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A Charge-Average Type SC DC-DC Converter for Cellular Phones

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Abstract—A charge-average type DC-DC converter for cellular phones is proposed in this paper. The converter is designed by using switched-capacitor (SC) techniques. The DC-DC conversion is performed by iterating the following processes. Firstly, the input voltage V_{in} is divided by the capacitors which are connected in series. In this timing, a stepped-down voltage is taken out from arbitrary terminals of the capacitors. Next, the electric charges in the capacitors are equalized by connecting the capacitors in parallel. Therefore, different from a conventional series-parallel type converter, the proposed converter can provide stepped-down voltages $(Q/P) \times V_{in}$ ($P \in \{1, 2, \ldots, N\}$ and $Q \in \{1, 2, \ldots, N\}$). Furthermore, the hardware cost for the proposed converter is smaller than that for the conventional SC power converters such as a ring-type converter, a series-parallel type converter, and so on. Concerning 3-stage power converters, SPICE simulations are performed to confirm the validity of the circuit design. For the input voltage $3.6V$, the power efficiency of the proposed circuit is more than 86 % in the output current about $300mA$.

1. Introduction

In the development of mobile equipments, a step-down power converter is one of the most important building blocks. For the realization of the step-down power converters, two major approaches have been studied : a power converter using inductors and an inductor-less power transformer using switched-capacitor (SC) techniques [1]-[8]. Although the converters using inductors can realize high efficiency of power conversion, they have the following disadvantages: the magnetic elements such as inductors cause the possibility of faulty operation for the neighboring circuits and the increase of volume and weight. In the design of the converters for mobile equipments such as cellular phones, thin circuit composition and light-weight are desirable. For this reason, several attempts have already been made for the realization of the SC power transformers. For example, Mak et al. realized a series-parallel type power converter [7] and Hara et al. proposed a ring-type type DC-DC converter [8]. The types of voltage-conversion depend on the structure of the SC power converters. In cellular phones, the DC voltage such as $2.3V$ is required for CPU's. Therefore the SC DC-DC converter which can generate a 2/3 stepped-down voltage is desirable, because the typical voltage of the lithium battery is about $3.6V$.

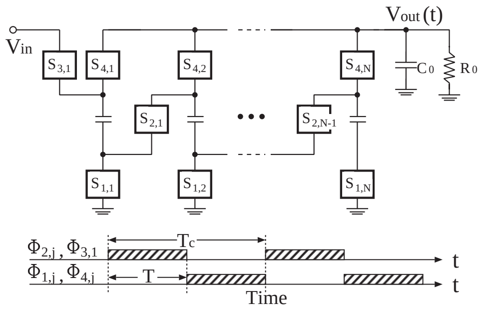

Fig.1 Series-parallel type power converter.

In this paper, a charge-average type DC-DC converter for cellular phones is proposed. The converter is designed by using SC techniques. The DC-DC conversion is performed by iterating the following processes. Firstly, the input voltage V_{in} is divided by the capacitors which are connected in series. In this timing, a stepped-down voltage is taken out from arbitrary terminals of the capacitors. Next, the electric charges in the capacitors are equalized by connecting the capacitors in parallel. Therefore, different from a conventional series-parallel type converter, the proposed converter can provide stepped-down voltages $(Q/P) \times V_{in}$ ($P \in \{1, 2, \ldots, N\}$ and $Q \in \{1, 2, \ldots, N\}$). Furthermore, the hardware cost for the proposed converter is smaller than that for the conventional SC power converters such as a ring-type converter, a series-parallel type converter, and so on. Concerning 3-stage power converters, SPICE simulations are performed to confirm the validity of the circuit design.

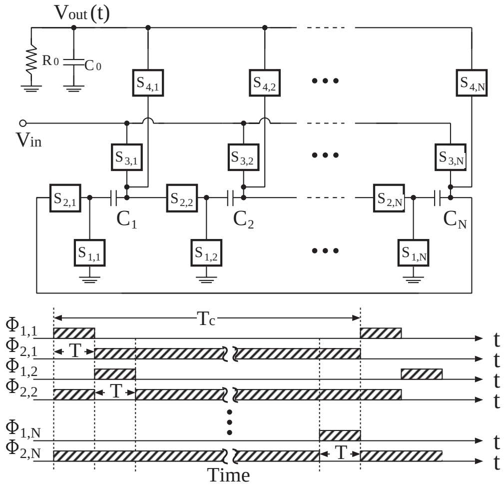

Fig.2 Ring-type power converter.

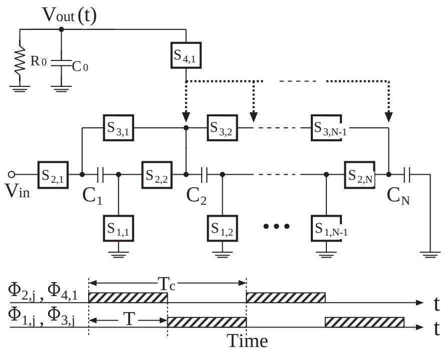

Fig.3 Proposed converter.

