BP30
SW Battery and Capacity drivers Specification

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1 Document Mission/Scope

1.1 Mission

The aim of this publication is to clarify concepts and algorithms used for battery capacity estimation. This argument is strictly related to battery charging, which is deeply treated in another document provided by N7.

1.2 Scope

This docment is addressed to engineers and software drivers developers, who are interested in battery charging and power management issues.

2 List of Acronyms

Abbreviation / Term	Explanation / Definition
PA	Power Amplifier
RMS	Round Mean Square
SW	Software
HW	Hardware

3 Introduction

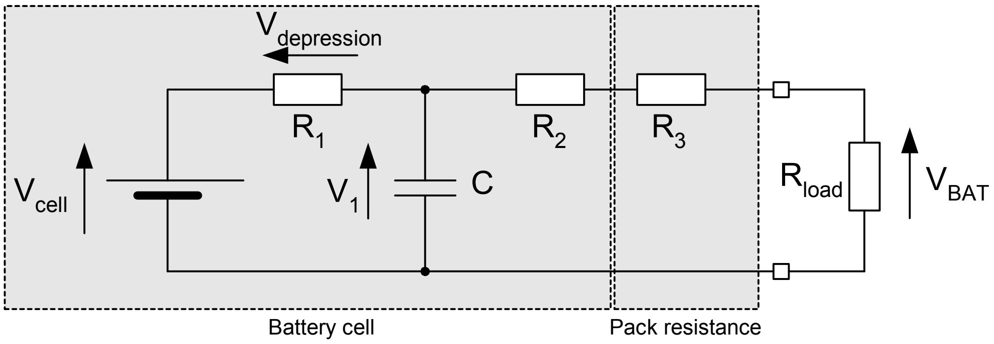
In GLOBEx platform, Battery Capacity estimation is done using SW driver solution. Interaction between battery measurements and capacity model is very strict, and also charger driver uses both these functionalities. Model is based on two carachteristics of battery: charging and discharging. So different parameters occurs when in charging or discharging, and also we must check if we are during TX or notl

4 Battery Capacity Estimation

The battery capacity estimation concept in the GLOBE x is derived directly from solution used in P2002 platform and it is a total redesign of the concept used in earlier projects. The reason for the change is cost reduction, to achieve this the gas gauge IC from earlier projects is removed. A substantial degradation of performance must be expected.

4.1 Concept

The battery capacity estimation concept relies on battery voltage measurements. Ideally, the battery voltage is an indicator of the residual capacity left in the battery, however a number of factors affect the measured voltage, as will be shown below.



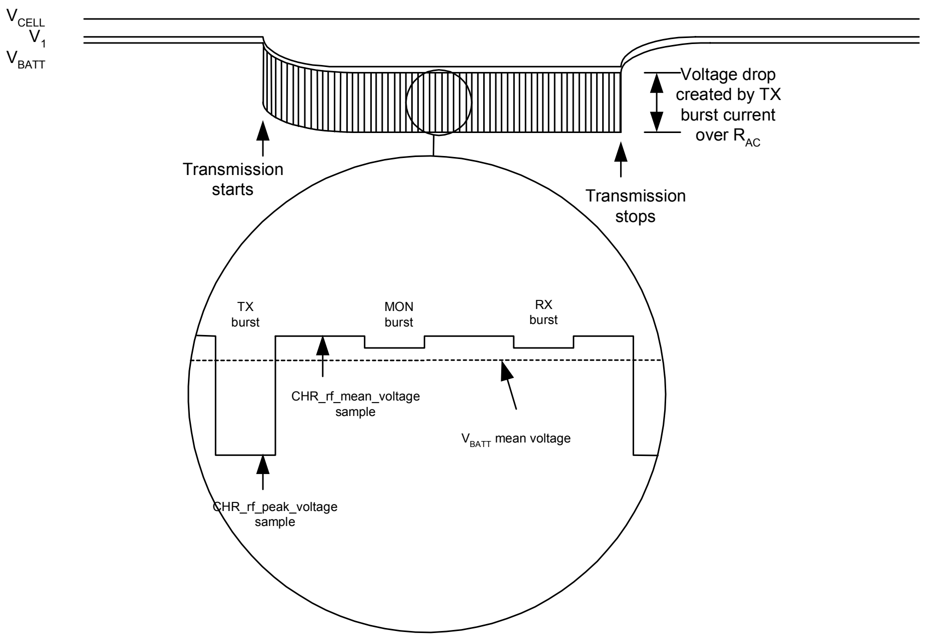
A simplified battery model is shown above. The model consist of a voltage generator V_{cell} representing the open circuit voltage of the battery, resistors R_1 representing the separator/electrolyte resistance, R_2 representing the electrode and internal connection resistance and R_3 representing the additional resistance added in the pack, such as protection circuit, wiring resistance etc., and C represents the electrode capacitance. For capacity estimation this model will be used to represent the battery voltage vs. capacity relationship. The following assumptions and approximations will be used:

V_{cell} is only a function of the residual capacity in the battery;	V_{cell}	=	f (c)
R_{DC} = $R_1 + R_2 + R_3$, is a function of temperature;	R_{DC}	=	f(t)
R_{AC} = $R_2 + R_3$, is a function of temperature;	R_{AC}	=	f (t)
C is considered constant for simplicity;	C	=	k_2

The time constant formed by R_1 and C is much larger than the GSM TDMA period at any temperature, hence the voltage across C is considered a pure DC voltage during transmission.

The measured voltage VBAT thus becomes a function of residual capacity, load and temperature. The capacity estimation concepts used will rely on battery temperature measured via a NTC resistor located in the battery pack, voltage measurements performed by the ADC in E-GOLDradio, and load estimations based on measured voltage difference between samples taken inside the TX bursts and samples taken outside the TX bursts, as well as on a look up table specifying the load for various peripherals.

The battery model consists of
(1); a piecewise linear approximation of the capacity vs. discharge voltage,
(2); a set of parameters derived from the AC resistance of the pack at various temperatures,
(3); a set of parameters specifying the DC resistance of the pack at various temperatures and
(4); a table specifying the load for various peripherals used.



The figure above depicts the influence of the elements of the battery model on the measured voltages. The effects on the various load current from the receiver and transmitter are clearly visible. From the picture it is clearly shown that the CHR_rf_peak_voltage sample is taken at a load greater than the average load, while the CHR_rf_mean_voltage is taken at a load smaller than the average load. This means that none of the voltage samples actually represents the voltage at the average load, hence a calculation yielding the “real” mean voltage is necessary. The following assumes that the load contribution from the transmitter is dominant compared to the contribution from the receiver:

VBATTmean=CHR_rf_mean_voltage–((CHR_rf_mean_voltage–CHR_rf_peak_voltage)/8/DTX_value)

where DTX_value can take the following values:

DTX_value	=	1,	if DTX is disabled,
DTX_value	=	2,	if DTX is enabled,

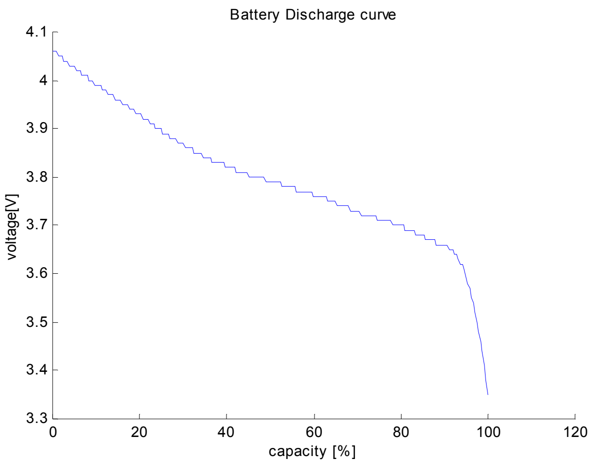
4.2 The battery model

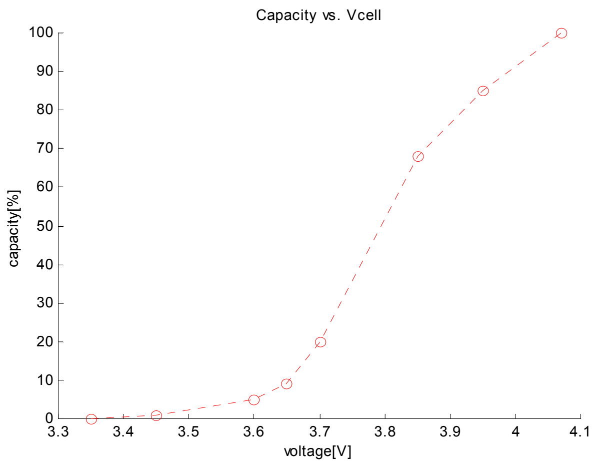
As described above the battery model consists of a set of parameters specifying the physical behaviour of the battery under various load conditions.

