Initial Charging of Lithium-Ion Batteries during Assembly of Portable ECG Machines

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Abstract — *Benefits of using Lithium-Ion batteries have made them the best choice for medical equipments like portable ECG Machines. Operating the machine on a battery can help rule out glitches that could arise in the event of power fluctuation. bqSWITCHER which is a Lithium-Ion charge management IC is used in the charger design circuit. A Lithium-Ion battery of two cells is selected. We have designed a jig to charge 12 Lithium-Ion batteries to 8.4V each. By using this battery which is charged to 8.4V the portable ECG machines can complete 500 three-channel or 250 one-channel ECGs. This paper introduces high speed charging of battery for fast assembly of portable ECG machines, which in turn will increase the production of portable ECG machines.*

Keywords – *Lithium-Ion batteries, jig, portable ECG machine, bqSWITCHER, charge, LCD*

I. INTRODUCTION

ECG (Electrocardiography) is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes. It is a non-invasive recording produced by an electrocardiographic device. A simple ECG can detect conditions right from the loud and clear heart attacks to the subtler arrhythmia. Hence the lightweight and portable ECG machines can be easily operated and allows the doctors to configure it to patient's needs for faster, more confident cardiac assessment and better patient care.

Lithium-Ion (Li-Ion) batteries can store about three times more energy than Ni-Cd batteries of same weight and volume. This quality makes them suitable for portable applications. The nominal voltage of a Li-Ion cell is 3.6V which is about three times as much as the voltage of a Ni-Cd or Ni-MH cell (1.2V). The typical internal resistance of a Li-Ion battery (around 100mΩ) is much more than the typical internal resistance of a Ni-Cd battery (around 5mΩ-20mΩ). This feature makes Li-Ion batteries more suitable for equipment which does not drain much current from battery (e.g. less than 1A). The Li-Ion batteries can be charged with radio frequency energy [1]. But this method requires frequency of 10MHz.

At present, during the manufacturing of the portable ECG machines each Li-Ion battery is placed into these machines and initially charged individually for approximately four hours, before it is shipped or delivered to the customers. This method of charging consumes more time, as the battery cannot be charged until the ECG machine is manufactured. So, have to wait until the portable ECG machine is manufactured and then insert the battery into it and charge the battery. In this method, it is difficult to analyze the condition of the battery i.e. whether it is properly charging, over charged or battery defect. This is very much required as Li-Ion batteries are sensitive to both over-charge and over-discharge [2]. There is no jig to charge the batteries alone without placing it into the portable ECG machines.

In this paper, a method is introduced to charge 12 Li-Ion batteries at a time by placing the batteries into the port that is available on the jig that is being developed to charge the batteries to 8.4V. The conditions of each battery are displayed on the LCD. This jig is designed based on microcontroller MSP430F2234 and Li-Ion charger management IC or bqSWITCHER - BQ24103.

II. CIRCUIT DESIGN

A. *The Block Diagram and System Description*

The block diagram of the battery charger jig is shown in Fig.1. The power supply of 12V is required for the functioning of the entire jig. The heart of the circuit is the ultra-low power microcontroller MSP430F2234 [3]. The charging of each battery is based on the Lithium-Ion charge management IC - bqSWITCHER. Along with this, the other components used are the analog-to-digital converter (ADC), buffers, operational amplifiers, voltage regulators and Liquid Crystal Display (LCD). The IC's are the integral part of the design. They are interlinked with the proper signal flow for communication between them. In between the IC's proper selection of resistors and capacitors are used to reduce noise.

Different components used in this circuit require different input voltage; hence a voltage regulator of 3.3V, 5V and 12V is used to provide the required input to particular IC's. Using the components above mentioned, the battery is charged up to the required voltage of 8.4V. Each battery is taken care by individual Lithium-Ion charge management IC. Hence, 12 of these IC's are used. The data obtained from the Li-Ion charge management IC is stored in the buffer 74HCT541. An LCD is used to display each battery condition which is updated every one second. The LCD is of 4 lines with 40 characters each. In each line four battery conditions can be displayed. This is controlled by the program in the microcontroller.

