AN2818
Application note

NiMH battery charger demonstration board through USB based on the ST7FLIT15BY0

Introduction

This application note describes a NiMH battery charger demonstration board used with a USB microcontroller. Basically, the battery charger demonstration board consists of two identified sections:

- a very low cost NiMH charger based on the ST7FLIT15BY0 microcontroller.
- a USB microcontroller – ST72F60E2M1 – used to control the charger.

Chapter 1 describes the basic theory to connect a USB to the NiMH battery charger, and also introduces the demonstration board STEVAL-ISB003V1. *Chapter 2* describes how to use the STEVAL-ISB003V1 demonstration board (USB to Li-Ion demonstration board) as NiMH battery charger. Refer to UM0497 for more information on the STEVAL-ISB003V1.

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1 Theory of operation

1.1 NiMH battery charging

The NiMH batteries follow a constant current-charging algorithm.

Figure 1. NiMH battery charging profile

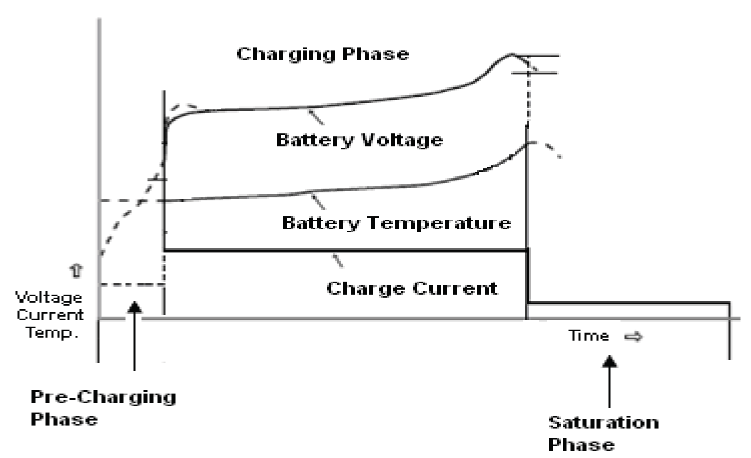


Figure 1 shows the NiMH battery voltage, temperature and current profile during charging. There are three main phases: the pre-charging phase, the charging phase and the saturation mode (shown in *Figure 1*).

The end of the NiMH battery charging is generally detected using the methods described in the following paragraphs. After the end of charging is detected, the charger switches to saturation mode during which a trickle-charging current is provided to the battery to compensate for the self-leakage.

1.1.1 Negative delta V method

As shown in *Figure 1*, the voltage of the NiMH battery drops a little at the end of the charge time. As a consequence, when the voltage curve versus time becomes negative, charging is stopped and trickle-charging is started.

1.1.2 Zero delta voltage method

This method is a variant of the negative delta V method. With a NiMH battery, there is a very slight voltage drop (5-10 mV/cell) at the end of the charge time which is very difficult to detect with a microcontroller's 10-bit ADC. There is also a risk of detecting the wrong end of charging due to noise. Therefore, instead of the negative delta voltage, it is possible to use a dV = 0 condition for a certain time duration, which gives a very good approximation for detecting the end of charging. For this reason, this is the method used in the present demonstration board instead of the negative delta method or the other ones described in the next paragraphs.

1.1.3 Maximum temperature detection method

With this method, if the temperature rises above a threshold, charging is stopped and trickle charging is started.

1.1.4 dT/dt detection method

With an NiMH battery, as shown in *Figure 1*, there is an increase in the temperature vs. time curve (approximately 1 to 2 °C/min) towards the end of charging. When a rise in the temperature is detected by the thermistor or any other temperature sensor (NTC in this case) during rapid charging, and the prescribed temperature increase is sensed, rapid charging is stopped and trickle charging is started.

