuit.

To allow for good heat exchange and good heat conduction, make sure to have a large surface area and a satisfactory thermal transfer between the battery and the housing.

10.6 Drop, Shock, Vibration

All RRC batteries are tested according to the current versions of IEC62133-2 and UN Transportation test requirements.

More questions?
Contact us

If your application requirements exceed the requirements of the norms mentioned above, then your battery compartment should protect the battery by dampening drop, shock, and vibration sufficiently. You would need to run your own tests to ensure compliance. Please contact us with any questions at **applicationsupport@rrc-ps.com**.

If the expected shocks and vibrations are beyond the specifications mentioned earlier, one suggestion is to securely clamp the battery while being careful not to crush the battery or damage the plastic battery housing. Clamping the battery can prevent movement inside the cavity during shock or vibration events. Ensure that the expected shock or vibration is in the direction of the *green arrows* (best case) or *orange arrows* (still okay).

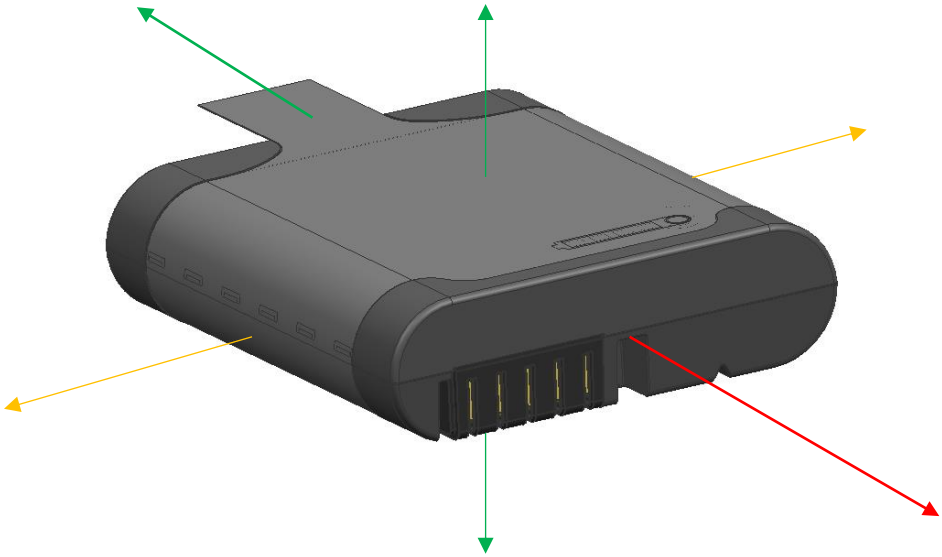


Figure 24 – Drop, shock, and vibration

Shock or vibration in the direction of the *red arrow* should be avoided, as all the weight of the battery cells would exert forces on the battery connector and the cell connectors inside of the battery, resulting in their bending and eventually breaking.

The orange direction may also bend the cell connectors, although not as much as the red direction. The tighter the clamping, the better.

The green direction would not result in a bending movement if the cells were clamped tightly, and the battery connector did not move relative to the battery.

An example of a worst-case scenario on drop, shock, and vibration follows:

Inside the battery, conductive tabs connect the cells and the PCB. These tabs can break. Eventually, they may scratch or pierce the insulation, creating short circuits inside of the battery.

When designing the battery enclosure and mounting scheme, ensure that the battery connector and battery movements are in alignment. If the connector sat still and stiff, it would exert a force on the PCB inside the vibrating or moving battery, which could break the internal conductive tabs. It would be better to suspend the connector softly.

10.7 IP Protection Class

More questions?
Contact us

Unless otherwise specified, RRC batteries are rated IP40. Battery cells and conductive tabs tend to be very sensitive to humidity. If your device is exposed to humidity, your battery compartment must be designed and tested accordingly. Please email us with any questions at **applicationsupport@rrc-ps.com**.

10.8 Positioning the Mating Connector (RRC20xx Batteries)

This section covers the RRC20xx batteries only. For the RRC21xx connectors, have a look at the next section.

Must always be positioned on the short side

90° Header RRC-MC20-90-10

The 90° mating connector **RRC-MC20-90-10** (RRC part number #210519) must *always* be positioned on the short side of the battery, as shown below. Please note that the mating connector should never sit on the long side as there is insufficient contact surface and it will not provide a robust connection.

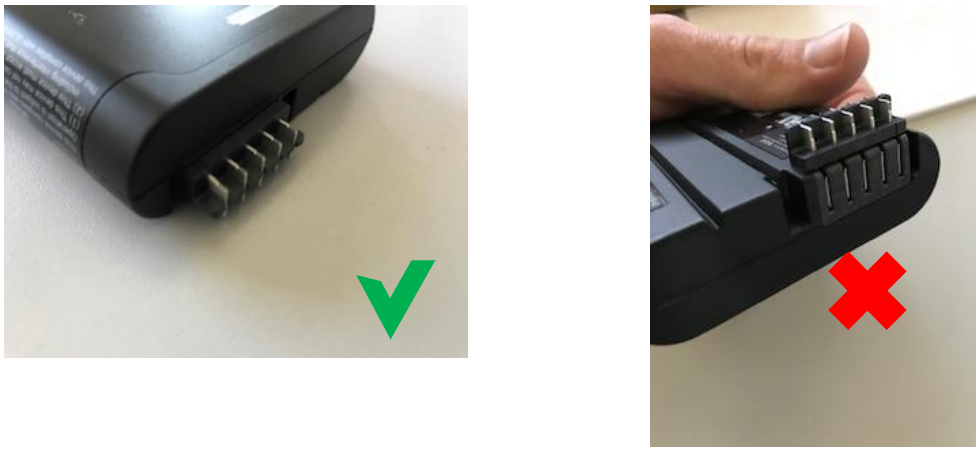


Figure 25 – Positioning of the 90° mating connector RRC-MC20-90-10

The following graphs show typical mating positions between the battery and the right-angle header RRC-MC20-90-10. The dimensions shown must be considered when designing device battery compartments and the header assembly with respect to the compartment.

While all configurations are possible, the first configuration will result in the best contact between the mating connector and the battery. All other configurations are acceptable but will have less overlap area with the connector contact in the battery. All values are *maximum* tolerances, given in mm (inch). They are given in a way so that there is at least a 1 mm overlap between both connectors.

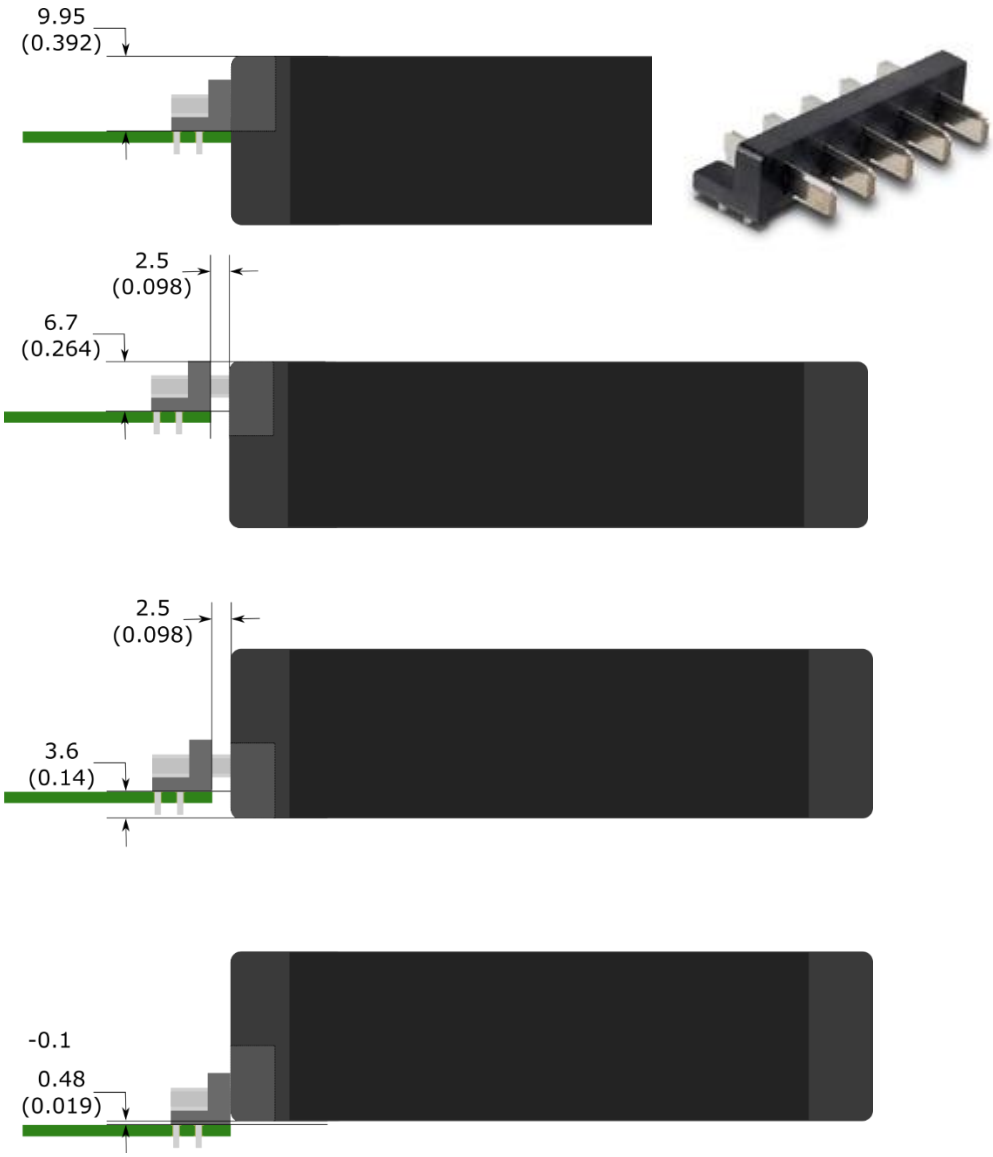


Figure 26 – 90° mating connector RRC-MC20-90-10

180° Header RRC-MC20-180-10

Can be positioned on both sides

In contrast to the 90° connector, the 180° mating connector **RRC-MC20-180-10** (RRC part number #210518) can also be positioned on the long side of the battery.

The following graphs show typical mating positions between the battery and the 180° header RRC-MC20-180-10. The dimensions shown must be considered when designing device battery compartments and the header assembly with respect to the compartment.

While all configurations are possible, the first configuration will result in the best contact between the mating connector and the battery. All other configurations are acceptable but will have less overlap area with the connector contact in the battery. All values are *maximum* tolerances, given in mm (inch). They are given in a way so that there is at least a 1 mm overlap between both connectors.

In any case, there is a gap between the PCB and the battery, which means the battery is inadequately supported. It would be best to place the 180° mating connector in a cavity recess so that the battery sits flat on the cavity surface.

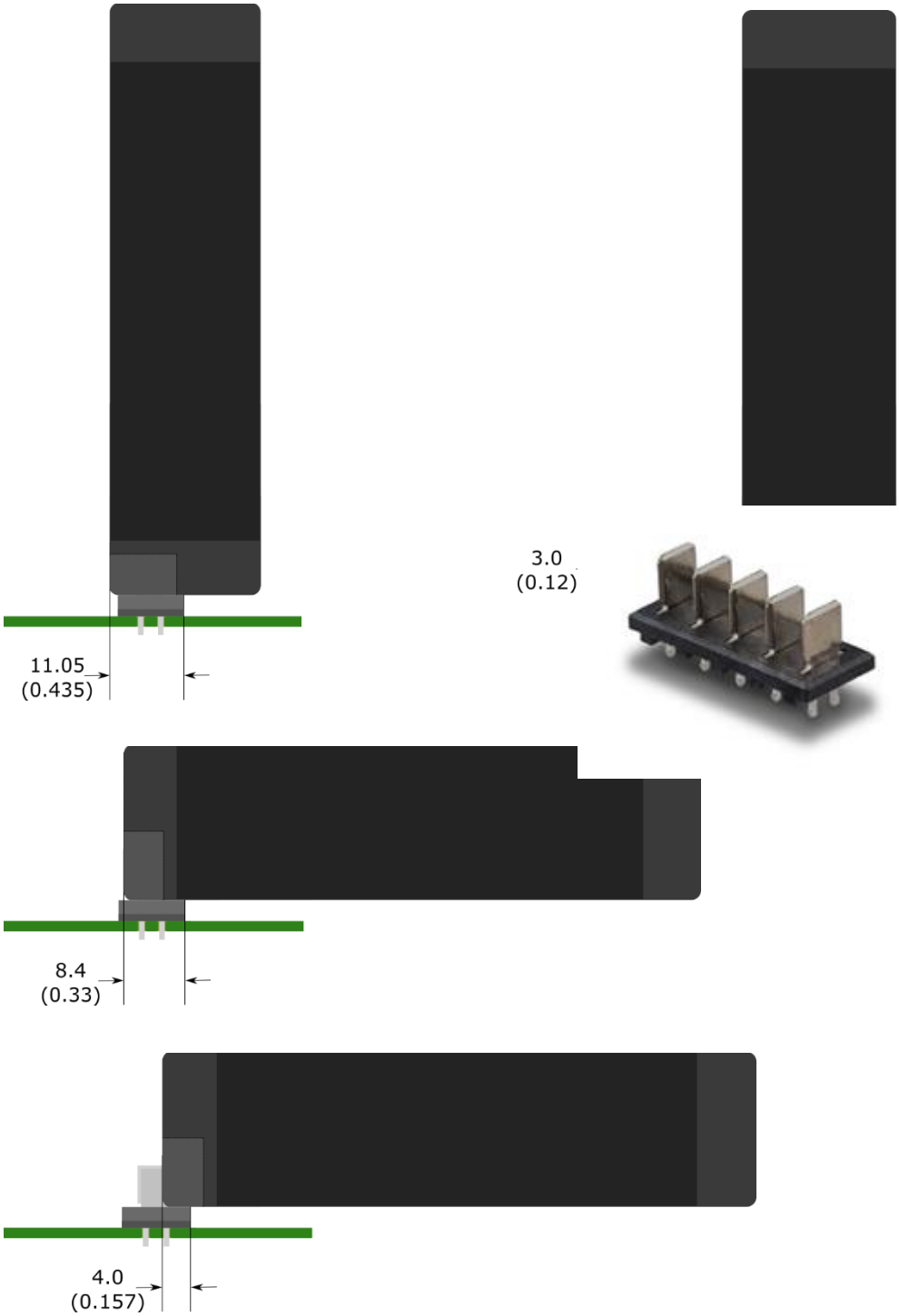


Figure 27 – 180° header RRC-MC20-180-10

10.9 Positioning the Mating Connector (RRC21xx batteries)

For RRC21xx batteries only

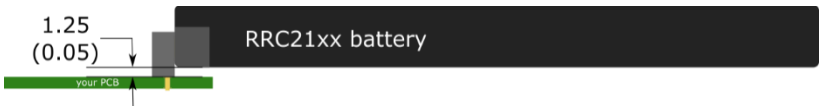
This section covers the RRC21xx batteries only. For the RRC20xx connectors, have a look at the previous section.

