Application Note

Finding the Correct Battery Charging Design to Power Vacuum Robot System

Gabriel Xu (Field Applications Manager), Eric Zhao (Applications Manager for Battery Chargers)

ABSTRACT

The vacuum or cleaning robot is getting popular because of the extensive features and the effectiveness for floor cleaning. A daily routine can be done to clear the floor without human involvement.

The battery management system (BMS) including battery charging, analog front end, and gauging are critical parts of the vacuum robots' power. This application note compares the charging designs from the application requirements, technical challenges, design integration, and some of the features that simplify the vacuum robot designs and improve the customer experience.

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1 Introduction

A vacuum robot is becoming an essential equipment for a typical family. The robot can vacuum the hard floors and carpets, and mop the hard floors automatically, saving a lot of clearing efforts and time for us. More and more features are equipped in the vacuum robot to be effective. The sucking power and the side rolling brushes are the key features to improve the effectiveness of the cleaning. Smart sensors for obstacle avoidance and floor type identification are essential parts of smart operation. All these features require power to operate. The battery capacity needs to keep the operation for several hours for a complete clearing cycle. Some advanced features including mopping and the automatic drying to avoid molding put more challenges to the power requirements and system thermal design.

2 Comparison Of Charging Dock And Onboard Charging Designs

There are two designs for battery charging – charging dock or on-board charging. The charging dock can be separated from the main moving clearing robot with less concern for size, weight, and heat dissipation. The traditional implementation for the charging dock is the isolated AC-DC converter with constant current (CC) and constant voltage (CV) regulation as shown in Figure 2-1. The single-stage approach with microcontroller (MCU) as the central power conversion control is relatively low cost. The major drawbacks are low charging accuracy and the battery voltage sensing point being far away from the battery charging system in the dock. There is increasing concern for the low accuracy of the battery charging from the MCU control and the battery lifetime can be compromised [1]. The several hundreds of kHz switching frequency of an MCU-controlled system is another disadvantage and the size of the design is not a good choice. Thirdly, the contact points for the main charging current flow can have increased impedance with the oxidation effect. As a result, the battery might not get fully charged after the oxidation, and the service time is reduced with a fully charged battery.

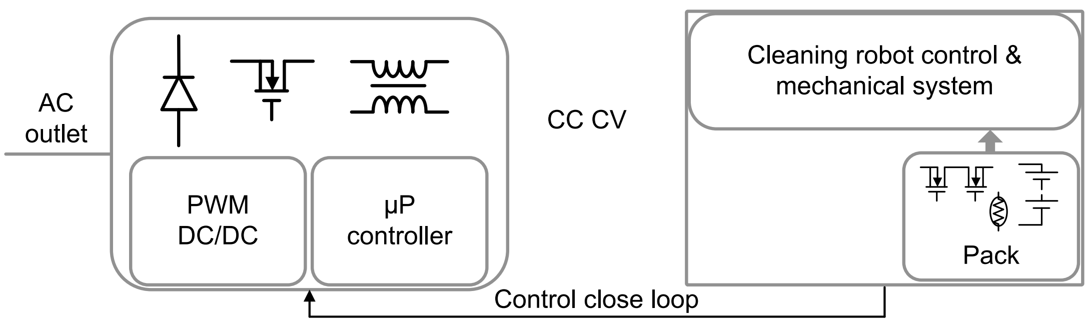

Figure 2-1. Charging Dock Design

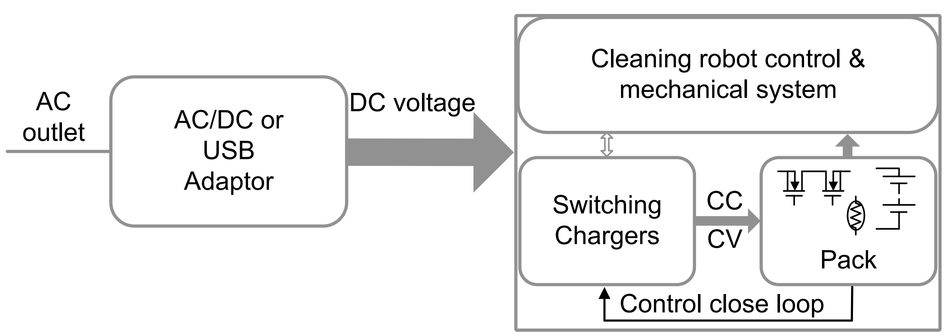

Figure 2-2. On-board Charging Design

The manufacturers look for long-term designs with high reliability to build the brand names. The accuracy of the battery charging, the size of the design, and the battery lifetime are among the major challenges for battery charging. The on-board design as shown in Figure 2-2 can provide charging with inherent high charging accuracy, a smaller design size with higher operation efficiency, and the flexibility for universal USB charging designs, and so on.

