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EMBEDDED LITHIUM-ION BATTERY MANAGEMENT AND CHARGING SOLUTIONS FOR MOBILE SERVICE ROBOTS

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Abstract: *Autonomous operation of the mobile service robots is provided by portable electric energy source, usually a rechargeable battery pack. In this article is presented battery management system (BMS) for lithium-ion battery pack for small sized service robots. It consist of two main parts: battery monitoring system and smart charging module. This architecture allows safe and reliable operation of battery under various working conditions.*

Key words: *Robotics, Service Robot, Cognitive Robot, Mobile Robot.*

1. INTRODUCTION

A run-time of a mobile service robot is one of the basic functions which determine his operational characteristics and abilities. It's mainly depends of available energy source used to power the robot.

A typical power source for a small sized mobile service robot is rechargeable lithium-ion battery. It offers high energy density, many charge-discharge cycles, and no memory effect [1]. The downside to lithium batteries is that they are more susceptible to explosion/fire, especially when battery is charged improperly or overheated. The other downside is that lithium-ion batteries can't be run down as deeply as other battery chemistries [2]. These specific properties of Li-Ion batteries require a sophisticated battery management system (BMS) which guarantees safe and reliable operation of battery and the robot itself. The presented concept is based on highly integrated BMS chip combined with smart charger integrated circuit (IC). This approach allows to achieve precise control of mains battery parameters: charge and discharge currents, operating voltage and temperature and ensures optimal working conditions for battery pack, which extends its service life.

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2. SYSTEM COMPONENTS

2.1. BATTERY MANAGEMENT SYSTEM (BMS)

The BMS subsystem is based on highly integrated IC - BQ40Z50 from "Texas Instrumented" This is a fully integrated, single-chip, solution that provides a rich array of features for gas gauging, protection, and authentication for 1-4 series cell Li-Ion battery packs. Using its integrated high-performance analog peripherals, the BQ40Z50 device measures and maintains an accurate record of available capacity, voltage, current, temperature, and other critical parameters in Li-Ion batteries, and reports this information to the system host controller over an SMBus v1.1 compatible interface.[3]. The main chip features include:

- Full array of programmable protection features:
  - Voltage
  - Current
  - Temperature
  - Charge Timeout
  - CHG/DSG FETs
  - AFE
- Sophisticated charge algorithms
- Diagnostic lifetime data monitor and black box recorder
- Supports two-wire SMBus v1.1 interface
- Compact package: 32-lead QFN (RSM)

The internal block diagram of the TI BQ40Z50 is presented on fig.1.

