Design of 50-mA Linear Battery Charger for Implantable Neuromodulation Medical Devices

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Abstract

Rechargeable Lithium-ion (Li-ion) batteries have been widely used in implantable medical devices (IMDs) for safety and reliability reasons. This work proposed a linear battery charger to charge the battery in a neuromodulation medical device. The linear battery charger can provide 50-mA charging current within less charging time. Constant-current (CC) and constant-voltage (CV) charging strategy are used in this work to ensure safety of the whole charging process. The proposed linear battery charger has been successfully integrated and verified in a neuromodulation SoC which was fabricated in TSMC 0.18-µm CMOS 1P6M process.

I. Introduction

Due to the increasingly complex function of implantable medical devices (IMDs). It is necessary that a reliable and enduring power source to IMDs. In recent years, rechargeable Lithium-ion (Li-ion) batteries have been widely used in IMDs for safety and reliability reasons. Wireless charging is used to charge IMDs with rechargeable batteries to avoid the need for frequent battery replacement by patients. This work proposed a linear battery charger powered by the rectifier to charge the battery in the neuromodulation SoC which is shown in Fig. 1 [1].

The typical operation voltage range of a Li-ion battery is between 3.3 V and 4.2 V. The recommended range of charging current for the Li-ion battery is 40 mA to 100 mA. The 50 mA charging current I_{Charge} is selected in this work for faster charging time. If the internal circuit is active during the charging period, actual current charged into the battery will be shared by the consumption current, resulting in a longer charging time. Recharging needs to follow a precise regulation limiting charging currents to ensure full capacity is reached without overcharging. The conceptual waveforms is shown in Fig. 2.

Constant-current (CC) and constant-voltage (CV) charging strategies are used in this work to ensure safety of the whole charging process, according to [2]. In the CC-mode, the linear battery charger provides a constant charging current for battery charging; as the battery voltage is near 4.2 V, the linear battery charger would turn into CV-mode. After the CV-mode is completed (end of charge), the charging current would reduce to zero, equivalent to disconnecting the circuit.

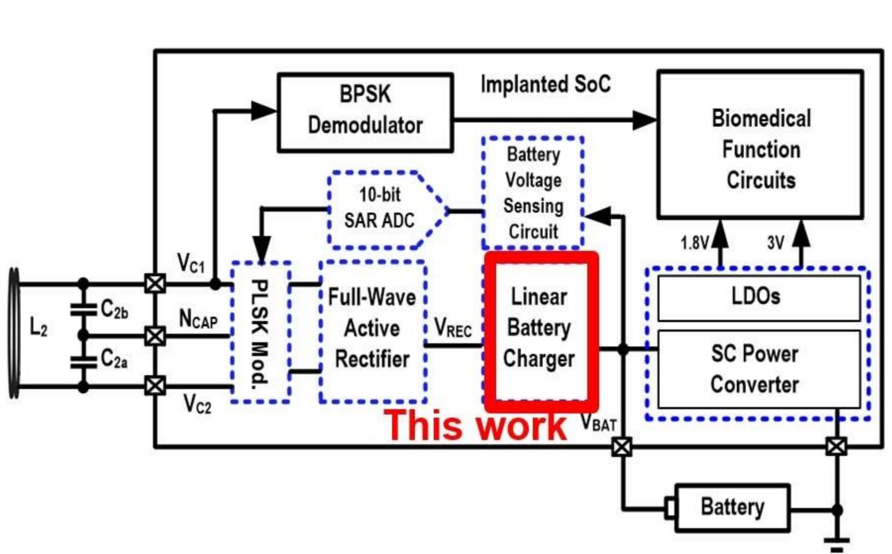

Fig. 1. Block diagram [1].

