Technical Note
Battery measurement ADC calibration

Edition 2006

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1 Document Mission/Scope

1.1 Mission

This document describes ADC calibration for battery voltage measurement. Calibration expressions are evaluated and a calibration example was explained.

1.2 Scope

This document is addressed to engineers that will deal with calibration procedures.

2 List of Acronyms

Abbreviation / Term	Explanation / Definition
ADC	Analog to Digital Converter
EEP	Electrically Erasable PROM
LSB	Least Significant Bit

3 Introduction

In order to obtain accurate voltage battery measurements it is recommended to perform a calibration of battery ADC to voltage conversion parameters.
Battery voltage is averaged 4 consecutive times from a 12-bit ADC and transformed in a voltage value expressed in mV through the following integral-operation linear expression (see chr_meas.c):

$$V = ((V_{ADC} + offset) \cdot gain) >> 14 \tag{1}$$

where $V_{ADC} = (V_{direct_1} + V_{direct_2}) - (V_{reverse_3} + V_{reverse_4})$ is the zero-offset cancellated ADC raw readout, ranging from 0 to 8190.

Substituting the right-shift operation with floating point operation, the above equation (1) can be rewritten in real domain using a subtraction of $2^{13} = 8192$ and division by $2^{14} = 16384$ (Note: `ADC_GAIN_SHIFT_FACTOR equates` 12 and 4 =2^2 samples, so 12+2=14):

$$V = \frac{(V_{ADC} + offset) \cdot gain - 2^{13}}{2^{14}} \tag{2}$$

In the code V_{ADC} is referenced (see l1d_ext.h) as `BATT_MEAS_STM_BATT_VOLT_VALUE`, i.e. `l1d_batt_MeasResults.BattVolt` (the actual ADC readout).
$offset$ is `EEP_static.chr_adjcomp.vbat_offset` and $gain$ is EEP`_static.chr_adjcomp.vbat_gain`, both to be calibrated.
V is the result expressed in mV, considered rounded to the nearest integer.

Result will be then assigned to the following snapshot variables:

1. CHR_MEAS_status.adc_result.vbat_inside_tx_adc if measured in dedicated mode with TX on;
2. CHR_MEAS_status.adc_result.vbat_outside_tx_adc if measured in dedicated mode with TX off;
3. CHR_MEAS_status.adc_result.vbat_idle_adc if measured in idle mode;

Defaults (i.e. averaged over various phones) values for $offset$ and $gain$ are reported in Table 3.1.

	offset	gain
GOLDFINCH (330k/100K)	-415	+9844
GLOBE3 GLOBE6 EVABOARD MODEM8M (390K/100K)	-426	+11265

Table 3.1 – Default offset and gain values

These values give a good approximation of the voltage value expressed in mV, but can be modified (i.e. calibrated) to obtain best accuracy values.

4 Calibration Formulas

To calibrate these values you must apply *V* for a couple (1,2) of high-accuracy applied voltages, possibly measured without cable-drop voltage, and measure from the mobile relevant V_{ADC}. We can solve for $offset$ and $gain$ the following linear equation obtained from (2) calculated for apex (1,2) voltages and relevant ADC read values:

$$\begin{cases} V_1 = \dfrac{(V_{ADC1} + offset)\cdot gain - 2^{13}}{2^{14}} \\ V_2 = \dfrac{(V_{ADC2} + offset)\cdot gain - 2^{13}}{2^{14}} \end{cases}$$

Let we solve for $gain$:

$$\frac{V_1 \cdot 2^{14} + 2^{13}}{gain} - V_{ADC1} = \frac{V_2 \cdot 2^{14} + 2^{13}}{gain} - V_{ADC2};$$

$$V_1 \cdot 2^{14} - V_{ADC1} \cdot gain = V_2 \cdot 2^{14} - V_{ADC2} \cdot gain;$$

$$(V_1 - V_2)\cdot 2^{14} = (V_{ADC1} - V_{ADC2})\cdot gain;$$

$$gain = \frac{(V_1 - V_2) \cdot 2^{14}}{V_{ADC1} - V_{ADC2}}$$

and then for $offset$:

$$V_1 \cdot 2^{14} + 2^{13} = (V_{ADC1} + offset) \cdot gain;$$

$$offset = \frac{(V_1 \cdot 2^{14} + 2^{13})}{gain} - V_{ADC1} =$$

$$= \frac{(V_1 \cdot 2^{14} + 2^{13}) \cdot (V_{ADC1} - V_{ADC2}) - V_{ADC1} \cdot (V_1 - V_2) \cdot 2^{14}}{(V_1 - V_2) \cdot 2^{14}} =$$

$$= \frac{2^{14} \cdot (V_2 \cdot V_{ADC1} - V_1 \cdot V_{ADC2}) + 2^{13} \cdot (V_{ADC1} - V_{ADC2})}{(V_1 - V_2) \cdot 2^{14}} =$$

$$= \frac{V_2 \cdot V_{ADC1} - V_1 \cdot V_{ADC2}}{V_1 - V_2} + \frac{2^{13}}{gain}$$