The charging accuracy is related to the best utilization of the battery capacity and the battery lifetime. TI battery chargers widely adopted in the vacuum robot's applications can achieve ±0.5% accuracy crossing the temperature range. For example, the buck-boost charger BQ25730 battery voltage accuracy spec $V_{BAT\_REG\_ACC}$ is ± 0.5% from 0ºC to 85ºC junction temperature [2].

The charging design size is reduced from the dedicated charger with a high operation frequency of 750KHz and above and the strong driver circuit is designed to achieve the best efficiency. The operation frequency can be 5 times or higher compared to the MCU. The performance is improved with the dedicated gate driver circuit for MOSFETs to achieve size reduction with better thermal performance. The on-board battery charging designs also provide the advantage of the flexibility to maximize the input source utilization and the potential total BOM cost reduction. The on-board switching charger can adopt an AC/DC adapter or the standardized USB adapter as the input source.

3 Key Design Considerations Of Battery Charging Designs

There are different design considerations to achieve the optimized performance and cost trade-off and to deliver a satisfactory user experience for the battery charging. We can discuss the design from the charger topology, design compactness, and special features for optimal design and customer user experience.

3.1 Selection of Charger IC Topology

Depending on the adapter and the battery's voltage, the on-board battery charging topology can be a buck or buck-boost type. For a buck charger, one high-side MOSFET and one synchronous FET are required. The charging operation frequency is improved to 700-800KHz. The design size is reduced. The buck charger requires the input voltage to have enough headroom to charge the battery to full. A 4S battery has a typical 16.8V fully charged voltage. The adapter voltage needs to have enough headroom to accommodate the voltage drop on the charging path from the non-designed components and increased contact resistance as shown in Figure 3-1. The BQ24725A is a charger controller widely adopted for the buck charging design when the adapter is available [3].

The buck-boost charger provides the flexibility to charge the different battery configurations from the different input voltages. The benefit is to have the same adapter for different generations or platforms of vacuum cleaning robots with different battery configurations, cell voltages, and capacities. This can help reduce the R&D cost and total system cost. The long-term benefit is that the standardized USB-PD charging adapters can be adopted as the input charging source, so the cost of the total design can be further reduced. Figure 3-2 shows the buck-boost charger controller BQ25730.