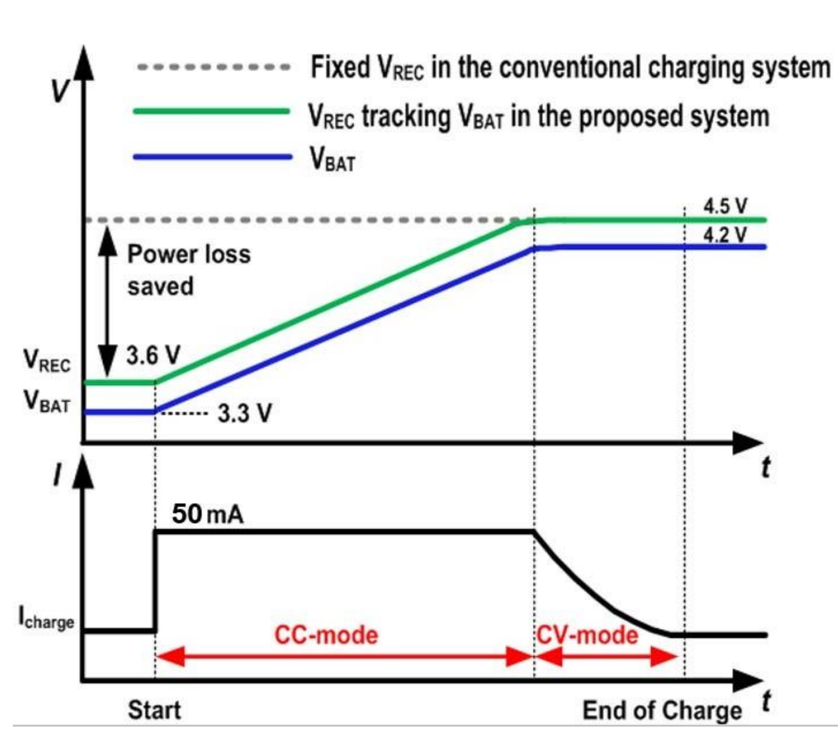

Fig. 2 The conceptual waveforms.

II. Design of Linear Battery Charger

A bandgap reference, three error amplifiers EA_{CC}, EA_{CV}, and EA_{CM}, a PMOS current mirror, two feedback resistors R_1 and R_2, and two switches M_{C1} and M_{C2} make up the linear battery charger circuit illustrated in Fig. 3. The error amplifier circuit is also depicted in Fig. 3. The feedback resistors R_1 and R_2 perceive V_{BAT} as $V_{FB} = V_{BAT}\, R_2 / (R_1 + R_2)$, where R_1 and R_2 are 700 K and 280 K, respectively. V_{FB} is less than V_{ref} generated by an on-chip bandgap reference when V_{BAT} = 3.3 V and V_{REC}= 3.5 V, as illustrated in Fig. 3. As a result, the output voltage of EA_{CV} is 0.2 V, while it of EA_{CC} is 3.2 V. NMOS M_{EA3} of EA_{CV} and PMOS M_{C1} are both switched on.

Through M_{C1}, M_{sense}, M_{charge}, and R_3 = 24 K, the EA_{CC} CC loop is activated. The output voltage of EA_{CC} is 3.2 V, which causes M_{C2} to switch off. As a result, the gate voltage of Msense/Mcharge is identical to the output voltage of EA_{CC}. Vset is forced to be V_{ref} = 1.2 V by the CC loop, resulting in a continuous current of $I_{sense} = V_{ref} / R3$ flowing through M_{sense}. The charging current I_{charge} of M_{charge} is equal to $1000 \times (V_{ref} / R_3)$, which is meant to be 50 mA, since the W/L ratio of M_{sense} and M_{charge} is 1:1000. EA_{CM} is utilized to make the drain-to-source voltage of M_{sense} equal to that of M_{charge}, resulting in a more accurate current mirror.

When V_{BAT} is charged to about 4.2 V, V_{FB} approaches V_{ref}, and the EA_{CV} output voltage rises. M_{C1} is switched off and M_{C2} is turned on when the output voltage of EA_{CV} exceeds 3.2 V. The charging current I_{charge} drops as the gate voltage of M_{charge} increases.

As a result, the linear battery charger switches from CC to CV mode. EA_{CV}, M_{C2}, M_{charge}, R_1, and R_2 create a negative feedback control loop that functions as a linear regulator and generates a steadily diminishing current in the CV mode. V_{BAT} is controlled at the maximum voltage of 4.2 V in CV mode to provide a safe charging operation and avoid over-voltage charging of the battery.