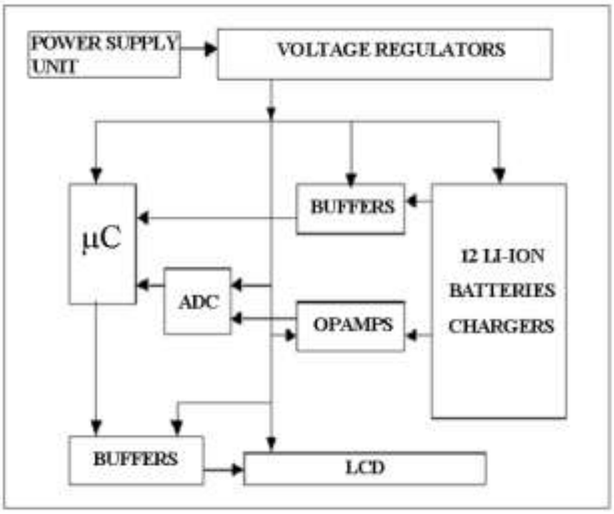

Fig.1 Block diagram of the battery charger jig.

B. *The Microcontroller- MSP430F2234*

MSP430F2234 is a mixed signal microcontroller with low supply voltage range of 1.8V to 3.6V. Hence a supply of 3.3V is selected. It has 8KB +256B flash memory and 512B RAM. The software used for programming is Code Composer Essential version 2. The energy consumption is measured on the Texas Instruments MSP430 microcontroller [4]. The device features a powerful 16-bit RISC CPU, 16-bit registers and constant generators that contribute to maximum code efficiency.

Microcontroller based low power systems using batteries must run at low clock frequencies with short activity periods to extend battery life [5]. An internal digitally-controlled oscillator (DCO) with frequency of 8MHz is used. The watchdog timer is initialized as it is used to perform a controlled system restart after a software problem occurs. If the selected time interval expires, a system reset is generated.

There are four 8-bit Input/ Output ports implemented that is, ports P1, P2, P3 and P4. Since read/write access to port control registers is supported by all instructions, port 2 is used to get the status of 12 batteries and their switch conditions. Port 4 is used to drive the data to LCD. Port 3 is used for peripheral communication with ADC and port 1 is used as enable to the buffer and test signal to JTAG.

The Joint Test Action Group (JTAG) is used for programming the microcontroller when the test signals i.e. the test clock signal, test data input and test mode select, is obtained from the microcontroller. The Universal Serial Communications Interface (USCI) module is used for serial data communication with ADC through 3 pins i.e., the clock, data in and data out.

C. *Lithium-Ion Charge Management IC- BQ24103*

Li-Ion charger management IC or bqSWITCHER is ideal for high efficient charger designs. A Li-Ion battery management chip can also be used [6]. Supply voltage range can be 20V, but a typical of 12V is selected and the output voltage for two cells Li-Ion battery packs is typically 8.4V. The output components for 1A charge current will be the inductor of 10μH, a capacitor of 10μF and the sense resistor of 0.1Ω is used. This IC helps to charge the battery to the required voltage. A single IC can monitor only one battery. The condition for battery failure is studied [7].

A cells input is indicated from the CE pin of the BQ24103. It has the low-level input voltage of range 0.0 to 0.4V and high-level input voltage of range 1.3 to Vcc. CE pin is an active low pin. A high-to-low transition on this pin also resets all timers and fault conditions. Across this pin, a switch is connected. Whenever the battery is placed this pin goes low and the input voltage is supplied. This condition of the switch is monitored by the microcontroller.

