Fast Charging Control with NTC Temperature Sensing

1. INTRODUCTION

The need for increased autonomy for new models of laptops and cellular phones has resulted in high-energy density power packs - Ni MH and Li-ion batteries.

These batteries can be charged quickly, on the condition that the fast charging complies with several criteria.

The techniques used are the following:

- For the Ni MH cells, the quick and fast charging operation uses the - ΔV, d^2V/dt^2, the maximum time, the TCO (Temperature Cut Off), or the $\Delta T/\Delta t$ techniques. The measurement of high temperature is used as a protection, but the temperature variation ($\Delta T/\Delta t$) can also be used for monitoring.
- For the Li-ion cells, the fast charging uses the CCCV techniques (Constant Current Constant Voltage). The initial temperature is measured in order to allow initiation of fast charging. If the temperature reaches a high threshold (TCO), the fast charging would stop.

The sophistication of the electronic system depends principally upon cost and upon the requirements of the batteries. Often, the fast charging is monitored by an IC, measuring the voltage of the batteries, the char-ging current via a sense resistor, and measuring the temperature of the batteries via one or several Negative Temperature Coefficient (NTC) thermistor(s). The IC's are almost always in the chargers or integrated in the battery pack (Li-ion). The thermistors are almost always integrated in the battery packs, sometimes placed in the charger, and/or in the final apertures (low cost cellular phones).

This application note explains how to design an NTC thermistor from Vishay BCcomponents for a BQ2005 from TEXAS INSTRUMENTS dual Ni MH batteries charging IC.

The computation methods performed here are sufficiently general to be extended to a lot of other configurations.

2. THE FAST CHARGE ALGORITHM FOR THE BQ2005

Referring to the notice of the BQ2005 IC, we will focus on the design part related to the temperature control of the charge operation (see figure 1).

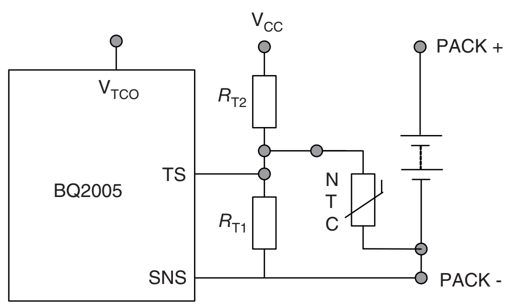

Figure 1

An NTC thermistor, together with fixed resistors R_{T1} and R_{T2}, is used in a voltage divider between V_{cc} and the current sense resistor input V_{SNS} of the IC.

At the beginning of a new charge cycle, the IC checks if the voltage $V_{temp} = V_{TS} - V_{SNS}$ is within the limits designed by the IC manufacturer (low temperature: 0.4 V_{cc} and high temperature: 0.1 V_{cc} + 0.75 V_{TCO}).

V_{TCO} is a cut off threshold defined by external resistors (not represented in figure 1): If after starting the fast charge phase, V_{temp} becomes lower than V_{TCO}, then the return to trickle mode is operated.

During the fast charge period, the IC samples the voltage V_{temp} and the return to trickle mode can also be operated when the variation in time of V_{temp} is going over a threshold.

This is called the $\Delta T/\Delta t$ termination: each 34 s, V_{temp} is sampled and if V_{temp} has fallen by 16 mV ± 4 mV compared to the value measured two samples earlier, then the fast charge is terminated.

The following table summarizes the voltage levels applicable here:

SYMBOL	PARAMETER	AVERAGE	TOLERANCE
V_{cc}	Supply voltage	5 V	± 10 %
V_{TCO}	Cut off voltage	Adjustable between 0.1 V_{cc} and 0.2 Vcc	
V_{low} temp	Low temperature fault	0.4 V_{cc}	± 30 mV
V_{high} temp	High temperature fault	0.1 Vcc + 0.75 V_{TCO}	± 30 mV
V_{therm}	TS input change for $\Delta T/\Delta t$ termination	16 mV/period of 2 x 34 s	± 4 mV

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3. CONFIGURATION OF EXTERNAL THERMISTOR/RESISTOR NETWORK

The voltage around the TS input is:

$$V_{TS} - V_{SNS} = \frac{R_{T2}R_{NTC}}{R_{T1}R_{T1} + R_{T1}R_{NTC} + R_{T2}R_{NTC}} (V_{CC} - V_{SNS}) \quad (1)$$

The voltage around the NTC for the low fault, high fault, and cut off temperatures has to comply to the thresholds designed for the BQ2005. This is expressed by equations (1a), (1b) and (1c).

$$V_{TS}\text{ (T low)} - V_{SNS} = 0.4\ V_{cc} \quad (1a)$$

$$V_{TS}\text{ (T high)} - V_{SNS} = 0.1\ V_{cc} + 0.75\ V_{TCO} \quad (1b)$$

$$V_{TS}\text{ (T cut off)} - V_{SNS} = V_{TCO} \quad (1c)$$

Normally V_{SNS} is of the order of 0.1 V. For simplicity, we will consider here that V_{SNS} = 0. Should this approximation not be valid, then the computations hereunder must be modified.