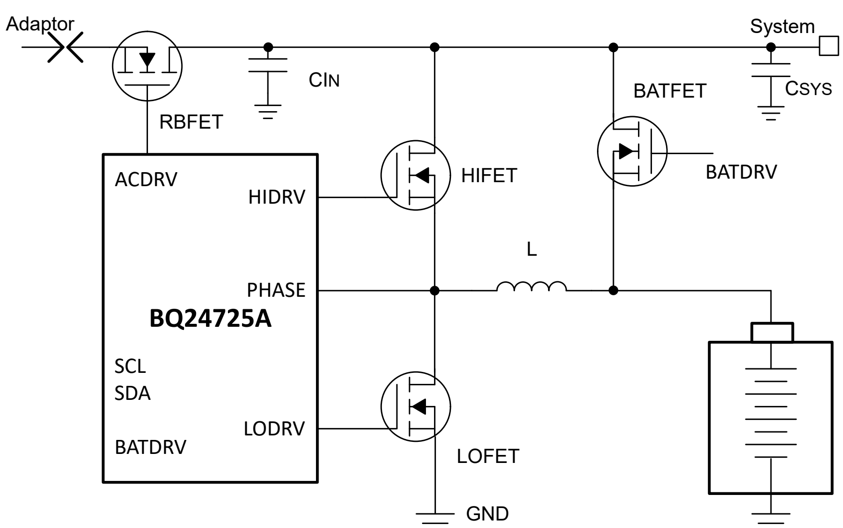

Figure 3-1. BQ24725 Buck Charger Controller

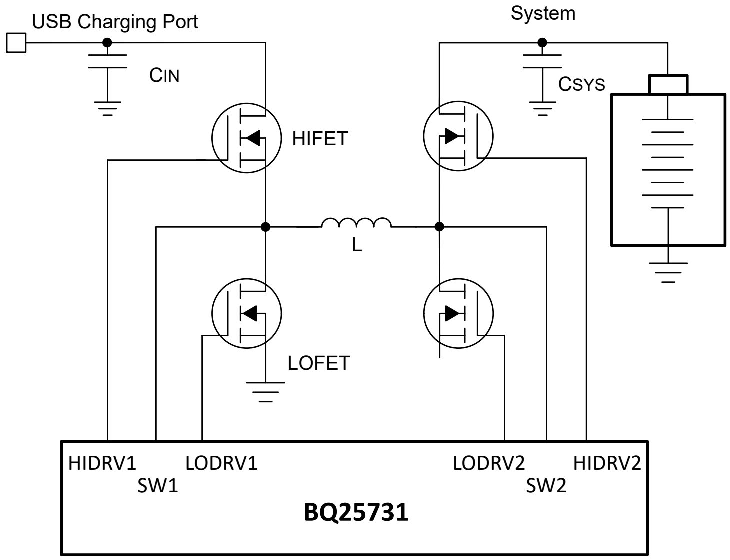

Figure 3-2. BQ25731 Buck-Boost Charger Controller

3.2 Selection of Charger IC Controller vs. Integrated Designs

The charging controller provides the flexibility of the customized designs of different power levels at a relatively low cost. Due to the space-limited nature of the on-board charging, a designer always wants to have fully integrated designs. The BQ25798 provides the option of buck-boost charging design with all MOSFETs and sensing element integrated design as shown by Figure 3-3 in a 4mm x 4mm QFN package [4]. BQ25798 has all the MOSFETs integrated and has been widely adopted for cleaning applications.

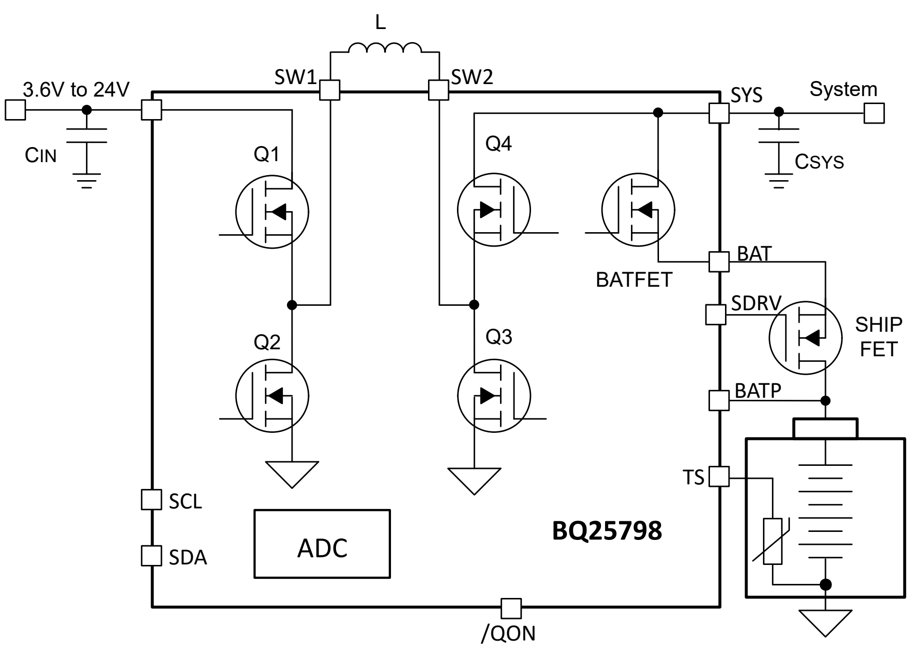

Figure 3-3. BQ25798 Fully Integrated Buck-Boost Charger

4 Battery Charger Features That Simplify Vacuum Robot Charging Design

There are many features the onboard chargers offered to simplify the design and improve the customer experience.

4.1 Detection and Protection of Abnormal Charging and Operation

It is important for the system host to have information on the input source's abnormal condition such as over-voltage (OV) or under-voltage (UV). This feature is very beneficial to vacuum robots with self-cleaning features. The strong vibrations associated with the self-cleaning operation can induce contact issues. The integrated ADC can monitor the input voltage to detect abnormal conditions resulting from the vibration.

4.2 Safe Charging With JEITA Temperature Profile for Long Battery Lifetime

The battery manufacturers provide the specifications of the temperature range. The JEITA profile is a popular charging voltage and current profile depending on the battery temperatures as shown by Figure 4-1. With the integrated temperature profile, there is no need for the host to perform the complicated temperature monitoring and the associated charging current or voltage adjustment. This feature not only helps extend the battery lifetime but also can reduce the charging time for a better customer experience for robotics with a mop function. When the mop is dried with the hot air for 10 to 30 minutes, the ambient temperature of the system is high. The battery charger with temperature profile management can still keep charging the battery within the JEITA profile without sacrificing the battery's lifetime. The overall charging time can be reduced and the customer can have a better user experience. T_{COOL} has 4 options of [5C, 10C, 15 and 20C], while the T_{WARM} has 4 options of [40, 45, 50, 55C]. The charger voltage and current have different percentages referring to the regulated values. For example, the I_{CHG} has 4 options controlled by ISETC[1:0] at T_{COOL} and has 4 options controlled by ISETH[1:0] at T_{WARM}. The combinations of I_{CHG} percentages and the different percentages cover a wide variety of the charging temperate profiles.

