Scope

This document provides a series of recommendations and best practices when developing a new project using an RRC1xxx smart battery.

1. "Semi-Smart" Battery Benefits

Most competing batteries of similar size and capacity are dumb batteries. Our RRC1xxx batteries, in contrast, are "semi-smart".

1.1. What is a "Semi-Smart" Battery?

Semi-smart batteries offer most of the functionality of smart batteries, as defined by the SMBus specifications. The difference is that semi-smart batteries do not necessarily follow the SMBus specification exactly, and instead of the SMBus protocol, they communicate over an independent protocol using I^2C.

You can make use of this functionality to the benefit of the user. RRC1xxx batteries share most of the features below: (for the difference between the models, refer to section 2)

Extra features

- Battery Status
- State of Charge
- State of Health
- Remaining Capacity
- Time To Empty
- Full-Charge Capacity
- Cycle Counter
- Temperature
- Charging parameters Identification
  with the manufacturer name and serial number

Extra safety

- Under-voltage protection
- Over-voltage protection
- Over-current protection
- Short-circuit protection
- Overtemperature protection

In order to enable I^2C communication, our RRC1xxx batteries offer a 4-pin design: (+), (-), (SCL) and (SDA). The RRC1130 also features an additional NTC thermistor tied to the SDA pin. That makes it possible for chargers not using the I^2C functionality to sense the battery temperature.

1.2. Closer look at Safety

RRC semi-smart batteries fully comply with UL2054 and IEC62133-2:2017. They also comply with worldwide applicable country-specific battery safety certificates, which add several redundant safety tests. This is how RRC1xxx batteries manage each of these single faults:

Over-Charging

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 12 V continuously.

Over-Discharging

If the user forces the battery to discharge below its 0% State of Charge (SOC), the protection circuit activates the safety protection. RRC semi-smart batteries ensure safety in over-discharge situations.

Over-Current or Short-Circuit

Suppose the user forces the battery to discharge at higher rates than specified. In that case, the battery activates its over-current, over-load[1], or short-circuit protection depending on the magnitude of the discharge current, as shown in Figure 1. You can find the thresholds in the respective battery specification. RRC batteries remain safe in any short-circuit situation by temporarily interrupting the current flow.

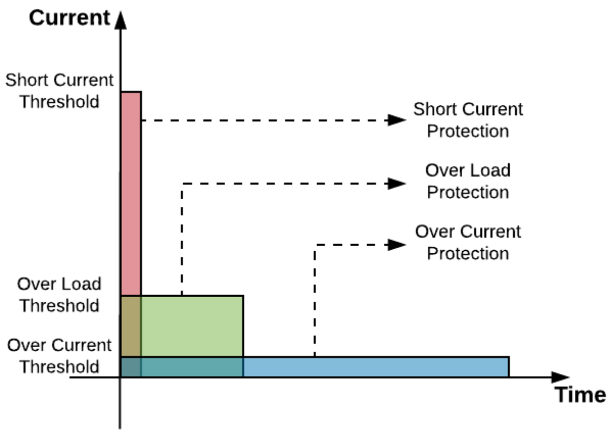


Figure 1 – Discharge current protections

Over-Temperature

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

[1] The RRC1130 offers over-current and short-circuit protection only, but has no over-load protection.

2. Architectural Details for the Interested Reader

Figure 2 and Figure 3 on the next page show the block diagrams of the RRC1120 and RRC1130 batteries at the time of writing. In the center of both block diagrams, you see the "Battery Management System" (BMS). It performs all measurements and controls. This is where we find the “smarts” of the battery.

You can communicate with the BMS using I^2C and request the status information. The red block of the schematics shows the ESD protection.

In the current path, you see two or four FETs, respectively. Those FETs 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.

The thermal breaker acts as a thermal fuse and breaks the output upon exceeding a specific current; but it automatically resets after the breaker has cooled down.

The current shunt R_{sense} serves to measure the current in and out of the battery.

The second overvoltage protection is an independent chip that can act on the Overvoltage FET ~~just~~ in case ~~that~~ the BMS would fail. That results in additional, redundant safety.