RRC offers two different connector types. Both have the same specifications but allow different positioning.

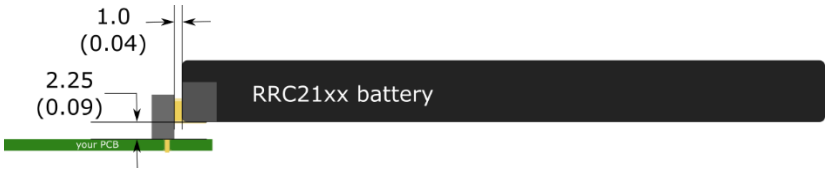
RRC-MC21-90-10 Connector

The **RRC-MC21-90-10** connector (RRC part number #211268) was designed to position the battery over the PCB level.

Best fit:



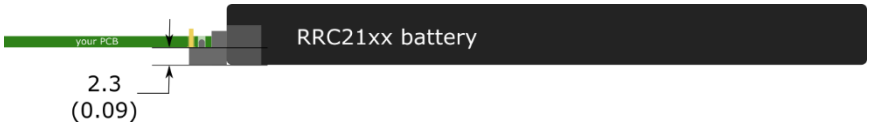
Worst case, but still acceptable fit:



RRC-MC21-90-20 Connector

The **RRC-MC21-90-20** connector (RRC part number #211278) was designed to position the battery in line with the PCB level.

Best fit:



Worst case, but still acceptable fit:

11 SMBus Communication – Electronics

11.1 Differences to I²C

RRC smart batteries communicate using SMBus as defined in System Management Bus Specification[6] revision 1.1.

SMBus specifications

The SMBus is very similar to I²C. In both cases, the devices have open-drain ports, and thus they need pull-ups on their communication lines. However, the hardware specification of SMBus devices is more restrictive to allow more energy-saving devices. Table *6* shows an excerpt of the official SMBus specifications.

Symbol	Parameter	Limits		Unit
f_{SMB}	SMBus Operating frequency	10	100	kHz
V_{IL}	Input Low Voltage	-0.5	0.8	V
V_{IH}	Input High Voltage	2.1	5.5	V
V_{OL}	Output Low Voltage		0.4	V
$I_{Pull-up}$	Current through pull-up resistor or current source	100	350	µA
T_R	Rise Time		1	µs

Table 6 – SMBus specifications

11.2 Communication with One Battery

SMBus setup

Figure 28 shows three SMBus participants (battery, charger, and host), the two communication lines SCL (Clock) and SDA (Data), and the pull-up resistors. **We recommend reserving an SMBus line exclusively for these three devices.** Section 11.4 Pull-up Design discusses how to choose the pull-up resistors (R_P).

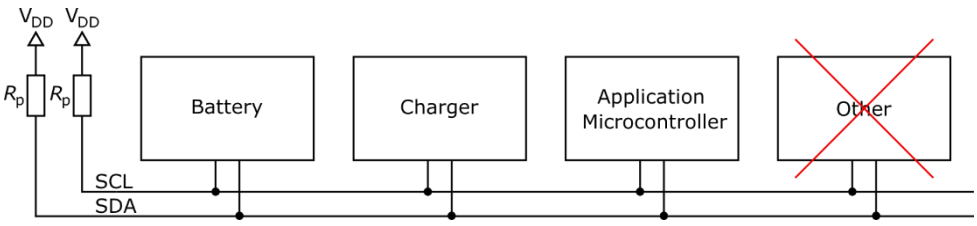


Figure 28 – SMBus setup

6 The complete specification is freely downloadable at http://smbus.org/specs/smbus110.pdf.

11.3 Communication with Two or More Batteries

SMBus setup with two or more batteries

All smart batteries share the same SMBus address. Hence, two batteries cannot connect at the same time to the same bus. If it is not possible to use separate buses, then it is necessary to use a multiplexer, as shown in Figure 29. The PCA9544A is a 4 to 1 multiplexer – it allows connecting 4 batteries to the same bus.

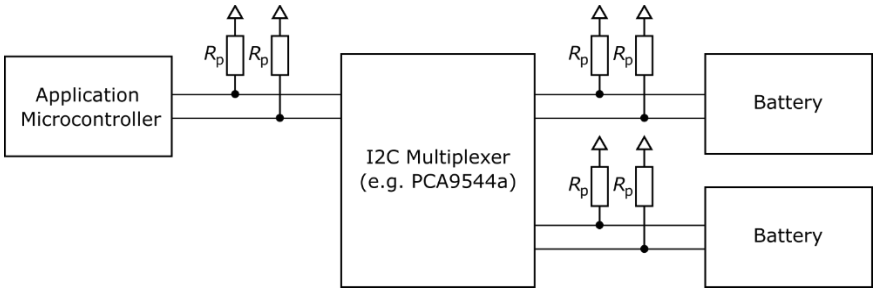


Figure 29 - SMBus setup with two or more batteries.

Note that every bus branch needs its own pull-up resistors. Although the PCA9544a supports up to 4 batteries, only 2 batteries are drawn for reasons of simplicity.

11.4 Pull-up Design

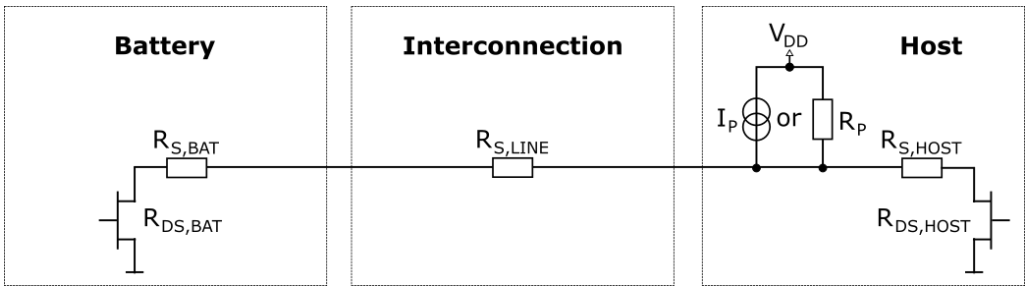


Figure 30 - SMBus Circuit Model

Figure 20 shows an SMBus circuit model with an SMB Device (e.g., the battery), an interconnection (e.g., cable and connector), and the SMB Host (e.g., the charger). The maximum series resistance of the interconnection and the SMB device must be less than 1.1 kΩ to assure the specified "maximum output low" voltage $V_{\mathrm{OL,max}}$:

[1] $R_{ESR,max} = R_{\mathrm{DS,BAT}} + R_{\mathrm{S,BAT}} + R_{\mathrm{S,LINE}} \leq \frac{V_{\mathrm{OL,max}}}{I_{\mathrm{Pull\text{-}up,max}}} = \frac{0.4\ \mathrm{V}}{350\ \mu\mathrm{A}} = 1.1\ \mathrm{k\Omega}$

The host needs to implement a pull-up circuit. This can either be done with a single resistor or a (constant) current source.

Pull-up Circuit Using Resistors

Typically, you want to use the most straightforward current source, which is a pull-up resistor.

The lower limit for this pull-up resistor derives from the maximum allowed current (refer to Table 6 on page 49):

[2] $R_{P_{MIN}} = \frac{V_{DD}}{350\mu A}$

The upper limit derives from the fact that even with maximum series resistances, at least 100 µA must flow (refer to equation 1):

[3] $R_{P_{MAX}} = \frac{V_{DD}}{100\mu A} - 1.1k\Omega$

Table 7 shows pre-calculated values for the pull-up resistor limits, depending on V_{DD}:

V_{DD}	R_{Pmin}	R_{Pmax}
2.4 V	6.9 kΩ	22.9 kΩ
2.7 V	7.8 kΩ	25.9 kΩ
3.0 V	8.6 kΩ	28.9 kΩ
3.3 V	9.5 kΩ	31.9 kΩ
3.6 V	10.3 kΩ	34.9 kΩ
4.2 V	12 kΩ	40.9 kΩ
5.0 V	14.3 kΩ	48.9 kΩ
5.5 V	15.8 kΩ	53.9 kΩ

Table 7 - Supply voltage-dependent limits for the pull-up resistor

The before-mentioned parameters are not the only ones to consider. To finish your calculation, you also need to respect the maximum rise time of T_R=1 µs, which depends on parasitic capacitance.

RRC smart batteries typically show a parasitic capacitance of less than 15 pF. The line and your circuit add some capacitance due to ESD protection and other components. As a good starting point, select your pull-up resistors to work with parasitic capacitances of up to 65 pF to allow clean communication.

Table 8 shows pre-calculated pull-up resistor values that respect the minimum and maximum current as well as the maximum rise time for a parasitic capacitance of 65 pF. Note that under these circumstances, finding a feasible value for VDD = 2.4 V is impossible.

Pull-up resistor values

V_{DD}	R_{Pmin}	R_{Pmax}
2.4 V	6.9 kΩ	6.2 kΩ
2.7 V	7.8 kΩ	10.1 kΩ
3.0 V	8.6 kΩ	13.4 kΩ
3.3 V	9.5 kΩ	16.6 kΩ
3.6 V	10.3 kΩ	19.6 kΩ
4.2 V	12 kΩ	25.6 kΩ
5.0 V	14.3 kΩ	33.5 kΩ
5.5 V	15.8 kΩ	38.4 kΩ

Table 8 – Possible pull-up values to use the system within SMBus specifications

Knowing your parasitic capacitance allows you to calculate the allowed pull-up resistor range more closely.[7] The SMBus standard specifies a maximum rise time of 1 µs (see Table 6). The rise time is defined by:

[4] $T_R = T(V_{IH_{MIN}} + 0.15V) - T(V_{IL_{MAX}} - 0.15V) = T(2.25\ V) - T(0.65\ V)$

Parasitic capacitances slow down the voltage edges. For (pull-up) resistors and capacitors, the voltage rises (and falls) in an exponential way:

[5] $V(t) = V_{DD} \cdot (1 - e^{-\frac{t}{C_{parasitic} \cdot R_P}})$

Hence, the rise time calculates to:

[6] $T_R = -R_P \cdot C_{parasitic} \cdot \ln\left(\frac{V_{DD}-2.25V}{V_{DD}-0.65V}\right)$

Transposing the equation lets you calculate the maximum allowed pull-up resistance for any given $C_{parasitic}$ and V_{DD}:

[7] $R_P = \frac{-T_R}{C_{parasitic} \cdot \ln\left(\frac{V_{DD}-2.25V}{V_{DD}-0.65V}\right)} = -1\mu s\ /\ \left(C_{parasitic} \cdot \ln\left(\frac{V_{DD}-2.25V}{V_{DD}-0.65V}\right)\right)$

Pull-up Circuit Using a Constant Current Source

If you are working with supply voltages < 3 V, or if you want to save current, consider using a constant current source instead of pull-up resistors. The advantage is that the rise time of a constant current source is linear:

[8] $V_{Bus}(t) = \frac{I_{Pull-up} \cdot t}{C_{parasitic}}$

Hence, the rise time can be calculated by:

[9] $T_R = 1.6\ V \cdot \frac{C_{parasitic}}{I_{Pull-up}}$

Even with parasitic capacitances as high as 150 pF, the rise time stays below 700 ns for a pull-up current of 350 µA, regardless of the supply voltage. We suggest designing for a pull-up current of 100 µA to allow for parasitic capacitances of around 65 pF.

[7] Note that after ESD events, the parasitic capacitance of ESD diodes may rise.