4.2.1 Capacity vs. voltage

The battery discharge curves are transformed into the capacity vs. voltage battery matrix as shown below. This matrix consists of a voltage vector specifying the points on the x-axis where the capacity is defined and a capacity vector specifying the corresponding capacity:

Vcell (c) = [3.35 3.45 3.60 3.65 3.70 3.85 3.95 4.07] [V]
[0 1 5 9 20 68 85 100] [%]





4.2.2 Battery DC resistance

The voltage drop vs. load is represented by a parameter specifying the DC resistance for each temperature. The parameters are scaled up by 128 to obtain sufficient resolution and accuracy in a fixed point math environment.

r_dc_vector = [-10 0 10 20 30 40 50 60] [°C]
[125 94 44 34 28 28 28 28] [Ohm scaled up by 128]

4.3 Battery load estimation

4.3.1 Using the battery AC resistance to estimate load in traffic

The RMS load on the battery on a GSM TCH consists of a constant contribution and a variable contribution.

The constant part is equal to the consumption of the baseband + the consumption of the RF minus the TX PA.

The variable part is the contribution from the TX PA, due to the variable output power. Hence the total load can be found by adding a table constant, tch_load_offset, with a variable, which is found by measuring the voltage drop created by the TX PA peak current across the AC resistance of the battery in the TX burst. The capacity estimation SW maintains the average voltage drop, calculated as CHR_rf_mean_voltage – CHR_rf_peak_voltage whenever the handset is in traffic mode. Since the AC resistance is temperature dependant, the variable is expressed as a vector. To ease the calculations in the SW, the reciprocal of the AC resistance is used in the battery model, properly scaled to fit into the fixed-point CPU environment, and rescaled to give the RMS current contribution from the 1/8 dutycycle TX PA peak load:

tch_drop_vector(t) = 128 / (R_{AC}(t) x 8)

The complete AC model then becomes a constant and a vector:

tch_load_offset = 75
tch_drop_vector = [-10 0 10 20 30 40 50 60] [°C]
[75 80 85 85 87 87 87 87]

The traffic mode load calculation is then:

$Load_{TCH}$ = tch_load_offset + ((CHR_rf_mean_voltage – CHR_rf_peak_voltage) x tch_drop_vector(t) / 128)

4.3.2 DTX

The RMS load during traffic will depend on the dutycycle of the transmitter, which again depends on the detected voice activity if DTX is enabled. An accurately estimation of the amount of DTX used would be very complicated, hence the effect of DTX will be approximated using the assumption that the dutycycle of DTX is 50%. The use of DTX will then modify the tch_drop_vector parameter with a factor of 2, since the average TX PA dutycycle will drop from 1/8 to 1/16. The calculation of load is then simply:

Load = tch_load_offset + ((CHR_rf_mean_voltage – CHR_rf_peak_voltage) x tch_drop_vector/DTX_value/128)

where DTX_value can take the following values:
DTX_value = 1, if DTX is disabled,
DTX_value = 2, if DTX is enabled,

4.3.3 Peripheral load table

For the current consuming peripherals, a parameter specifying the load for each peripheral is used, thus the complete table of load parameters becomes:

Parameter	Value	Unit
backlight_enabled	tbd	MA
vibrator_enabled	tbd	MA
TTY adapter enabled	tbd	MA
camera_enabled	tbd	MA
datacable_enabled	tbd	MA
chatboard_enabled	tbd	MA
idle_mode	tbd	MA

(tbd) to be defined: it depends heavily from the HW devices used in the platform. It should be determined from technical specifications or by measurements.