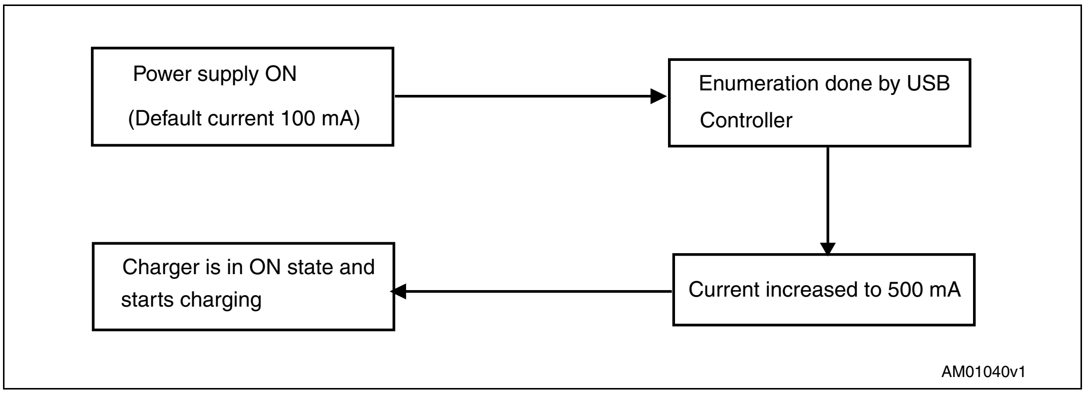
In the example implementation mentioned in *Chapter 4*, the zero delta voltage method is used as the primary technique for terminating the charge. Time out, max voltage and max temperature are used as the secondary or backup methods for ending the charge. Once the battery is saturated, its voltage is still monitored to prevent the battery from discharging completely and a saturation current is provided to compensate for the self-leakage.

2 Implementation of the USB-based NiMH battery charger

2.1 Introduction

The demonstration board is powered directly by a USB bus. Only a 100-mA current is available by default from the USB bus. As a consequence, the charger is initially kept in shutdown mode. This shutdown operation is controlled by the USB controller (ST72F60E2M1) of the charger (pin 13 of the USB controller configured in output mode connected to pin 14 of the charger controller in input mode via a 100-kΩ resistor and 2STR1215). Once the enumeration of the USB bus has been done by the USB controller to increase the current limit to 500 mA, the charger turns ON and the battery starts charging (as shown in *Figure 2*).