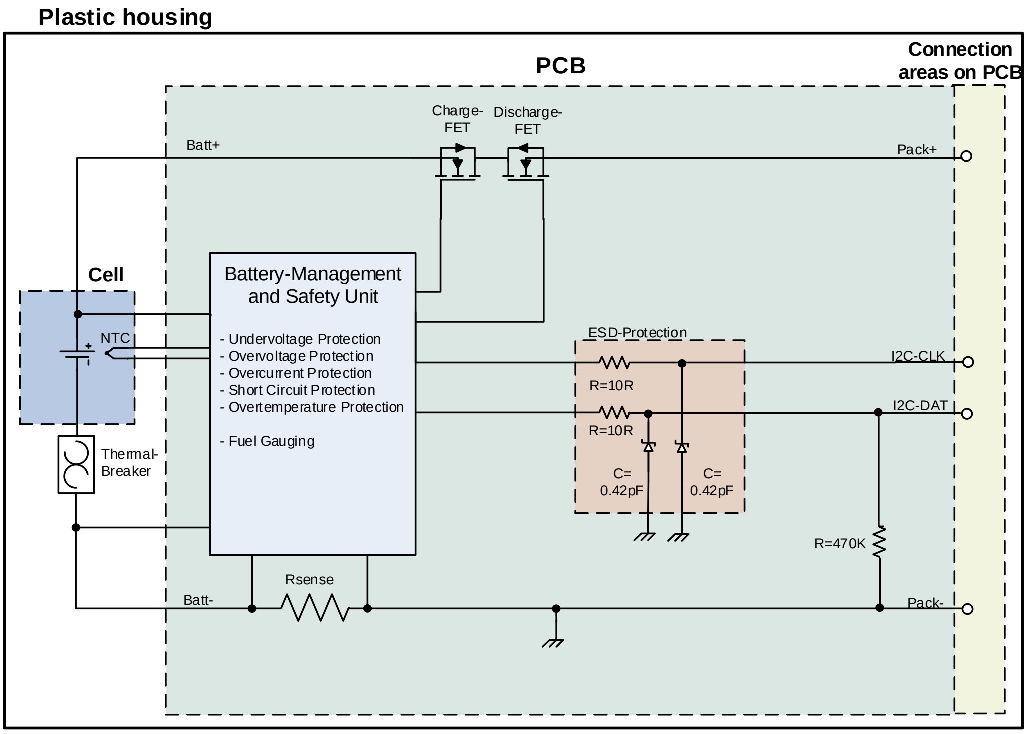


Figure 2 - RRC1120 schematics

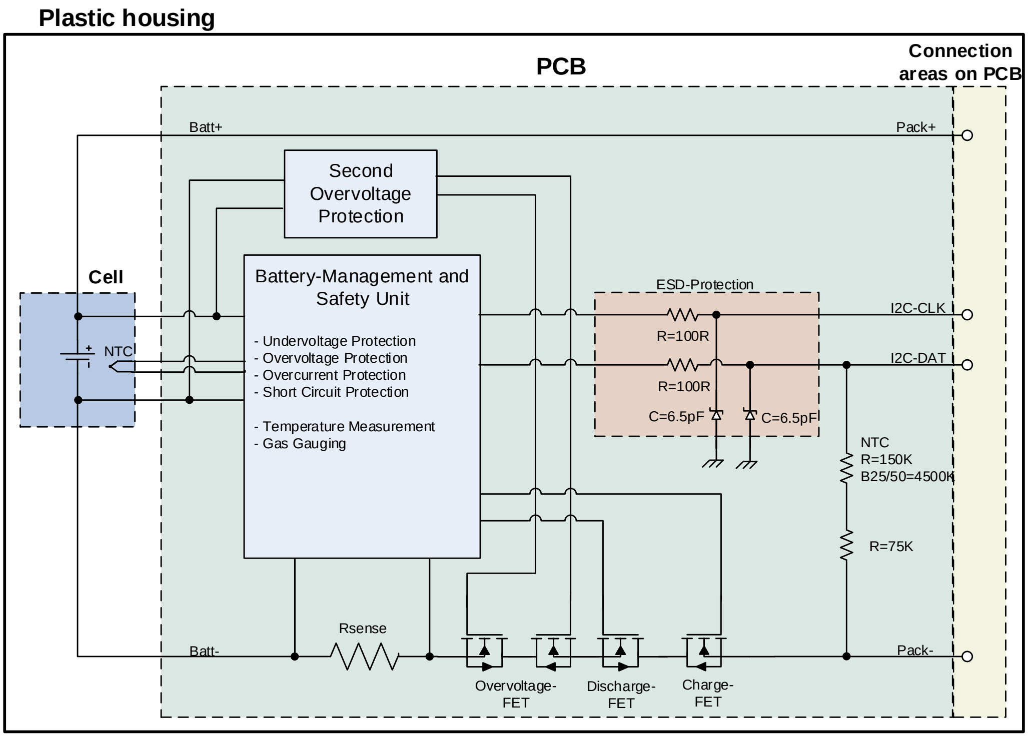


Figure 3 - RRC1130 schematics

3. Charging the battery

3.1. Removable or non-removable battery

When starting a new design, you need to decide the users' access to the battery: will you charge your battery internally (not removable) or externally (removable)?

Removable

Removable batteries have one main advantage: 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. For an external charger, RRC offers the SCC1120 and the SCC1130 for charging the RRC1120 and the RRC1130, respectively.

Non-Removable

Non-removable batteries make it easier to build sealed and dust or water-resistant devices, which is crucial 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.

Instead of an external charger, you need an internal one; see section 3.3 for more details.

Which design is better?

This is application-dependent. 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.

3.2. Smart Charging Capability

The BMS uses the I²C interface to communicate the desired charging voltage and current to the charger. Thus, the charging process is dynamic and optimized, increasing the life expectancy of the battery pack.

The JEITA[2] profile defines a temperature-dependent charging current. Table 1 shows an example from the RRC1120 at the time of writing. With JEITA, the battery requests a charging current that adapts to the cell temperature, thus avoiding stress on the Li-Ion cells. Using a charger following the JEITA profile is essential to ensure battery performance over lifetime.

Temperature Range	Charging Voltage	Charging Current
T < 0 °C	0 V	0 mA
0 °C < T < 10 °C	4.2 V	795 mA
10 °C < T < 55 °C	4.2 V	1590 mA
T > 55 °C	0 V	0 mA

Table 1 – Example for the JEITA profile of an RRC1120 battery.