12 SMBus Communication – Software

RRC smart batteries communicate via SMBus, which is similar but not equal to I2C. You can use your microcontroller's I2C ports while paying attention to the differences described in section 9.1. Differences to I^2C. On top of the hardware layer, the protocol to be used is the SMBus protocol as described in Smart Battery Data Specification[8] **[SBDS]** revision 1.1.

12.1 SMBus Device Address Assignment

SMBus device addresses

Amongst other things, this specification defines the slave addresses of all bus participants as listed in Table 9. To send a write or a read command, that 7-bit device address must be shifted to the left. The last, 8th bit declares a read or write.

Description	7-bit Address	Write Address	Read Address
SMBus Host	_000 1000 (0x08)	0001 000 0 (0x10)	0001 000 1 (0x11)
Standard Smart Battery Charger	_000 1001 (0x09)	0001 001 0 (0x12)	0001 001 1 (0x13)
PMM20	_001 0000 (0x10)	0010 000 0 (0x20)	0010 000 1 (0x21)
Smart Battery	_000 1011 (0x0B)	0001 011 0 (0x16)	0001 011 1 (0x17)

Table 9 – SMBus device addresses

The battery operates as a

- *Master* – to broadcast its charging parameters and alarms, as described in section 12.4.1 Smart Battery Broadcast.
    - This section also provides instructions on how to disable broadcasts and make the battery slave-only.
- *Slave* – when the host queries the battery.

To communicate with the battery, the user has to set up a host (e.g., a microcontroller) using the **[SMBS]** protocol to query the registers as listed in the **[SBDS]** and in section 12.3 Clock Stretching.

Appendix A lists two tools that allow a user to quickly read the battery SMBus registers for testing purposes, without the need to develop an application for that.

[8] Smart Battery Data Specification Revision 1.1, see http://sbs-forum.org/specs/sbdat110.pdf.

12.2 Bus Protocol

12.2.1 How to Write and Read

The Smart Battery supports four access protocols – **Write Word**, **Read Word**, **Read Block**, and **Write Block**. In the following pictures, a "non-shaded" block indicates a message sent by the master, and a "shaded" block indicates a message sent by the slave:

# of bits of the command	8	8
Command name	SMBus Master	SMBus Slave

According to the **[SMBS]**, the bits shown below define the following operations:

S	A	/A	Wr	Rd	P
1	2	3	4	5	6

1 – Start condition; 2 – Acknowledge (ACK); 3 – Not Acknowledge (NACK) 4 – Write bit; 5 – Read bit; 6 – Pause condition

Write Word

After the Start Condition, the master writes the Battery (slave) write address, which is 0x16 (refer to Table 9). The slave Acknowledges (ACK) and then the master sends the command code. The slave ACK again and the master sends the data word. The slave ACK each byte and the entire transaction ends with a stop condition.

1	7	1	1	8	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	Data Byte Low	A	Data Byte High	A	P

Read Word

After the Start Condition, the master writes the Battery (slave) write address, which is 0x16 (refer to Table 9). The slave acknowledges and then the master sends the command code. The slave ACK and the master send a repeated start condition followed by the battery address and the read bit. The slave ACK then sends the two bytes of data. The master ACK the data byte low, NACK the data byte high, and finishes the transaction with a stop condition.

1	7	1	1	8	1	1	7	1	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	S	Battery Address	Rd	A	Data Byte Low	A	Data Byte High	/A	P

Write Block

A Write Block is similar to the Write Word protocol, except that the number of bytes to be written is specified in "Byte Count". Up to 32 data bytes of data can be written. The low byte data is transferred first.

1	7	1	1	8	1	8	1	8	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	Byte Count=N	A	Data Byte 1	A	(...)	A	Data Byte N	A	P

Read Block

A read block is similar to the Read Word protocol except that the first data byte received from the slave contains the number of bytes to be returned, and it is capable of transferring up to 32 data bytes. The low byte data is transferred first.

1	7	1	1	8	1	1	7	1	1	8	1	8	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	S	Battery Address	Rd	A	Byte Count=N	A	Data Byte 1	A	(…)	A	Data Byte N	/A	P

12.2.2 Example – Read SMBus register RelativeStateOfCharge()

To read the battery register RelativeStateOfCharge(), the host must send the command code 0x0D (listed in Table 10) using the Read Word protocol. The example below shows the sequence of bits exchanged in this operation where the battery returns a relative state of charge of 25% (0x19). Values in red are represented in binary, and values in blue are in hexadecimal form.

S	Battery Address	Wr	A	Command Code	A	S	Battery Address	Rd	A	Data Byte Low	A	Data Byte High	/A	P
S	0001 011	0	A	0000 1101	A	S	0001 011	1	A	0001 1001	A	0000 0000	1	P
S	0x16		A	0x0D	A	S	0x17		A	0x19	A	0x00	/A	P

12.3 Clock Stretching

The slave can use clock stretching to indicate to the host that it is busy (see Figure 31). Any time the clock is low, the slave may keep it low by pulling it as long as required (however, not longer than 25 ms as it would cause a packet timeout).

When programming your host, be prepared that the battery may use clock stretching.

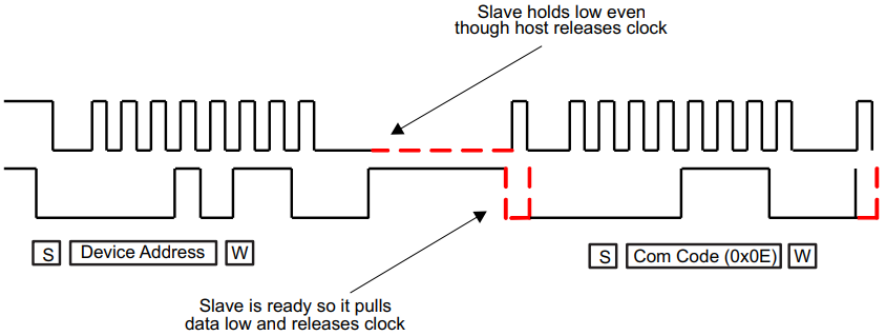


Figure 31 – Clock stretching (Picture is from TI document "SMBus Made Simple")

12.4 Standard Battery SMBus registers

The list of standard SMBus registers is defined in the **[SBDS]** documentation. The host can master the SMBus line and query the smart battery for its registers. Table 10 below lists the standard registers that are available on the RRC smart batteries.

List of standard SMBus registers

Function	Command	Access Protocol	Description
Manufacturer Access()	0x00	R/W word	Returns and sets manufacturer specific data (refer to chapter 12.5 Extended SMBus Registers).
Remaining Capacity Alarm()	0x01	R/W word	Sets the threshold for the Remaining Capacity Alarm (RCA) flag (refer to section 12.4.3 BatteryStatus() Register).
Remaining TimeAlarm()	0x02	R/W word	Sets the threshold for Remaining Time Alarm (RTA) flag (refer to section 12.4.3 BatteryStatus() Register).
BatteryMode()	0x03	R/W word	Refer to chapter 0.
AtRate()	0x04	R/W word	Refer to chapter 12.4.4 AtRate() Function.
AtRateTime ToFull()	0x05	Read word	Predicted remaining charging time in minutes, if charging continues with AtRate() current.
AtRateTime ToEmpty()	0x06	Read word	Predicted remaining operating time in minutes, if discharging continues with AtRate() current.
AtRateOK()	0x07	Read word	Returns a Boolean value that indicates whether or not the battery can deliver the AtRate() current for another 10 seconds. If the AtRate() current is zero or

Function	Command	Access Protocol	Description
			positive, AtRateOK()will ALWAYS return TRUE.
Temperature()	0x08	Read word	Internal battery pack temperature in units 0.1 Kelvin.
Voltage()	0x09	Read word	Battery voltage in mV, as measured at the cell stack.
Current()	0x0a	Read word	Current in mA. Positive values while charging, negative while discharging. Two's complement used for negative values.
AverageCurrent()	0x0b	Read word	Average current over one minute, in mA. Positive values while charging, negative while discharging. Two's complement used for negative values.
MaxError()	0x0c	Read word	Uncertainty of the SOC value, in %.
RelativeStateOfCharge()	0x0d	Read word	Remaining battery capacity in % of FullChargeCapacity().
AbsoluteStateOfCharge()	0x0e	Read word	Remaining battery capacity in % of DesignCapacity().
RemainingCapacity()	0x0f	Read word	Remaining battery capacity in mA or mWh.
FullChargeCapacity()	0x10	Read word	Battery capacity when fully charged, in mAh or mWh.
RunTimeToEmpty()	0x11	Read word	Predicted remaining operating time in minutes, if discharging continues with the present rate of discharge.
AverageTimeToEmpty()	0x12	Read word	Predicted remaining operating time in minutes, if discharging continues with the present 1-minute average rate of discharge.
AverageTimeToFull()	0x13	Read word	Predicted remaining charging time in minutes, if discharging continues with the present 1-minute average rate of charge.
ChargingCurrent()	0x14	Read word	Maximum requested charging current in mA.
ChargingVoltage()	0x15	Read word	Maximum requested charging voltage in mV.
BatteryStatus()	0x16	Read word	Refer to section 12.4.3 BatteryStatus() Register.
CycleCount()	0x17	Read word	Number of cycles the battery has experienced. RRC defines one battery cycle as the accumulated discharge of 90% of the design capacity.

Function	Command	Access Protocol	Description
DesignCapacity()	0x18	Read word	Design capacity of the new battery.
DesignVoltage()	0x19	Read word	Design voltage of a new battery.
SpecificationInfo()	0x1a	Read word	Version number of the **[SBDS]** that the battery pack supports, as well as voltage and current scaling information.
ManufactureDate()	0x1b	Read word	Manufacturing date of the battery.
SerialNumber()	0x1c	Read word	Battery serial number.
ManufacturerName()	0x20	Read word	Returns a character array (ASCII representation) containing the manufacture's name.
DeviceName()	0x21	Read block	Returns a character array (ASCII representation) containing the battery's name.
DeviceChemistry()	0x22	Read block	Returns a character array (ASCII representation) containing the battery's chemistry.
ManufacturerData()	0x23	Read block	Returns manufacturer specific data.

Table 10 – List of Standard SMBus Registers

12.4.1 Smart Battery Broadcast

Standard-wise the battery acts as SMBus master and transmits a broadcast, containing the ChargingCurrent(), ChargingVoltage() and the BatteryStatus() registers. This is done by default; you can change this behavior using the BatteryMode() register if you want to stop broadcasts and poll actively instead.

It is easier to implement a system where you are polling the registers. In that case, the battery never becomes the master. You would not need to worry about implementing multi-master capability. Note that after every battery reset, you need to disable the broadcasts again.

To disable the broadcasts of ChargingCurrent() and ChargingVoltage():

- Access the register BatteryMode() and set bit #14 "Charger Mode" to "1" .
- Repeat step 1 every time the battery has been unplugged.

As long as the "Charger Mode" is set, the smart battery does *not* broadcast the charging voltage and current. The host or charger must read both the ChargingCurrent() and ChargingVoltage() registers at least once every 60 seconds to ensure that the battery charges optimally.

To disable the broadcasts of AlarmWarning():

- Access the register BatteryMode() and set bit #13 "Alarm Mode" to "1" (refer to section 0).
- Repeat step 1 every 45 seconds, because "Alarm Mode" flag is cleared after the battery goes into sleep or shipping mode.

As long as the "Alarm Mode" bit is set, the battery does *not* broadcast AlarmWarning(). In this case, the host or charger must read the BatteryStatus()

register at least once every 10 seconds. Except the lowest nibble (4 bits), AlarmWarning() is equal to BatteryStatus().

12.4.2 BatteryMode() Register

Table 11 shows the BatteryMode() registers. You can use bits 13 to 15 to change the behavior of RRC smart batteries.

Note that on battery reset (due to shipping mode or deep-discharge), these bits are also reset to their default value.

Battery Mode flags description

Bit	Name	Access	When set (1)	When cleared (0)	Defaul t
15	Capacity Mode	Write/ Read	Battery registers reported in mW and mWh.	Battery registers reported in mA and mAh.	0
14	Charger Mode	Write/ Read	ChargingVoltage( ) and ChargingCurrent( ) broadcasts are disabled.	ChargingVoltage() and ChargingCurrent() broadcasts are enabled.	0
13	Alarm Mode	Write/ Read	AlarmWarning() broadcasts are disabled.	AlarmWarning() broadcasts are enabled.	0
12-8	RSVD	Read	-/-	-/-	0
7	Conditio n Flag	Read	Battery requests a conditioning cycle to recover fuel gauge accuracy.	The battery does not need to be conditioned.	0
6-0	RSVD	Read	-/-	-/-	

Table 11 – BatteryMode() flags description

Capacity Mode

As per default, the battery reports capacity information in mA and mAh. Setting [Capacity Mode] to "1" configures the battery to report its capacity in multiples of 10 mW and 10 mWh.

- If your device has an LDO input stage, you should select mA and mAh.
- If your device has a DC-DC converter input stage, you should select mW and mWh.

Suppose you would have a DC-DC converter input stage, but you would apply the mA and mAh setting. Towards the end of a discharge phase, the percentage of the SOC reading would then decrease at a higher speed. This is because to maintaining the same input power, the current must increase as the battery voltage decreases. Avoid this behavior by setting the Capacity Mode to mW and mWh.

