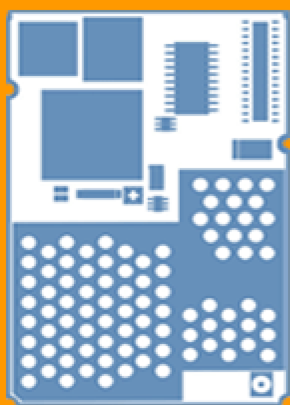
CINTERION
WIRELESS MODULES

Rechargeable Lithium Batteries in GSM Applications



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Application Note 07

Application Note 07: **Rechargeable Lithium Batteries in GSM Applications**

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0 Document History

Preceding document: "Rechargeable Lithium Batteries in GSM Applications" Version 04
New document: " Rechargeable Lithium Batteries in GSM Applications" Version **05**

Chapter	What is new
3.2, 6.2.1	Added information related to the resistor of charging circuit for modules AC75i, MC75i, TC63i and TC65i.

Preceding document: "Rechargeable Lithium Batteries in GSM Applications" Version 03
New document: " Rechargeable Lithium Batteries in GSM Applications" Version 04

Chapter	What is new
1	Updated list of supported products.
2.3	Updated battery specifications in Table 1.
2.3.1	Added information related to specific types of batteries.
3.1	Added product specific details.
6	Removed subsection on battery parameterization.
6.2.1	Further details on how to increase charge current.
7.1	New chapter: Appendix with data sheets of tested batteries.

Preceding document: "Rechargeable Lithium Batteries in GSM Applications" Version 02
New document: " Rechargeable Lithium Batteries in GSM Applications" Version 03

Chapter	What is new
2.3, 7	Removed all information related to specific types of batteries and specific vendors.

Preceding document: "Rechargeable Lithium Batteries in GSM Applications" Version 01
New document: " Rechargeable Lithium Batteries in GSM Applications" Version 02

Chapter	What is new
3.1	Added duration of charging.
3.2	Updated Figure 4: Sample application based on the MC75 module.
6.2.1	Updated Figure 12: External charging circuit recommended for increased charger output current.

1 Introduction

This Application Note[1] provides technical assistance in integrating rechargeable Lithium Ion and Lithium Polymer batteries into host applications based on the following modules:

- MC75, MC75i
- TC63, TC63i
- TC65, TC65i
- AC75, AC75i
- AC65
- XT65
- XT75
- EES3
- EGS3
- EGS5
- BGS3

The document describes the requirements for batteries and chargers, discusses appropriate charging circuits and explains operational issues typical of battery powered GSM/GPRS applications.

1.1 Related Documents

[1] Hardware Interface Description of your module
[2] AT Command Set for your module
[3] Release Notes related to the firmware of your module

1.2 Approval Considerations

The modules listed above are type approved for use with the Cinterion Wireless Modules reference equipment described in [1].

When designing a GSM application you are advised to make sure whether or not the final product is standard compliant. This is particularly important for mobile phones, PDAs or other handheld transmitters and receivers incorporating a GSM module. Depending on the individual design, such devices may require additional type approval.

Outside of Europe, there may be further international, national or government standards and regulations to be observed for type approval.

1. The document is effective only if listed in the appropriate Release Notes as part of the technical documentation delivered with your Cinterion Wireless Modules product.

1.3 Terms and Abbreviations

Abbreviation	Description
B	Thermistor Constant
B2B	Board-to-board connector
CE	Conformité Européene (European Conformity)
dBm0	Digital level, 3.14dBm0 corresponds to full scale, see ITU G.711, A-law
ESD	Electrostatic Discharge
GPRS	General Packet Radio Service
GSM	Global Standard for Mobile Communications
Li-Ion / Li+	Lithium-Ion
Li battery	Rechargeable Lithium Ion or Lithium Polymer battery
NTC	Negative Temperature Coefficient
PCB	Printed Circuit Board
PCL	Power Control Level
PCM	Pulse Code Modulation
RF	Radio Frequency
Rx	Receive Direction
Tx	Transmit Direction
UART	Universal asynchronous receiver-transmitter
URC	Unsolicited Result Code
V_{BATT+}	Battery Voltage

2 Requirements for Battery Management

2.1 Hardware Requirements

The GSM modules have no on-board charging circuit. To benefit from the implemented charging management you are required to install a charging circuit within your application according to the Figure 4.

2.2 Software Requirements

Use the command AT^SBC, parameter <current>, to enter the current consumption of the host application. This information enables the GSM module to correctly determine the end of charging and terminate charging automatically when the battery is fully charged.

If the <current> value is inaccurate and the application draws a current higher than the final charge current, either charging will not be terminated or the battery fails to reach its maximum voltage. Therefore, the termination condition is defined as: final charge current (50mA) plus current consumption of the external application. If used the current flowing over the VEXT pin of the application interface (typically 2.9V) must be added, too.

The parameter <current> is volatile, meaning that the factory default (0mA) is restored each time the module is powered down or reset. Therefore, for better control of charging, it is recommended to enter the value every time the module is started.

See [2] for details on AT^SBC.

2.3 Battery Requirements

The modules support trickle charging and software controlled charging of Lithium Ion and Lithium Polymer batteries. For using the implemented charge control an external charging circuit must be installed within the host application as explained in Section 3.2 or Section 6.2. Furthermore, to ensure proper operation, maximum capacity over a long run and long battery life, the battery needs to be compliant with the specifications listed below:

- The Lithium battery must be specified for a maximum charging voltage of 4.2V. Since charging and discharging largely depend on the battery temperature, the battery should include an NTC resistor for battery detection and temperature monitoring. If the NTC is not inside the battery, it must be at least in thermal contact with the battery. Charging will not start if the NTC is not present.
- Ensure that the battery incorporates a protection circuit capable of detecting overvoltage (protection against overcharging), undervoltage (protection against deep discharging) and overcurrent. Due to the discharge current profile typical of GSM applications, the circuit must be insensitive to pulsed current.
- The internal resistance of the battery and the protection should be as low as possible. It is recommended not to exceed 150mΩ, even under extreme conditions at low temperature. The battery pack should be approved to satisfy the requirements of CE conformity.

Figure 1 shows the circuit diagram of a typical battery pack design including the protection elements described above.

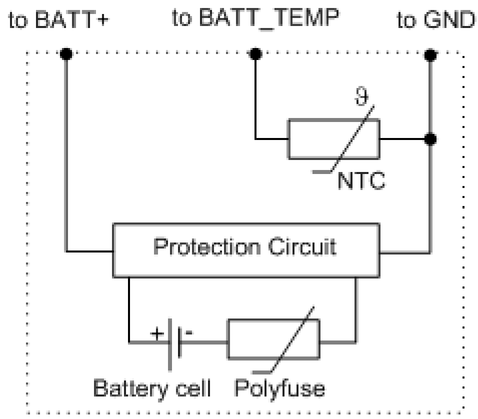


Figure 1: Battery pack circuit diagram

Failure to comply with these specifications might cause
- the charging process not to start
- premature termination of charging
- short battery lifetime or a destroyed battery.