Figure 2. Block diagram: from USB enumeration to start of charge

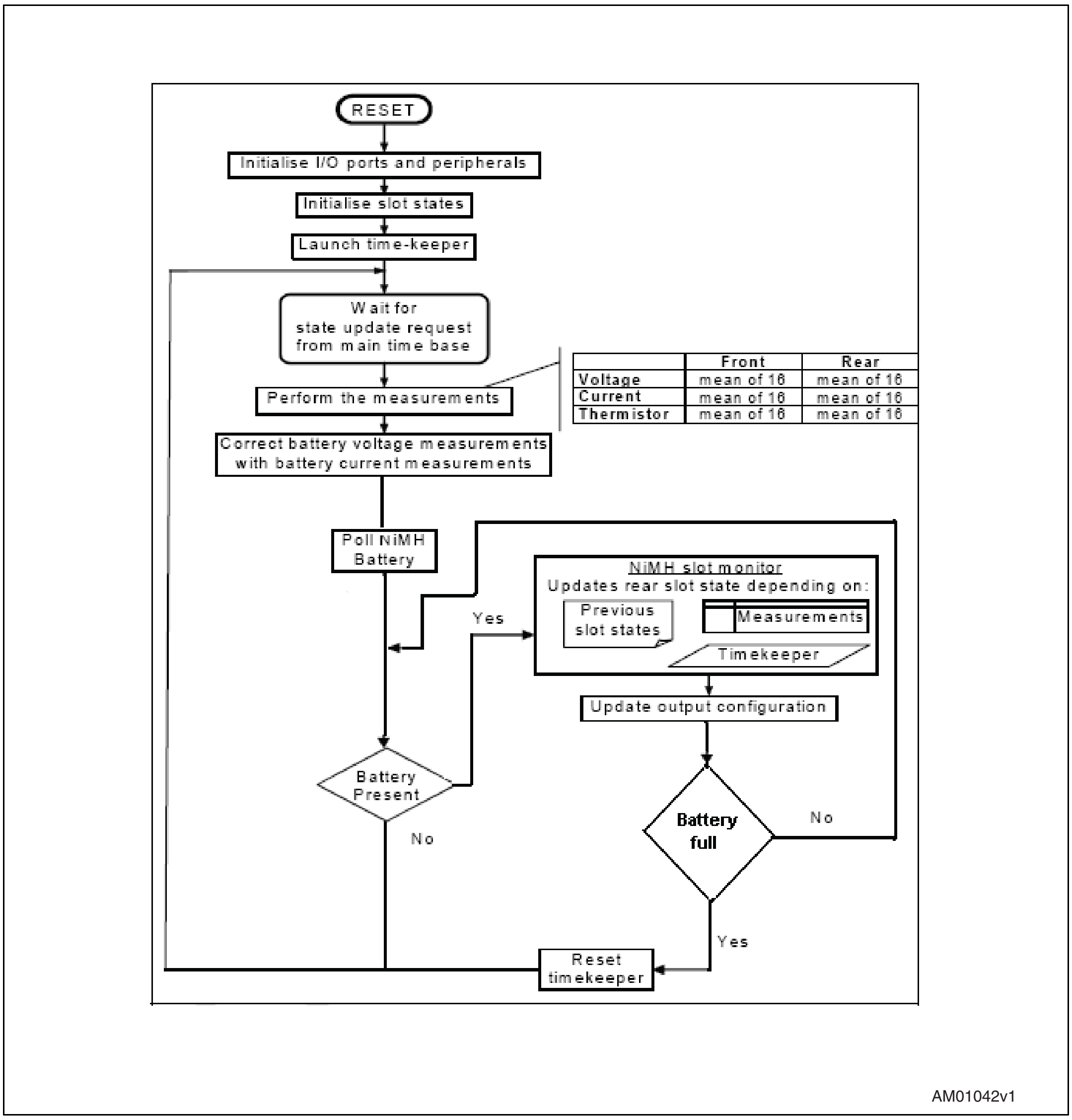


In addition, a current limiter (ST890B) is provided in series with the USB supply. The demonstration board has a status LED that is connected to the fault pin of this current limiter. The LED switches to ON when the current goes above 500 mA. A potentiometer (R43) is used on the demonstration board to reduce this current.

2.2 Flow chart of the NiMH charging algorithm

Figure 3 shows the flow chart of the NiMH charging algorithm.

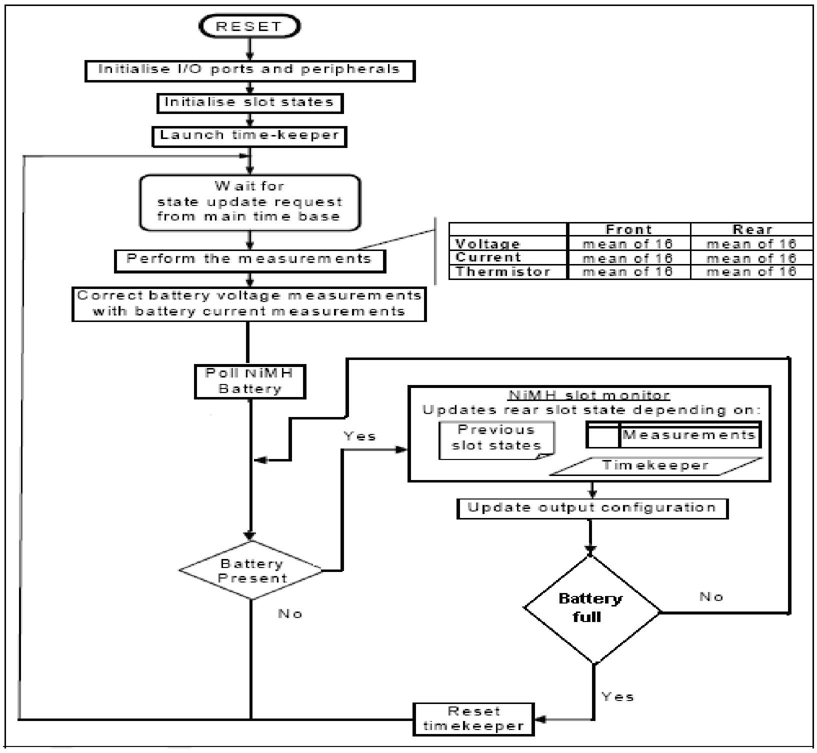
Figure 3. NiMH charging algorithm



2.3 NiMH battery detection algorithm

If the battery current is below a predefined threshold, the battery voltage is measured. If the battery voltage is less than a certain threshold (0.9 V/cell for NiMH), the battery is considered connected, otherwise it is considered to be disconnected from the demonstration board (see *Figure 4*).

Figure 4. NiMH battery detection algorithm



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Vmax = 3.8 V and Vmin = 1.8 V (for 2-cell NiMH battery).

3 Example of USB NiMH charger implementation using the STEVAL-ISB003V1

3.1 Introduction to the STEVAL-ISB003V1

This board consists of a low-speed USB controller based on the ST72F60E2M1 and a battery charger based on the ST7FLIT15BY0.

The board includes a power selector circuit to select the appropriate power supply source and a step-up converter circuit based on a synchronous step-up converter (L6920) device to provide a fixed O/P voltage to the USB controller. The power supply for the battery charger controller is generated from an adjustable voltage reference (TL1431) keeping in mind the accuracy requirement for charging. An additional current limiter is also located in series with the USB power supply to show any incorrect behavior through a status LED.