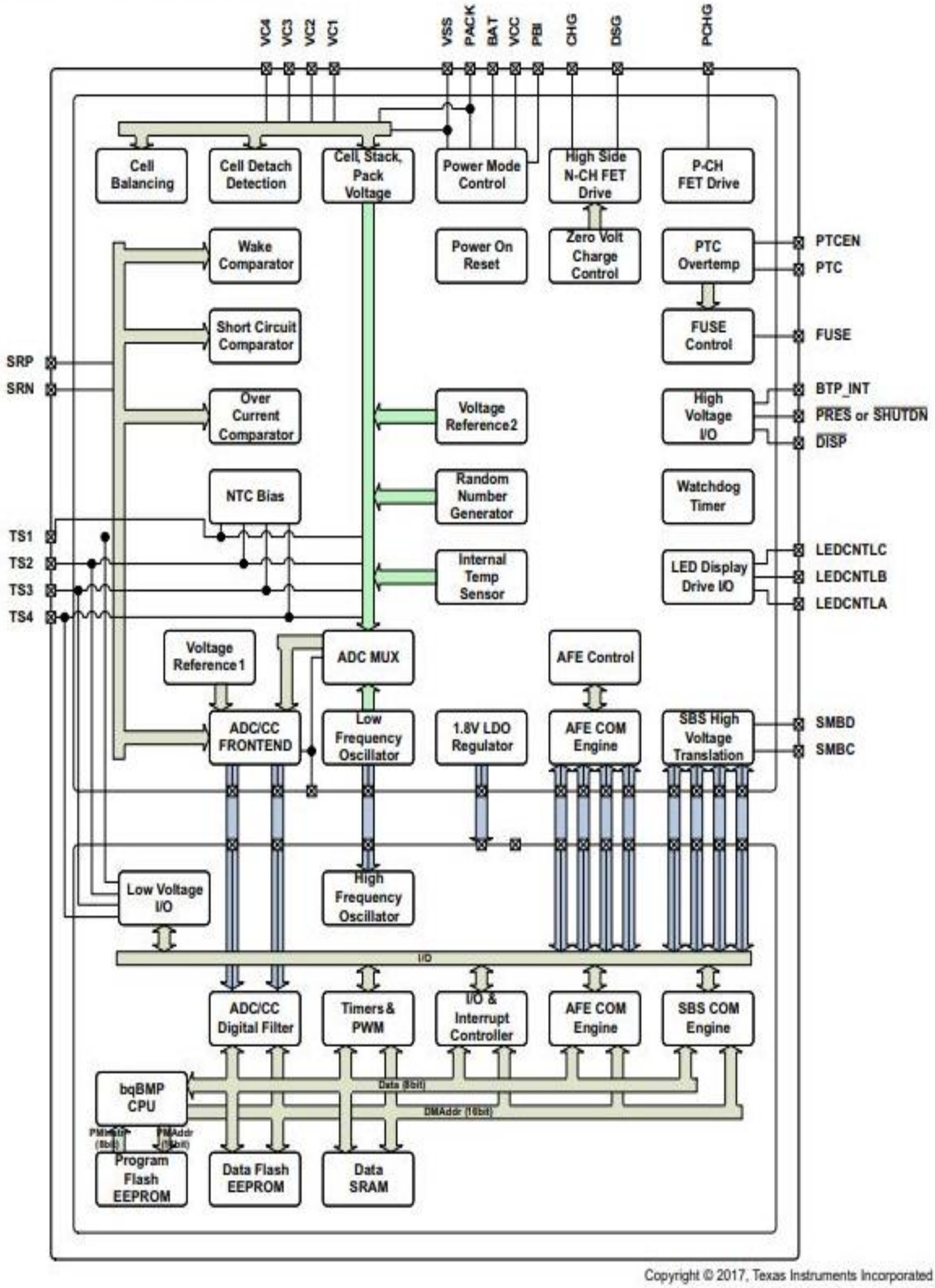

Fig.1. Block diagram of BQ40Z50

Figure 2 show developed PCB prototype of BQ40Z50 BMS, based on TI reference design [4].