When a GSM call or a GPRS connection is established, the battery is discharged at a rate determined by the current profile typical of the GSM (GPRS) transmitting and receiving bursts. In normal conditions, the transmit burst current rises up to 2A when the module is transmitting at EGSM 900 / Power Level (PCL) 5. Under worst case conditions, such as antenna mismatch, the transmit burst current might even reach 3A. See also Sections 4 and 5 for more details.

Table 1: Specifications of battery packs suitable for use with the modules

Battery type	Rechargeable Lithium Ion or Lithium Polymer battery
Nominal voltage	3.6V / 3.7V
Capacity	>500mAh
NTC	10kΩ ± 5% @ 25°C approx. 5 kΩ @ 45°C approx. 26.2 kΩ @ 0°C B value range: B (25/85) = 3423K to B = 3435K ± 3%
Overcharge detection voltage	4.325 ± 0.025V
Overdischarge detection voltage	2.4V
Overdischarge release voltage	2.6V
Overcurrent detection	>3A
Overcurrent detection delay time	4~16ms
Short detection delay time	50µs
Internal resistance	<130mΩ Note: A maximum internal resistance of 150mΩ should not be exceeded even after 500 cycles and under extreme conditions.
Charging temperature	0° to 45°C
Discharging temperature	-20° to 60°C

2.3.1 Recommended Batteries

When you choose a battery for your GSM application you can take advantage of one of the following two batteries offered by VARTA Microbattery GmbH. Both batteries meet all requirements listed above. They have been thoroughly tested by Cinterion Wireless Modules and proved to be suited for the modules.

- LIP 653450 TC, type Lithium Ion
  This battery is listed in the standard product range of VARTA. It is incorporated in a shrink sleeve and has been chosen for integration into the reference setup.
- PLF 503759C.PCM, type PoLiFlex® Lithium Polymer
  This battery has been especially designed by VARTA for use with electronic applications like mobile phones, PDAs, MP3 players, security and telematic devices. It has the same properties as the above Li-Ion battery, except that it is type Polymer, is smaller, lighter and comes without casing.

Specifications, construction drawings and sales contacts for both VARTA batteries can be found in Section 7.1.

3 Charging Management

3.1 Stages of Charging

If the battery meets the requirements listed above and your application uses one the external charging circuits shown in Figure 4 or Section 6.2, then charging is enabled in various stages depending on the battery condition:

Trickle charging:
- Trickle charge current flows over the VCHARGE line.
- Trickle charging is done when a charger is present (connected to VCHARGE) and the battery is deeply discharged or has undervoltage.
- Charging rate:
  - If deeply discharged (Deep Discharge Lockout at VBATT+= 0…2.5V) the battery is charged at 30mA (AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3, BGS3) resp. 5mA (all other supported modules).
  - In case of undervoltage (Undervoltage Lockout at VBATT+= 2.5…3.0V) the battery is charged at 60mA (AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3, BGS3) resp. 30mA (all other supported modules).
  - If VBATT+= 3.0V... 3.2V the battery is charged at 100mA (AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3, BGS3) resp. 30mA (all other supported modules).

Software controlled charging:
- Controlled over the CHARGEGATE.
- Temperature conditions: 0°C to 45°C
- Software controlled charging is done when the charger is present (connected to VCHARGE) and the battery voltage is at least above the undervoltage threshold. Software controlled charging passes the following stages:
  - Power ramp: Depending on the discharge level of the battery (i.e. the measured battery voltage V_{BATT+}) the software adjusts the maximum charge current for charging the battery. The duration of power ramp charging is very short (less than 30 seconds).
  - Fast charging: Battery is charged with constant current (approx. 500mA) until the battery voltage reaches 4.2V (approx. 80% of the battery capacity). Options for applying a fast charging current higher than 500mA are described in Section 6.2.1.
  - Top-up charging: The battery is charged with constant voltage of 4.2V at stepwise reducing charge current until full battery capacity is reached.

Duration of charging:
- The module provides two charging timers: a software controlled timer set to 4 hours and a hardware controlled timer set to 4.66 hours.
  - The duration of software controlled charging depends on the battery capacity and the level of discharge. Normally, charging stops when the battery is fully charged or, at the latest, when the software timer expires after 4 hours.
  - The hardware timer[1] is provided to prevent runaway charging and to stop charging if the software is not responding. The hardware timer will start each time the charger is plugged to the VCHARGE line.

1. Not supported by AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3, BGS3

The stages of software controlled charging are illustrated in Figure 2.