Let us call R_{NTC} (low temperature fault), R_{NTC} (high temperature fault) and R_{NTC} (cut off temperature) - respectively R_{nL}, R_{nH}, and R_{TCO}.

Introducing (1) in (1a) and solving with respect to R_{T2}, we obtain:

$$R_{T2} = \frac{0.666\ R_{T1}R_{nL}}{(R_{nL} - 0.66\ R_{T1})} \quad (2a)$$

Introducing (1) and (2a) in (1c) we obtain:

$$R_{T1} = \frac{R_{TCO}R_{nL}}{(R_{nL} - R_{TCO})}\left(\frac{V_{CC}}{V_{TCO}} - 2.5\right) \quad (2a)$$

Once the thermistor characteristics and V_{TCO} are defined, R_{T1} and R_{T2} will be defined.

We also have to compute the speed of variation of temperature on the thermistor, which will induce the voltage V_{therm} operating the $\Delta T/\Delta t$ termination.

Assuming the exponential dependence of the electrical resistance of the thermistor in function of the temperature:

$$R_{ntc}(T) = R25\ \exp(B\ (1/T - 1/298.15)) \quad (3)$$

where R25 is the electrical resistance of the NTC at 25 °C, B is the B25/85 characteristic of the component (K), and T is the absolute temperature (K).

We can derive from equations (1) and (3):

$$\frac{\Delta V_{TS}}{\Delta t} = \frac{\Delta V_{TS}}{\Delta T}\frac{\Delta T}{\Delta t} = \frac{-B\ R_{T1}R_{T2}{}^2R_{NTC}V_{CC}}{T^2\,(R_{T1}R_{T2} + R_{T1}R_{NTC} + R_{T2}R_{NTC})^2}\frac{\Delta T}{\Delta t} \quad (4)$$

$\Delta T/\Delta t$, T_{low} and TCO are given by the battery manufacturer. $\Delta V_{TS}/\Delta t$ is defined by TI.

The characteristics of the thermistor are defined by Vishay BCcomponents T_{low} and TCO values. The B value can be found in the catalog or by using the Steinhart & Hart interpolation polynoms calculation.

These parameters are given in the appendix for several currently used Vishay BCcomponents thermistors.

On this base, all the remaining parameters can be defined with the help of relations (2a), (2b), and (4) which have to be verified simultaneously: R_{T1} and R_{T2} are chosen to respect T_{low} and TCO via equation (2a) and (2b).

V_{TCO} will be defined so that the required $\Delta T/\Delta t$ (equation (4)) will be respected.

At last, T high fault will be computed with equation (1b).

4. NUMERICAL EXAMPLE

Example 1

The following data are currently applicable to Ni MH batteries:

- T low fault = 10 °C
- T cut off = 50 °C
- $\Delta T/\Delta t$ = 1 °C/min ± 0.3 °C/min

Then:

- Using V_{cc} = 5 V, dV/dt = 16 mV / (2 x 34 s)
- Designing for the sensor the Vishay BCcomponents leaded thermistor NTCLE203E3103JB0:
  R25 = 10 kΩ ± 5 % B25/85 = 3977K ± 0.75 %
- Using V_{TCO} = 1.6 V arbitrarily

We derive R_{T1} = 2753 Ω and R_{T2} = 2020 Ω

Then we compute $\Delta T/\Delta t$ for different temperatures from 10 °C to TCO. The results are shown in the following table:

CHARACTERISTICS	TEMP (°C)	R_{NTC} (Ω)	V_{TS} (V)	$V_{threshold}$ (V)	$\Delta V_{TS}/\Delta T$ (mV/°C)	$\Delta T/\Delta t$ (°C/Min)
Low fault	10	19872	1.999	2.000	- 5	2.57
High fault	42.5	4824	1.704	1.700	- 13	1.07
Cut off	50	3605	1.599	1.600	- 15	0.95

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We see that the $\Delta T/\Delta t$ falls into the range of 1 °C/min ± 0.3 °C/min. If it would not be the cause, then one should have let the V_{TCO} slightly change.

The tolerances on the electrical characteristics introduce also a variation on the thresholds:

For the limit case: Let us make the calculations for the value of the thermistor being at the limits ± 5 % and the B value at ± 0.75 %. We will also take into account the errors introduced by the tolerances on the fixed resistors (supposed ± 1 %).

The error ΔT in the thresholds (low fault temperature and TCO) due to these tolerances are simply obtained by performing the calculations of the V_{TS} at the fixed temperature (10 °C and 50 °C) and by comparing these values with the requested ones, and dividing these differences by the sensitivity $\Delta V_{TS}/\Delta T$.