4.4 Capacity estimation algorithm

From the deductions above the complete capacity estimation algorithm then becomes the following:

1. measure voltages CHR_rf_mean_voltage and CHR_rf_peak_voltage

2. measure battery temperature CHR_battery_mean_temperature
3. find load using temperature, the R_{AC} vector and the measured voltage drop if in traffic
4. Calculate the “real” mean voltage from CHR_rf_mean_voltage and the TX dutycycle
5. Find the voltage drop caused by the DC resistance and the load
6. find V_{cell} using the mean voltage and the voltage drop found above
7. find capacity using interpolation in the voltage vs. capacity model

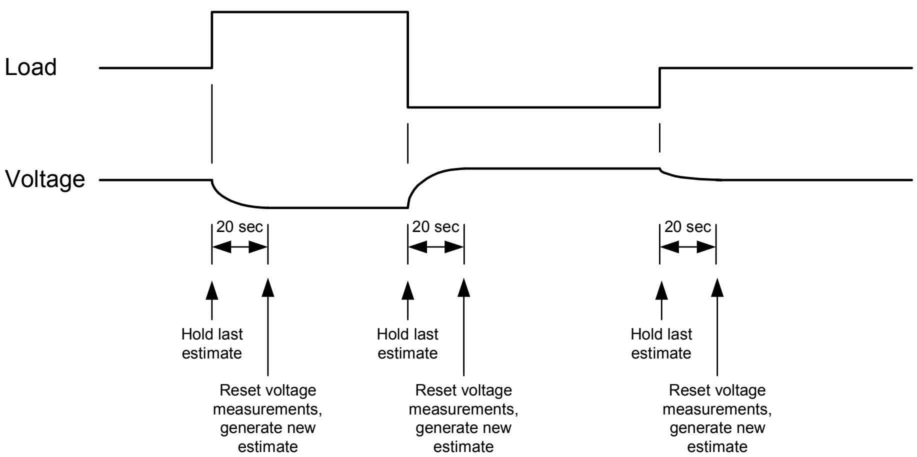
Example:
CHR_rf_mean_voltage = 3850 mV
CHR_rf_peak_voltage = 3630 mV
CHR_battery_mean_temperature = 10 °C
DTX is used
No backlight

3. Load = 75 + ((3850 – 3630) x 85/2/128)= 148 mA
4. Mean voltage = 3850 – ((3850 – 3630)/8/2) = 3836 mV
5. R_{DC} voltage drop = 148 x 44 / 128 = 51 mV
6. Vcell = 3836 + 51 = 3887 mV
7. Capacity = 69 % (by interpolation)

4.5 Load changes

When the load on the battery changes, the voltage does not change instantaneously. The time constant formed by R_1 and C in the battery model means that there is a finite rise and fall time during load changes. In low temperatures, this time constant is in the order of 10 - 20 seconds, hence the capacity estimation SW needs to take this into account.
Basically this is handled by “freezing” the current estimation for 20 seconds when a load change has been detected, before a new estimation is performed using the new load data. Theoretically this means that if load changes happen more frequently than every 20 seconds, the capacity estimation would be stalled forever, however in real life this is very unlikely to happen.

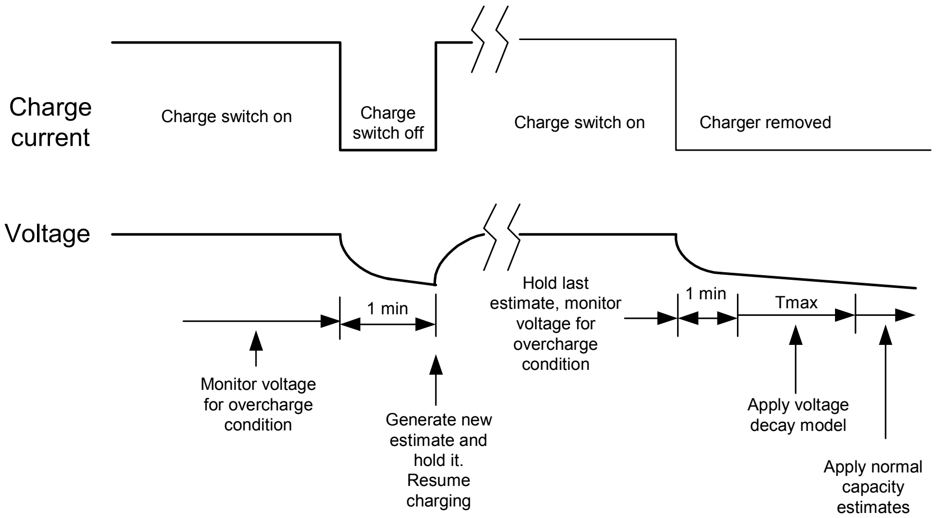
The voltage sample buffer must be reset before a new estimation is done:



Note: Even though capacity estimation is frozen during the 20 sec. settling period, the voltage should still be monitored during this period to detect if it drops below the shutdown threshold.