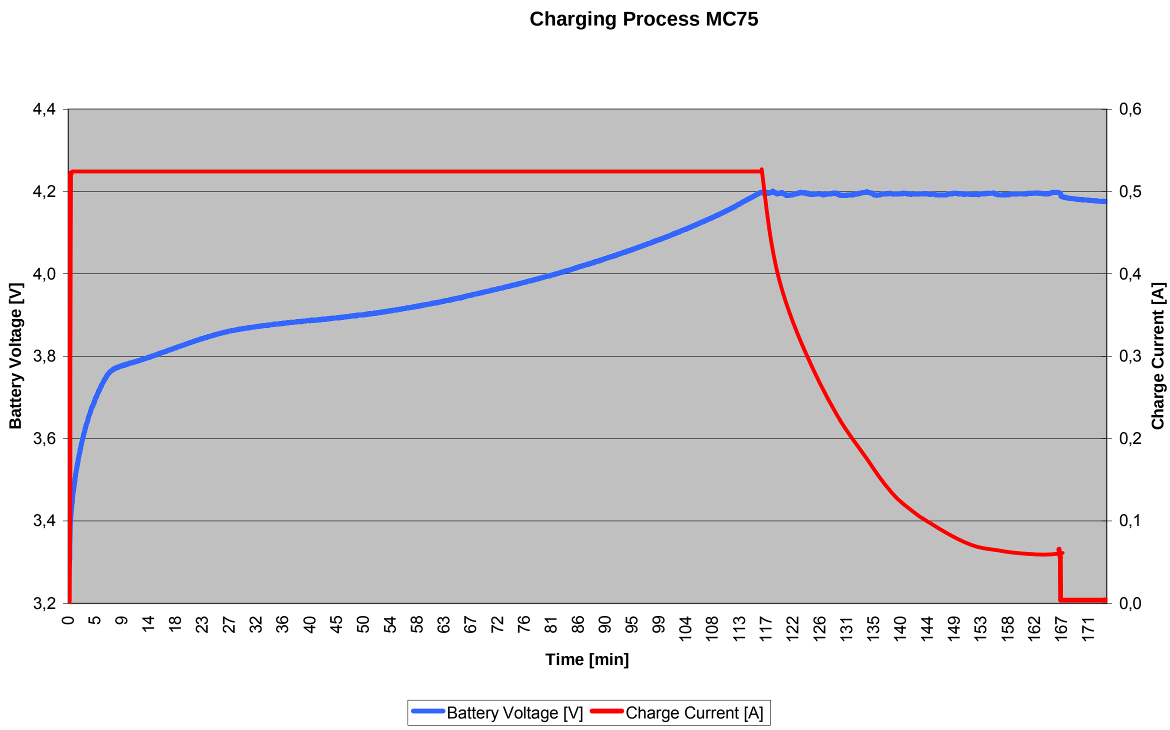


Figure 2: Stages of software controlled charging

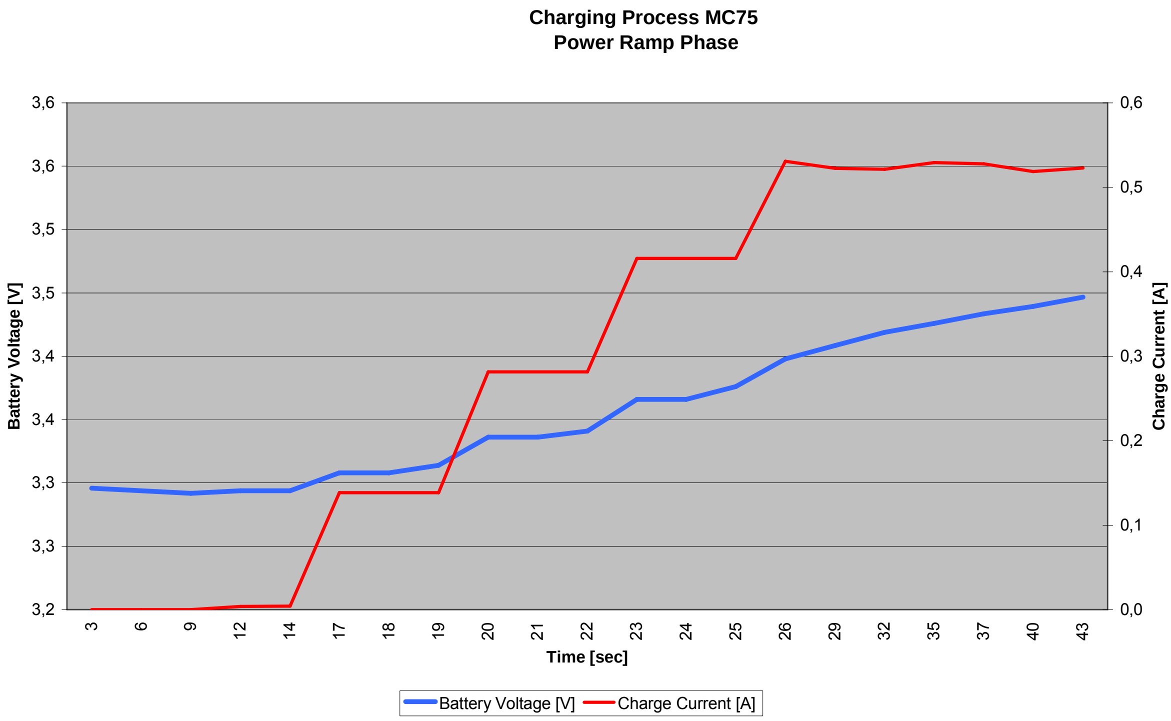


Figure 3: Charging details of power ramp phase

3.2 Sample Application with Referencing Charging Circuit

The reference charging circuit shown in Figure 4 assumes that the charger has the following parameters:

- Output voltage: 5.2Volts ±0.2V (stabilized voltage). AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3 and BGS3 accept voltages up to 7V.
- Output current: 500mA
  Chargers with a higher output current are acceptable, but please consider that only 500mA will be applied when a 0.3Ohms shunt resistor is connected between VSENSE and ISENSE. For using chargers with higher output current see Section 6.2.
- For the above mentioned products the use of a resitor (which is connected to the charge transistor's gate-source) with half of the value given in Figure 4 results in a better adjustment range of the charge current.

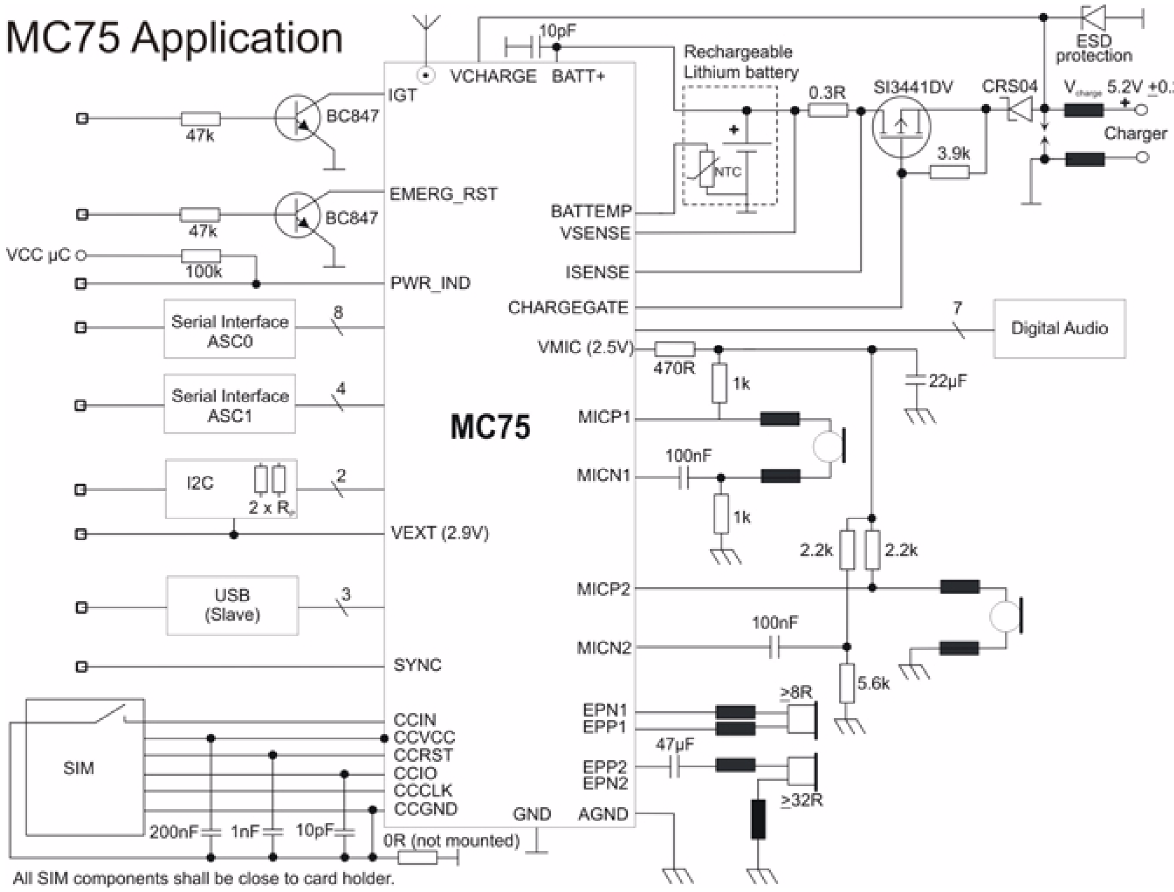


Figure 4: Sample application based on the MC75 module

Note: Charging circuits for host applications incorporating other modules listed above can be designed in the same way.

Disclaimer
No warranty, either stated or implied, is provided on the sample schematic diagram shown in Figure 4 and the information detailed in this section. As functionality and compliance with national regulations depend to a great amount on the used electronic components and the individual application layout manufacturers are required to ensure adequate design and operating safeguards for their products using the modules.