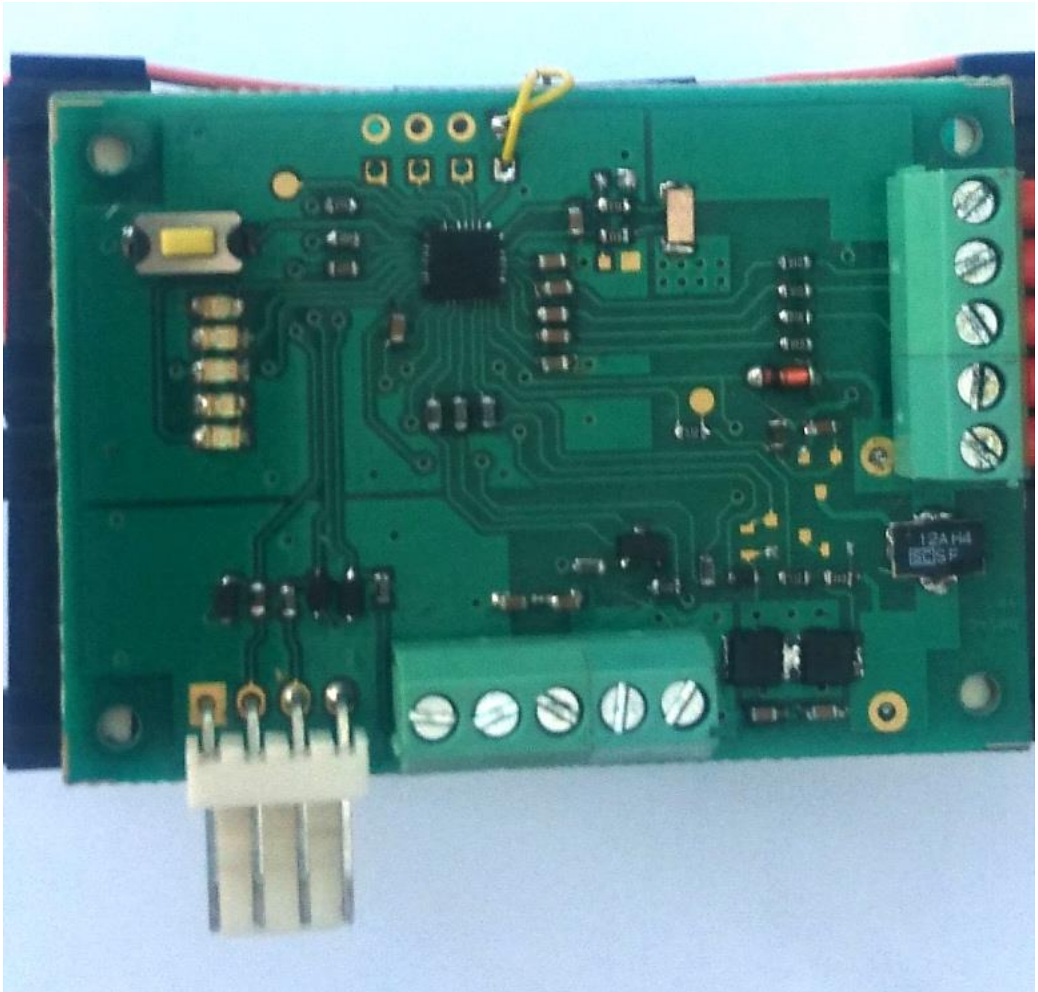

Fig.2. BQ40Z50 PCB prototype

- Supports 3 to 4 series li-ion cell.
- up to 10A charge/discharge currents.
- up to 4 NTC (10k) sensors for cells temperature monitoring.
- LED indication of charge state.
- Chemical protection fuse.

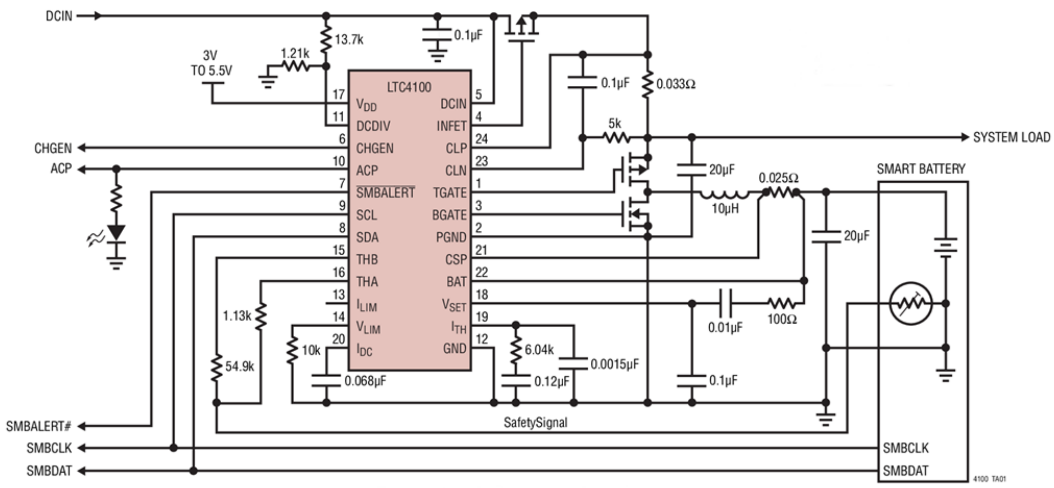

Fig. 3. Typical connection diagram of LTC4100

The main chip features include:

- Single chip smart battery charger controller
- SMBus compliant (Rev. 1.1) support allows for operation with or without host
- Wide output voltage range: 3.5V to 26V
- High efficiency synchronous buck charger
- ±0.8% voltage accuracy; ±4% current accuracy
- Up to 4A charging current capability
- 10-Bit DAC for charge current programming
- 11-Bit DAC for charger voltage programming
- User-selectable overvoltage and overcurrent limits

The typical connection diagram of LTC4100 is presented on fig.3.

Figure 4 shows a PCB prototype of LTC4100 smart charger, based on reference design DC512B [6] from “Analog Desvices”.