Charger Mode

By default, the battery acts as SMBus master and sends ChargingVoltage() and ChargingCurrent() messages as a broadcast. Set the [Charger Mode] bit to "1" if you want to keep the battery silent. The host or charger then must actively poll the corresponding BatteryStatus() register at least once every 5 to 60 s.

Note that the [Charger Mode] bit resets to "0" automatically upon unplugging the battery or putting it into shipping mode.

Alarm Mode

By default, the battery acts as SMBus master and sends AlarmWarning() messages as a broadcast. Set the [Alarm Mode] bit to "1" if you want to keep the battery silent. Because the [Alarm Mode] flag is automatically reset when the battery goes into either sleep mode or shipping mode, you should set [Alarm Mode] to "1" every 45 seconds.

The host or charger then must actively poll the corresponding BatteryStatus() register at least once every 10 s. The BatteryStatus() register contains the same information, and in addition the lower 4 bits contain an Error Code (see Table 12).

Condition Flag

Over time & usage, the accuracy of the State-of-Charge reading decreases (as expressed by the MaxError()). If MaxError() exceeds 5%, the battery requests a conditioning cycle to restore a reasonable accuracy. To manually perform a conditioning cycle, follow these steps:

1. Fully charge the smart battery;
2. Disconnect it from the charger;
3. Let the battery rest still for five hours;
4. Discharge the battery below 10% RSOC with a discharge current lower than 0.5C;
5. Disconnect the battery from the load;
6. Let the battery rest still for five hours;
7. Fully charge the smart battery.

Alternatively, you can use the RRC smart charger RRC-SMB-UBC or RRC-SMB-DBC. These chargers automatically start a conditioning cycle when you insert a battery with active [Condition Flag].

12.4.3 BatteryStatus() Register

Battery Status flags description

Bit	Name	Bit is Set When	Required Action When Set:	Required Action When Cleared:
15	Over Charged Alarm (OCA)	The battery is fully charged and charging is complete.	Immediately stop charging.	Charging may resume.
14	Terminate Charge Alarm (TCA)	Charging should be suspended temporarily.	Stop charging.	Charging may resume.
13	Reserved	-/-	-/-	-/-
12	Over Temperature Alarm (OTA)	Temperature is above the preset limit.	Immediately stop charging / discharging.	Charging may resume.

Bit	Name	Bit is Set When	Required Action When Set:	Required Action When Cleared:
11	Terminate Discharge Alarm (TDA)	Battery capacity is depleted.	Stop discharging as soon as possible.	Discharge is no longer detected. No action is required.
10	Reserved		-/-	
9	Remaining Capacity Alarm (RCA)	RemainingCapacity() is less than RemainingCapacityAlarm().	Notify the host that the remaining capacity is below the defined threshold.	No action is required.
8	Remaining Time Alarm (RTA)	AverageTimeToEmpty() is less than RemainingTimeAlarm().	Notify host that the remaining time is below the defined threshold.	No action is required.
7	INIT – Initialized	Gauge initialization is complete.	No action is required.	Wait – Initialization is in progress.
6	DSG – Discharging	The battery is discharging or in a relaxed mode (not charging).	No action is required.	The battery is accepting charge current.
5	Fully Charged (FC)	The battery is fully charged.	Stop charging.	You may continue charging.
4	Fully Discharged (FD)	The battery is fully depleted.	Stop discharging.	You may continue discharging.
3-0	EC – Error Code	See Table 13.		

Table 12 – BatteryStatus() flags description

Table 13 lists the Communication Error Codes, represented by the last 4 bits in BatteryStatus().

Error Codes of Battery Status

Code	Error	Description
0x0000	OK	No error.
0x0001	Busy	The battery is temporarily unable to process commands.
0x0002	Reserved Command	Battery detected access to a reserved command or Battery detected access to an unsupported optional function.
0x0003	Unsupported Command	Battery does not support this function.
0x0004	Access Denied	Battery detected a write to a read-only function/register.
0x0005	Overflow/Underflow	Battery detected a data overflow/underflow.
0x0006	Bad Size	Battery detected an attempt to write with an incorrect data block size.
0x0007	Unknown Error	Battery detected an unidentifiable error.

Table 13 – Description of Error Codes of BatteryStatus()

12.4.4 AtRate() Function

Three functions provide an estimate of how long the battery will last if you charge (or discharge) it using a specific constant current or constant power:

- AtRateOK(): Indicates whether the battery can deliver the specific current/power for at least 10 s (1=yes, 0=no).
- AtRateTimeToEmpty(): Returns the remaining time to fully *discharge* (in minutes) the battery.
- AtRateTimeToFull(): Returns the remaining time to fully *charge* (in minutes) the battery.

To prepare the use of any of those functions, you need to follow these two steps:

- First, you select whether you want to assume a charge/discharge at a constant current or at a constant power.
- You do this by selecting the Capacity Mode Bit in register BatteryMode() (refer to chapter 0).
- Second, you write the expected current (in mA) or power (in steps of 10 mW) into the AtRate() register.
- When the AtRate value is *positive* (+), the AtRateTimeToFull() function returns the predicted time to fully charge at the AtRate value of *charge*.

  When the AtRate value is *negative* (-), the AtRateTimeToEmpty() function returns the predicted operating time at the AtRate value of *discharge*.

ATRate() function results

AtRate()	AtRateTimeToFull ()	AtRateTimeToEmpty()	AtRateOK()
Positive value (charge)	Time remaining to fully-charged at a charge rate specified in AtRate().	65535(*)	TRUE (non-zero)
Zero	65535(*)	65535(*)	TRUE (non-zero)
Negative value (discharge)	65535(*)	Time remaining to fully-discharge at the discharge rate specified in AtRate().	TRUE if AtRate() can be supported for > 10 seconds. If not, then FALSE (zero).

Table 14 – AtRate() function results.

(*)The value 65535, or 0xffff, means: not applicable, e. g. AtRateTimeToFull() when the battery is discharging.

Note:

- Upon changing the Capacity Mode bit, you need to rewrite to the AtRate() function using the appropriate units.
- While calculating the result based on a new AtRate() value, the Smart Battery may NACK a request on AtRateTimeToFull(), AtRateTimeToEmpty() and AtRateOK(). Instead, it will return a 'Busy' error code in BatteryStatus(). Or, the Smart Battery may use clock stretching in order to gain time to calculate the result.

12.4.5 ManufactureDate() Register

Manufacture Date register structure

This function returns the date when the battery pack was manufactured. Table 15 shows the representation of the date:

Field	Bits used	Format	Allowable Values
Day	0 to 4	5 bit binary value	1 to 31 (corresponds to day)
Month	5 to 8	4 bit binary value	1 to 12 (corresponds to month)
Year	9 to 15	7 bit binary value	0 to 127 (corresponds to year biased by 1980)

Table 15 – ManufactureDate register structure

Example: ManufacturerAccess() register returns:
0b **0101 0000 1001 1101 =** 0x509D

1. **0101 000** = 40 in Decimal (1980 + 40 = 2020)
2. **0 100** = 04 (April)
3. 1 1101 = 29

The battery pack was manufactured on 29th April of 2020

12.5 Extended SMBus Registers

RRC batteries offer additional information not included in the SMBus standard. You can find this information in the – as we call them – "extended" registers. You may use these registers, but please note that they may be subject to change from one battery generation to the next. Within these extended registers, you can read:

- 0x0010 Shipping()
- 0x0050 SafetyAlert()
- 0x0051 SafetyStatus()
- 0x0052 PermanentFailAlert()
- 0x0053 PermanentFailStatus()
- 0x0054 OperationStatus()
- 0x0055 ChargingStatus()
- 0x0056 GaugingStatus()
- 0x0060 LifetimeDataBlock1()
- 0x0062 LifetimeDataBlock2()
- 0x0063 LifetimeDataBlock3()
- 0x0064 LifetimeDataBlock4()
- 0x0070 ManufacturerInfo()
- 0x0071 DAStatus1()
- 0x0072 DAStatus2()

These registers allow you to monitor alert and status information in real time. Although the smart battery is safe by itself, it can provide an additional level of reliability to your application if you adapt the behavior of your application to these alerts. You can also use the status registers for a deeper fault analysis after the battery has switched off due to a safety event.

12.5.1 How to Read Data from the Registers

You cannot access these registers directly; instead, you use three so-called "auxiliary registers" to obtain the information. Table 16 shows these auxiliary registers:

Auxiliary Registers for accessing extended registers

Register Name	SMBus command
ManufacturerAccess()	0x00
ManufacturerBlockAccess()	0x44
ManufacturerData()	0x23

Table 16 – Auxiliary Registers for accessing extended registers

You request the desired information by:

- either writing to ManufacturerAccess() in Big Endian[9] using Write Word (see section 12.2.1 How to Write and Read),
- or writing to ManufacturerBlockAccess() in Little Endian[10] using Write Block (see section 12.2.1 How to Write and Read).

You then receive the result by sending a Read-Block command to ManufacturerData() or ManufacturerBlockAccess(), respectively. The data is returned in Little Endian (low byte first). Please note that the first two bytes returned by ManufacturerBlockAccess() contain the address of the requested register (also returned in Little Endian).

Example:

As an example, let's access the information in SafetyAlert(), address 0x0050:

1. Use the Write Word protocol (refer to section 12.2.1 How to Write and Read) with the command 0x0050 to ManufacturerAccess()

   in Big Endian:

1	7	1	1	8	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	Data Byte Low	A	Data Byte High	A	P
S	0x16		A	0x00	A	0x50	A	0x00	A	P

   Note: This operation requests Big Endian, but the Write-Word protocol request first "Data Byte low" and then "Data Byte High".

2. Then use the Read Block protocol (refer to section 12.2.1 How to Write and Read) to ManufacturerData(). The data is returned

   in Little Endian (low byte first). The SafetyAlert() register has 4 Bytes of data (refer to Table 19):

1	7	1	1	8	1	1	7	1	1	8	1	8	1	8	1	8	1	1
S	Battery Address	Wr	A	Command Code	A	S	Battery Address	Rd	A	Byte Count=N	A	Data Byte 1	A	(...)	A	Data Byte 4	/A	P
S	0x16		A	0x23	S	S	0x17		A	4	A	0x00	A	(...)	A	0x00	/A	P

[9] Big Endian: {MSB, LSB}

10 Little Endian: {LSB, MSB}

12.5.2 Alert, Safety, and PermanentFail Registers

Difference between Alert, Safety, and PermanentFail

What is the difference between Alert and Safety status registers? An alert indicates ahead of time that a protection *is going to* activate. In contrast, a safety status shows that that protection *has been* activated. Let's take an example:

Time window of the safety events

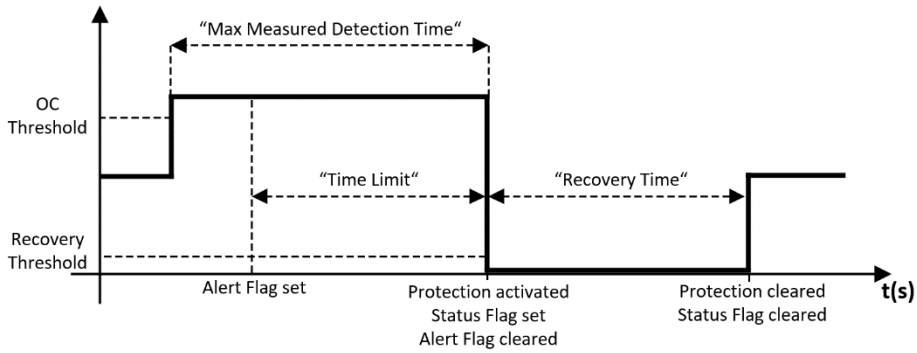


Figure 32 – Time window of the safety events

Figure 32 shows an overcurrent event. The *alert flag* warns the user that the overcurrent protection threshold was exceeded and that a safety switch-off (by the protection system FETs) is imminent. After a time delay, denoted as "Time Limit", the safety switch-off occurs by activating the protection and setting the respective *status flag*.

Within this "Time Limit" window, the user can either prepare its application for the sudden battery switch off or avoid it by reducing the current below the "OC Threshold". The "Max Measured Detection Time" is the maximum time window between reaching the protection threshold and activating the protection. Once the protection is activated, the current needs to drop below the "Recovery Threshold" for a period higher or equal to "Recovery Time". Once these conditions are met, the protection and the status flag are cleared, and the current may flow again (FET is reactivated).

Table 17 shows the thresholds and limits as defined in the RRC battery specification:

Over Current (OC) protection during discharge

OC Threshold [A]	OC Time Limit [s]	OC Recovery Threshold [mA]	OC Recovery Time [s]	Max Measured Detection time [s]
10.50	2	200	5	< 4

Table 17 –Over Current (OC) protection during discharge

This example above is also valid for other protections defined in the RRC battery specification (e.g., over-temperature, overcharging, over-discharging, overload, short circuit).

If the 1st level of protection should fail to interrupt the current, there is a 2nd protection level where the battery can set itself in a safe state by activating fuse. In that case, the PermanentFail() status indicates the event that has triggered the second protection level.

Figure 33 illustrates the sequence of transitions between regular operation and the safety states:

Normal state means that the battery is working normally. As soon as any safety threshold is reached, the battery jumps to the *SafetyAlert()* state. If that threshold is underrun again within the specified *Safety Time Limit*, then the battery status jumps back to the *Normal State*.