The buck-boost charger provides the flexibility to charge the different battery configurations from the different input voltages. The benefit is to have the same adapter for different generations or platforms of vacuum cleaning robots with different battery configurations, cell voltages, and capacities. This can help reduce the R&D cost and total system cost. The long-term benefit is that the standardized USB-PD charging adapters can be adopted as the input charging source, so the cost of the total design can be further reduced. shows the buck-boost charger controller BQ25730.

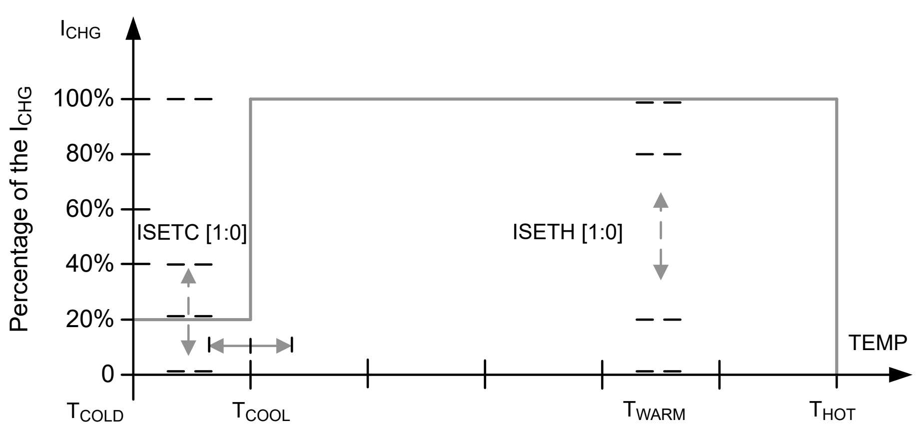

Figure 4-1. BQ25798 Charging Current Temperature Profile

4.3 Low Power Consumption for Service Time and Long Shelf Time

The battery charger power consumption needs to be very low when not working for longer standby time. To implement such a feature, BQ25798 implemented the feature that the charger IC can be set in SHIPMODE by turning off the optional SHIP FET as shown in Figure 3-3 to achieve the lowest power consumption of 11uA. The parameter test conditions in the EC table as shown in Table 4-1 from the BQ25798 data sheet.

Table 4-1. The Quiescent Current Specification

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
IQ_BAT_OFF	Quiescent battery current (BATP) for when the charger is in ship mode	VBAT = 8V, No VBUS, I2C enabled, ADC disabled, in ship mode, TJ < 85 °C		11	16	µA

The vacuum robot system can be woken by pulling QON low (push the ON button) as shown in Figure 3-3. All these features are implemented by the hardware and help the system design.

5 Summary

Vacuum robots are becoming popular thanks to the robots extensive automatic features and the effectiveness of floor cleaning. Table 5-1 compares the key parameters of different designs in the application note for the applications [2] [3] [4]. Battery charging management and the design play very important roles in building the brand name. The onboard charger designs provide designed for designs for the maximum use of battery capacity without sacrificing the battery lifetime. The designs also achieve high power density with a good tradeoff of the total BOM cost. The protection features, JEITA temperature profile, and low quiescent current simplify the design and help achieve long service time and the ultimate goal of better customer experience.

Table 5-1. Comparison of the Chargers for Vacuum Robotics

	BQ25725A	BQ25730	BQ25798
Topology	Buck	Buck-boost	Buck-boost
Switching frequency (KHz)	615, 750, 885	400, 800	750, 1500
Battery configuration	1S-4S	1S-5S	1S-4S
External FETs required	2 (SW) + 1 (PP)[(1)] + 1 (RBFET)	4	0
V_{BAT} charging accuracy	± 0.5%	± 0.5%	–0.65% to 0.55%
Thermistor	No	No	JEITA
ADC	No	8-bit	16-bit
Ship mode and Iq	No	No	Yes, 11uA
Package (mm x mm)	3.5x3.5 QFN	4x4 QFN	4x4 QFN

(1) SW = switching, PP = power path

6 References

1. *Factors that affect cycle-life and possible degradation mechanisms of a Li-Ion cell based on LiCoO2*, Soo Seok Choi, Hong Slim, Journal of Power Sources 111 (2002) pp. 130-136.
2. Texas Instruments, *BQ25730: I²C 1-5 cell NVDC buck-boost battery charge controller with power path and USB-C® PD OTG* , product folder.
3. Texas Instruments, *BQ24725A: SMBus 1-4 cell Buck battery charge controller with N-Channel power MOSFET selector*, product folder
4. Texas Instruments, *BQ25798: I²C controlled, 1-4-cell, 5-A buck-boost solar battery charger with dual-input selector and MPPT*, product folder.