2. Circuit Structure

2.1. Series-Parallel type DC-DC Converter

Figure 1 shows a series-parallel type power converter. The conventional converter consists of $3N$ power switches. By controlling the power-switches $S_{i,j}$ ($(i = 1, \ldots, 4)$ and $(j = 1, 2, \ldots, N)$), the converter converts a voltage to other by means of changing the connections of capacitors. The power-switches $S_{i,j}$ are driven by non-overlapped 2-phase pulses $\Phi_{i,j}$. When the output current is 0 and the voltage-drop caused by power-switches is free, the output voltage $V_{out}(t)$ is given by

$$V_{out}(t) = \frac{1}{P} V_{in}, \tag{1}$$

where $P \in \{1, 2, \ldots, N\}$ denotes the number of the capacitors connected to the input terminal. As Eq.(1) shows, the series-parallel type power converter cannot provide a 2/3 stepped-down voltage.

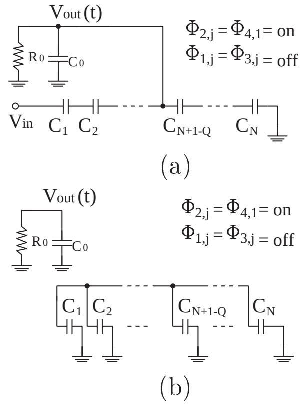

Fig.4 Instantaneous equivalent circuits. (a) $State-I$. (b) $State-II$.

2.2. Ring type DC-DC Converter

Figure 2 shows a ring-type power converter. The conventional converter consists of $4N$ power switches. In Fig.2, the clock pulses for $S_{1,j}$ are non-overlapped N-phase pulses $\Phi_{i,j}$, and the clock pulses for $S_{2,j}$ are set to the inverted pulses of $\Phi_{1,j}$. The switches $S_{3,j}$ and $S_{4,j}$ are driven by the clock pulses obtained by shifting the clock-pulses $\Phi_{1,j}$ cyclically. The output voltage $V_{out}(t)$ is given by

$$V_{out}(t) = \frac{Q}{P} V_{in}, \tag{2}$$

where P and $Q \in \{1, 2, \ldots, N\}$ denote the number of the capacitors connected to the input terminal and the output terminal, respectively. The parameters P and Q are determined by the timing of the clock pulses for $S_{3,j}$ and $S_{4,j}$, respectively. As Figs.1 and 2 show, the hardware-cost for the ring-type power converter is larger than that for the series parallel-type power converter, and the control of the power-switches is complex. However, the ring-type power converter can generate various types of output voltages and the ripple noise of the output voltage is small.

2.3. Proposed Power Converter

Figure 3 shows the proposed charge-average type power converter. The power converter consists of $3N - 1$ power switches. As Figs. 1 $\sim$ 3 show, the charge-average type power converter can realize small hardware-cost and simple control of the power-switches. Figure 4 shows instantaneous equivalent circuits of the proposed converter. In the case of $State - I$, the capacitors C_j are connected in series via $S_{2,j}$. In this timing, the stepped-down voltage is taken out from arbitrary terminals of C_j via $S_{4,1}$ [1] (see

[1] In the case of $1/P$ step-down conversion, the power-switch $S_{4,1}$ is shorted.

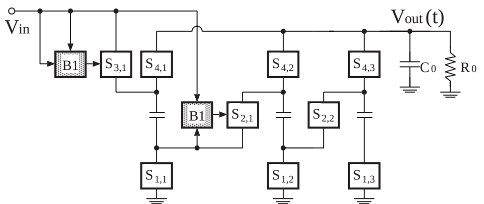

Fig.5 3-stage series-parallel type power converter.

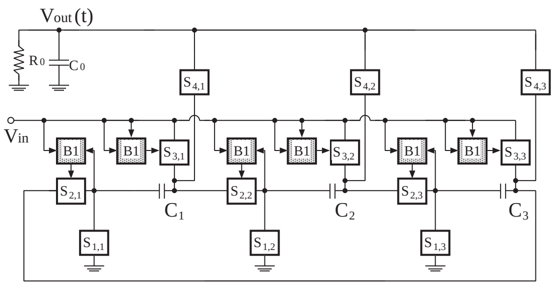

Fig.6 3-stage ring-type power converter.

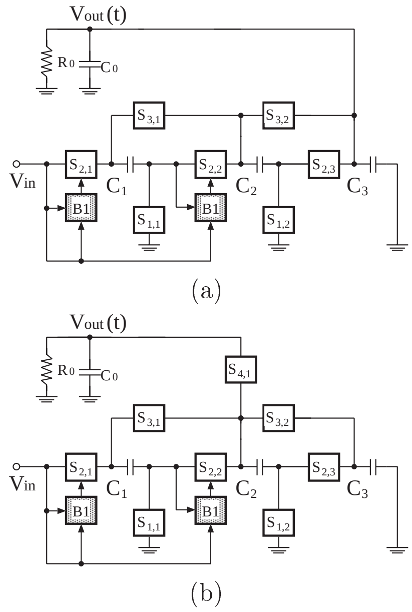

Fig.7 3-stage charge-average type power converter. (a) 1/3 step down. (b) 2/3 step down.

in Fig.3). Hence, the electric charges in the capacitors from $j = N + 1 - Q$ to N is consumed by the output load. However, in the case of $State - II$, the electric charges in C_j are averaged by connecting the capacitors in parallel. The DC-DC conversion is performed by iterating these processes. When the output current is 0 and the voltage-drop caused by power-switches is free, the output voltage $V_{out}(t)$ is given by

$$V_{out}(t) = \frac{Q}{P} V_{in}, \tag{3}$$

where $Q < P$.