[2] Japan Electronics and Information Technology Industries Association

3.3. Choosing the Charger

External Chargers

At the time of writing, RRC offers two external chargers for the RRC semi-smart batteries:

- RRC-SCC1120 for charging the RRC1120 battery
- RRC-SCC1130 for charging the RRC1120 battery

Both chargers adapt their output to the temperature-adjusted battery charging voltage and current.

Internal Chargers

If you design your own (internal) charger, consider using the I^2C interface to make the charging *smart*. RRC *strongly* recommends using a smart charger with our batteries

Advantages of using a smart charger are:

1. Optimized charge process depending on battery temperature, health, and age.
2. **Compatibility with future revisions of each battery model**. RRC 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. The charger should communicate with the battery, therefore charging the battery with the correct voltage. Not using this feature could lead to future incompatibility issues.

RRC offers an Application Note titled "Charger circuit design for the RRC1120 and RRC1130", where you can find details on how to design a charger on your own.

4. Using Multiple Batteries in Parallel or Serial Configuration

4.1. Charging multiple batteries

If you want to charge multiple batteries, you should charge every battery with a dedicated charging circuit, each one communicating with the battery and adapting its output to the temperature-adjusted charging voltage and current.

4.2. Communicating with multiple batteries

All semi-smart batteries share the same I^2C address. Hence, two batteries cannot connect simultaneously to the same bus. If it is not possible to use separate buses, you need to use a multiplexer (e.g., PCA9544A), as shown in Figure 4.

4.3. Discharging in parallel configuration

You can use any number of batteries connected in parallel. Figure 4 shows how:

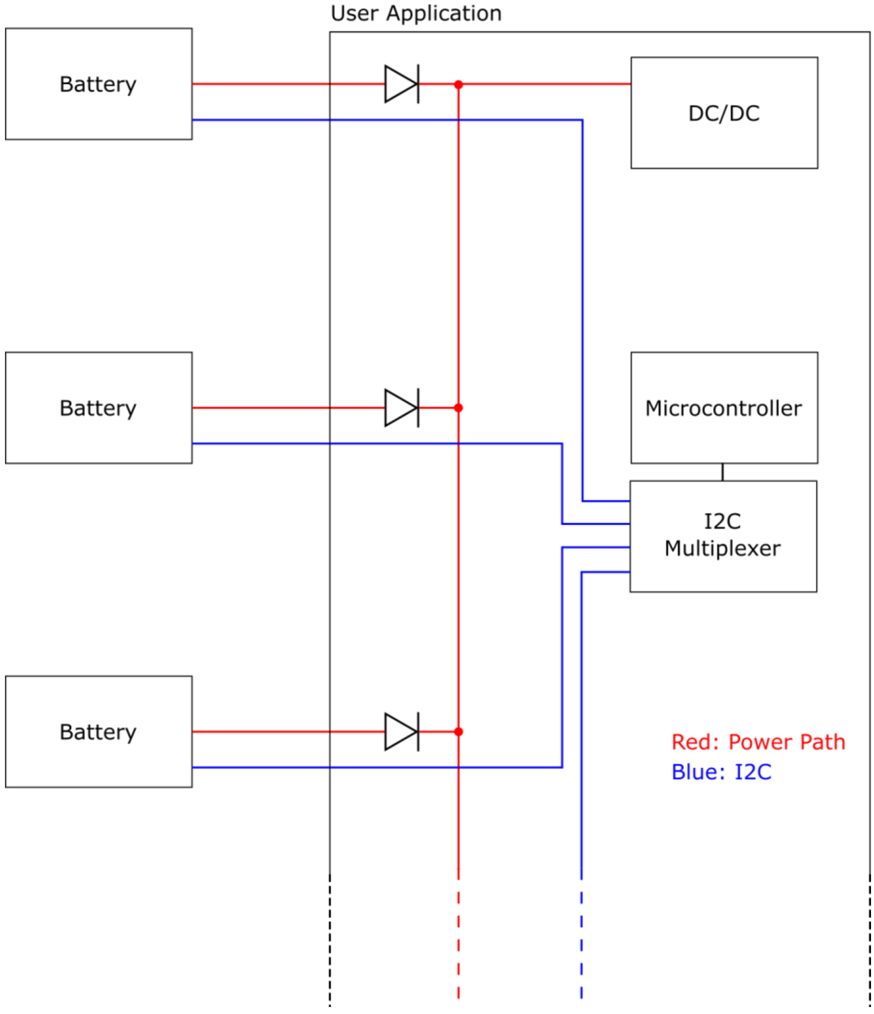


Figure 4 – Using several batteries in a parallel configuration. The number of batteries is not limited.

- To avoid back-driving currents, use ideal diodes (e.g., LM5050 from TI).
- Use a multiplexer (e.g., PCA9544a). This is necessary because all batteries share the same I^2C address.
- Take care of inrush currents, as they might not distribute equally among all batteries.
- To have balanced discharge rates between the batteries, ensure that the State-of-Charge of all batteries is approximately the same.
- Do not use batteries with considerably different "age" (the combination of the number of cycles and production dates).

Why is there a need to have equally charged batteries?

Imagine having 8 batteries in parallel where one is fully charged, and the 7 others are almost empty. In this extreme case, the full battery takes 100% of the load until its voltage falls to the level of the other 7 batteries. From that point on, all batteries share the current.

The one battery that is fully charged mustn't fail while it supports the load "all alone".