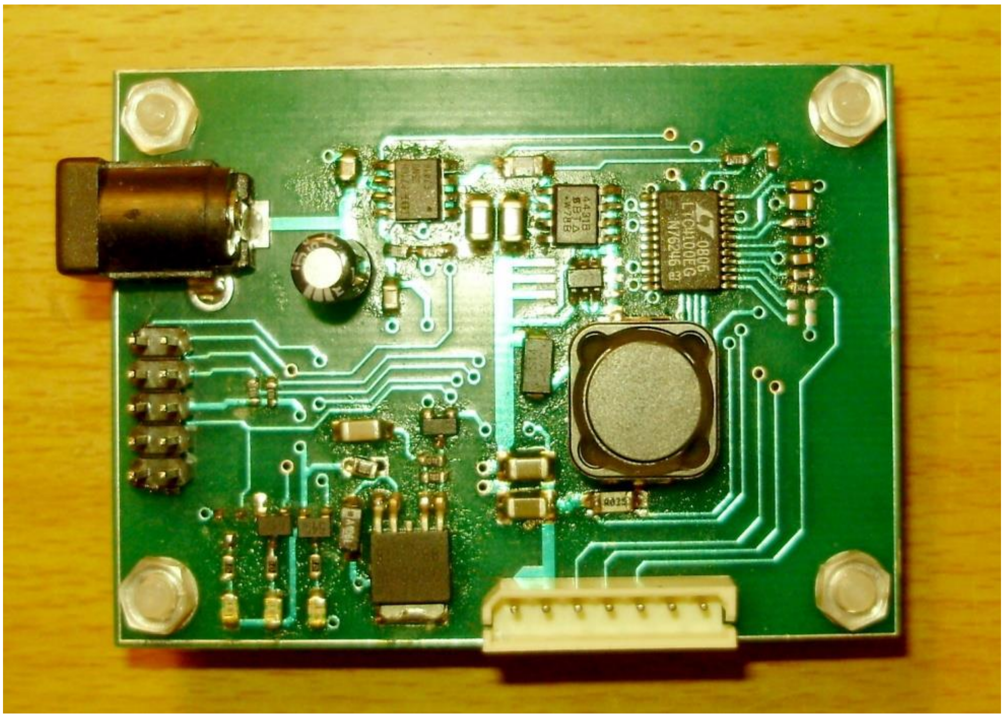

Fig.4. LTC4100 PCB prototype.

2.3. BATTERY PACK

Evaluation of presented BMS and smart charger modules is done by using a battery pack composed of 8 Li-Ion cells: Panasonic NCR18650A [7]. They are connected in 4S2P configuration, which gives 14.4V nominal package voltage and nominal capacity of 5900mAh.

Table.1. NCR18650A parameters

Rated capacity(1)	Min. 2900mAh
Capacity(2)	Min. 2950mAh Typ. 3070mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1475mA, 4.20V, 4.0 hrs
Weight (max.)	47.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density(3)	Volumetric: 620 Wh/l Gravimetric: 225 Wh/kg

(1) At 20°C (2) At 25°C (3) Energy density based on bare cell dimensions

The cells are arranged in rectangular matrix of 4x2 (fig.5). Mechanical support is done by dedicated cell holders. They provide optimal distance between cells and improve thermal battery management. The cells are connected using specialized spot welder which ensures optimal connection between each cell in a pack and reduces thermal stress to the cells during assembly. The BMS circuit board is mounted on the short side of the pack and there are electrical connections to each cells group for voltage and temperature monitoring. For safety reason each cell is fully discharged before pack assembly. Table 2 shows battery pack parameters.

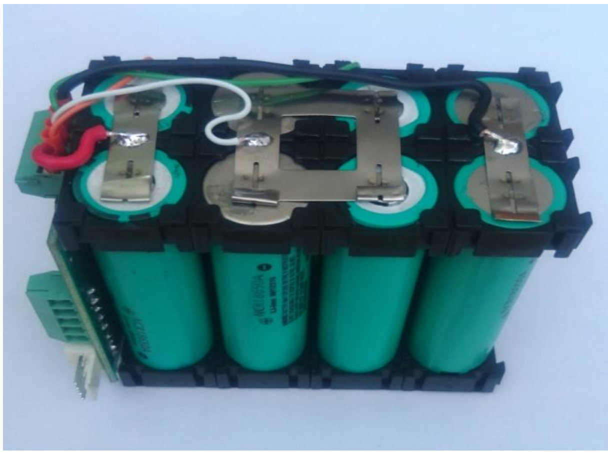

Fig. 5. Picture of assembled battery pack.