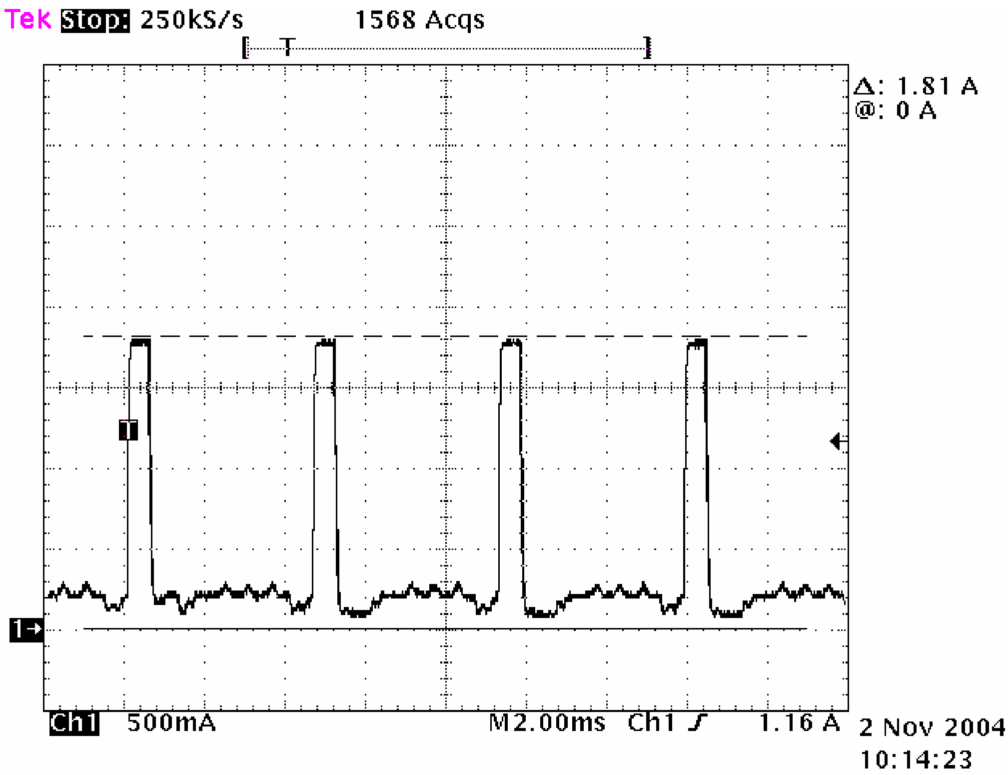
4 Current Load of GSM Applications

4.1 Current Consumption during Transmit Burst

Due to the maximum RF power level of approximately 2W, the battery discharge current is modulated at 2A (approx.) pulses of 0.577ms every 4.6ms. During the low current period, the current consumption during a GSM call is about 70mA.

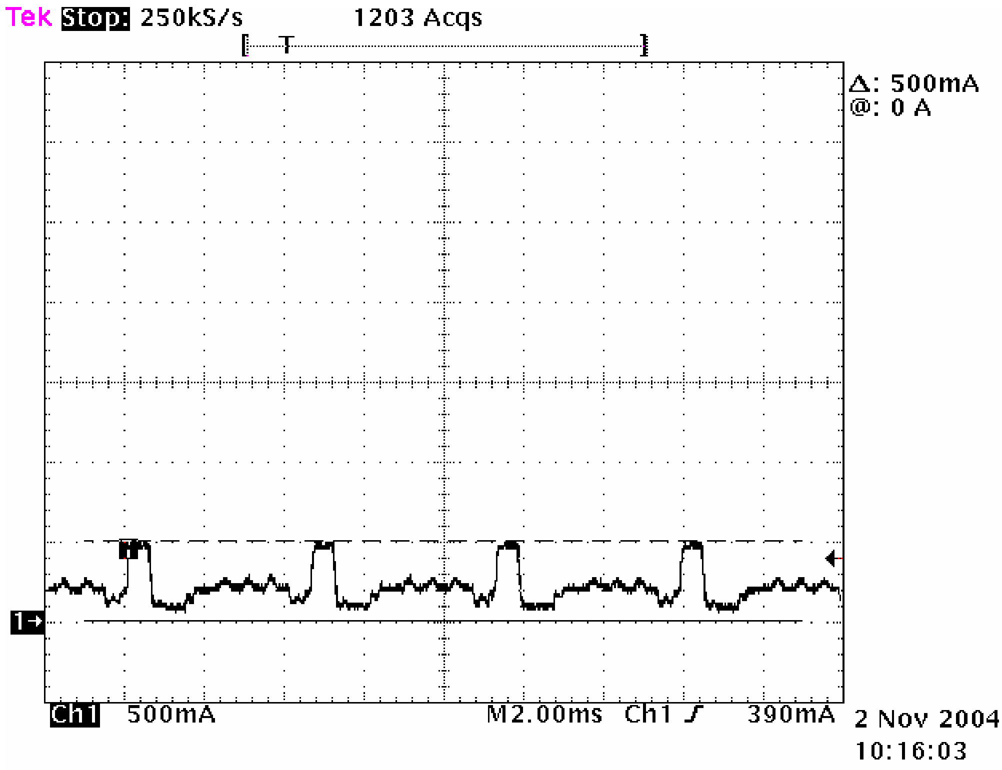
The current profile is illustrated in Figure 5 and Figure 6 The measured values refer to the GSM band 900MHz at maximum power level (PCL 5) and minimum power level (PCL 19) with a real 50Ω load. These values may increase up to 2...3A if the antenna is badly matched.

Depending on the overall power supply resistance, the corresponding voltage drops measured at the module's connector may reach higher values.



(Tx burst = 577µs)

Figure 5: Current consumption during voice call or GPRS Class 8 connection at PCL5



(Tx burst = 577µs)

Figure 6: Current consumption during voice call or GPRS Class 8 connection at PCL 19