So we will use the found relationships here below to solve for best $gain$ and $offset$:

$gain = \frac{(V_1 - V_2) \cdot 2^{14}}{V_{ADC1} - V_{ADC2}}$	$offset = \frac{V_2 \cdot V_{ADC1} - V_1 \cdot V_{ADC2}}{V_1 - V_2} + \frac{2^{13}}{gain}$

where:

V_1 is the first (e.g. maximum) applied reference known voltage in [mV]
V_2 is the second (e.g. minimum) applied reference known voltage in [mV]
V_{ADC1} is the ADC stable conversion readout when V_1 is applied
V_{ADC2} is the ADC stable conversion readout when V_2 is applied

Note: above operations shall be considered in the real (i.e. floating-point) domain, but gain and offset have to be rounded to the nearest integer .

4.1 Note about values for V_1 and V_2

V_1 and V_2 values should be as different as possible, taking into account of the power supply applicable range, to obtain the greatest voltage difference, hence the best accuracy in calibration.

Maximum voltage is limited by absolute maximum ratings specification (4300 mV, see E-POWERlite datasheet table 5-2) and by 390k/100k or 330k/100k partition values, taking into account of Measurement Interface input impedance and full-scale input sensitivity without input clipping (this is not relevant for limitation).

TIP: Input clipping can be detected by a reported VADC value equal to 8190. If this eventually occurs, please reduce applied voltage until the readout value will be less than 8190.

Conversely, minimum voltage is limited only by the undervoltage hardware reset generation on E –POWERlite (2960 mV, see E-POWERlite datasheet table 5.4, maximum undervoltage shutdown).

TIP: minimum voltage can be as low as 2960 mV only if mobile was previously turned on with an applied voltage at least above 3220 mV, else mobile does not turns on at all. This behaviour is due to undervoltage logic worst case hysteresis.

