Advanced Power Management IC’s for Li-Ion Powered Mobile & IoT Devices

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BACKGROUND

Most modern mobile, wearable, and Internet of Things (IoT) devices utilize Li-ion batteries as power supplies. Since the 2.8-4.2V Li-ion output voltage range is not compatible with the 0.6-1.0V voltage requirements of most system-on-chips (SoCs) implemented in scaled CMOS, a DC-DC converter, typically implemented as a discrete power management integrated circuit (PMIC), is placed between the battery and the load.

TECHNOLOGY DESCRIPTION

Researchers at UC San Diego have an invention that enables a pragmatic solution for high efficiency fully integrated Li-ion-compatible (2.8V<Vin<4.5V) DC-DC conversion in scaled CMOS (<=28nm CMOS technology), using the 1.5V transistors available in scaled technology, for powering wearable and IoT devices.

To achieve high efficiency, PMICs tend to use inductive switching converter topologies, and to support the Li-ion voltage range, they are typically implemented in larger-geometry CMOS nodes (e.g., 180- 350nm). Both decisions yield larger than desired implementation area and board complexity.

In place of an off-chip PMIC, integrating all DC-DC conversion functionality onto the load SoC itself can help minimize area and complexity, and the small on-chip passive elements enable high-frequency switching that enables fast transient voltage tracking and reduced voltage droop. However, there are two principal challenges that, taken together, have prevented prior-art from becoming a pragmatic replacement of discrete PMICs:

- the quality of on-chip passives (i.e., inductors and high-density capacitors) is poor; and the large Li-ion voltage range is not compatible with low-voltage transistors or high-density capacitors in scaled CMOS.

To enable operation at Li-ion-compatible voltages in scaled CMOS, it is necessary to stack low-voltage transistors (or flying capacitors) such that each transistor (or capacitor) experiences only a fraction of the battery voltage across any of its terminals. Unfortunately, stacking devices incurs large conduction and switching losses, and increases driver complexity due to the need to integrate level shifters. Similarly, the large series resistance and low inductance of on-chip inductors yield large conduction losses and thus requires higher-than-desired switching frequencies which incur high switching losses. While switched-capacitor (SC) converters can achieve higher on-chip efficiency, this occurs only at limited ratios of input-to-output voltages, with efficiency degrading significantly at large (i.e., Li-ion to SoC voltage) ratios.

APPLICATIONS

This invention enables a pragmatic solution for high efficiency fully integrated Li-ion-compatible (2.8V<Vin<4.5V) DC-DC conversion in scaled CMOS (<=28nm CMOS technology), using the 1.5V transistors available in scaled technology, for powering wearable and IoT devices.

ADVANTAGES

This work introduces a modified 4-level hybrid converter that achieves high efficiency with 1.5V transistors and on-chip flying passives by:

- stacking three 1.5V transistors to block voltages up to 4.5V when driving an inductor in a buck configuration;
- connecting flying capacitors to the internal nodes of the transistor stack, thereby exploiting the existing internal nodes to convert the nominal buck converter into a four-level hybrid converter, which reduces the switching frequency by up to 23x for an up to 33% efficiency improvement;
- soft-charging/discharging the capacitors through the inductor, thereby eliminating capacitor charge sharing losses (which tend to dominate the losses in SC converters);
- modifying the 4-level switched-capacitor circuit with overstress-reducing transistors to reduce the voltage on the first flying capacitor and reducing its implementation area by 4x;
- operating the converter in discontinuous conduction mode (DCM) to achieve high efficiency at low loads;
- adding freewheel switches across the inductor to improve the efficiency and reliability in the zero current switching phase with negligible effect on losses; and

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OTHER INFORMATION

KEYWORDS

IoT, battery tech, hardware, wireless, mobile

CATEGORIZED AS

- Communications
  - Wireless
- Computer
  - Hardware

RELATED CASES

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- exploiting the naturally switching voltages across the flying capacitors as power rails for the power stage drivers, eliminating the need for dedicated power rails, level shifters, or power-hungry pass transistors.

STATE OF DEVELOPMENT

A working prototype in silicon has been demonstrated

INTELLECTUAL PROPERTY INFO

Patent pending with worldwide right available.

RELATED MATERIALS

- Sally Safwat Amin ; Patrick P. Mercier. A 78%-efficiency li-ion-compatible fully-integrated modified 4-level converter with 0.01–40mW DCM-operation in 28nm FDSOI. 2018 IEEE Custom Integrated Circuits Conference (CICC). 10.1109/CICC.2018.8357019 - 05/10/2018

PATENT STATUS

Patent Pending

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