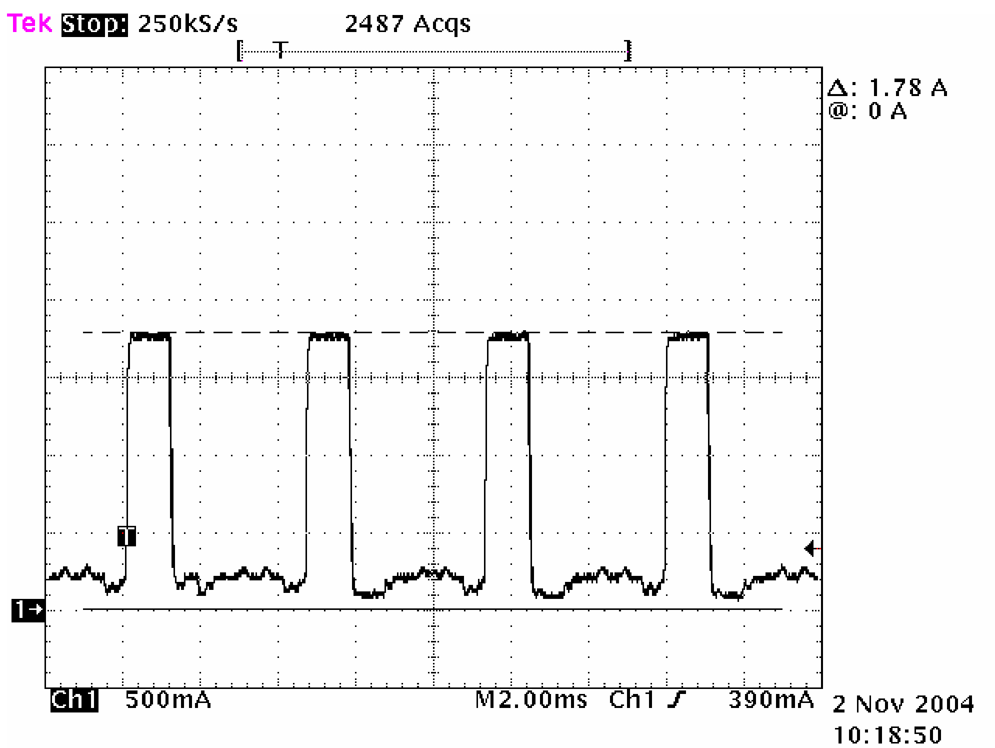


Figure 7: Current consumption during GPRS Class 10 connection at PCL5

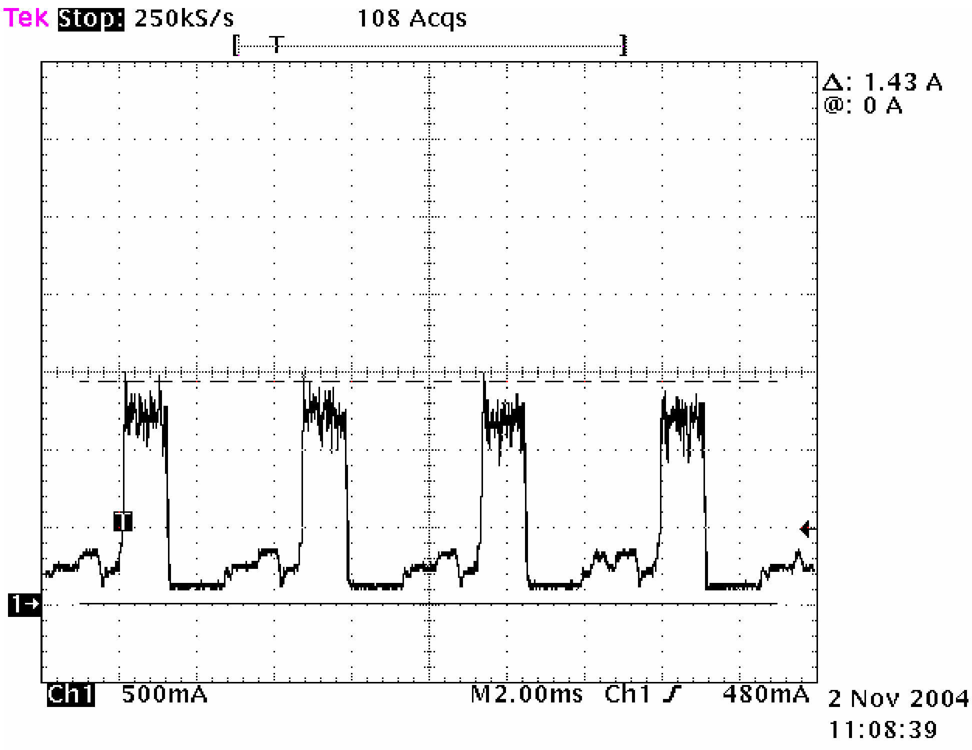


Figure 8: Current consumption during EGPRS Class 10 connection at PCL5

Please note that ripple and spikes during the transmit burst depending on the noise-induced amplitude modulation as shown in Figure 7.

4.2 Peak Current during Transmit Burst

The following table shows the typical peak current consumption during transmit bursts measured in different GSM bands and different modulation schemes at an antenna load of 50 Ohms.

Table 2: Typical peak current in transmit burst

Band	Modulation	Current (Ampere)
900	GMSK	<2
900	8PSK	1.2
1800	GMSK	1.9
1800	8PSK	1.3
850	GMSK	<2.2
850	8PSK	1.3
1900	GMSK	<1.6
1900	8PSK	<1.2

For good performance, the return loss of an antenna should be better than 10dB (within the given frequency range).

5 Strategies for Maximizing Battery Capacity

The most important feature when using batteries in a mobile application such as cellular telephones or PDAs, is the capacity per volume. This section describes battery properties and other influences that reduce the battery capacity. The overall power supply resistance and the temperature have the biggest influence.

5.1 Effects of Application Power Supply Resistance

The power supply resistance of a mobile application typically results from the following parameters:

Table 3: Typical resistance of a power supply line

Battery	Cell resistance	10...40mΩ
	Resistance of battery protection circuit	80...100mΩ
Application	Resistance of PCB and connectors	20...100mΩ (depends on design)
Total:	Minimum overall resistance	>110mΩ

A transmit burst current of 2A causes a voltage drop of 0.22V across the power line. The undervoltage shutdown threshold of a module is 3.2V. This means that when making a call at a battery voltage of V_{BATT+} 3.42V the GSM module reaches its shutdown threshold, due the internal resistance, and switches off.

Figure 9 illustrates a measurement under realistic conditions, assuming battery discharge due to 10mA current consumption in idle mode and a 1-minute GSM call made every hour at PCL5 with a current profile 2A / 70mA, until the battery is empty.

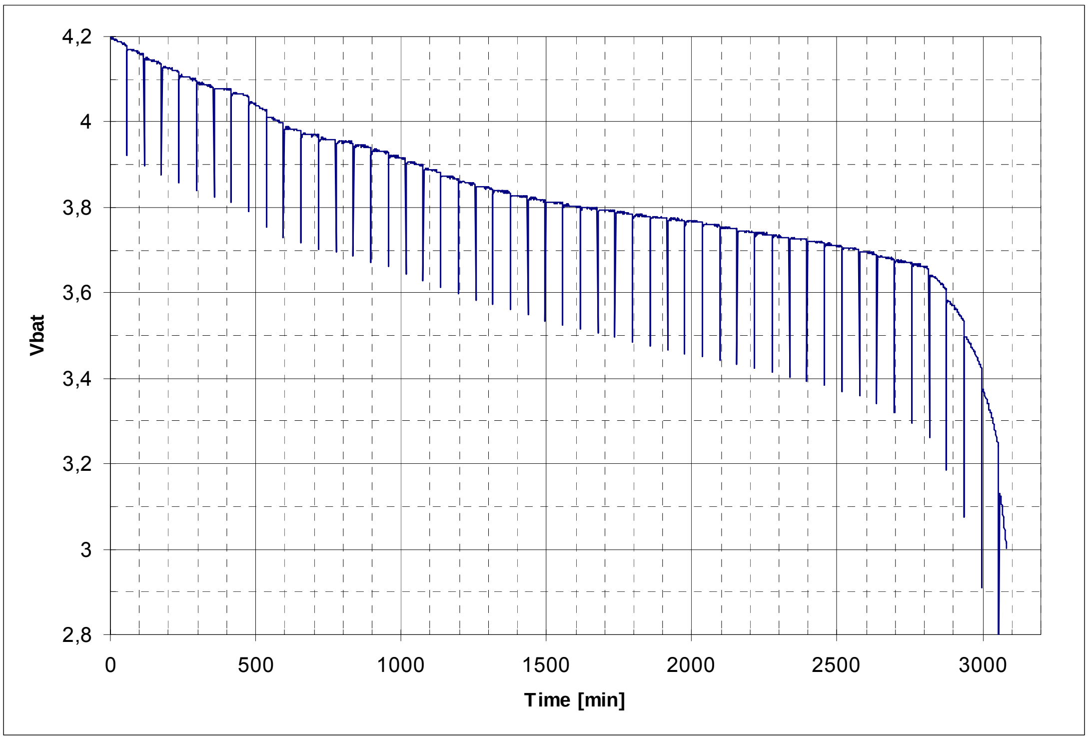


Figure 9: Voltage level of a typical 1000mAh Li battery discharged at 20°C

In addition to voltage drops caused by the internal resistance the effect of the recovery voltage is significant (see Section 5.2). Both effects together will lead to voltage loss during operation. The lower the battery voltage, the greater is the voltage loss.