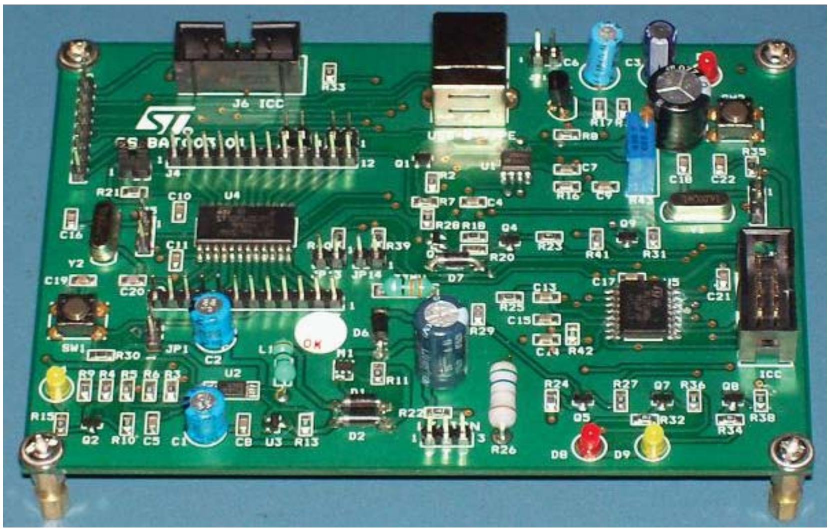
Any external low-speed USB controller can be used with this demonstration board to control the charger operation.

The charger used in the present demonstration board uses a modified form of non-inverting buck-boost converter to support the charging voltage requirement for single-cell Li-Ion batteries. In-circuit programming (ICP) connectors are also available with the demonstration board to program the USB controller and charger system if necessary.

3.2 Customizing the STEVAL-ISB003V1 for NiMH charger

The STEVAL-ISB003V1 is a platform used to implement the USB-based Li-Ion battery charger application. Refer to UM0497 for more information on the STEVAL-ISB003V1 demonstration board.

Figure 5. USB-based battery charger demonstration board (STEVAL-ISB003V1)



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3.2.1 Negative temperature coefficient (NTC) resistor selection

Unlike Li-Ion batteries which have an in-built NTC, there is no such internal NTC in NiMH batteries. Therefore, an external NTC (+/- 5% accuracy) is used in close proximity to the battery.

3.2.2 Man-machine interface

The charger (ST7FLIT15BY0) periodically checks for the presence of a battery, therefore no buttons are needed to start or stop charging. The demonstration board has two LEDs that show the charging status, as mentioned in *Section 4.3*. A reset button is also included on the demonstration board to manually reset the application if necessary.

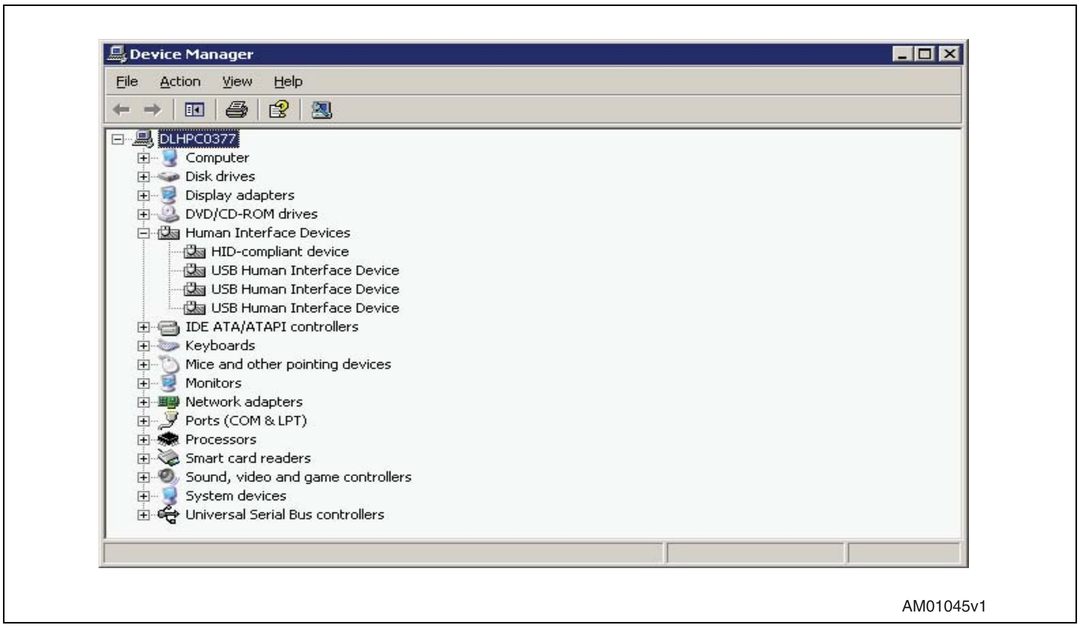
4 Working with the demonstration board

Except for connecting the NTC and NiMH battery, the settings are the same as for the USB for the Li-Ion demonstration board described in UM0497. Refer to section 1.2.7 of UM0497 for the jumper settings. Once all the jumpers are connected, the demonstration board is ready to be used.