4.6 Capacity estimation during charge

During charge, the battery voltage will exhibit an overvoltage caused by the charge current generating a voltage drop over the resistances R_1, R_2 and R_3. This overvoltage will decay with a time constant determined by C and R_1, R_2 and R_3. To avoid errors originating from this, the charge current is interrupted by turning the charger switch off while voltage samples are taken. Unfortunately, in addition to the overvoltage created by R_1, R_2 and R_3 also an overvoltage with a considerably longer decay time is present. Since it is not practical to interrupt the charge current until the voltage has decayed to its final value, a compensation has to be made.



Estimation during charge:

While charging:

1. Interrupt the charge current
2. Wait 1 minute
3. Subtract charge offset voltage V_c from measured mean voltage
4. Generate capacity estimate based on this calculated voltage
5. Resume charging

v_charge_offset = 25 [mV]

Charger disconnection:

Because of the long decay time when the charge current is interrupted described above, special precaution has to be taken when the charger is disconnected during charge. A mathematical model describing the decay of the voltage to its final value will be used, thus the procedure becomes:

Charger disconnect:

1. Start timer
2. Apply 2 – 4 from above
3. using the timer value and the measured battery voltage, apply the model.
4. Continue until timer value equals charger_t_reset_no_supply
5. Stop using the voltage decay model

Model describing the voltage decay:

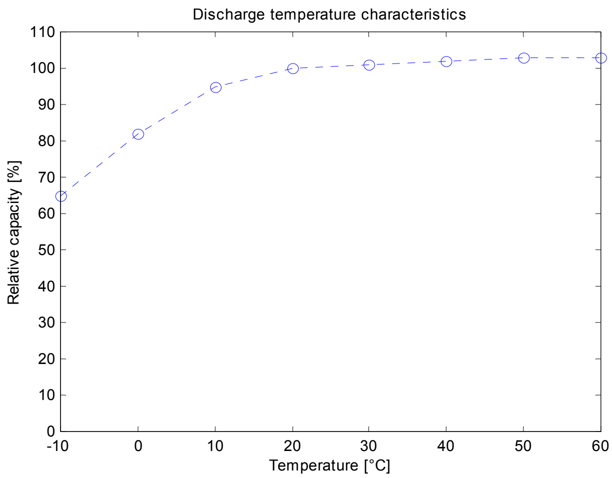
V_{decay} = V_c x ((charger_t_reset_no_supply – timer value)/charger_t_reset_no_supply) ^{2}
V_{cell} = V_{cell} found in 4.3 - V_{decay}

V_{decay} approaches 0 when the timer value approaches charger_t_reset_no_supply.

4.7 Empty & low battery detection

4.7.1 Battery low warning in idle

The battery capacity is considered low, when it is no longer possible to sustain the necessary operating voltage to make a call. The consequence of this is that at low temperatures, the voltage in idle mode might be sufficient to sustain idle mode for a long time, however, due to the voltage drop during a call the operating voltage will drop below the operating range. Since it is impossible to know at which power level the call will be established, a worst case approach is used. Effectively this means that the capacity estimation SW will issue a low battery warning to the MMI at higher voltage in low temperature. This is handled by using a table describing the capacity as function of temperature, measured during traffic at full TX power; ie. during worst case conditions.



$C_{dchg}(t) =$ [-10 0 10 20 30 40 50 60] [°C]
[65 82 95 100 101 102 103 103] [%]

capacity < 100 - $C_{dchg}(t)$ + battery_low_capacity => issue low battery warning

4.7.2 Battery low warning in traffic

During a call, the peak voltage CHR_rf_peak_voltage is continuously monitored and used in addition to the low battery criteria used above to issue the low battery warning. Although the same approach used in idle could be used also here, a method based directly on the measured voltage overcomes the inevitable tolerances on the battery model and ensures that a reliable a predictable warning will be issued in all operating conditions.