The recharge threshold voltage is typically 100mV/cell. The power good status output is obtained at the low active PG pin of BQ24103. The transistor turns on when a valid input voltage is detected. It is turned-off in the sleep mode. This pin is used to drive a LED. This condition is required to indicate the flow of current to that particular port because sometimes even if the battery that is to be charged is good and the flow of input to that port is absent due to some short circuit, there might be an misconception that battery is not good.

There are two status pins that indicate the battery condition during charging. The status of the battery that is being charged can be known through these pins. Charge status 1 is indicated by the STAT1 pin of the BQ24103 IC. When the transistor turns on it indicates charge in process. When it is off and in conjunction with the condition of STAT2 indicates various charger conditions as in TABLE 1. Similarly, charge status 2 is indicated by the STAT2 pin. When it is off and in conjunction with the condition of STAT1 indicates various charger conditions as in TABLE 1.

TABLE 1
STATUS PIN SUMMARY

Charge State	**STAT 1**	**STAT 2**
Charge-in-progress	ON	OFF
Charge complete	OFF	ON
Charge suspend, battery absent, over voltage	OFF	OFF

The bqSWITCHER supports a precision Li-Ion charging system for two-cell applications. The best method for charging these cells is constant current-constant voltage method [8]. A typical charge profile is shown in fig.2. The functional description for stand-alone version of BQ24103 is obtained as follows,

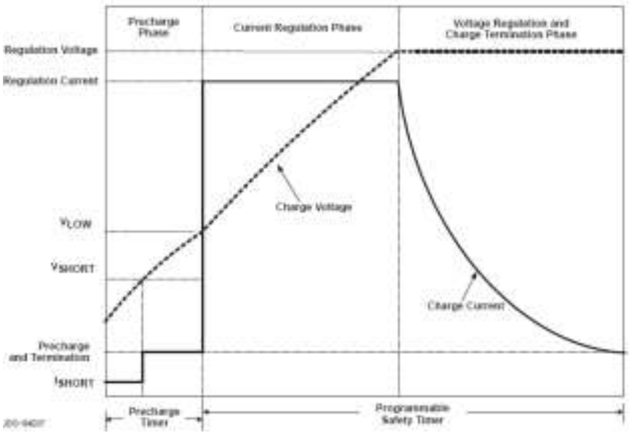

Fig.2 Typical Charging Profile

*1) **Battery Precharge**:* On power up, if the battery voltage is below the V_{LOWV} threshold i.e. the precharge to fast-charge transition voltage threshold is typically 71.4% of output voltage, the bqSWITCHER applies a pre-charge current I_{PRECHG} to the battery. This feature revives deeply discharged cells. The bqSWITCHER activates a safety timer, t_{PRECHG} during the conditioning phase. If the V_{LOWV} threshold is not reached within the timer period, the bqSWITCHER turns off the charger and enunciates FAULT on the STATx pins. In the case of a FAULT condition, the bqSWITCHER reduces the current to I_{DETECT}. I_{DETECT} is used to detect a battery replacement condition. Fault condition is cleared by battery replacement. The magnitude of the precharge current, $I_{O(PRECHG)}$, is determined by the value of programming resistor, $R_{(ISET2)}$, connected to the ISET2 pin as in (1). The precharge current is calculated to be 100mA.

$$I_{O(PRECHG)} = \frac{K_{(ISET2)} \mathrm{X} V_{TERM}}{(R_{(ISET2)} \mathrm{X} R_{(SNS)})} \qquad (1)$$

Where,
$R_{(SNS)}$ is the external current-sense resistor
V_{TERM} is the output of the ISET2 pin
$K_{(ISET2)}$ is the A/V gain factor
V_{TERM} and $K_{(ISET2)}$ are specified in the datasheet to be 100mV and 1000 V/A respectively.

The same equation (1) can be used to calculate the charge termination which is 100mA. The bqSWITCHER monitors the charging current during the voltage regulation phase. Once the termination threshold is detected, the bqSWITCHER terminates charge. The termination current is selected by the value of programming resistor $R_{(ISET2)}$, connected to the ISET2 pin.