At first, determine whether the most extreme case would exceed the safety thresholds of the single battery. If not, then there is no need for additional circuitry. If yes, consider using current limiting circuitry to limit the current under the safety-threshold level.

Depending on your application, you could also consider implementing a software solution: You could read out the SOC and the battery voltages. If the batteries are not balanced, you could consider sending a message like "change battery xy" and wait until it's done before consuming more current.

4.4. Discharging in series configuration

While it is possible, we don't recommend using RRC1xxx batteries in series. You would require an isolated I2C bus for each battery. Occasionally, you may still encounter transient over-voltages beyond our safety-tested levels. That happens if any failure event leads to switching off one of the batteries in the series stack, which could damage your batteries.

If you require a series configuration, it might be worth looking at our RRC Smart Battery portfolio (RRC2xxx), using two or more cells in series.

5. Battery Mechanical Design

This section focuses on cavity design and how to use the mating connectors.

5.1. 3D models and mechanical drawings

RRC can provide a 3D model as a STEP file for every battery model. 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 that document. Please email us with any questions to sales@rrc-ps.de or https://www.rrc-ps.com/kontakt.

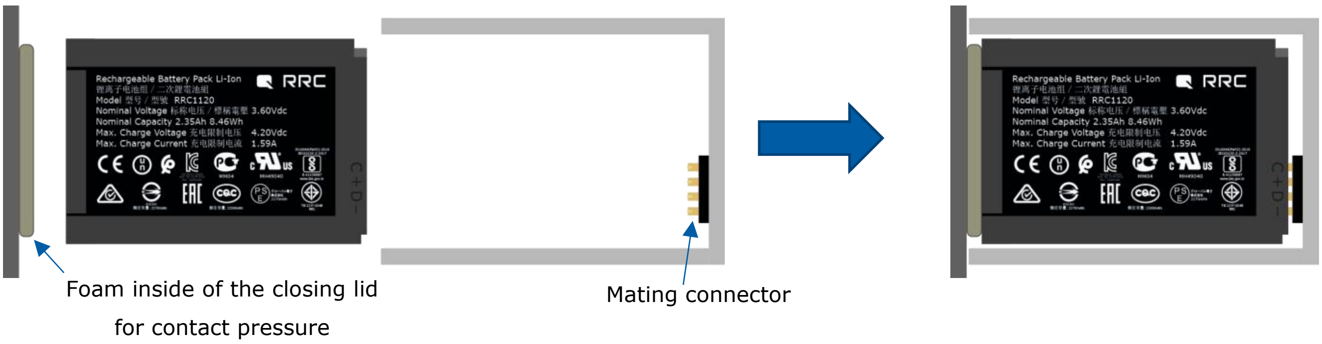
5.2. Slot or bay

This section compares a battery slot (where the battery is inserted from the side) to a battery bay (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.

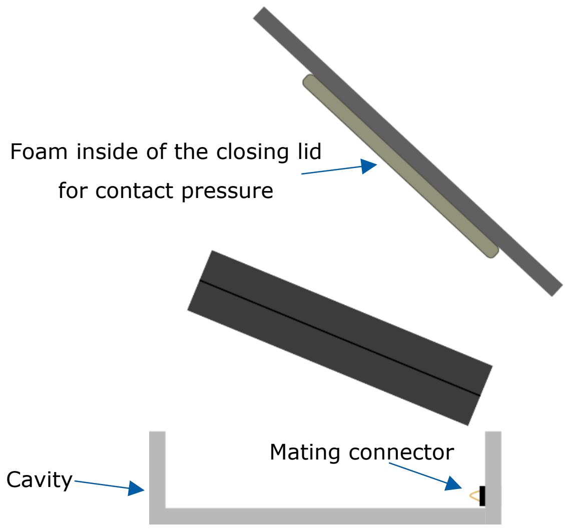
In most designs, there is vibration, or the device can be turned upside-down, and the battery should remain in its position. We suggest closing the battery slot with a lid that gently pushes the battery inside, using foam or a spring.



Bay

Suppose you want your application to have a non-removable battery. In that case, 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 to gently push the battery down into the cavity and onto the mating connector.



5.3. Battery Temperature

Lower temperature aids in longer battery life

A battery ages with temperature. In general, the lower the temperature is, 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 in use. According to the Arrhenius equation, the reaction speed roughly doubles with every 10°C of 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.de), the electrolyte inside the battery cells can freeze, which may cause permanent damage to the battery.

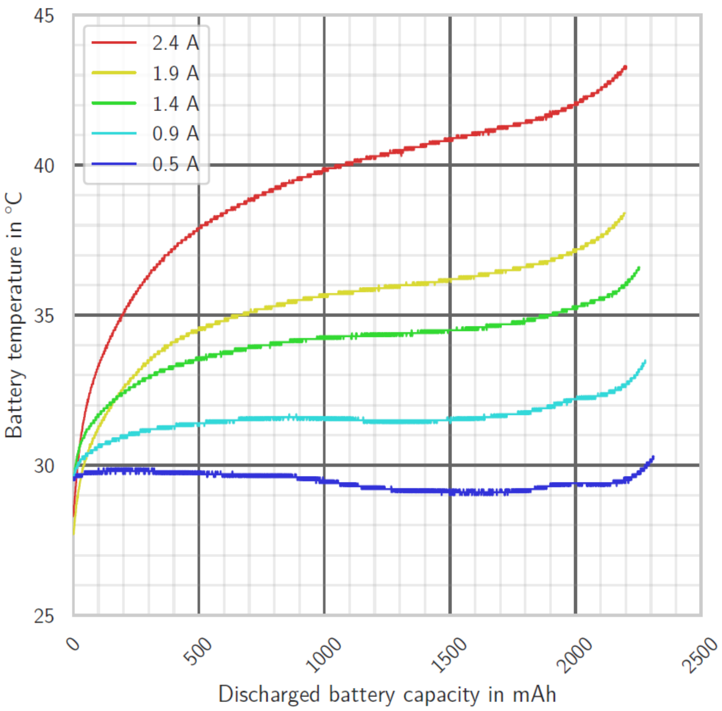
Shield the battery from external heat sources

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.