CHR_rf_peak_voltage < v_low_traffic
OR
capacity < 100 - C_{dchg} (t) + battery_low_capacity=> issue low battery warning

4.7.3 Empty

The capacity estimation SW issues a power off request when CHR_rf_mean_voltage drops below v_shutdown_idle when in idle mode, or when CHR_rf_peak_voltage drops below v_shutdown_traffic when in traffic.

CHR_rf_peak_voltage < v_shutdown_traffic => shutdown (traffic)
CHR_rf_mean_voltage < v_shutdown_idle => shutdown (idle)

4.8 Displayed capacity

The big question in capacity estimation is : "which information should be issued to the user"? Although a high performance concept can deliver accurate estimations, this is not always desirable because of possible misinterpretations by the user. The capacity available for discharge depends heavily on temperature, but will the user understand if a low battery indication comes when the battery level indicator still shows 30% remaining capacity?
The solution for this project will be to display the estimated capacity relative to the maximum capacity at the current temperature. Thus the rate at which the battery level indicator will count down will be faster at low temperatures than at high temperatures, also the user might experience that the displayed capacity rises when going from a colder to a warmer environment even without charging:

Displayed capacity = (capacity – (100 - C_{dhg}(t))) / C_{dchg}(t) x 100

5 Capacity estimation EEPROM parameters

Following tables shows an example of EEP settings (related to charger and battery section)*

Parameter Name	Description	Format	Unit	Default value
Capacity Estimation Parameters				
v_shutdown_idle	Specifies shutdown voltage. Valid in idle mode, measured without RF RX activity	u_int16	mV	3200
v_shutdown_traffic	Specifies shutdown voltage. Valid in traffic mode measured during TX burst	u_int16	mV	3000
battery_low_capacity	When the calculated capacity drops below this limit, a battery low warning is issued.	u_char	%	10
v_low_traffic	Specifies battery low threshold in traffic	u_int16	mV	3050
backlight_enabled	Specifies load current when backlight is on	u_char	mA	?
vibrator_enabled	Specifies load current when vibrator is on	u_char	mA	?
Mp3_player_enabled	Specifies load current when mp3 player is on	u_char	mA	?
camera_enabled	Specifies load current when camera is on	u_char	mA	?
data_cable_enabled	Specifies load current when datacable is on	u_char	mA	?
chatboard_enabled	Specifies load current when chatboard is on	u_char	mA	?
idle_mode	Specifies idle mode base current	u_char	mA	?
Capacity estimation parameters, one set per battery type				
v_charge_offset	Specifies offset voltage in charge mode	u_char	mV	25
tch_load_offset	Specifies traffic mode base current	u_char	mA	75

* These values are for example pourpose only. They are strongly dependant from HW configuration and battery cell supported by the board. They should be reconfigured for each HW release and battery cell devices to be supported.

Parameter Name	Description	Format	Unit	Default value
voltage_vector[0:7]	Specifies voltage at which capacity_vector is defined	8 x 1 array of u_int16	mV	3350 3450 3600 3650 3700 3850 3950 4070
capacity_vector[0:7]		8 x 1 array of u_char	%	0 1 5 9 20 68 85 100
temperature_vector[0:7]	Temperature at which vectors below are defined.	8 x 1 array of s_char	°C	-10 0 10 20 30 40 50 60
capacity_temp_vector[0:7]	Relative maximum discharge capacity vs. temperature.	8 x 1 array of u_char	%	65 82 95 100 101 102 103 103
R_dc_temp_vector [0:7]	DC resistance vs. temperature	8 x 1 array of u_char	Ohm x 128	125 94 44 34 28 28 28 28
tch_drop_temp_vector[0:7]	TX voltage drop coefficient vs. temperature	8 x 1 array of u_char		75 80 85 85 87 87 87 87

6 References

6.1 External

[1] None

6.2 Internal

Title	Doc ID
None	

7 Document change report

	Change Reference		Record of changes made to previous released version	
Rev	**Date**	**CR**	**Section**	**Comment**
1.0	05/01/2006			Document created

8 Approval

Revision	Approver(s)	Date	Source/signature
1.0	Valter Jelicic	05/01/2006	Document stored on server