If not, the battery goes to *SafetyStatus()* and activates the 1st level protection (FETs). Typically, the battery won't charge or discharge anymore, and the measurement value in question should fall under the *Recovery Threshold* again. After a time longer than *Recovery Time*, the battery status jumps back to the *Normal State*.

Safety states diagram

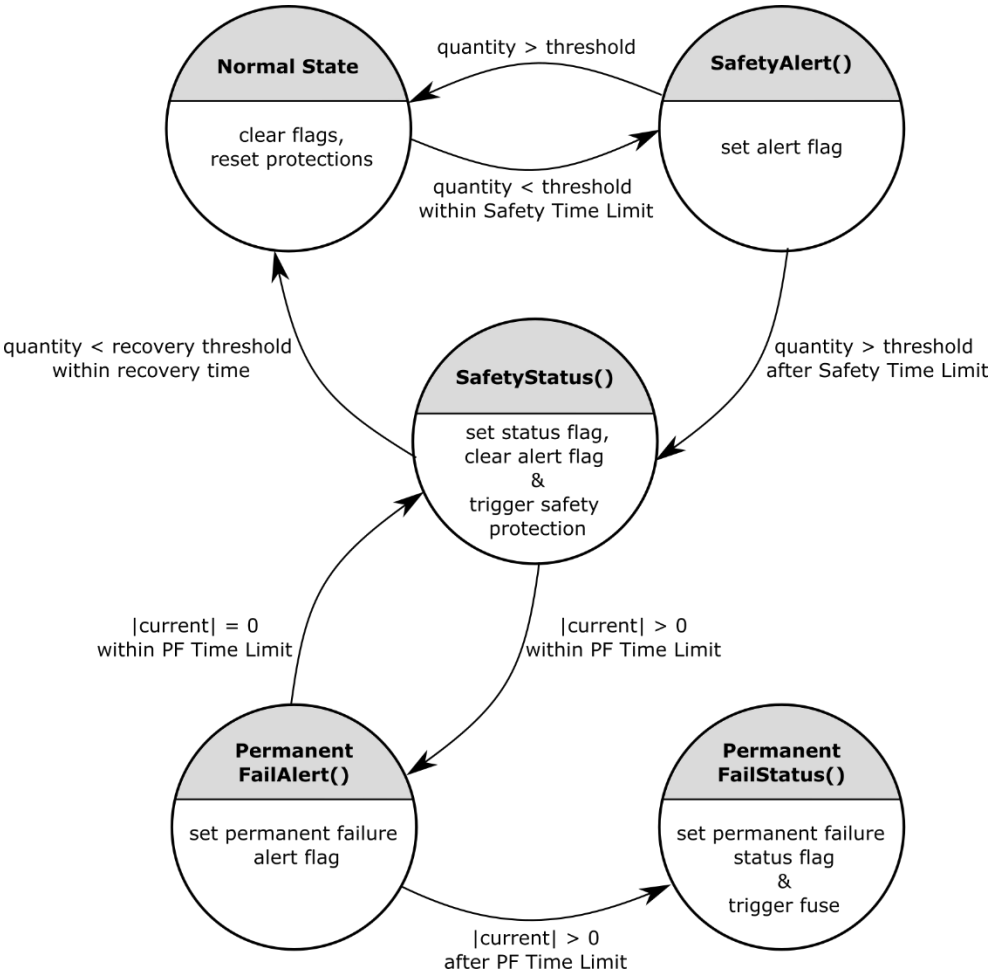


Figure 33 – Safety states diagram

1st level protection

However, if 1st level protection fails and the battery continues charging or discharging, the battery status changes to *PermanentFailAlert()*. If the battery current stops within *PF Time Limit*, the battery status jumps back to *SafetyStatus().*

2nd level protection

If not, the 2nd level protection kicks in. The battery assumes a critical failure and jumps to *PermanentFailStatus()* state, and the fuse is tripped. In this scenario, the battery enters the permanent failure mode. This is a safe state, where no further charge or discharge is possible.

In general, during the alert phases, the user can react by either disconnecting the load or preparing his application for a sudden battery switch-off.

Table 18 shows the addresses of the safety registers. Refer to section 12.5 for instructions to read those registers. The register value is returned in Little Endian:

Register Name	SMBus command
SafetyAlert()	0x0050
SafetyStatus()	0x0051
PermanentFailAlert()	0x0052
PermanentFailStatus()	0x0053

Table 18 – Safety registers SMBus commands

SafetyAlert() – SMBus Command 0x0050

SafetyAlert () register description

SafetyAlert() shows which Safety Alert is active. Table 19 describes the necessary action to avoid triggering the 1st level safety protection.

Bit	Name	Bit is Set When	Action When Set:	Action When Cleared:
31-21	Reserved	-/-	-/-	-/-
20	Charge Time Out (CTO)	Battery charged for too long without detecting a discharge.	Discharge at least 2 mAh with a current higher than 100 mA.	Charging may resume.
19-14	Reserved	-/-	-/-	-/-
13	Over Temperature Discharge (OTD)	The temperature is above the protection threshold.	Stop discharging.	Check SafetyStatus() in Table 20.
12	Over Temperature Charge (OTC)	The temperature is above the protection threshold.	Stop Charging.	Check SafetyStatus() in Table 20.
11-5	Reserved	-/-	-/-	-/-
4	Over Current Discharge (OCD)	The discharge current is above the protection threshold.	Reduce discharge current below the protection threshold.	Check SafetyStatus() in Table 20.
3	Reserved	-/-	-/-	-/-
2	Over Current Charge (OCC)	The charge current is above the protection threshold.	Reduce charge current below the protection threshold.	Check SafetyStatus() in Table 20.
1	Cell Over Voltage (COV)	Cell voltage is above the protection threshold.	Immediately stop charging.	Check SafetyStatus() in Table 20.
0	Cell Under Voltage (CUV)	Cell voltage is below the protection threshold.	Immediately stop discharging.	Check SafetyStatus() in Table 20

Table 19 – SafetyAlert() register description

SafetyStatus() - SMBus Command 0x0051

SafetyStatus() shows which Safety Status has triggered 1st level safety protection. Table 20 describes the necessary action to recover from the safety condition and clear the respective flag.

Safety Status() register description

Bit	Name	Bit is Set When	Action When Set:	Action When Cleared:
31-21	Reserved	-/-	-/-	-/-
20	Charge Time Out (CTO)	Battery charged for too long without detecting a discharge.	Discharge at least 2 mAh with a current higher than 50 mA.	Charging may resume.
19-14	Reserved	-/-	-/-	-/-
13	Over Temperature Discharge (OTD)	The Temperature exceeded the protection threshold.	Wait for "Recovery Time" to clear protection.	Discharging may resume.
12	Over Temperature Charge (OTC)	The Temperature exceeded the protection threshold.	Wait for "Recovery Time" to clear protection.	Charging may resume.
11-5	Reserved	-/-	-/-	-/-
4	Over Current Discharge (OCD)	The discharge current exceeded the protection threshold.	Wait for "Recovery Time" to clear protection.	Discharging may resume.
3	Reserved	-/-	-/-	-/-
2	Over Current Charge (OCC)	The Charge current exceeded the protection threshold.	Wait for "Recovery Time" to clear protection.	Charging may resume.
1	Cell Over Voltage (COV)	Cell voltage exceeded the protection threshold.	Discharge below "Recovery Threshold" to clear protection.	Charging may resume.
0	Cell Under Voltage (CUV)	Cell voltage went below the protection threshold.	Charge above "Recovery Threshold" to clear protection.	Discharging may resume.

Table 20 - SafetyStatus() register description

PermanentFailAlert() - SMBus Command 0x0052

PermanentFailAlert() shows that triggering the fuse is imminent, and Table 21 describes the symptom of why that may happen.

Bit	Name	Description
31-23	Reserved	-
22	2LVL	Cell over-voltage detected
21-18	Reserved	-
17	DFTEF	Discharge FET failure detected
16	CFETF	Charge FET failure detected
15-13	Reserved	-
12	VIMA	Critical cell voltage imbalance detected while charging
11-0	Reserved	-

Table 21 –PermanentFailAlert() and PermanentFailStatus()

PermanentFailAlert() and PermanentFailStatus() registers have the same bit positions and significations.

PermanentFailStatus() - SMBus Command 0x0053

After the output fuse has been activated by the battery, PermanentFailStatus() shows you the symptom of why that happened. PermanentFailStatus() has the same bit positions as PermanentFailAlert(); you find its description in Table 21. The battery is now permanently damaged and must be replaced.

12.5.3 Data Registers

You can use the following registers for additional information to increase the performance of your application. You access these registers via the extended register set. All values, with the exception of ManufactureInfo(), are returned in Little Endian.

Data registers SMBus commands

Register Name	SMBus command
OperationStatus()	0x0054
ChargingStatus()	0x0055
GaugingStatus()	0x0056
ManufacturerInfo()	0x0070

Table 22 – Data registers SMBus commands

OperationStatus() - SMBus Command 0x0054

Operation Status() register description

Bit	Name	Description	Flag is set when	Flag is cleared when:
31-29	Reserved	-/-	-/-	-/-
28	CB	Cell Balancing Status	Battery performs cell balancing while charging	Cell balancing not active.
27-25	Reserved	-/-	-/-	-/-
24	INIT	Initialization after full reset	Battery initialized.	Battery is initializing; wait until bit is set.
23-17	Reserved	-/-	-/-	

Bit	Name	Description	Flag is set when	Flag is cleared when:
16	SHM	Shipping/Shutdown mode command sent	Shipping/Shutdown mode has been sent and battery will enter this mode.	No shipping/shutdown mode command detected.
15	SLEEP	Sleep mode	Battery is in sleep mode.	Battery is in normal operation mode.
14	XCHG	Charging disabled	Charge MOSFET switched-off.	Charge MOSFET switched-on.
13	XDSG	Discharging disabled	Discharge MOSFET switched-off.	Discharge MOSFET switched-on.
12	PF	Permanent Failure Mode	Battery in permanent failure mode.	Battery not in permanent failure mode.
11	SS	Safety switch-off occurred. Check safety status register	Safety switch-off occurred. Check SafetyStatus().	No safety switch-off detected.
0-10	Reserved	-		

Table 23 – OperationStatus() register description

ChargingStatus() – SMBus Command 0x0055

Charging Status() register description

Bit	Name	Description	Flag is set when	Flag is cleared when:
31-7	Reserved	-/-	-/-	-/-
6	OTR	Over Temperature Region	Charging disabled due to over-temperature. ChargingCurrent() set to 0.	Charging may resume.
5-1	Reserved	-/-	-/-	-/-
0	UTR	Under Temperature Region	Charging disabled due to under-temperature. ChargingCurrent() set to 0.	Charging may resume.

Table 24 – ChargingStatus() register description

GaugingStatus() - SMBus Command 0x0056

Gauging Status() register description

Bit	Name	Description	Flag is set when	Flag is cleared when:
31-7	Reserved	-/-	-/-	-/-
7	CF	Condition Flag	MaxError() register > 5% Conditioning requested.	Battery has been conditioned.
6-4	Reserved	-/-	-/-	-/-
3	TC	Terminate Charge	Charging should be interrupted.	Charging may resume.
2	TD	Terminate Discharge	Discharging should be interrupted.	Discharging may resume.
1	FC	Fully Charged	Battery is fully charged.	Charging may resume.
0	FD	Fully Discharged	Battery is fully discharged	Discharging may resume.

Table 25 – GaugingStatus() register description

ManufactureInfo() - SMBus Command 0x0070

This register outputs 32 bytes of battery pack manufacture info, as described in Table 26. The returned data entities are represented in ASCII. Bytes from Manufacture Date (Byte 26 to 24) are represented in base-36. The manufacture year (byte 24) is decoded by adding 2000 (in decimal). The result is returned in Little Endian and needs to be converted to Big Endian to match the description in Table 26.

Little Endian: aaAA bbBBCC DD EE FF ggGG hhHH iiIIjjJJ KK llLLmmMMnnNNOO ppPPqqQQrrRRssSSTT UU

Big Endian: AAaa BBbbCC DD EE FF GGgg HHhh IIiiJJjj KK LLllMMmmNNnnOO PPppQQqqRRrrSSssTT UU

Manufacture Info() register description

Byte	Description
AAaa	Firmware revision
BBbbCC	Pack Serial Number
DD	Manufacture Date: Day
EE	Manufacture Date: Month
FF	Manufacture Date: Year (shifted by 2000)
GGgg	Factory Code
HHhh	Battery Revision
IIiiJJjj	Model code
KK	Commodity Code
LLllMMmmNNnnOO	Reserved and set to 0
PPppQQqqRRrrSSssTT	Unique serial number for every PCBA
UU	Factory dependent

Table 26 – ManufactureInfo() register description

12.5.4 Lifetime Data Registers

RRC smart batteries provide access to lifetime data. This data is distributed over four registers as shown in Table 27. You access these registers via the extended register set.