The results are summarized in the following tables:

R_{NTC} (25 °C) = 10 500 Ω B25/85 = 3977K - 0.75 %

R_{T1} = - 1 % R_{T2} = + 1 %

	TEMP (°C)	R_{NTC} (Ω)	V_{TS} (V)	$V_{threshold}$ (V)	$\Delta V_{TS}/\Delta T$ (mV/°C)	$\Delta T/\Delta t$ (°C/Min)	ΔV (mV)	ΔT (°C)
Low fault	10	20 755.49	2.027	2.000	- 5	2.66	27	- 5.01
Cut off	50	3814.942	1.639	1.600	- 15	0.97	39	- 2.70

R_{NTC} (25 °C) = 9500 Ω B25/85 = 3977K + 0.75 %

R_{T1} = + 1 % R_{T2}= - 1 %

	TEMP (°C)	R_{NTC} (Ω)	V_{TS} (V)	$V_{threshold}$ (V)	$\Delta V_{TS}/\Delta T$ (mV/°C)	$\Delta T/\Delta t$ (°C/Min)	ΔV (mV)	ΔT (°C)
Low fault	10	18 978.88	1.971	2.000	- 6	2.48	- 29	5.12
Cut off	50	3398.598	1.558	1.600	- 15	0.93	- 42	2.73

With these tolerances:

- Low temperature fault will fall in the range 10 °C± 5 °C approx.
- Temperature cut off will fall in the range 50 °C ± 2.7 °C approx.

If such variations should not be acceptable, then design a thermistor with R25 tolerance down to ± 1 % (code number: NTCLE203E3103FB0) instead of ± 5 %: The tolerances on the definition of threshold will become negligible compared to inherent tolerances of the IC.

Example 2
The same calculations for all the SMD NTC thermistors (NiSn terminations, sizes 0805, 0603, or 0402 described in the appendix) give the following results:

Adjusting slightly V_{TCO} to 1.55 V, in order to keep $\Delta T/\Delta t$ nominal at 1 °C/min at the high fault temperature, we then can compute:

COMPONENT	CHARACTERISTIC	TEMP (°C)	R_{NTC} (Ω)	V_{TS} (V)	$V_{threshold}$ (V)	$\Delta V_{TS}/\Delta T$ (mV/°C)	$\Delta T/\Delta t$ (°C/Min)	R_{T1} (Ω)	R_{T2} (Ω)
NTCS0805E3103xMT SMD 0805 NiSn terminations	Low fault High fault Cut off	10 41.8 50	18 515 5331 4004	1.999 1.668 1.549	2.000 1.663 1.550	- 7 - 14 - 15	1.98 1.01 0.93	3708	2850
NTCS0603E3103xMT SMD 0603 NiSn terminations	Low fault High fault Cut off	10 41.9 50	18 664 5271 3960	1.999 1.668 1.549	2.000 1.663 1.550	- 7 - 14 - 15	2.01 1.01 0.92	3649	2794
NTCS0402E3103xLT SMD 0402 NiSn terminations	Low fault High fault Cut off	10 41.75 50	18 290 5408 4079	1.999 1.668 1.549	2.000 1.663 1.550	- 7 - 14 - 15	1.95 1.02 0.94	3811	2947

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5. CONCLUSION AND GENERAL COMMENTS

Due to their low tolerances, low cost, and high sensitivity, NTC thermistors are perfectly suited for fast charging monitoring and protection of the battery packs.

The notes and calculations described in this note can be easily extrapolated to other IC's, for example the BQ2954 for Li-ion packs. In this case, the $\Delta T/\Delta t$ charge termination is not of application, which makes it even more simple.
The greatest care should be used when positioning the thermistor into the pack to ensure close contact between the thermistor and the batteries. Otherwise, all calculations about tolerances on will not be applicable.

Further information of the different mechanical executions (insulated leads, SMD version) suitable for these applications are available from the Vishay BCcomponents offices.

6. APPENDIX

Different thermistors Steinhart & Hart characteristics

Formula : $\ln(R(T)/R25) = A + B/T + C/T^2 + D/T^3$ where T is expressed in Kelvins (°C + 273.15)

CODE NUMBER	TOL. R (25 °C)		TYPE	B25/85 (K)	TOLERANCE	STEINHART & HART COEFFICIENTS			
						A	B	C	D
NTCLE203E3103xB0	x = F x = G x = H x = J	1 % 2 % 3 % 5 %	Leaded	3977	0.75 %	- 14.63372	4791.842	- 115 334	- 3 730 535
NTCS0805E3103xMT	x = F x = G x = H x = J	1 % 2 % 3 % 5 %	SMD 0805 NiSn terminations	3570	3 %	- 13.40886	4547.961	- 176 965.9	3 861 154
NTCS0603E3103xMT	x = F x = G x = H x = J	1 % 2 % 3 % 5 %	SMD 0603 NiSn terminations	3610	1 %	- 13.40957	4481.799	- 150 521.7	1 877 103
NTCS0402E3103xLT	x = F x = G x = H x = J	1 % 2 % 3 % 5 %	SMD 0402 NiSn terminations	3490	3 %	- 12.0714	3503.902	109 391	- 24 154 454.74