4.2 Example of a real calibration using PhoneTool

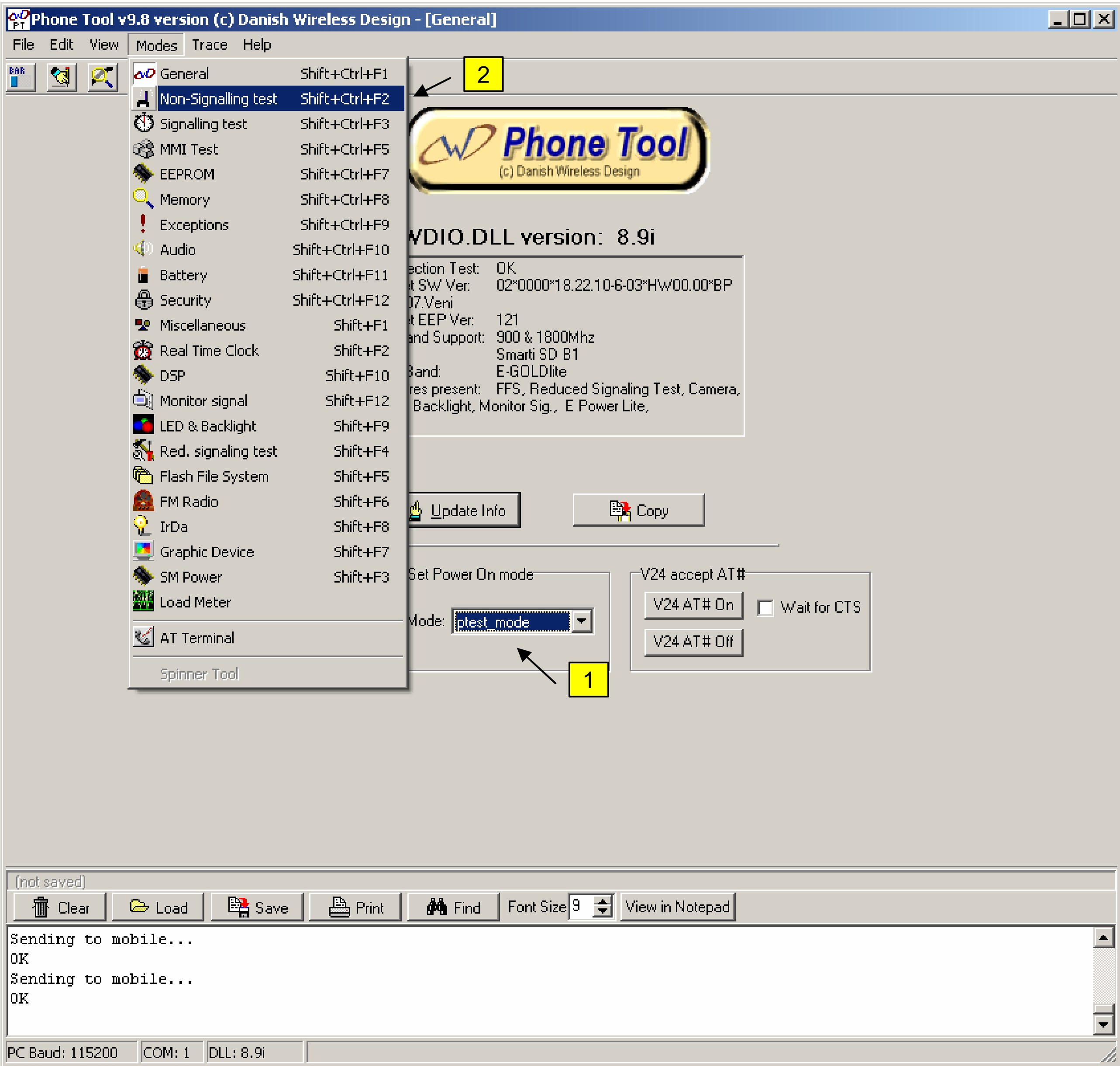

Figure 1 – PhoneTool startup window (General).

1) Connect Phonetool with mobile previously settled in ptest_mode.
2) Enter Mode / Non-signalling test control panel.