4.1 Hand-shaking with the PC

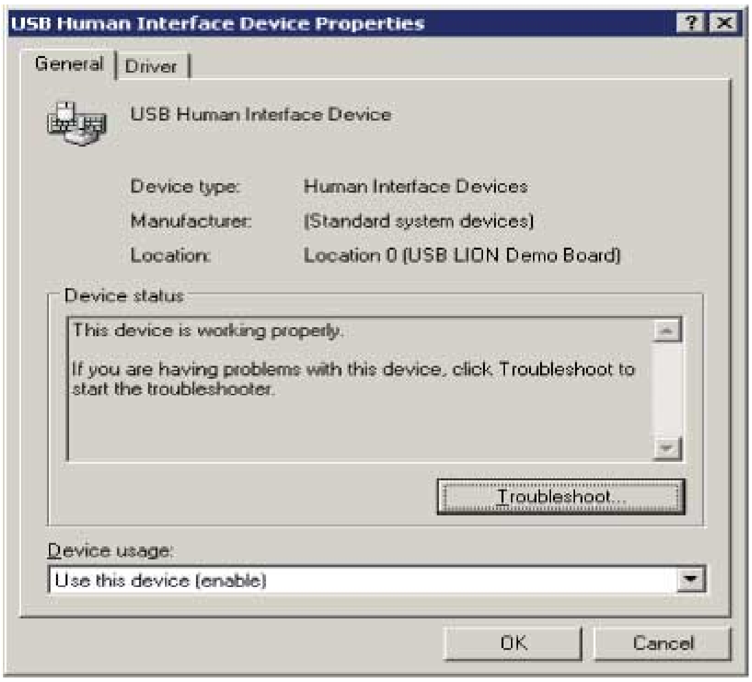
As soon as you connect the USB connector to the demonstration board, you should find the demonstration board enumerated as a HID device, as shown in *Figure 6* (device manager).

Figure 6. Enumeration result of the device manager



If you check the properties of all the HID devices in the device manger, you should find the HID device depicted in *Figure 7*.

Figure 7. USB LI-Ion demonstration board HID

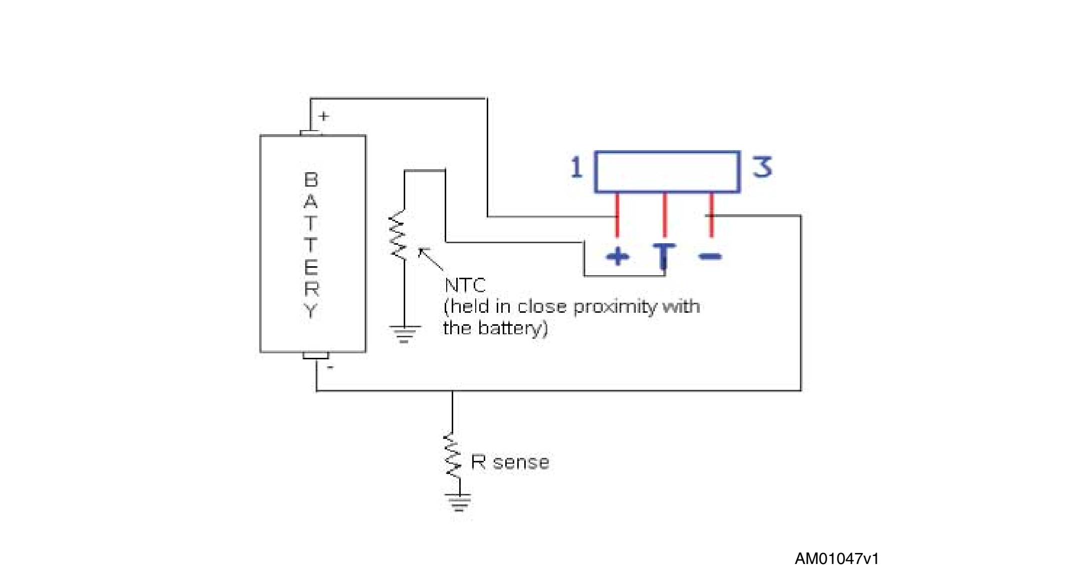


The device status ensures that the demonstration board is correctly connected to the USB and ready to be used.