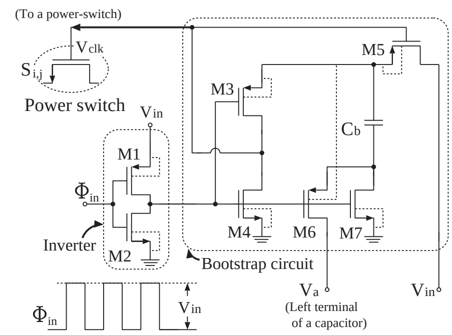

Fig.8 An example of bootstrap circuit (B1).

3. Simulation

To confirm the validity of the circuit design, SPICE simulations were performed concerning 3-stage power converters shown in Figs.5 ∼ 7. To avoid the threshold voltage drop caused by power-switches, bootstrap circuits shown in Fig.8 were attached to the power-switches in these converter.

Figures 9 and 10 show the power efficiency and the voltage efficiency of the power converters, respectively. The SPICE simulations were performed under the conditions that the input voltage $V_{in} = 3.6V$ [2] , $C_j = 5\mu F$, $C_o = 5\mu F$, $C_b = 2nF$, and the on-resistance of the power-switch $R_{on} = 0.9\Omega$. As these figures show, the proposed converter is superior to the ring-type power converter in respect of efficiency. When 2/3 step-down conversion [3] , the power efficiency of the proposed converter is more than 86% [4] in the output current about $300mA$. Table 1 shows the material cost for the power converters. As Table 1 shows, the hardware-cost for the proposed converter is smaller than that for the conventional converters.

4. Conclusion

A charge-average type DC-DC converter for cellular phones has been proposed in this paper. The validity of the circuit design was confirmed through SPICE simulations. The simulations showed the following results. 1. For the input voltage $3.6V$, the power efficiency of the proposed converter is more than 86 % in the output current about $300mA$. 2. The material cost for the proposed converter is smaller than that for

[2]In cellular phones, the typical voltage of the lithium battery is about $3.6V$.

[3]The series-parallel type power converter cannot provide a 2/3 stepped-down voltage.

[4]The power efficiency of the proposed converter can be improved by using the power-switches with small on-resistance.

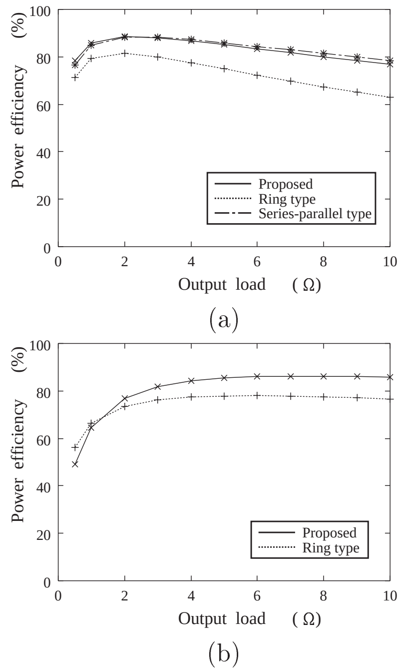

Fig.9 Power efficiency. (a) 1/3 step-down. (b) 2/3 step-down.

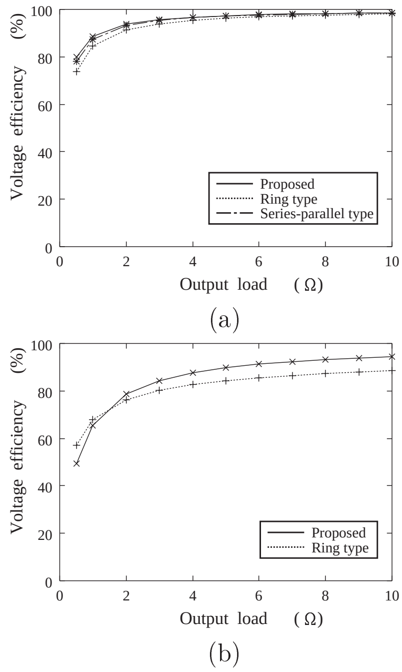

Fig.10 Voltage efficiency. (a) 1/3 step-down. (b) 2/3 step-down.

the conventional converters.

The further improvement of efficiency is left to the future study.

Table 1 Material cost.

	Power switch	Bootstrap circuit	Capacitor
Proposed (1/3 step down)	7	2	4
Proposed (2/3 step down)	8	2	4
Ring-type	12	6	4
Series-parallel type	9	2	4

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