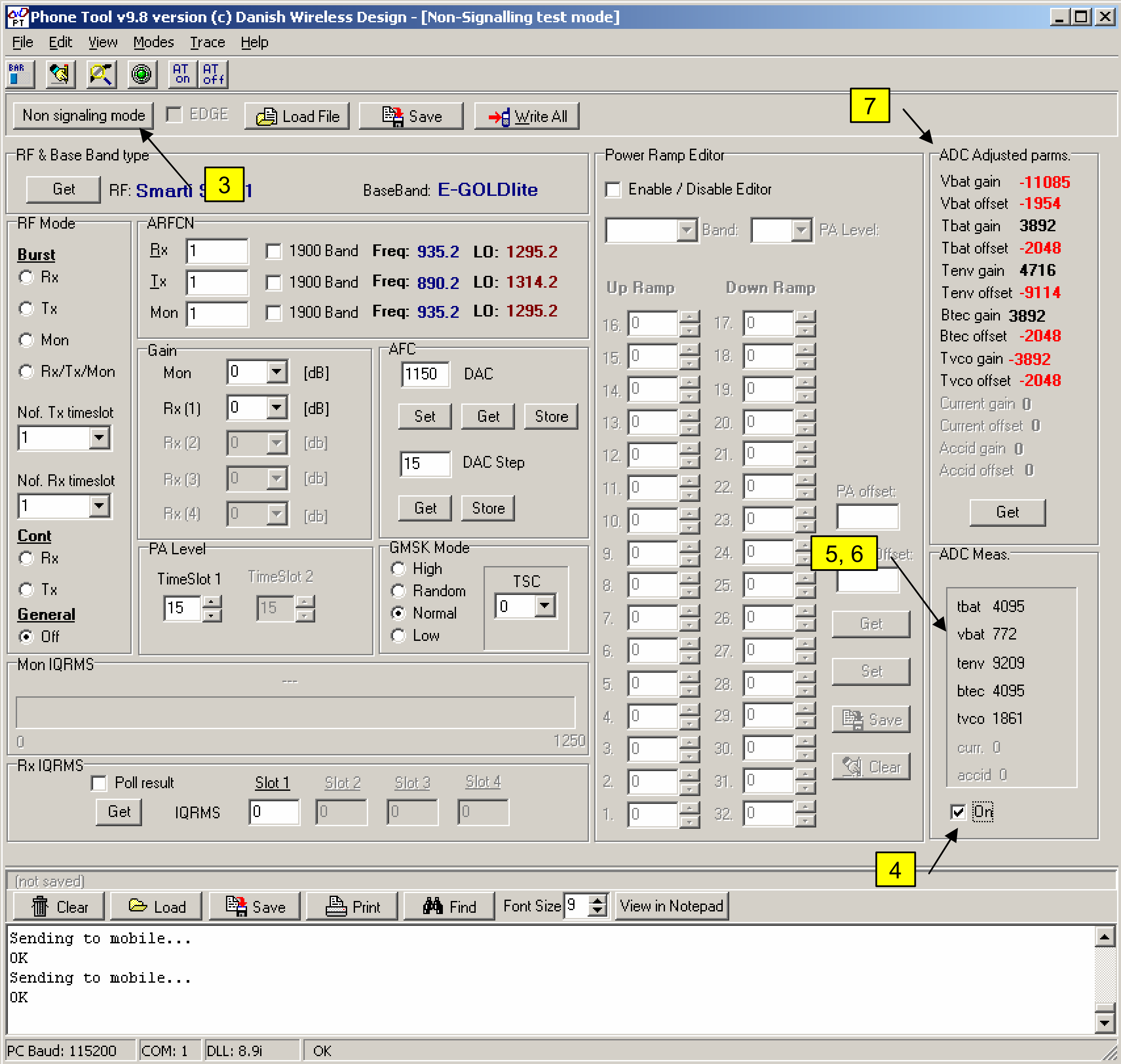

Figure 2 - PhoneTool Non-Signalling test mode Control Panel

3) Activate Non-signalling test mode by pressing Non signalling mode upper left button.
4) Activate ADC continuous measurement by checking On in the ADC meas. group. ADC value vbat will be periodically (i.e every second) updated, tracking real applied Vbat voltage.
5) Apply 4300 mV. Read ADC conversion value. Conversion value of 7573 is read (e.g.).
6) Apply 2960 mV. Read ADC conversion value. Conversion value of 5342 is read. (e.g.)

Hence we easy obtain:

$$gain = \frac{(V_1 - V_2)\cdot 2^{14}}{V_{ADC1} - V_{ADC2}} = \frac{(4300-2960)\cdot 16384}{7573-5342} = 9840.68 \cong 9841$$

$$offset = \frac{V_2 \cdot V_{ADC1} - V_1 \cdot V_{ADC2}}{V_1 - V_2} + \frac{2^{13}}{gain} = \frac{2960 \cdot 7573 - 4300 \cdot 5342}{4300 - 2960} + \frac{8192}{9840.68} = -412.98 \cong -413$$

We can note that the second term $\frac{2^{13}}{gain}$ of $offset$ calculation may be discarded, since it is not very relevant, but it can affect bit-approximation results.

Values shall be updated into EEP via Phonetool and verified by reading back in the ADC Adjusted parms. group (see callout n.7).

We can verify calibration values applying them in (2):

$$V_1 = \frac{(V_{ADC1} + offset) \cdot gain - 2^{13}}{2^{14}} = \frac{(5342 - 413) \cdot 9841 - 8192}{16384} = 2960.09 \cong 2960$$
$$V_2 = \frac{(V_{ADC2} + offset) \cdot gain - 2^{13}}{2^{14}} = \frac{(7573 - 413) \cdot 9841 - 8192}{16384} = 4300.13 \cong 4300$$

We can also verify effective mobile software conversion using integer math with right-shift operation substituting in (1):

$$V_1 = ((V_{ADC1} + offset) \cdot gain) >> 14 = ((5342 - 413) \cdot 9841) >> 14 = 2960$$
$$V_2 = ((V_{ADC2} + offset) \cdot gain) >> 14 = ((7573 - 413) \cdot 9841) >> 14 = 4300$$

Bit-accuracy of the ADC battery voltage is $\frac{4300 - 2960}{7573 - 5342} = 0.6$ mV/LSB. We note that all the floating-point math checking results are accurate within half of this value. This can be obtained by averaging 4 repeated adjacent measurements.

5 Document change report

	Change Reference		Record of changes made to previous released version	
Rev	**Date**	**CR**	**Section**	**Comment**
1.0	24/08/2004	N/A	All	First Release
2.0	11/11/2005	N/A	1.2, 3 and 4	Adapteation of document to new ADCbattery driver release.

6 Approval

Revision	Approver(s)	Date	Source/signature
1.0	Stefano Godeas	24/08/2004	Document stored on server
2.0	Stefano Godeas	11/11/2005	Document stored on server