Consider using a thin metal sheet between hot components and the battery. The shield would spread the heat evenly over a larger surface, which would protect the battery as a whole. Although in many cases, an air gap between the PCB and the battery may 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.



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 RRC1120 safety circuit would protect the battery from permanent damage by temporarily disconnecting the battery from your circuit.

In the case of the RRC1130, however, your application is responsible for switching off when the battery temperature rises above safety thresholds.

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

5.4. Drop, Shock, Vibration

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

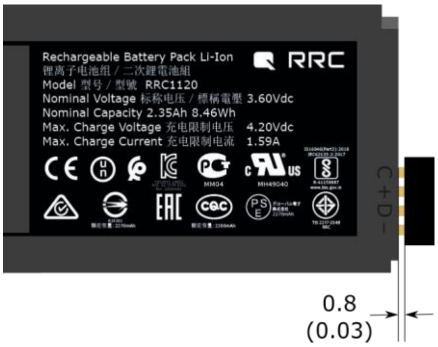
If your application requirements exceed the requirements of the norms mentioned above, then your battery compartment should protect the battery by dampening drop, shock, and vibration sufficiently. You would need to run your own tests to ensure compliance. Please contact us with any questions at applicationsupport@rrc-ps.de.

5.5. IP protection class

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.de.

5.6. Positioning the mating connector

We offer the 90° mating connector RRC-MC11-90-2 (RRC part number #210520). To provide a robust connection with respect to all tolerances, ensure that the distance between battery housing and connector is between 0 and 0.8 mm.



6. I²C Communication – Electronics

6.1. Electrical specifications

RRC semi-smart batteries communicate using standard I²C. Table 2 shows the specifications of the RRC1xxx I²C interface.

Symbol	Parameter	Limits		Unit
f_{I2C}	Clock frequency[3]		400	kHz
V_{IL}	Input Low Voltage	-0.5	0.5	V
V_{IH}	Input High Voltage	1.4	5.5	V
V_{OL}	Output Low Voltage @ 1 mA		0.4	V
t_r	Signal Rise Time		300	ns
t_f	Signal Rise Time		300	ns
$t_{w(H)}$	SCL pulse width (high)	600		ns
$t_{w(L)}$	SCL pulse width (low)	1.3		µs
$t_{su(STA)}$	Setup for repeated start	600		ns
$t_{d(STA)}$	Start to first falling edge of SCL	600		ns
$t_{su(DAT)}$	Data setup time	1000		ns
$t_{h(DAT)}$	Data hold time	0		ns
$t_{SU(STOP)}$	Setup time for stop	600		ns
t_{BUF}	Bus free time between stop and start	66		µs

Table 2 – RRC11xx I²C interface specifications

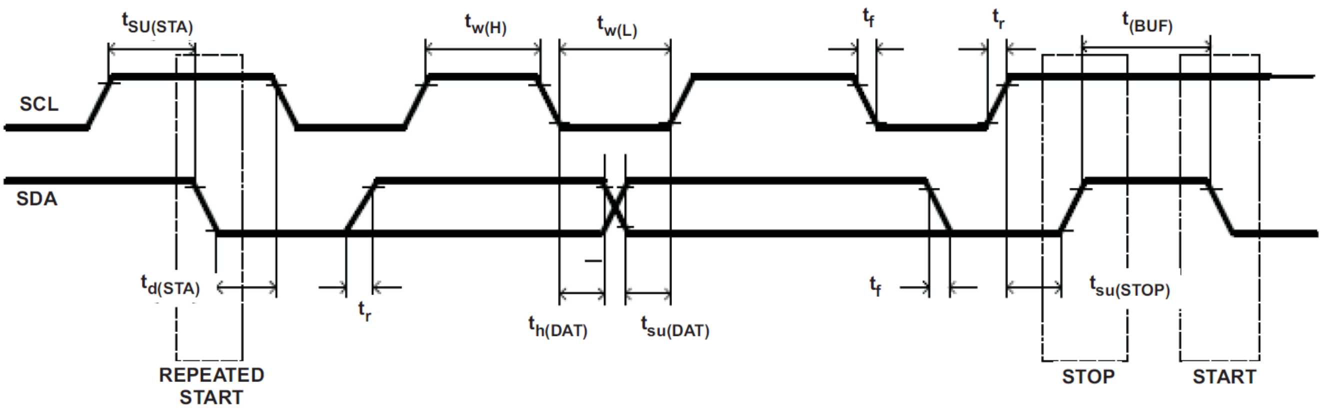


Figure 5 – Timing diagram

If you want to use several batteries in parallel, you need multiplexers. See section 4.2 for details.