Table 4: Measured resistance and voltage drops of a typical 1000mAh battery

Internal resistance @ 4.2V / 3.6V	90mΩ / 100mΩ (to multiply by 2A)
Recovery voltage @ 4.2V / 3.6V	80mV / 210mV
Voltage loss @ 4.2V / 3.6V	260mV / 410mV

In Table 4 you can see a voltage loss of 260 / 410mV resulting from the total of the recovery voltage and the voltage drops due to internal resistance. This means: At a voltage of 3.6V the module is close to its shutdown threshold, because a 1-minute call at PCL5 would discharge the battery down to 3.2V where the module switches off automatically. Note that at 3.6V a typical battery has only about 5% capacity left – the voltage is falling rapidly compared to the nominal voltage range as well under idle load (10mA). See Figure 9 for details.

To sum it up: The available battery capacity depends on the recovery voltage and the power supply resistance. Therefore, design engineers are advised to choose a battery with a low recovery voltage and a low internal resistance. Also the power supply lines on the application PCB should be dimensioned for with low resistance.

5.2 Effects of Recovery Voltage

The recovery voltage is caused by the inner chemical idleness. The battery voltage recovers almost to its old value after a heavy load is stopped as can be seen in Figure 10.

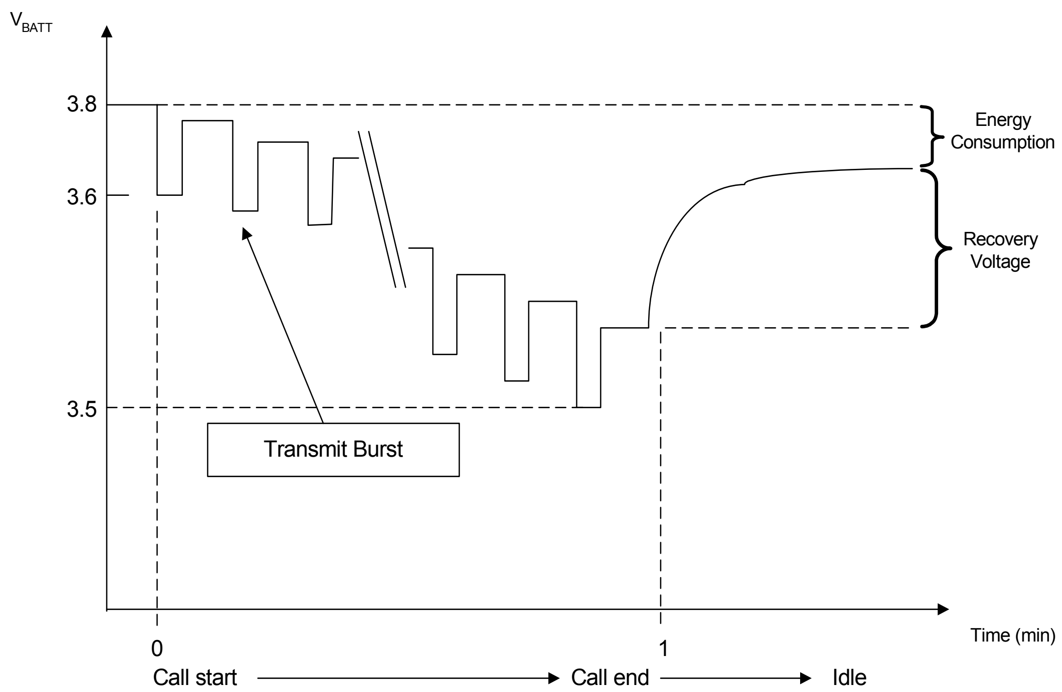


Figure 10: Recovery voltage and voltage drops of a typical Li battery at GSM PCL5 load

Furthermore, recovery voltage and voltage drops will rise with lower battery voltage and lower temperature. The recovery time depends on the battery and is typically in the range of 2 to 10 minutes after the end of a call or data connection. If the battery is discharged only by GSM load, the recovery voltage has no effect, because the battery has no time for recovering.

The implemented software and battery parameters of the module account for these effects to achieve best results. In Idle state the module software calculates the voltage loss (internal resistance and recovery voltage) likely to occur when a call is started. During idle mode, when the battery voltage is too low to ensure a trouble free active call, the module shuts down. The intention is to guarantee enough power left at least for a 1-minute call (e.g. an emergency call).

5.3 Effects of Temperature

The temperature has the biggest influence on the available capacity. Figure 11 illustrates the dramatic difference of the available capacity at three different temperatures.

The measurement has been taken under realistic conditions, assuming battery discharge due to 10mA current consumption in idle mode and a 1-minute GSM call made every hour at PCL5 with a current profile 2A / 200mA, until the battery is empty.