*2) **Battery Charge Current**:* The battery charge current, $I_{O(CHARGE)}$, is established by setting the external sense resistor, $R_{(SNS)}$, and the resistor, $R_{(ISET1)}$, connected to the ISET1 pin. In order to set the current, first choose $R_{(SNS)}$ based on the regulation threshold V_{IREG} across this resistor. In equation (2), let V_{IREG} be 100mV and $I_{OCHARGE}$ be 1A. Calculated the R(SNS) value to be 10kΩ.

$$R_{(SNS)} = \frac{V_{IREG}}{I_{OCHARGE}} \qquad (2)$$

Where,
V_{IREG} is the voltage regulated across R_{SNS}
$I_{OCHARGE}$ is the battery charge current
R_{SNS} is the external current sense resistor

As a safety backup, the bqSWITCHER also provides a programmable charge timer. Equation (3) is used to program the charge time by the value of a capacitor connected between the TTC pin and GND.

$$t_{CHARGE} = C_{(TTC)} \times K_{(TTC)} \qquad (3)$$

Where,
$C_{(TTC)}$ is the capacitor connected to the TTC pin
$K_{(TTC)}$ is the multiplier

The value of capacitor chosen is 0.1µF and the value of the multiplier is chosen from the electrical characteristic of the bqSWITCHER, it is given to be 2.6 min/nF. The charge timer is calculated to be 4.3 hours. The time profile of a typical charge or discharge cycle for a lithium ion battery cell which is charged at constant current to a cut of 4.2V for single cell is viewed [9].

D. *Buffer- 74AHC541*

The 74AHC541 is a 20-pin octal non-inverting buffer/line driver with three state bus compatible outputs as shown in the TABLE 2. A supply voltage of 3.3V is used. In this table, 'H' is the high voltage level of 3V, 'L' is the low voltage level of 0V, 'X' is don't care condition and 'Z' is the high impedance off-state. The buffer is used to hold the battery status and the switch conditions received from the bqSWITCHER IC's used. Hence total of five buffers are used, three for battery status and two for switch conditions.

TABLE 2
FUNCTIONAL TABLE

INPUT			**OUTPUT**
0E1	OE2	An	Yn
L	L	L	L
L	L	H	H
X	H	X	Z
H	X	X	Z

E. Operational Amplifier- LM324

The LM324 is a single supply quad operational amplifier with true differential inputs. The quad amplifier operates at a supply voltage as low as 3.0V or as high as 32V, hence a 12V supply is used. The common mode input range includes the negative supply, thereby eliminating the necessity for external biasing components.

Each amplifier is biased from an internal voltage regulator which has a low temperature coefficient thus giving each amplifier good temperature characteristics as well as excellent power supply rejection; this condition is very much required when the battery charge voltage is amplified. Hence, four of the battery condition of Li-Ion management IC can be amplified and the output is given to the ADC for conversion.

F. Analog to Digital Converter - MAX1270

The MAX1270 is multi-range, 12-bit data acquisition systems that require only a single +5V supply for operation, yet accept signals at their analog inputs that can span above the power supply rail and below ground. This system provide eight analog input channels that are independently software programmable for a variety of ranges, here the range selected is from 0 to +10V.

In addition, this converter is fault protected to +/- 16.5V; a fault condition on any channel will not affect the conversion result of the selected channel. An external clock of 32 clock cycles is selected, 110 kilo samples per second throughput rate is present with an internal reference of 4.096V. The MAX1270 serial interface directly connects to serial peripheral interface devices without external logic.
Input data (control byte) is clocked in at DIN pin at the rising edge of System clock. The CS pin enables communication with the MAX1270. After the CS falls, the first arriving logic 1 bit represents the start bit of the input control byte.