Lifetime data registers

Register Name	SMBus command
LifetimeDataBlock1()	0x0060
LifetimeDataBlock2()	0x0062
LifetimeDataBlock3()	0x0063
LifetimeDataBlock4()	0x0064

Table 27 - Lifetime data registers

LifetimeDataBlock1() - SMBus Command 0x0060

This command returns the lifetime data, which is described in Table 28 with the format shown below.

aaAAbbBBccCCddDDeeEEffFFggGGhhHHiiIIjjJJkkKKllLLmmMMNNOOPPQQRRSS

Lifetime DataBlock1() description

Bytes	Description	Unit
AAaa	Cell 1 Maximum Voltage	mV
BBbb	Cell 2 Maximum Voltage	mV
CCcc	Cell 3 Maximum Voltage	mV
DDdd	Cell 4 Maximum Voltage	mV
EEee	Cell 1 Minimum Voltage	mV
FFff	Cell 2 Minimum Voltage	mV

Bytes	Description	Unit
GGgg	Cell 3 Minimum Voltage	mV
HHhh	Cell 4 Minimum Voltage	mV
IIii	Maximum Delta Cell Voltage	mV
JJjj	Maximum Charge Current	mA
KKkk(1)	Maximum Discharge Current	mA
LLll(1)	Maximum Average Discharge Current	mA
MMmm(1)	Maximum Average Discharge Power	mW
NN	Maximum Cell Temperature	°C
OO	Minimum Cell Temperature	°C
PP	Reserved	-/-
QQ	Maximum temperature Internal sensor	°C
RR	Minimum Temperature Internal sensor	°C
SS	Reserved	-/-

Table 28 – LifetimeDataBlock1() description

(1) – Apply Two's Complement to get the correct discharge current or power.

LifetimeDataBlock2() - SMBus Command 0x0062

This command returns the lifetime data, which is described in Table 29 with the format shown below.

aaAAbbBBccCCddDDeeEEffFFggGGhhHH

Lifetime DataBlock2 () description

Bytes	Description	Unit
AAaa	Total FW Runtime	hours
BBbb	Time Spent in UT (Under Temperature)	hours
CCcc	Time Spent in LT (Low Temperature)	hours
DDdd	Time Spent in STL (Standard Low Temperature)	hours
EEee	Time Spent in RT (Recommended Temperature)	hours
FFff	Time Spent in STH (Standard High Temperature)	hours
GGgg	Time Spent in HT (High Temperature)	hours
HHhh	Time Spent in OT (Over Temperature)	hours

Table 29 – LifetimeDataBlock2() description

LifetimeDataBlock3() - SMBus Command 0x0063

This command returns the lifetime data, which is described in the table with the format shown below.

aaAAbbBBccCCddDDeeEEffFFggGGhhHHiiIIjjJJkkKKllLLmmMMnnNNooOOppPP

Lifetime DataBlock3 () description

Bytes	Description	Unit
AAaa	Number of Cell Over Voltage events	Counts
BBbb	Last Cell Over Voltage event	Cycle
CCcc	Number of Cell Under Voltage events	Counts
DDdd	Last Cell Under Voltage event	Cycle
EEee	Number of Over Current during Discharge 1st Tier events	Counts
FFff	Last Over Current during Discharge 1st Tier event	Cycle
GGgg	Number of Over Current during Discharge 2nd Tier events	Counts
HHhh	Last Over Current during Discharge 2nd Tier event	Cycle
IIii	Number of Over Current during Charge 1st Tier events	Counts

Bytes	Description	Unit
JJjj	Last Over Current during Charge 1st Tier event	Cycle
KKkk	Number of Over Current during Charge 2nd Tier events	Counts
LLll	Last Over Current during Charge 2nd Tier event	Cycle
MMmm	Number of Over Load in Discharge events	Counts
NNnn	Last Over Load in Discharge event	Cycle
OOoo	Number of Short Circuit in Discharge events	Counts
PPpp	Last Short Circuit in Discharge event	Cycle

Table 30 – LifetimeDataBlock3() description

(1) – Apply Two's Complement to get the correct discharge current or power.

LifetimeDataBlock4() - SMBus Command 0x0064

This command returns the lifetime data, which is described in the table with the format shown below.

aaAAbbBBccCCddDDeeEEffFFggGGhhHHiiIIjjJJkkKKllLLmmMMnnNNooOOppPP

LifeTime DataBlock4 () description

Bytes	Description	Unit
AAaa	Number of Short-Circuit in Charge events	Counts
BBbb	Last Short-Circuit in Charge event	Cycle
CCcc	Number of Over Temperature in Charge events	Counts
DDdd	Last Over Temperature in Charge event	Cycle
EEee	Number of Over Temperature in Discharge events	Counts
FFff	Last Over Temperature in Discharge event	Cycle
GGgg	Reserved	-
HHhh	Reserved	-
IIii	Number of valid charge termination	Counts
JJjj	Last valid charge termination	Cycle
KKkk	Number of Qmax updates	Counts
LLll	Last Qmax update	Cycle
MMmm	Number of Ra updates	Counts
NNnn	Last Ra update	Cycle
OOoo	Reserved	-
PPpp	Reserved	-

Table 31 – LifeTimeDataBlock4() description

DAStatus Registers

Mostly for debugging purposes, you can retrieve single cell voltages and temperatures using the registers DAStatus1() and DAStatus2(). You access these registers via the extended register set.

DAStatus1() – SMBus Command 0x0071

aaAAbbBBccCCddDDeeEEffFFggGGhhHHiiIIjjJJkkKKllLLmmMMnnNNooOOppPP

DAStatus1() description

Bytes	Description	Unit
AAaa	Cell 1 voltage	mV
BBbb	Cell 2 voltage	mV
CCcc	Cell 3 voltage	mV
DDdd	Cell 4 voltage	mV
EEee	Cell stack voltage	mV
FFff	Pack voltage (at connector)	mV
GGgg	Reserved	-
HHhh	Reserved	-
IIii	Reserved	-
JJjj	Reserved	-
KKkk	Reserved	-
LLll	Reserved	-
MMmm	Reserved	-
NNnn	Reserved	-
OOoo	Power: Voltage()*Current()	cW
PPpp	Average Power	cW

Table 32 – DAStatus1() description

DAStatus2() – SMBus Command 0x0072

aaAAbbBBccCCddDDeeEEffFFggGGhhHH

DAStatus2() description

Bytes	Description	Unit
AAaa	Reserved	-
BBbb	TS1 temperature	0.1 K
CCcc	TS2 temperature (if available)	0.1 K
DDdd	TS3 temperature (if available)	0.1 K
EEee	TS4 temperature (if available)	0.1 K
FFff	Cell temperature (Equal to Temperature())	0.1 K
GGgg	FET temperature (if available)	0.1 K
HHhh	Reserved	-

Table 33 – DAStatus2() description.

TS is short for "temperature sensor".

13 Quality

13.1 Quality Management

RRC products are engineered in Germany and developed according to ISO13485 and FDA QS-Reg.820, which are standards used to design and manufacture medical devices. RRC manufacturing facilities are certified in accordance with ISO9001 and ISO14001.

13.2 Supported Regions and Certificates

In each RRC battery specification, you find the complete list of the respective battery's certificates. You also find them printed on the battery label. Table 34 shows the supported regions and their respective certificates and certification marks.

RRC battery certificates are regularly updated – you never have to pay or wait for them. A Product Change Notification (PCN) will inform you of any added or updated certificates.

Worldwide Approvals

Region	Certificate	Mark	Region	Certificate	Mark
International	**CB**	-/-	India	**BIS**	
Europa	**CE**		South Korea	**KC**	
UK	**UKCA**		Taiwan	**BSMI**	
USA / Canada	**UR**		Thailand	**TISI**	
Australia / New Zealand	**RCM**		Russia	**GOST-R**	
Japan	**PSE**		Belarus / Kazakhstan / Kyrgyzstan	**EAC**	
China	**CCC**		Morocco	**CMIM**	

Table 34 - Correspondence between certificate mark and country

14 Shipping and Storing

14.1 Shipping Batteries

All RRC smart batteries are certified to UN38.3 and IATA DGR and can be shipped worldwide.

Depending on the kind of transport (road, sea, air), there are different requirements on the packaging and the stickers on the packaging. If you ship the batteries over the air, you must also ensure that the battery state of charge is no more than 30%.[11] For more complete and up-to-date information, you can find the latest shipping guidelines at **https://www.rrc-ps.com/downloads/**. This document contains information on how to ship all sizes of batteries – but since RRC batteries have a capacity of less than 100 Wh, the relevant chapters are:

- Chapter 5.1 – Instructions on how to ship batteries by Truck, Rail, or Sea Freight;
- Chapter 5.3 – Instructions on how to ship batteries by Air Freight.

The IATA DGR requirements are the reason why RRC ships all batteries with a state of charge of less than 30%. If you are looking for a dedicated charger to set the batteries to 30% and put them into shipping mode automatically, ask your local salesperson for the "RRC-SMB-UBC-DIS" charger.

14.2 Storing Batteries (Shelf-Life)

When shipping batteries or storing them for several months, set them in the so-called "shipping mode". RRC specifies a shelf-life of 12 months when stored in shipping mode, at 25°C and an initial state of charge of 30%.

We are aware that the 12-month statement is very conservative. The yearly self-discharge in shipping mode is expected to be smaller than 3%. But because of the influence of your actual storage conditions and because we have seen workers accidentally storing batteries that have not been in shipping mode, we encourage you to make a least a random check once per year. If you want, you can experiment with the storage time and prolong it as you wish, at your own risk.

If you are looking for a dedicated charger to set the batteries to 30% and put them into shipping mode automatically, ask your local salesperson for the "RRC-SMB-UBC-DIS" charger.

Lithium-ion technology stores even better at a state of charge of 60% (and in shipping mode, of course). If you do not plan to ship your batteries over the air, which requires a state of charge of no more than 30%, this is what we recommend. The chemical processes inside the battery are most balanced at 60%, leading to a longer battery life expectation. And any self-discharge would not kick the battery into a deep-discharged state so quickly.

The storage temperature is more critical than the charge level. It's best to store a battery at 25°C or below. The self-discharge rate roughly doubles with every 10 °C temperature increase; also, the permanent capacity loss due to lithium plating increases at temperatures above 30°C.

[11] Exception: if the batteries are packed with or contained within the end product.

14.3 Shutdown / Shipping Mode

"Shutdown" and "shipping mode" are synonymous terms.

Even if not in use, the electronics inside of a battery lead to a self-discharge of 2 to 5% per month. In a device, you may add the amount of energy drawn by your electronics. Limited shelf life is the result. Note that it can generally harm batteries if they become deeply discharged for a long time.[12]

When shipping batteries or storing them for several months, set them in the so-called "shipping mode". The electronics internal to the battery shut down; Also, there will be no voltage at the battery terminals anymore. If you would set the shipping mode while the battery powers your application, your application would shut down at the same time as the battery. The self-discharge rate decreases to a magnitude of 0.05% to 0.25% per month under ambient temperature conditions. To wake up the battery, you need to apply a charging voltage.

Set the battery into shipping mode

To set the battery into shipping mode, use the Write word protocol and send the shipping mode command (0x0010) over the ManufacturerAccess() register (address 0x00) twice within 4 seconds. Follow the steps below:

1. Send two shipping mode commands within 4 seconds.
2. Send no other commands in-between the two shipping mode commands.
3. Discharge the battery terminals into a resistor (e.g., 10 kΩ or 100 kΩ).

Depending on the model, the battery requires 3 to 5 s before entering shipping mode.[13]

There are three different ways to confirm the battery entered shipping mode:

1. Press the push button (refer to chapter 10.1 LED Push Button) and verify that no LED lights up;
2. Verify that the battery does not establish SMBus communication (NACK when addressed);
3. Verify that the battery output voltage is 0 V.

If you are looking for a dedicated charger to set the batteries to 30% and put them into shipping mode automatically, ask your local salesperson for the "SMB-UBC-DIS" charger.

Wake the battery from shipping mode

Connect the battery to a charger – charging wakes the battery up. Wait 3 to 5 seconds before initiating SMBus communication from your host to the battery. This ensures that the battery is fully initialized before communication starts.

12 The battery ages faster, with the consequence of a higher internal impedance and unbalanced cells. Depending on the level and duration of deep-discharge, the battery may not be able to be charged again.

13 Early RRC smart batteries have taken 30 s before entering shipping mode. Those batteries do not sell anymore today.

15 Replacing Batteries

15.1 Battery Lifetime

RRC recommends replacing batteries after two years of use or after 300 cycles, whatever first comes. Most of our medical customers consider this a good practice.

If you want to use the batteries longer, be sure to check that, with battery degradation due to aging and usage, your device's specifications can still be met. Ask RRC Application Support for battery-specific lifetime data.

15.2 RRC Life Cycle Management (No-Obsolescence Promise)

No Obsolescene

Product life cycles in the medical, industrial, and military markets are often up to 15 years. This means that these customers need suppliers whose products are available for this amount of time.

As battery technology improves, the life cycle of Li-Ion cells is becoming shorter and shorter. Cells are often discontinued on short notice, and battery pack manufacturers must react quickly. This implies that RRC needs to:

1. Always search for new suitable cells;
2. Incur long development time and high development costs;
3. Re-certify the battery pack.

RRC's "No-Obsolescence Promise" means that RRC manages the previously mentioned tasks and delivers an updated battery revision that is backward compatible (drop-in replacement) with our existing designs. Figure 34 illustrates how the next battery generation is typically developed 4 to 5 years after the previous battery release. RRC uses a Change Notification (CN) process to inform customers of these updates.