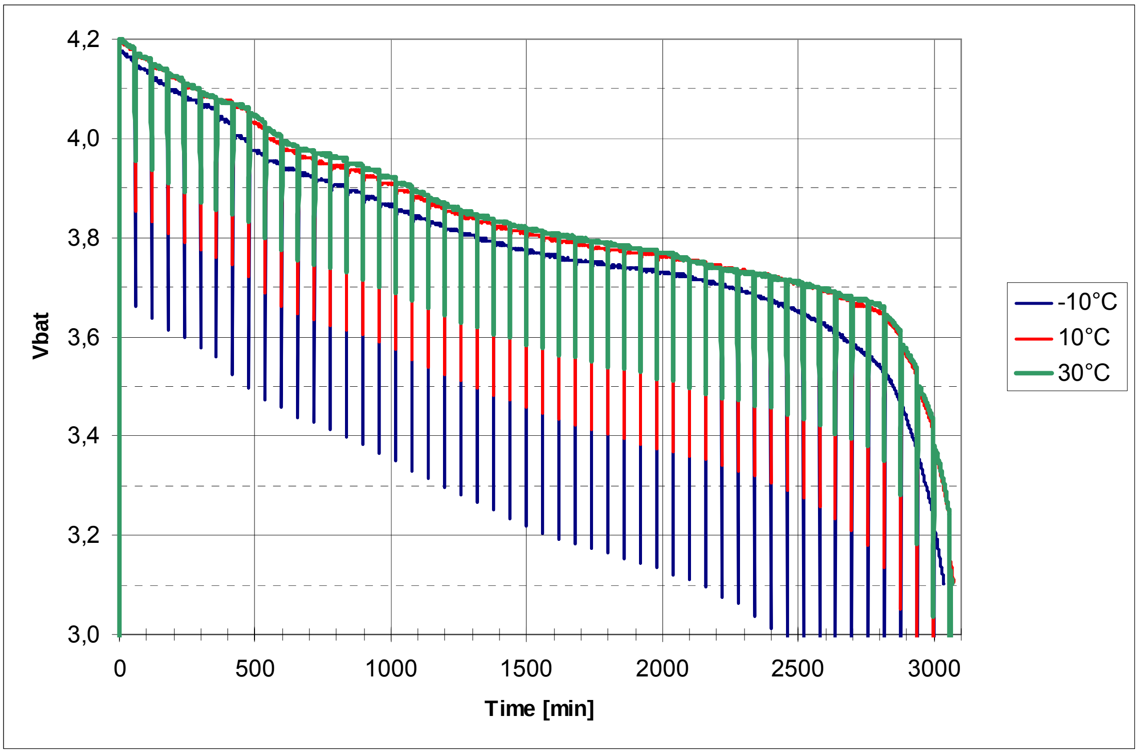


Figure 11: Voltage of a typical 1000mAh Li battery measured at different temperatures

As you can see, the capacity decreases at lower temperatures. This is caused by significant rise of the internal resistance and the recovery voltage. The spikes in Figure 11 represent a 1-minute call, not only a sending burst. Table 5 shows the measured values in detail.

Table 5: Parameters of a typical 1000mAh Li battery measured at different temperatures

Temperature	Relative capacity	Internal resistance	Recovery voltage
-10°C	54%	115mΩ	490mV
10°C	92%	95mΩ	330mV
30°C	100%	85mΩ	140mV

To operate the mobile equipment at low temperatures, design engineers are advised to choose a battery with the lowest recovery voltage to achieve maximum capacity. Even a battery with a lower nominal capacity and low recovery voltage may be much more suitable than a battery with higher nominal capacity and higher recovery voltage.

The described effects are accounted for through the sophisticated software and battery parameters of the module.

6 Design Advice

6.1 Reducing Resistance between Battery and Module

Generally, the PCB tracks connecting the module with the battery and, if used, a flex cable running from the board-to-board connector to the application, should be as short and low resistant as possible.

To minimize the effect of voltage drops (max. 400mV recommended), you can decrease the GND resistance by using additional ground connections from the module to the customer application. This can be done by using a screw or spring contact.

Typical resistance values are listed in the table below. These values increase up to 80% when the temperature drops to –10 degrees Celsius.

Table 6: Typical values of a battery application at 2A transmit burst

Cause of the resistance	Measured resistance at 25°C	Voltage loss on module
Battery and protection circuitry	≈100mΩ	200mV
Battery spring connections	2 x 6mΩ	24mV
PCB and B2B connector	2 x 9mΩ	36mV
Total:	≈130mΩ	260mV

6.2 Modifying External Charging Circuits

For using chargers other than the type recommended in Section 3.2 the charging circuit of the host application can be modified as described below.

6.2.1 Increasing Charge Current

If the shunt resistor connected between VSENSE and ISENSE is R_{shunt} = 0.3 Ohms then the maximum fast charging rate is 500mA no matter whether the battery charger is providing more. To enable a higher charger output current it is possible to connect a shunt resistor R_{shunt} = 0.15 Ohms between VSENSE and ISENSE. In this case the charger output current reaches 1A as calculated below:

$$I_{CHARGE} = \frac{150mV}{R_{Shunt}}$$

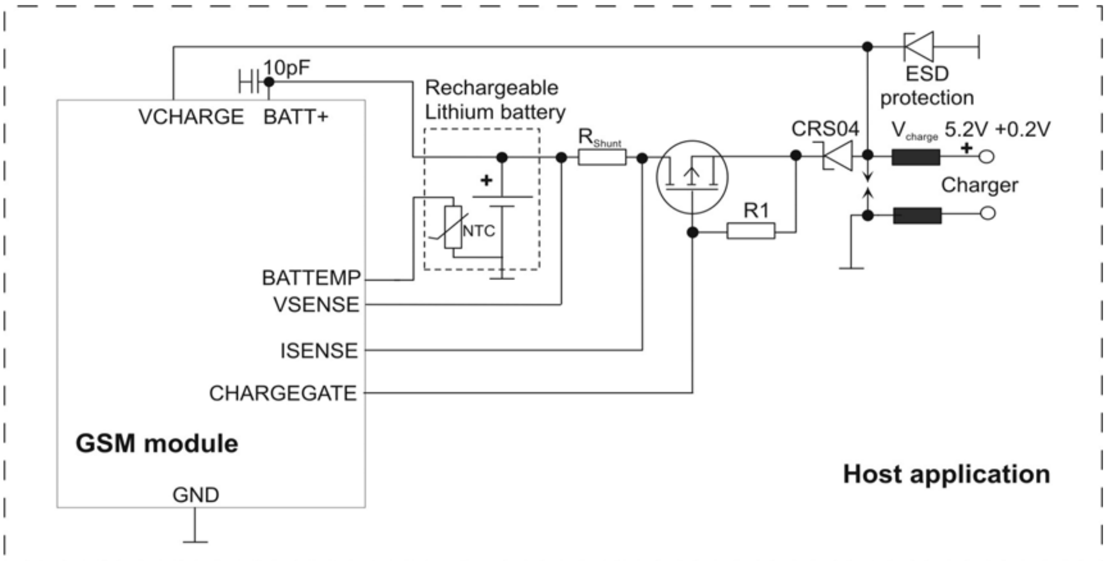


Figure 12: External charging circuit recommended for increased charger output current

R1 is depending on the gate-source voltage of the used FET and the maximum chargegate sink current. The resistor shall enable the FET just to achieve the full charge current I_{charge} at a chargegate sink current $I_{CHARGEGATE}$ = -0.5mA. This way, R1 can be assumed to be in the range from 3.9k to 10k. For AC75i, MC75i, TC63i, TC65i, EES3, EGS5, EGS3 and BGS3 see also description regarding R1 in Section 3.2.

Keep in mind that the gate-source voltage varies with the temperature and, sometimes, even product tolerances of the FET.