External clock frequency range is selected to be 2MHz. This is selected through the program controlled by the microcontroller. The channels get the battery voltage from the Li-Ion battery management IC. Hence two ADC's are used to get all the twelve battery voltages after amplification for conversion. Each channel is selected based on the control byte. In external clock mode, the clock shifts data in and out of the MAX 1270 and controls the acquisition and conversion timings. When the acquisition is done, SSTRB pulses high for one clock cycle and conversion begins.

III. FLOW CHART FOR BATTERY CHARGING

The flow chart to charge Li-Ion battery is shown below in fig 3. The charge of the battery begins when the power is 'on' in the jig and the battery is being placed to be charged. The CE pin is in bqSWITCHER. If the current is flowing to that particular IC, then it goes low and the charging of the battery begins. During charging if the battery voltage cross the reference voltage of 8.4V, then a fault is indicated, if not charging is continued till the battery is charged to 8.4V.

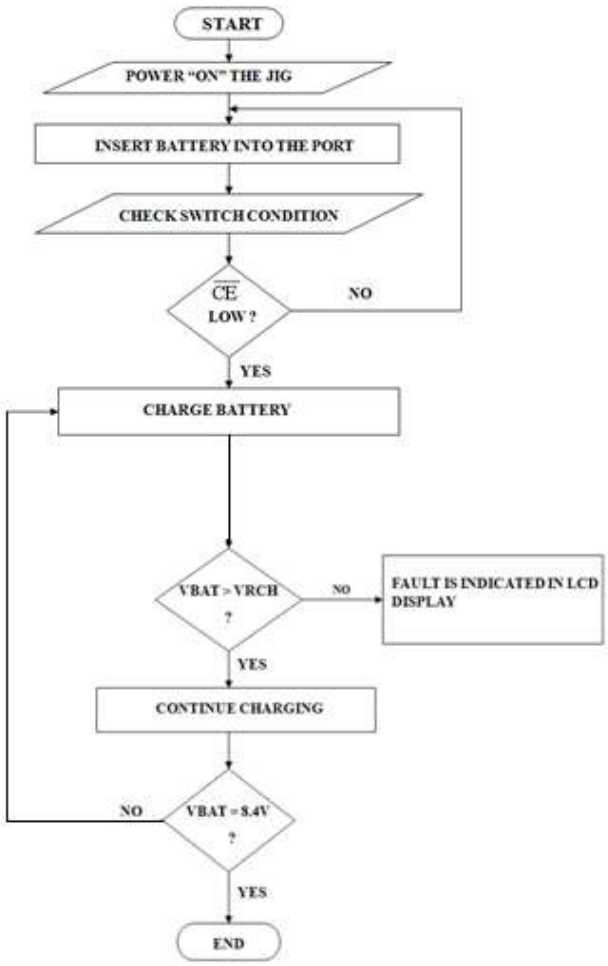

Fig.3 Steps followed to charge a Li-Ion battery

IV. EXPECTED RESULTS

The expected result is to charge 12 Li-Ion batteries at a time to 8.4V each. A single jig is used to supply power to all the 12 Li-Ion charge management IC's. The program is written in such a way that all the conditions of the battery are displayed on the LCD. It is made easy to identify the fault in charging of battery during mass production of portable ECG machines.

V. CONCLUSIONS

In the manufacture of portable ECG machines and in order to process mass production of these ECG machines promptly, high speed conveyance of battery charger is demanded aside from the fast assembly of the portable ECG machines. In addition, from the viewpoint of space-saving, resource-saving and energy-saving, there is an increasing demand for a battery charger instrument having the characteristics of small size, light weight, stability during temperature or humidity changes. The requirement may be only for the battery to be tested and to switch on the portable ECG machine. Hence this jig is useful to charge and test the batteries that are going to be inserted into the portable ECG machines. This will increase the manufacturing process of the portable ECG machines efficiently.

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