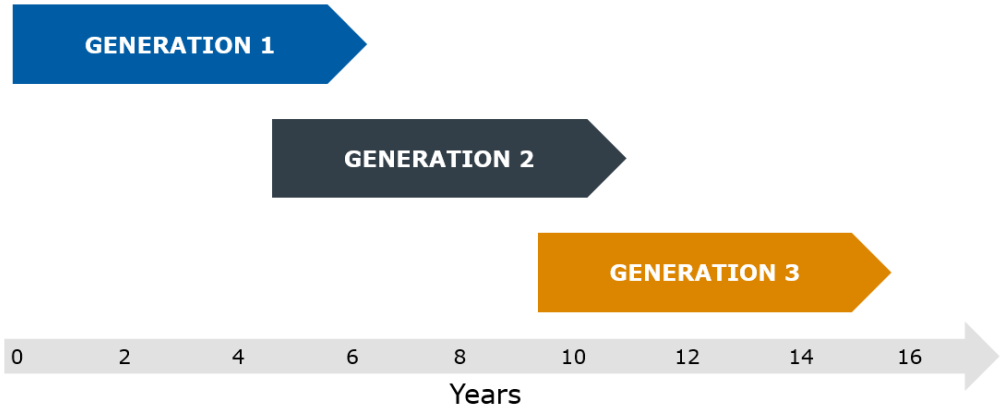


Figure 34 – RRC Life Cycle Management

16 Additional product portfolio

16.1 Our product portfolio at a glance

Highest quality and safety standards

As a leading manufacturer of mobile energy supply solutions for demanding industries, RRC power solutions is setting new standards on the market. Our product portfolio ranges from standard and customized battery packs to chargers, car adapters, and other suitable accessories.

Our products fulfill the highest quality and safety standards and have all the necessary global approvals. For our customers, this means a short time-to-market and considerable savings in development costs.

Our innovative solutions are used as energy sources for portable and mobile applications in markets with the highest requirements, such as medical and defense technology, instrumentation, robotics, and powering drones.

16.2 Flatpaq product overview

RRC PowerPAQs	Nominal Voltage (V)	Nominal Capacity (Ah)	Energy (Wh)	Discharge Current (A)
RRC1120	3.60	2.35	8.46	2.30
RRC1130	3.80	3.81	14.47	3.00
RRC3570	25.20	3.90	98.28	30.00

You can download the complete product portfolio of RRC **here**.

17 RRC locations worldwide

Worldwide availability

Germany / Headquarters

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Technologiepark 1
66424 Homburg / Saar

Tel.: +49 6841 98090
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Hai An District
180000 Hai Phong City

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Appendix

A Tools to Read Battery SMBus registers

If you cannot set up a microcontroller to communicate with the battery via SMBus, other options are available to access the battery registers:

SMBus Reader

Figure 35 shows an SMBus reader developed by RRC. It does not need extra power as the battery itself powers it. Simply connect it to the battery and use both push buttons to scroll through the battery's SMBus registers.

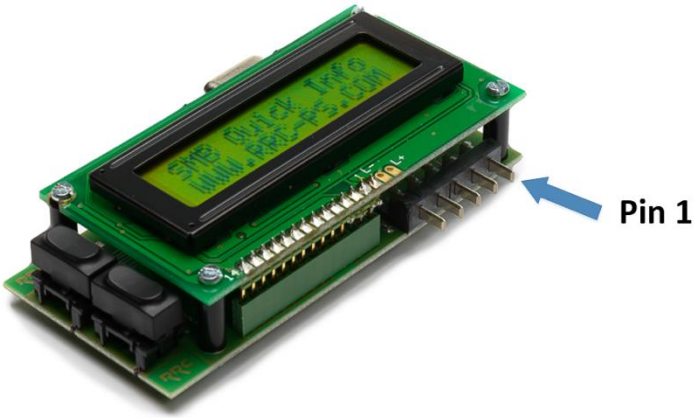

Figure 35 – SMBus Reader

SMBus Reader Pinout

Pinout	Legend	Description
1	(-)	Negative Terminal
2	(T)	Identifier pin
3	(D)	SMBus Data
4	(C)	SMBus Clock
5	(+)	Positive Terminal

Table 35 – SMBus Reader Pinout

EV2400 Box

The EV2400 box from Texas Instruments makes it possible to read the battery SMBus registers using a Windows computer. To set it up, please follow the steps below:

1. Download and install the software "Battery Management Studio (bqStudio) Software" from Texas instruments;
2. Make sure the battery has woken up by verifying whether the battery LED lights up (refer to chapter 10.1 LED Push Button). If not, insert the battery into a charger and recheck LEDs.
3. Connect the USB cable to the computer;
4. Connect the other end of the same USB cable to the EV2400 box (Figure 36);
5. Connect the bus cable to the SMB port of the EV2400 (red rectangle in Figure 36);
6. Using the other end of the bus cable, strip the wires and solder them to a battery mating connector (e.g., RRC-MC20-90-10). Make sure that SCL, SDA and GND match the battery pinout (refer to battery specification);

7. Connect the mating connector to the battery;
8. Launch the bqStudio software and read and display the SMBus registers.

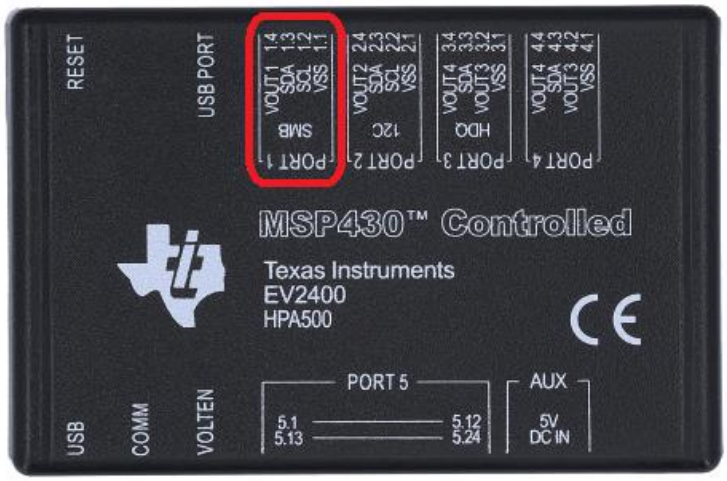

Figure 36 – EV2400 Box

B Practical Advice: Stop Discharging in Time

As shown in Figure 37, the battery voltage drops most while discharging the final few percent of the battery capacity. The current needs to rise proportionally to cover the required amount of power. In addition, the internal battery impedance is highest just in the remaining battery capacity range.

Example

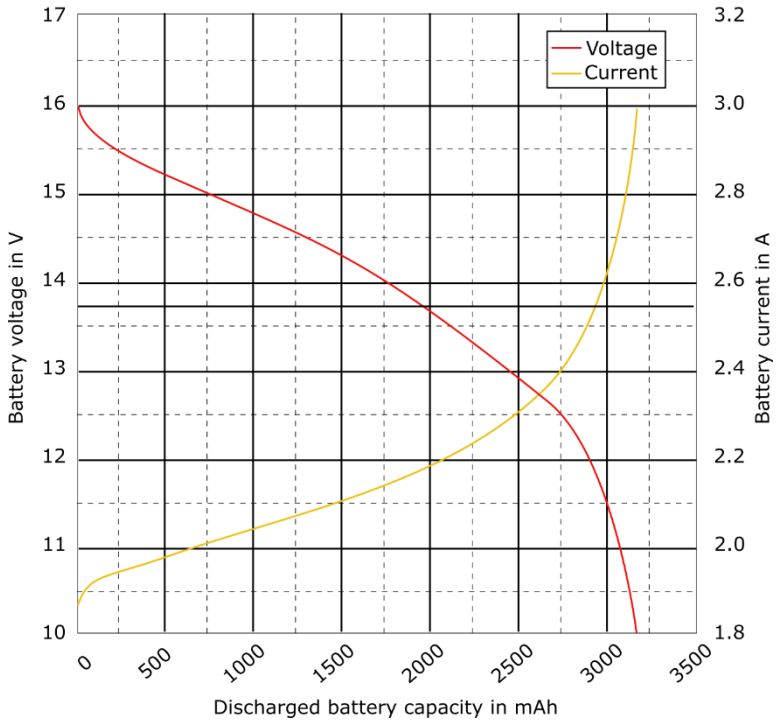

Figure 37 –Discharging voltage and current at a continuous output power of 30 W.

There is another reason: Lithium ions crystallize at or below 0% SOC (≤ 2.5 V per cell) and create dendrites, potentially leading to a higher self-discharge rate.

This is why we at RRC usually recommend powering down the device before reaching 5% SOC or 3.0 V per cell. To make your users' experience seamless, scale the reported capacity (e.g., 100% down to 5%) in a way that the user sees (100% down to 0%).

By doing this, you receive the following advantages:

1. Reduced probability that the battery becomes deeply discharged.
2. Longer life expectancy.

C Power Modes and Self-Discharge Rate

The battery offers different power modes to save energy, as shown below.

- The "Normal Mode" is, as the name suggests, the mode where the battery is supposed to work most of the time. It is responsive and can communicate over the SMBus, to the expense of some self-discharge.
- The battery enters "Sleep Mode" after the SMBus is inactive for more than 20 seconds. The battery measures voltage, current, and temperature less often to minimize self-discharge. Even then, then self-discharge lies in the range of 2 to 5% per month.
- If the battery is in "Shipping Mode", sometimes also called "Shutdown Mode", the fuel gauge shuts down and you can no longer communicate with the battery. The self-discharge is at an absolute minimum, with a remaining self-discharge of 0.05 to 0.25% per month. The battery cannot supply any current in this mode. You need to charge it with a small current to wake it up. See section 14.3 Shutdown / Shipping Mode for more details. Shutdown / Shipping Mode

State diagram of the available power modes

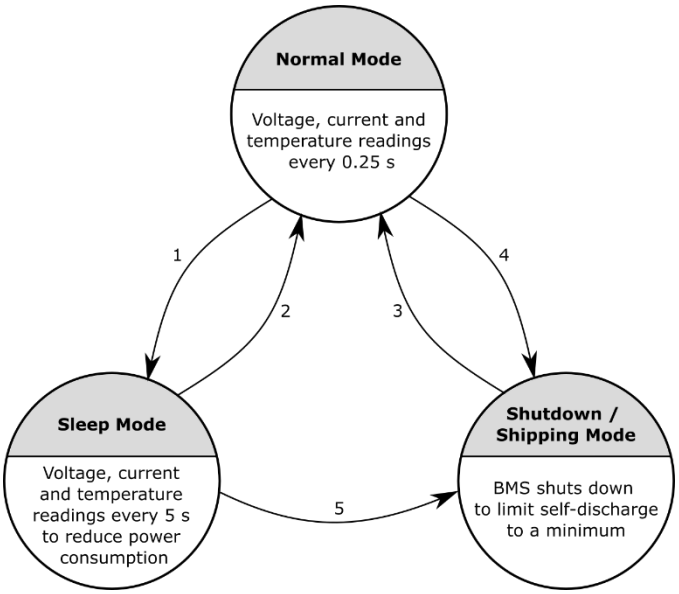

Figure 38 – State diagram of the available power modes

The requirements to jump from one state to another are:

1. No charger or application was detected for an interval greater than 20 seconds
2. Charger or communication detected
3. Shipping() command sent twice over ManufacturerAccess() within 4 seconds, or severe undervoltage detected
4. Charging voltage applied to the terminals of the battery
5. Shipping() command sent twice over ManufacturerAccess() within 4 seconds, or severe undervoltage detected

D Inrush Current

Due to their small internal impedance, RRC2xxx batteries can deliver a high peak inrush current on startup events. The theoretical peak current ranges from approx. 70 A for the **RRC2037** to 170 A for the **RRC2024** battery. The impedance rises over time and usage, but for new batteries, your circuit should be able to withstand short spikes of inrush currents of this magnitude.

Theoretical approach

Battery	Initial DC Impedance (approximate value)	Theoretical inrush current peak	Maximum Capacity
RRC2020	80 mΩ	160 A	8000 µF
RRC2024	100 mΩ	170 A	6000 µF
RRC2037	125 mΩ	70 A	5000 µF
RRC2040	175 mΩ	70 A	20000 µF
RRC2040-2	100 mΩ	130 A	12000 µF
RRC2054	225 mΩ	75 A	4500 µF
RRC2054-2	125 mΩ	135 A	5500 µF
RRC2057	75 mΩ	110 A	30000 µF
RRC2130	125 mΩ	70 A	10000 µF
RRC2140	175 mΩ	70 A	6000 µF

Table 36 – Theoretical approach of how high you can expect the inrush current peak to be.

This table is not an authoritative forecast because of impedance changes over SOC, temperature, time, production lots, and battery generations. However, it gives you a starting point for your design simulation.

Do I need a start-up current limiter?

In most cases, you do *not* need a start-up current limiter. However, there are two cases where you do.

Generally, on start-up, all capacitors are empty. The inrush current is so high because it needs to fill these capacitors. The current is highest during the first few microseconds when the capacitors represent a "short-circuit".

Case 1

If this “short-circuit” lasts sufficiently long, the battery may switch off due to its short-circuit protection. You should simulate the start-up current if your total input capacitance comes close to or exceeds the value listed in the “maximum capacity” column of Table 36. Depending on the capacitor and line impedances, it is possible that you exceed the short circuit protection threshold, as specified in the respective battery specification sheet.