[3] If the clock frequency is > 100 kHz, use 1-byte write commands for proper operation.

6.2. Pull-up resistors

The host needs to implement pull-up resistors for the SCL and the SDA lines. Table 3 shows pre-calculated values for the pull-up resistor limits, depending on V_{DD} and assuming a total parasitic line capacitance of 65 pF. See the calculation below for details. For the longest battery standby time, use a pull-up resistor close to the maximum allowed value for saving current, but verify the rise time through measurement.

V_{DD}	R_{Pmin}	R_{Pmax}
2.4 V	2.0 kΩ	5.4 kΩ
2.7 V	2.3 kΩ	5.4 kΩ
3.0 V	2.6 kΩ	5.4 kΩ
3.3 V	**2.9 kΩ**	**5.4 kΩ**
3.6 V	3.2 kΩ	5.4 kΩ
4.2 V	3.8 kΩ	5.4 kΩ
5.0 V	**4.6 kΩ**	**5.4 kΩ**
5.5 V	5.1 kΩ	5.4 kΩ

Table 3 – Supply voltage-dependent limits for the pull-up resistor

For the interested reader, this section closes with calculating these resistor values.

The lower limit for the pull-up resistors derives from the maximum allowed current (refer to Table 2). A small resistor value could prevent the I²C pin from driving the line low.

$$R_{P_{MIN}} = \frac{V_{DD} - V_{OL,max}}{1\ \text{mA}} \quad (1)$$

The bus capacitance limits the maximum pull-up resistance due to I²C standard rise time specifications. The rise time is defined by:

$$V(t_1) = 0.3 \cdot V_{DD} \cdot \left(1 - e^{-\frac{t1}{C_{parasitic} \cdot R_P}}\right);\ \text{so}\ t_1 = 0.3567 \cdot C_{parasitic} \cdot R_P \quad (2)$$

$$V(t_2) = 0.7 \cdot V_{DD} \cdot \left(1 - e^{-\frac{t2}{C_{parasitic} \cdot R_P}}\right);\ \text{so}\ t_2 = 1.204 \cdot C_{parasitic} \cdot R_P \quad (3)$$

RRC semi-smart batteries define a maximum signal rise time of 300 ns (see Table 2):

$$t_R = t_2 - t_1 = 0.8473 \cdot C_{parasitic} \cdot R_P = 300\ \text{ns} \quad (4)$$

Thus, you calculate the maximum pull-up resistance as a function of the maximum rise time:

$$R_{P_{MAX}} = \frac{t_R}{0.8473 \cdot C_{parasitic}} \quad (5)$$

The battery itself has a parasitic capacitance of about 10 pF. The I²C line, ESD protection, and other components on the host side add to the total parasitic capacitance. Table 3 shows pre-calculated values for a total parasitic capacitance of 65 pF.

7. I²C Communication – Software

7.1. I²C Address

You can exchange information with RRC semi-smart batteries via I²C. The 7-bit device address is 0x55, which is shifted to the left and appended with the write (0) or read (1) bit (refer to Table 4). In contrast to SMBus, the semi-smart battery operates as *slave*-only.

Because all batteries share the same I²C address, you need multiplexers to use several batteries in parallel. See section 4.2 for details.

Description	7-bit Address	Write Address	Read Address
Semi-Smart Battery address	_101 0101 (0x55)	1010 101**0** (0xaa)	1010 101**1** (0xab)

Table 4 – 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

7.2. Bus Protocol – How to write and read information

When specifying a master to communicate with the RRC1130 battery, be aware that the RRC1130 may utilize clock stretching when returning data. The master must support this feature.

The RRC11xx semi-smart battery supports the standard I²C protocol, capable of executing four protocols:

- 1-byte write,
- 1-byte read,
- incremental read and
- quick read.

The following diagrams show two types of blocks: a "non-shaded" block indicates a message sent by the host (your device), and a "shaded" block indicates a message sent by the battery:

# of bits of the command	8	8
Command name	Sent by the Host	Sent by the Battery

In these diagrams, these blocks below indicate bits that define the following operations:

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

Where:

1 – Start condition;

2 – Acknowledge (ACK);

3 – Not Acknowledge (NACK)

4 – Write bit = '0';

5 – Read bit = '1';

6 – Pause condition

1-Byte Write

After the Start Condition, the host writes the battery write address, which is 0xaa. After the battery acknowledges (ACK), the host sends the command code. The battery ACKs again, and the host sends the data byte. The slave ACKs each byte, and the entire transaction ends with a stop condition.

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

1-Byte Read

After the Start Condition, the host writes the battery write address, which is 0xaa. After the battery acknowledges (ACK), the host sends the command code. The battery ACKs, and the host repeats the start condition followed by the battery read address, which is 0xab. The battery ACKs and answers with one data byte. The host NACKs the data byte and finishes the transaction with a stop condition.

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

Incremental Read

The Incremental Read works like the 1-Byte Read, except that the battery continues delivering data bytes while the host keeps acknowledging them. The battery only stops after the host NACKs a data byte.

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

Quick Read

The quick read returns data at the address indicated by the address pointer. The address pointer, a register internal to the I²C communication engine, increments whenever data is acknowledged by the fuel gauge IC or the I²C master.