4.2 Connecting the NiMH battery

The demonstration board is not provided with any specific battery slot in order to avoid making it package-specific. Instead, a 3-pin connector is provided on the demonstration board as shown in *Figure 8*.

Figure 8. NiMH battery and NTC connection to the 3-pin connector



To properly connect the battery to the slot, It is good practice to start by soldering a particular slot to this connector and then connect the battery to this slot. You can connect the battery directly to the connector, but note that improper connection can affect the accuracy of the analog measurement, which in turn can affect the overall accuracy of the charge.

The battery terminals are connected to pins 1 and 3. One end of the NTC is connected to pin 2, while the other end is connected to ground (*Figure 8*). Additionally, the NTC is placed close to the battery so as to have an accurate temperature reading of the battery.

4.3 Monitoring the battery charging status

The demonstration board has two LEDs: D8 and D9. The functions of these LEDs are explained in *Table 1* and show the charging status.

Table 1. Charging status LEDs

Case	Charging status	Red LED (D8)	Green LED (D9)
1	Battery not present/idle	OFF	OFF
2	Charging ongoing	ON	OFF
3	Charging done	OFF	ON
4	Charging error	ON	ON

Note: A charging error occurs when:

- *there is a hot or cold condition*
- *there is a short-circuit condition*
- *the impedance of the battery is very low.*

Note: When the impedance of the battery is very high, the current ceases to flow through the battery. In this case, charging is stopped and the status LED shows "charging done" (case 3 in Table 1).

4.4 Practical results

Some practical tests have been performed on the charging performances of the 2-cell NiMH battery. Before the tests were started, the battery was completely discharged. *Table 2* shows the test results.

Table 2. Charging results

Time for complete charging	Peak voltage attained (in Volt)	Current in charging state (in mA)	Current at end of charging (in mA)
9hrs 40 mins	3.66	350	102
9 hrs 20 mins	3.65	352	100

5 Using the external USB controller

Before using the external USB controller, you must remove all the jumpers (JP1, JP3, JP12, JP13, JP14 and JP15) and make all the necessary connections.

Follow these steps to control the charging operation using the external USB controller.

1. Disable the SHDN_CHG pin by switching it to LOW to switch OFF the charger.
2. Do the proper enumerations of the USB controller to increase the current limit up to 500 mA.
3. Since the USB controller is also powered by the USB, during battery charging the power consumption of the system should be kept under 150 mA, otherwise you may not achieve the targeted 250-mA charging current.
4. After completing steps 1, 2 and 3, enable the SHDN_CHG pin by switching it to HIGH to enable the charging operation.
5. Connect the battery.
6. Start monitoring the status of the battery charging by monitoring the status pins ST1 and ST2. These status pins can be used to control the activity of the external USB controller to minimize the current consumption while the battery is being charged.
7. Disable the SHDN_CHG pin again by switching it to LOW to reduce any charger consumption.
8. Follow steps 1 to 7 again to charge another battery.