7 Appendix

7.1 Data Sheets of Recommended Batteries

The following two data sheets have been provided by VARTA Microbattery GmbH.
Click here for sales contacts and further information: http://www.varta-microbattery.com

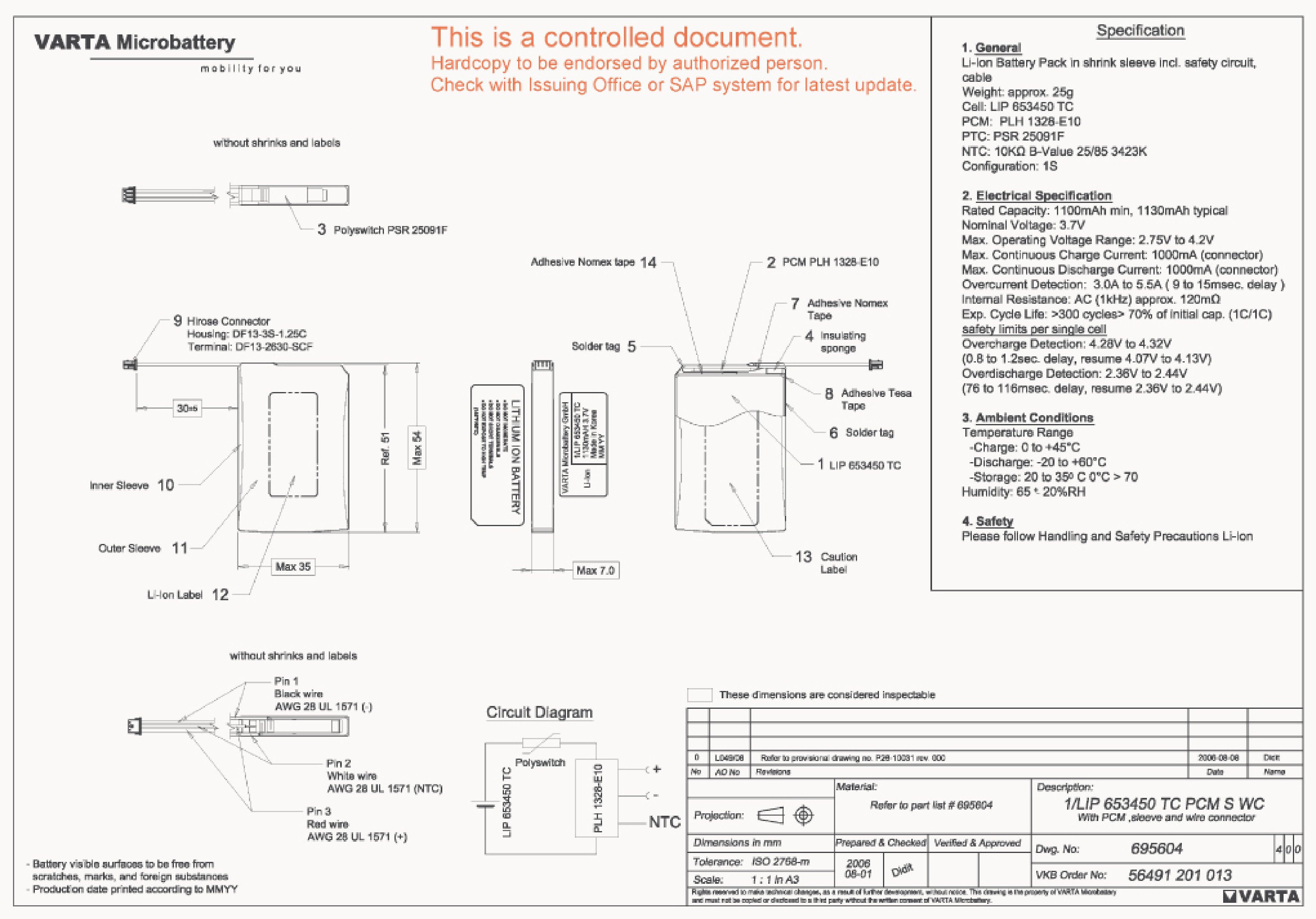


Figure 13: VARTA Lithium Ion battery

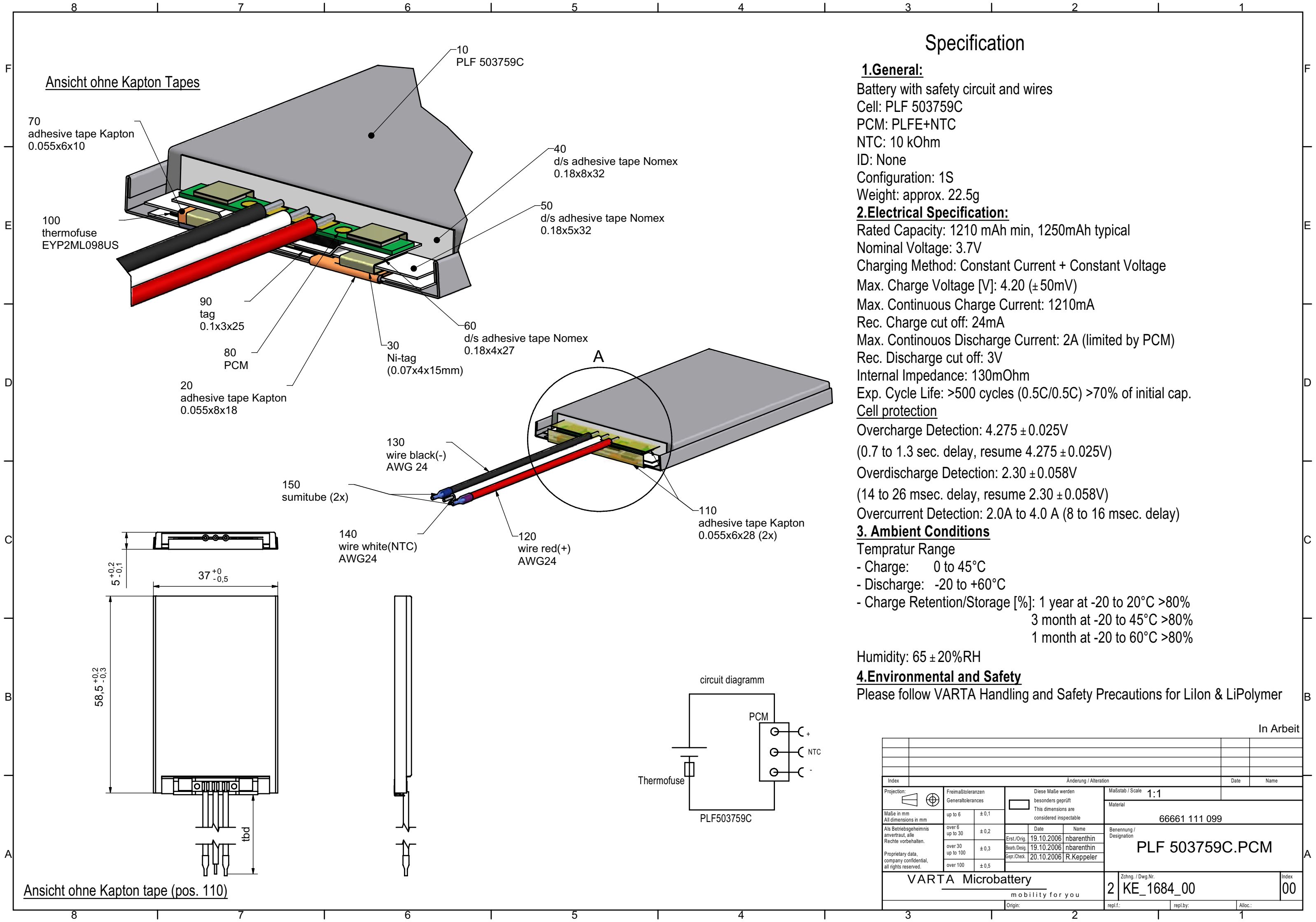


Figure 14: VARTA PoLiFlex® Lithium Polymer battery