1	7	1	1	8	1	1
S	Battery Address	Rd	A	Data Byte	/A	P

Example – Read RelativeStateOfCharge()

The RelativeStateOfCharge() is split into two registers: 0x2c and 0x2d (listed in Table 5). Let's access both of them via the Incremental Read 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 hexa-decimal form.

S	Battery Ad-dress	Wr	A	Command Code	A	S	Battery Address	Rd	A	Data Byte Low	A	Data Byte High	/A	P
S	1010 101	0	A	0010 1100	A	S	1010 101	1	A	0001 1001	A	0000 0000	1	P
S	0xaa		A	0x2c	A	S	0xab		A	0x19	A	0x00	/A	P

7.3. Semi-Smart Battery Registers

Table 5 below lists the registers supported by RRC semi-smart batteries.

Function	Size (bit)	Command	Description	Unit	Access
ControlStatus()	16	0x00/0x01	-	-	R/W
ManufacturerAccess()	15	0x3e/0x03f	-	-	R/W
Temperature()	16	0x06/0x07	Returns the pack internal temperature.	0.1 K	R
Voltage()	16	0x08/0x09	Returns the battery's voltage (measured at the cell stack).	mV	R
RemainingCapacity()	16	0x10/0x11	Returns the predicted remaining battery capacity.	mAh	R
FullChargeCapacity()	16	0x12/0x13	Returns the predicted battery capacity when fully charged.	mAh	R
Current()	16	0x14/0x15	Returns the current being discharged (negative) or charged (positive) through the battery's terminals.	mA	R
AverageTimeToEmpty()	16	0x16/0x17	Returns the predicted remaining time to discharge at the present rate of discharge.	Minutes	R
CycleCount()	16	0x2a/0x2b	Returns the number of charge/discharge cycles the battery has experienced. A full cycle is considered to approximately equal to the design capacity.	Counts	R
StateOfCharge()	16	0x2c/0x2d	Returns the predicted RemaningCapacity() expressed as percentage of FullChargeCapacity().	%	R
StateOfHealth()	16	0x2e/0x2f	Returns de predicted FullChargeCapacity() expressed as a percentage of DesignCapacity().	%	R
DesignCapacity()	16	0x3c/0x3d	Returns the design capacity of the battery.	mAh	R
ChargeVoltage()	16	0x30/0x31	Returns the desired charging voltage to the charger	mV	R
ChargeCurrent()	16	0x32/0x33	Returns the desired charging current to the charger	mA	R

Table 5 – List of RRC semi-smart battery registers

RRC batteries offer additional information via the ControlStatus() and ManufacturerAccess() registers. You may use these registers, but please note that they may be subject to change from one battery generation to the next. You can read e. g. the manufacturer name, device name, and serial number within these extended registers. Please reach out to your local RRC salesperson to get this information or email us at sales@rrc-ps.de to get valid information for the battery you want to use.

8. Quality

8.1. Conformity

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 conform to ISO9001 and ISO14001.

8.2. RRC Smart Battery Certificates

In each RRC battery specification, you find the complete list of the respective battery certificates. You also find them printed on the battery label. Table 6 shows the correlation between the certification mark and the respective country. RRC can share the test reports with your testing agencies when you start your certification process.

RRC battery certificates are regularly updated – customers do not have to pay or wait for new certificates as these are automatically added to the next battery generation. A Change Notification (CN) system notifies our customers of new and updated certificates.

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

Table 6 - Correspondence between certificate mark and country

9. Storing and Shipping

9.1. How to store batteries (Shelf-Life)

If your battery supports it, make sure to set it in the so-called "shipping mode" before storing or shipping. In this mode, the battery circuitry shuts down to eliminate parasitic current draw, thus dramatically increasing shelf life. At the time of writing, only the RRC1120 supports shipping mode. Refer to the specification document for details.

We ship our batteries at 30% state of charge (SOC) because of the UN38.3 requirements (refer section 9.2). At 30% SOC and 25°C, we specify the shelf life to 12 months.

You obtain a longer shelf life by charging the battery up to 60%, which is also more gentle (less stress) for the battery. Generally, we advise against long term storage at > 60% SOC as it means more stress on the battery and the self-discharge rate will increase as well.

In any case, ensure to give the battery a recharge at least once a year. Batteries that have been deeply discharged run the risk of being non-recoverable and will need to be discarded.

9.2. Guidelines for Shipping and Repackaging

All RRC smart batteries are certified to UN38.3 and can be shipped by air worldwide.

In general, you are allowed to ship RRC batteries pre-charged up to 30%. If you ship the batteries contained in the end-product, you may charge them up to 100%.

If you want to add parts (by attaching or even gluing them) to our batteries, you may need to repeat the IATA air freight 1.2 m drop test.

You find the latest shipping guideline for more complete and up-to-date information under 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.

Each chapter shows a table that lists the requirements for shipping batteries. Below, you see an excerpt of the table explaining how to ship batteries by air freight: 1. Without equipment (e.g., spare parts) 2. Packed with equipment (but not contained inside equipment) 3. Contained in equipment.