6 Warnings/restraints

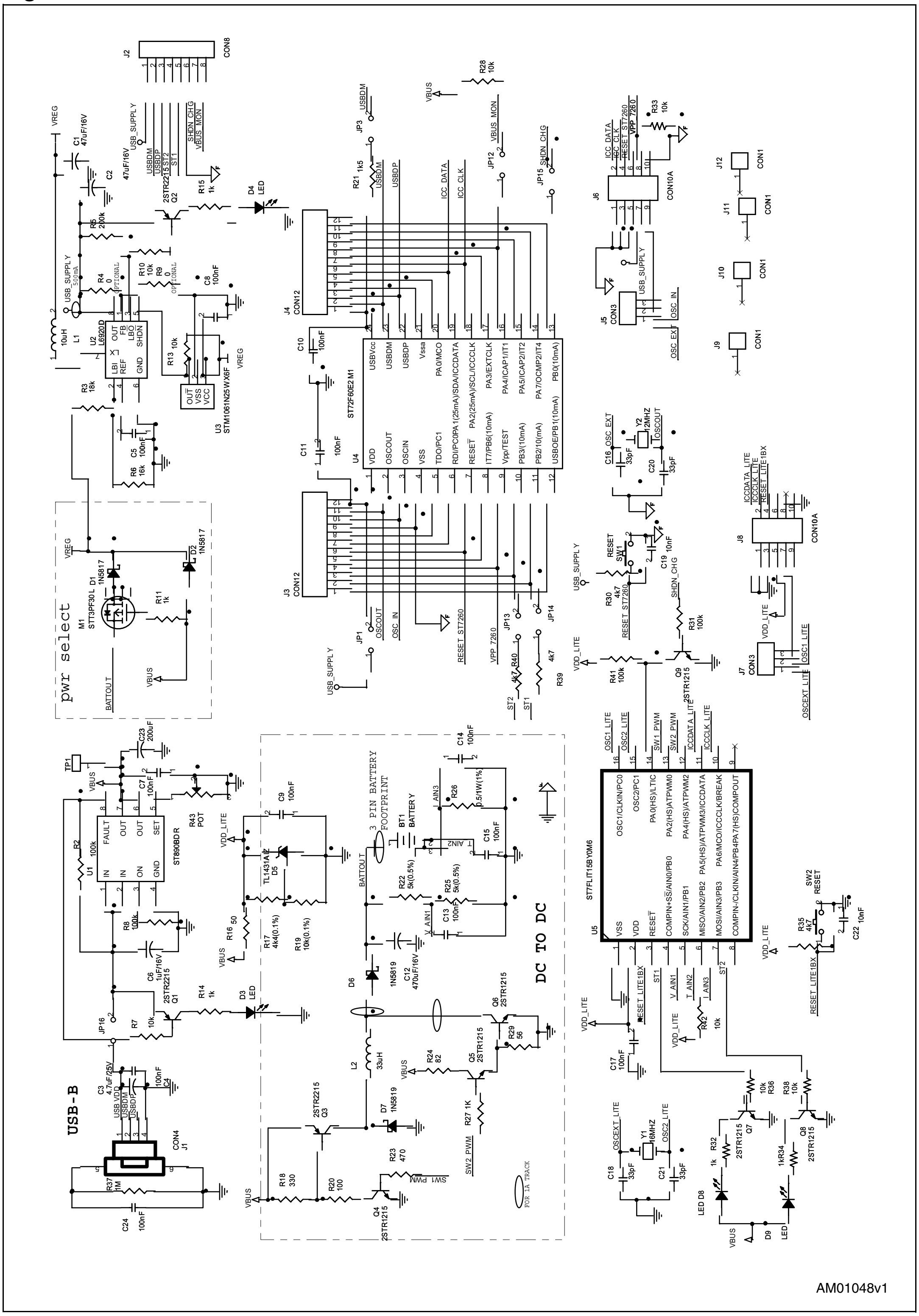
- There is no protection for reverse battery polarity connection. However, this can be provided as per customer requirements.
- The charging current is limited to 300 mA using the USB supply. You can use an external supply to increase the charging current by using it in standalone mode.

7 References

1. AN2390: a flexible universal battery charger
2. UM0497: USB Li-Ion battery charger evaluation board.

8 Board schematics

Figure 9. Schematic



8.1 Bill of materials

Table 3. Bill of materials

Index	Qty	Reference	Value/generic part number	Package	Manufact.	Manufacturer's ordering code/ orderable part number
1	2	C1,C2	47 µF/16 V	Electrolytic cylindrical	Any	
2	1	C3	4.7 µF/25 V	Electrolytic cylindrical	Any	
3	12	C4,C5,C7,C8,C9,C10, C11,C13,C14,C15, C17,C24	100 nF	805	Any	
4	1	C6	1 µF/16 V	Electrolytic cylindrical		
5	1	C12	470 µF/16 V	Electrolytic cylindrical	Any	
6	4	C16,C18,C20,C21	33 pF	805	Any	
7	2	C19,C22	10 nF	805	Any	
8	1	C23	200 µF	Electrolytic cylindrical	Any	
9	2	D1,D2	1N5817	DO41	ST	1N5817
10	4	D3,D4,D8,D9	LED	Axial LED	Any	
11	1	D5	TL1431AIZ	TO-92	ST	TL1431AIZ
12	2	D6,D7	1N5819	DO41	ST	1N5819
13	7	JP1,JP3, JP12, JP13, JP14, JP15, JP16	Jumper	SIP-2	Any	
14	1	J1	CON4	SIP-4	Any	
15	1	J2	CON8	SIP-8	Any	
16	2	J3,J4	CON12	SIP-12	Any	
17	2	J5,J7	CON3	SIP-3	Any	
18	2	J6,J8	CON10A	Box header	Any	
19	4	J9,J10, J11, J12	CON1	Mounting holes	Any	
20	1	L1	10 µH	Axial inductor	Any	
21	1	L2	33 µH	Axial inductor	Any	
22	1	M1	STT3PF30L	SOT23-6L	ST	STT3PF30L
23	3	Q1,Q2,Q3	2STR2215	SOT-23	ST	2STR2215
24	6	Q4,Q5,Q6,Q7,Q8, Q9	2STR1215	SOT-24	ST	2STR1215
25	4	R2,R8, R31,R41	100 kΩ	805	Any	
26	1	R3	18 kΩ	805	Any	