Case 2

Resistors, diodes, FETs, and especially ferrites may have difficulties dealing with high currents, leading to permanent damage of these components and, consequently, device failure in the field. If you have any of these components in the main power path, you should evaluate whether these components withstand the start-up current. If it turns out that you are having trouble, consider using a current-limiting circuit like the one presented below.

Easy start-up current limiting circuit

As an easy current-limiting circuit, you can use a resistor in series to your circuit. Put a switch (preferably a FET transistor) in parallel to that resistor, as shown in the picture below:

Easy current limiting circuit

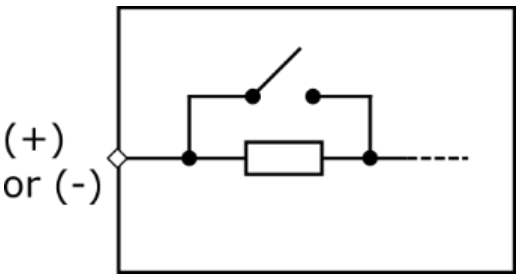

Figure 39 – Easy current limiting circuit using a switch as a resistor.

Upon start-up, the FET shall be open, and all the current passes through the resistor. The resistor slows down the inrush current. After a specific time, or after reaching a defined voltage level, either an MCU or an analog circuit (slowed down by an RC filter) can close the FET, thus permitting full load current. You can use an NFET in the GND line or a PFET in the (+) path.

When choosing the resistor, pay attention to its impulse load. Let's make an example:

Example on choosing a suitable resistor

In the LTSpice simulation below, we see a simple model of the battery on the left-hand side, the application on the right-hand side, and a switch in-between. The switch S1 and the resistor R1 serve only for simulation purposes – they are needed so that the capacitor C1 is empty at the beginning of the simulation.

The example application incorporates a big 2.2 mF input capacitor. We want to limit the inrush current with a series resistor of 100 Ω. Earlier, we spoke about a FET parallel to that resistor – in the simulation, we omit that FET for clarity.

Inrush current simulation

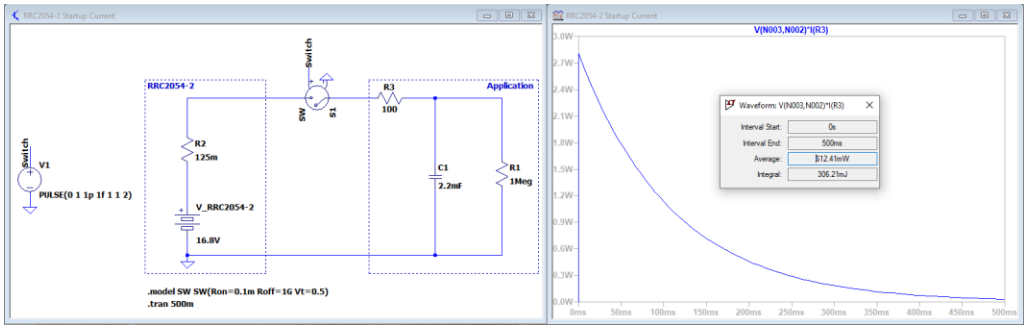

Figure 40 – Inrush current simulation.

As you can see in the simulation result, the capacitor needs approximately 500 ms to fully charge. The peak power dissipated across the resistor is 2.8 W, and the total energy loss is 306 mJ.

In resistor datasheets, you usually find the permitted single pulse power. To convert the above simulation result into a single pulse load, you

- Take the simulated peak power as pulse load
- Calculate the single pulse duration by t = E / P

In our case, the pulse load is 2.8 W, and the duration is 306 mJ / 2.8 W = 109 ms. Compared to the datasheet of an arbitrary manufacturer (refer to Figure 41), you see that a case size of 1210 would be necessary to ensure the power capability.

You could still optimize the schematic by playing with the resistance or looking for other manufacturers and case types.

Single pulse power

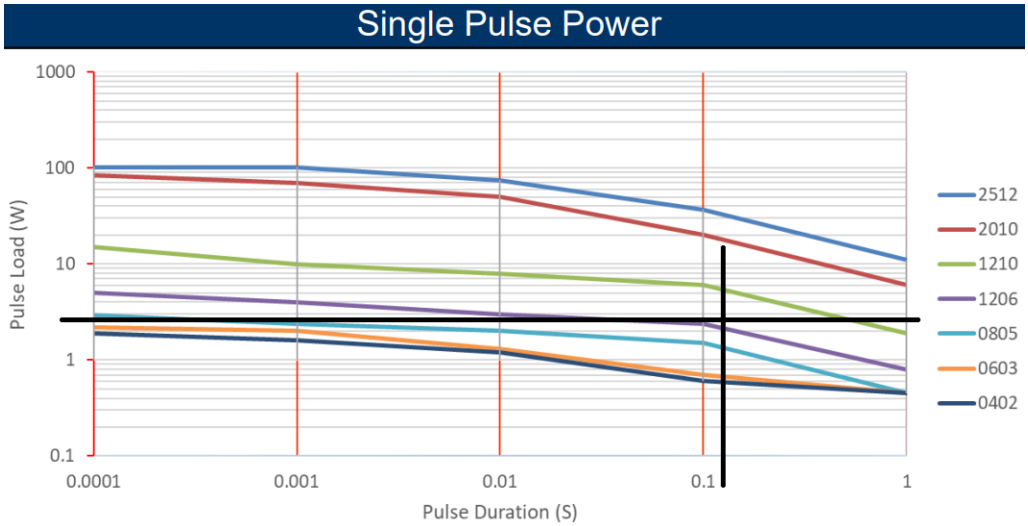

Figure 41 – Datasheet from an arbitrary manufacturer.

The calculated single pulse load requirement is drawn into the graph using black lines.

E Battery Life Expectancy and How to Prolong it

Expected battery lifetime

life expectancy around 5 years or 500 cycles

Batteries are like a sensible, living species. If you take good care of them, they can grow old; but if you don't, they can die very young. On average, the life expectancy of a Lithium-Ion battery is around 5 years or 500 cycles (whatever comes first). This section intends to show you what you can do to make it live that long.

A word of warning at the beginning: If you design your application for the medical industry or for any application where reliability is a must, it is common practice to change the batteries after 2 years or 300 cycles, whatever comes first. We strongly advise you to comply with this common practice because old battery age may result in sudden capacity loss, compromising runtime, or even failure.

When to change the battery

Old battery age typically implies impairments like lower capacity and higher internal resistance; it depends on your specific application if they may still serve well enough.

The full charge capacity decreases as the lithium ions build permanent chemical compounds with the electrodes. Most users want to discard the battery once the remaining full charge capacity has reached 80% of the design capacity.

Not only has the device runtime decreased to about 80% of the original value; All aging processes now happen at a much higher speed and can lead to a sudden battery death. Only uncritical applications that can live with such an incident should continue using such a battery.

Figure 42 shows that an **RRC2054-2** typically does 300 cycles under the below-mentioned conditions. Note that calendar age would add up on those test results, which were taken over the course of two months only.

Typical cycle characte-ristics

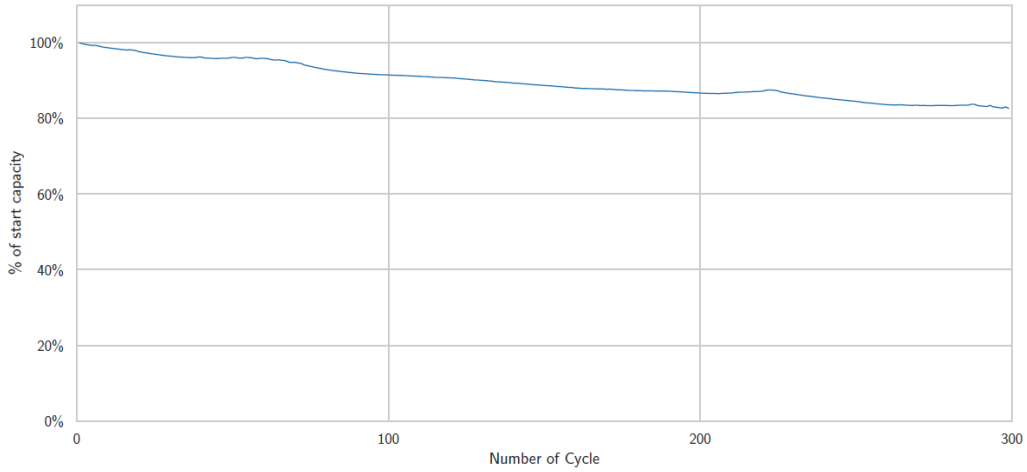

Figure 42 – Typical cycle characteristics of an RRC2054-2.

Test conditions:
Charge to 100% with 3.35 A during the constant current phase; Discharge to 0% at 3.35 A, at an ambient temperature of 25°C.

Why can batteries age particularly fast at a state of health below 80%?

First, there is also an increase in impedance. The higher the current, the more the impedance translates to a voltage dropdown and an elevated power loss. Thus, the useable capacity shrinks even more, and the temperature-dependent aging processes happen faster.

Second, a chain is always as strong as the weakest link – and a battery pack is only as strong as its weakest single cell. A battery pack like the **RRC2054-2** consists of eight cells, all aging at a slightly different speed. The weakest cell gets hammered by its healthier brothers, so its forces vanish even faster. If the cell health differs too much, the battery management system needs to interrupt the current flow for security reasons, leading to a sudden battery death. That only happens during charging and oftentimes after the battery was deeply discharged before.

How to prolong battery life

The critical elements to maintaining good battery health are:

- Temperature
- State of Charge
- Current

Keep the batteries at room temperature

Care begins by keeping the batteries at room temperature.

Cooler temperatures may not improve the battery life much, but temperatures higher than 30°C / 85°F lead relatively quickly to a permanent capacity loss. According to Arrhenius law, the speed of chemical reactions doubles roughly every 10°C or 20°F; so do unwanted chemical reactions that lead to premature permanent capacity loss.

Keep the batteries at an inter-mediate state of charge

Keeping the batteries at an intermediate state of charge is also very beneficial for longevity.

A cell voltage of 3.92 V, which corresponds to a state of charge of approximately 60%, is optimal because it relieves the lithium-ion cell from voltage-related stress. Above that voltage, and significantly above 4.1 V (85%), the electrolyte oxidizes at the cathode, leading to a highly increased loss in full-charge capacity.

Worst scenario

The worst scenario for a battery is to stay fully charged at an elevated temperature.

A low state of charge also increases the capacity loss due to the formation of surface layers on the anode. Discharging below 25% may permanently increase the battery impedance. And keeping the battery below 2.5 V (0%) leads to permanently higher self-discharge due to the growth of copper dendrites.

Charge more often, but not for so long

Charge your device more often, but not for so long (Li-Ion does not suffer from the memory effect).

For all these reasons, using the battery at medium charge levels is beneficial. Charging to 75% and discharging to 25% (thus, halving the depth-of-discharge) as opposed to charging to 100% and discharging to 0% can double or even triple the battery cycle life.[14]

Store at 30% SOC

Store at 30%, and don't forget the shipping mode.

For long-time storage, a low SOC has proved to be beneficial for battery life. We recommend a 30% SOC because that's a good compromise between longevity and possible storage time. It also complies with the UN38.3 requirements for transporting the battery via air freight: See section 14 Shipping and Storing for details. You can increase the SOC if needed, but we discourage you from exceeding 60%.

Charge and discharge at a moderate current

Charge and discharge the battery at a moderate current.

Due to their electrochemical impedance, the Lithium-ion cells heat up in direct correlation to the current amplitude. And because chemical decay processes happen faster at higher temperatures, that could lead to increased aging. The cell components may also saturate while charging. Using an ultrafast charger stresses the battery, often unnecessarily. If you need a fast-charging speed or a high continuous discharge current, you may want to consider oversizing the battery or using two batteries in parallel.

14 RRC defines one battery cycle as the accumulated discharge of 90% of the design capacity.

F On using Single-Board Computers (SBC)

Single-board computers can communicate directly with smart batteries. For instance, the battery icon in the Windows tray does not require any dedicated driver or programming work from your side. It is the job of the ACPI, which is part of the computer bios, to interface with the battery.

Not every bios manufacturer is aware of minor deviations from the SMBus standard because most SMBus chips are very timing-tolerant. Also, while we support the more energy-efficient SMBus V1.1 standard, some computer manufacturers support newer and speedier standards. In that case, you must review the pull-up resistors.

In case you don't succeed in integrating the battery from the start, follow these steps:

1. Review the pull-up resistors. Most of the time, there are pull-up resistors on the computer that cannot (and sometimes should not) easily be unsoldered. You can isolate the pull-up resistor instead, using e. g. an I2C multiplexer like in section 11.3 Communication with Two or More Batteries.

On the battery side, you can then set the required pull-up resistor value:

- If you use the PMM20, there should be no pull-up resistors, as those are already included on the PMM20.
- If you attach the battery directly, set the pull-up resistor to 10 k (see section 11.4 Pull-up Design for details).

2. Try establishing working communication with the battery by reading out any battery register over I2C using this computer. Be sure to obey the SMBus timings (see section 11.1 Differences to I2C for details).
3. If step #2 works, contact the bios manufacturer (but let us know: **applicationsupport@rrc-ps.com**).

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SETTING STANDARDS
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