	Airfreight (IATA)			
	For lithium ion cell the Watt-hour rating is not more than 20 Wh. For lithium ion battery the Watt-hour rating is not more than 100 Wh. Lithium ion batteries subject to this provision shall be marked with the Watt-hour rating on the outside case, except those manufactured before 1 January 2009			
Packing Instructions	**IATA PI965 Section IB**	**IATA PI965 Section II**	**IATA PI966 Section II**	**IATA PI967 Section II**
Transportation Mode	Batteries (without equipment) 		Batteries packed with equipment 	Batteries contained in equipment 
Max. Quantity	none (more than 8 cells or 2 batteries per packaging)	2 batteries per package, 1 package per consignment 1 package per overpack	number required for equipment plus 2 spare	none
Weight Limit PAX	prohibited	prohibited	5 kg net battery weight per packaging	
Weight Limit CAO	10 kg net per packaging	N/A		

10.Replacing Batteries

10.1. Battery Lifetime

RRC recommends replacing batteries after two years of use or after a specific number of cycles (500 for the RRC1120, 300 for the RRC1130), whatever first comes. The majority 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, the specifications of your device can still be met. Ask the RRC Application Support for battery-specific lifetime data.

10.2. RRC Life Cycle Management (No-Obsolescence Promise)

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 have to 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" guarantees that RRC manages the previously mentioned tasks and delivers an updated battery revision that is backward compatible (drop-in replacement) to our existing designs. Figure 6 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.

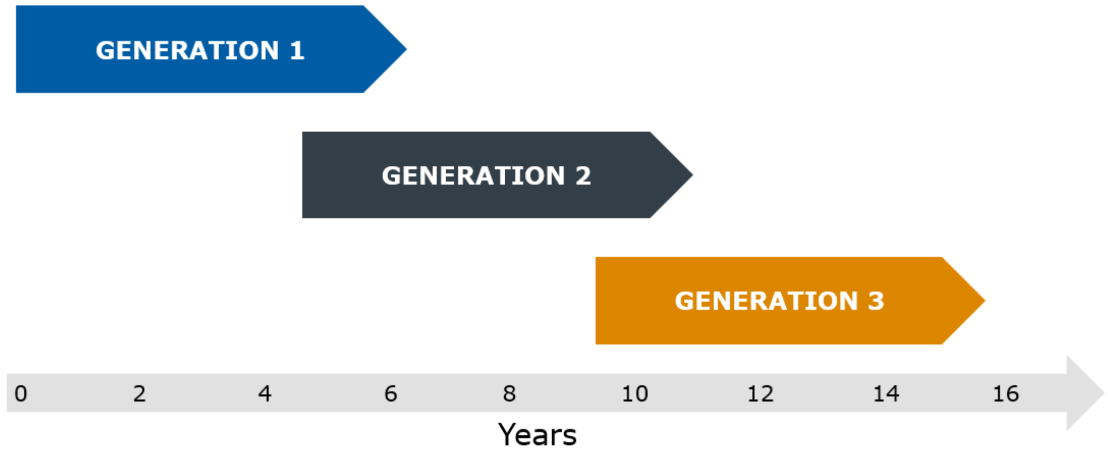


Figure 6 – RRC Life Cycle Management

Appendix

A. Practical advice: Stop discharging in time

As you see in Figure 7, 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 in that small range of remaining battery capacity.

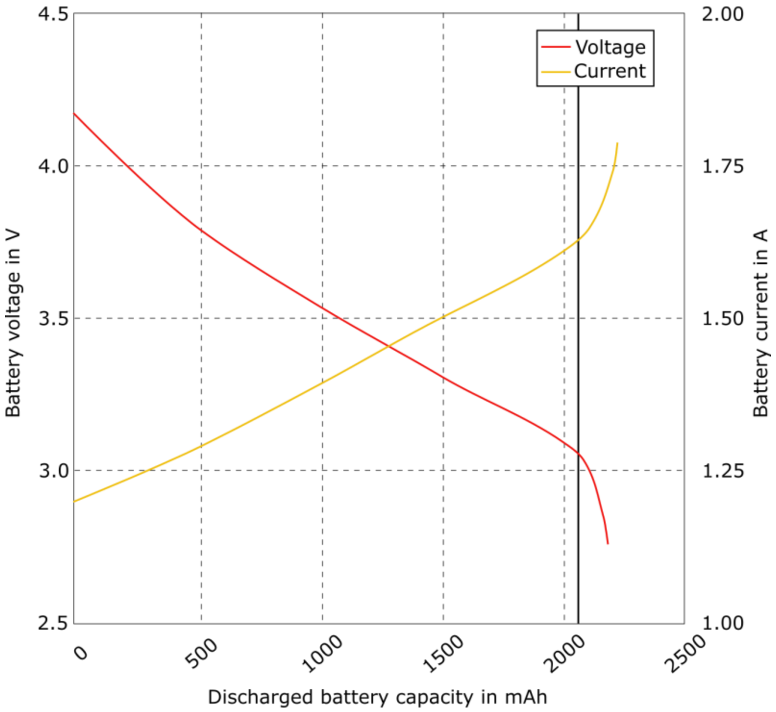


Figure 7 – Example: RRC1120 discharging voltage and current at a continuous output power of 5 W.

This is why RRC usually recommends powering down the device between 5 and 10% remaining SOC. By doing this, you receive the following advantages:

1. Reduced probability that the battery becomes deeply discharged.
2. Longer life expectancy. It is not possible to estimate by how much because this depends on the customer use-case, but in general, a battery tends to stay healthy longer if it is used over less than the whole capacity range.

To make the experience for your users seamless, scale the reported capacity (e. g. 100% down to 10%) in a way that the user sees (100% down to 0%).

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