Configuration of the BMS board is done by software tool “Battery Management Studio (bqStudio)” provided by TI [8]. Physical connection between SMBus pack interface and computer is done by EV2300 [9] communication adapter.

Table 2. Battery pack parametres

Configuration	4S2P 8 cells
Nominal voltage	14.4V
Nominal capacity	5.9 Ah 84Wh
Weight	0.5kg
Specific energy	168 Wh/kg
Max. discharge current	6.0A
Operational voltage	12.0-16.2V
Charging voltage	16.8
Charging current	3.0A
Operating temperature	10 – 50 ºC
Protections	Cell overvoltage Cell undervolatge Battery overload Overtemperature Undertemperature Short circuit Battery overcharge

3. TEST RESULTS

Battery pack is charged by external charger to 100% state of charge (SOC). Measured capacity is 5824 mAh. This value is very close to designed capacity of 5900 mAh. Then battery is fully discharged to a lower limit of operational voltage (12.0V) at rate of 1400mA. During discharge stage is performed data-collection with “bqStudio” evaluation software (fig. 6). Based on collected data a usable operational range of designed pack is between 12.0V and 16.2V. At the lower limit (12.0V) the battery pack has a remaining capacity of around 400 mAh, equivalent to SOC level of 7 %. This remaining charge can be used as reserved capacity in emergency cases. This also prevents battery pack form deep discharge and extends its service life. The SOC accuracy can be improved by performing a few charge-discharge cycles. This process allows BMS chip to adapt to battery performance.

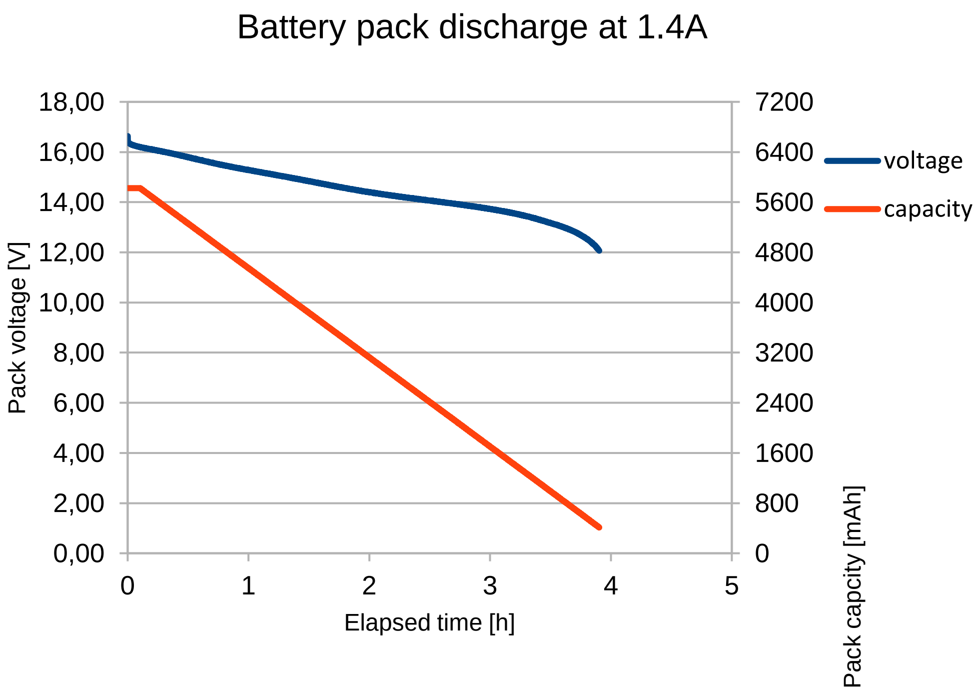

Fig. 6. Battery pack discharge at 1.4 A

4. CONCLUSION

The recent battery management systems can provide a numerous advantages to a battery pack used in today's mobile service robots They provide a various types of pack protections and can track precisely its state of charge. This helps to estimate a run-time of a robot under various working conditions.

The BMS presented in this article can be used in small-sized service robots like vacuum and other service robots. It also can replace existing power solutions based on NiMH battery packs.

The current design of smart charger module allows direct connection to communication bus of BMS module, thus creating an intelligent power system, which can be operated as standalone device or controlled by system host.

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