Table 3. Bill of materials (continued)

Index	Qty	Reference	Value/generic part number	Package	Manufact.	Manufacturer's ordering code/ orderable part number
27	2	R4,R9	0 (optional)	805	Any	
28	1	R5	200 kΩ	805	Any	
29	1	R6	16 kΩ	805	Any	
30	8	R7,R10, R13,R28,R33,R36,R38,R42	10 kΩ	805	Any	
31	6	R11,R14,R15,R27,R32,R34	1 kΩ	805	Any	
32	1	R16	50	805	Any	
33	1	R17	4k4(0.1%)	805	RS Components	215-3112
34	1	R18	330	805	Any	
35	1	R19	10 kΩ (0.1%)	805	RS Components	215-3493
36	1	R20	100	805	Any	
37	1	R21	1k5	805	Any	
38	2	R22,R25	5 kΩ (0.5%)	805	RS Components	215-3162
39	1	R23	470	805	Any	
40	1	R24	82	805	Any	
41	1	R26	0.5/1 W(1%)	RES Axial	Vishay	CPF1R500000FL
42	1	R29	56	805	Any	
43	4	R30,R35, R39,R40	4k7	805	Any	
44	1	R37	1M	805	Any	
45	1	R43	POT	Top notch 3296	Any	
46	2	SW1,SW2	Reset	Push button	Any	
47	1	TP1	Test point	Single berg pin	Any	
48	1	U1	ST890BDR	SO-8	ST	ST890BDR
49	1	U2	L6920D	TSSOP8	ST	L6920D
50	1	U3	STM1061N25WX6F	SOT23-3	ST	STM1061N25WX6F
51	1	U4	ST72F60E2M1	SO24	ST	ST72F60E2M1
52	1	U5	ST7FLIT15BY0M6	SO16	ST	ST7FLIT15BY0M6
53	1	Y1	16 MHz	Crystal oscillator	Any	
54	1	Y2	12 MHz	Crystal oscillator	Any	

8.2 Controlling/changing the charging parameters

Table 4 provides methods to configure various NiMH battery-charging parameters.

Table 4. NiMH parameter configuration

Signal no.	Parameter name	Function	Formulae	Comments
1	NiMH_VF_H	To define constant voltage threshold or to fix the constant voltage level	X = [(Threshold / {2 * 3.6})] * 1024	Example: X = 597 for 4.2 V threshold
2	NiMH _VFAST	Voltage to switch from pre-charge level	X = [(Threshold / {2 * 3.6})] * 1024	Example: X = 469 for 3.3 V pre-charge threshold
3	NiMH _VFAIL	Not used		
4	NiMH _VF_L	Not used		
5	NiMH _VSC	Used along with LION_TFAIL to define bad battery condition	X = [(Threshold / {2* 3.6})] * 1024	Example: X = 213 for 1.5 V threshold
6	NiMH _VSAT	Voltage to switch from pre-charge level	X = [(Threshold / {2 * 3.6})] * 1024	Example: X = 469 for 3.3 V pre-charge threshold
7	NiMH _ICONST	Current level during constant current charging	Y = Current_Thre / 2.5	Example: Y = 120 for 300 mA charging current
8	NiMH _ITRI_1	Constant current level during pre – charging phase	Y = Current_Thre / 2.5	Example: Y = 20 for 50 mA pre - charging current
9	NiMH _ITRI_2	Not used		
10	NiMH _IFAIL	Short circuit current threshold	Y = Current_Thre / 2.5	Example: Y = 140 for 350 mA short circuit current
11	NiMH _ISAT	Current threshold to end the charging	Y = Current_Thre / 2.5	Example: Y = 18 for 45 mA short circuit current
12	NiMH _VHEAT_UP	Heat condition indicator threshold	Z = {R1 / (10 kΩ + R1)} * 256	Example: Z = 80 for 45 deg temperature (here R1 is in kΩ)
13	NiMH _VHEAT_DOWN	Cold condition indicator threshold	Z = {R1 / (10 kΩ + R1)} * 256	Example: Z = 195 for 0 deg temperature (Here R1 is in kΩ)
14	NiMH _TFAIL	Used with LION_VSC		
15	NiMH _TEXP	Expiry condition in minutes	W = (expected time expiry value in minutes) / 2	Example: W = 150 for a 5 hour time expiry condition

9 Revision history

Table 5. Document revision history

Date	Revision	Changes
02-Apr-2009	1	Initial release.