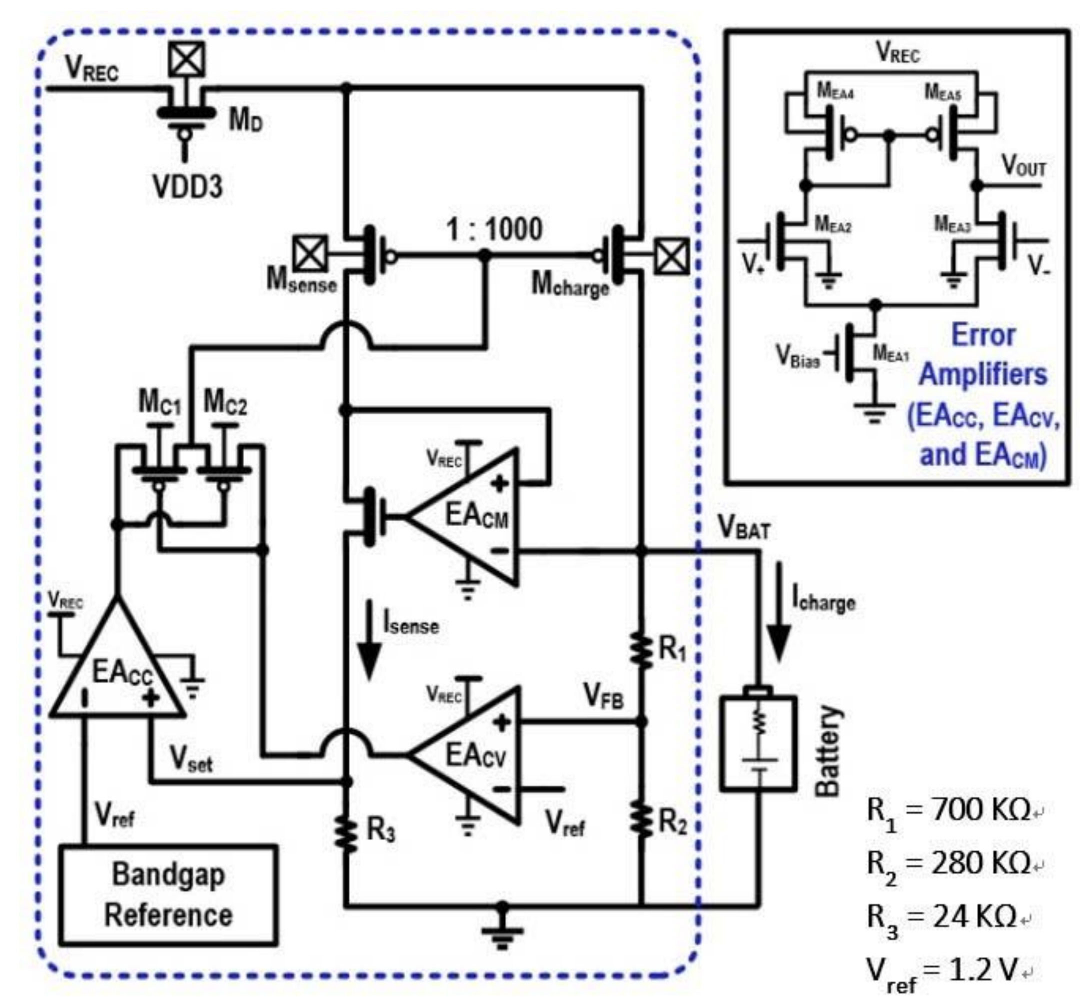

Fig. 3 Circuit design of the linear battery charger.

III. Measurement Results

Fig. 4 is the partial die microphotograph of the SoC integrated with the proposed 50-mA linear battery charger, which was fabricated in TSMC 0.18-µm CMOS 1P6M process.

The measurement results of linear battery charger are shown in Fig. 5. The voltage on the 1000 µF capacitor used in the measurement setup as a battery is charged from 3.3 V to 4.2 V. The charging current I_{charge} is 49.61 mA calculated by the slope of voltage increasing multiplied by the capacitance of the capacitor.

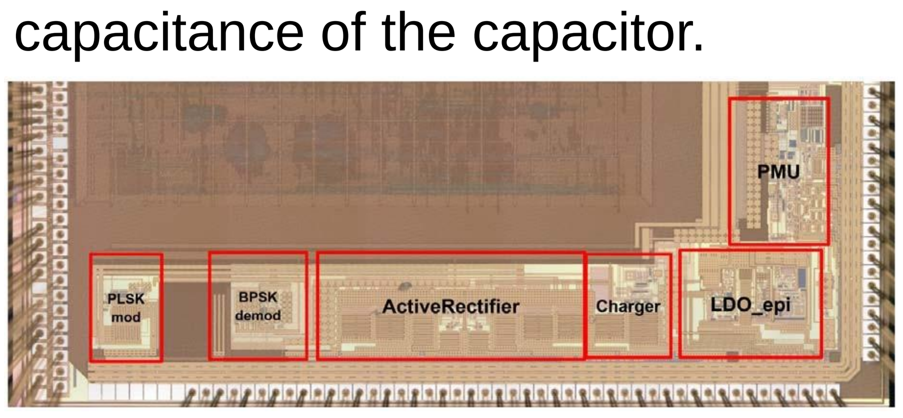

Fig. 4 Partial die microphotograph of a neuromodulation SoC integrated with the proposed 50-mA linear battery charger.

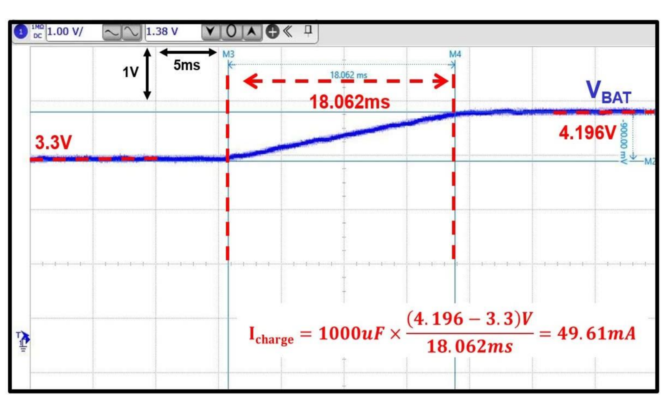

Fig. 5 The measurement results of linear battery charger.

IV. Conclusions

A linear battery charger has been designed for integrated into a neuromodulation SoC and successfully verified. It can provide a charging current of 50 mA with less charging time. The CC mode and CV mode charging strategies are used in this work to ensure safety of the whole charging process.

REFERENCE

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