Single Inductor Dual Output DC-DC Converter Design with Exclusive Control

Yasunori Kobori, Qiulin Zhu, Murong Li, Feng Zhao, Zachary Nosker, Shu Wu, Shaiful N. Mohyar, Masanori Onozawa, Haruo Kobayashi, Nobukazu Takai, Kiichi Niitsu
Department of Electronic Engineering
Gunma University, 1–5–1 Tenjin–cho
Kiryu, Gunma 376-8515 Japan

Takahiro Odaguchi, Isao Nakanishi, Kenji Nemoto
AKM Technology Corporation
13-45, Senzui 3-chome
Asaka, Saitama, 351-0024 Japan

Jun-ichi Matsuda
Asahi Kasei Power Devices Corporation
1587 Yamamoto
Tateyama, Chiba 294-0014 Japan

Abstract—This paper proposes a single inductor dual output (SIDO) DC-DC Converter with exclusive control circuit. We propose two kinds of converter: a buck-buck and a boost-boost converter. Multiple voltage outputs are controlled exclusively, using error voltage feedback. This approach requires few additional components (a switch, a diode and a comparator), requires no current sensors and does not depend on the value of output voltage or output current. We describe circuit topologies, operation principles and simulation results.

I. INTRODUCTION

DC-DC converters are indispensable for virtually all electronic devices, from cell phones to large manufacturing machinery. In many applications, multiple output voltages are required. In a conventional system, the DC-DC converter needs a single inductor for each output, hence many inductors are needed in the system as a whole. In order to reduce cost and volume of the system, it is desirable to reduce the number of required inductors.

Single-inductor multi-output (SIMO) converters have been recently reported, especially dual output (SIDO) converters [1], [2].

In this paper we propose a new control method for SIDO converters which requires few additional components (a switch, a diode and a comparator), while not requiring current sensors (of the inductor or the loads). We introduce their operating principles and show simulation results to verify their basic operation and performance.

II. SIDO CONVERTER WITH TWO BUCK CONVERTERS

A. Proposed Circuit and Operation

The proposed buck-buck SIDO converter is shown in Fig. 1 and Fig. 2, where the red solid line shows the direction of current flow when the inductor is charged, and the blue dashed line shows the current flow when the inductor is discharged. Fig. 1 shows the condition when converter 1 ($V_1$) is selected to be controlled and Fig. 2 shows when converter 2 ($V_2$) is controlled.

Consider the situation when the converter 1 is selected and the output voltage $V_1$ is controlled, as shown in Fig. 1 and Fig. 3a. In this case, switch $S_2$ is always OFF and switch $S_0$ is controlled ON/OFF by the PWM1 signal at a frequency of 500 kHz. Additionally, switch $S_0$ is ON (closed) and the inductor is charged when the PWM1 signal is HI. Next, PWM1 goes LO, the switch $S_0$ turns OFF (open) and the inductor is discharged through diodes $D_0$ and $D_1$. In this case, converter 2 is not charged and the load current is supplied from the bulk...
capacitor $C_2$.

Next, consider the case when converter 2 is selected and the output voltage $V_2$ is controlled, as shown in Fig. 2 and Fig. 3b. In this case, switch $S_2$ is always ON and diode $D_1$ is always OFF, since $V_1 > V_2$. In this system, we set $E=9V$, $V_1=6V$ and $V_2=4V$. In this situation, converter 2 is operated just like a usual buck converter. Note that while converter 2 is selected, converter 1 is not charged and the load current is supplied from the bulk capacitor $C_1$.

B. Simulation Results

The circuit schematic for simulation is shown in Fig. 4. Both outputs of the error amplifiers are compared at comparator1, which determines whether to select $\Delta V_1$ or $\Delta V_2$. The selected error voltage is compared at comparator2 with a sawtooth wave in order to get a PWM signal. The switch controller operates $S_0$ with a PWM signal and $S_2$ with the select signal.

The parameters of the SIDO converter in this simulation are shown in Table I. In this case, the value of the inductance is $L=0.5\mu H$, and the circuit operates in discontinuous conduction mode (DCM) as shown in Fig. 6. The peak current at $t = 3.39$ and $4.04ms$ is a result of the control signal changing from converter 1 to converter 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>9.0 V</td>
</tr>
<tr>
<td>$L$</td>
<td>0.5 $\mu$H</td>
</tr>
<tr>
<td>$C$</td>
<td>470 $\mu$F</td>
</tr>
<tr>
<td>$V_1$</td>
<td>6.0 V</td>
</tr>
<tr>
<td>$V_2$</td>
<td>4.0 V</td>
</tr>
<tr>
<td>$F_{ch}$</td>
<td>500 kHz</td>
</tr>
</tbody>
</table>

![Fig. 4: Simulation circuit.](image)

![Fig. 5: Timing chart of Fig. 4.](image)

The waveforms of output voltage $V_1$, $V_2$ and output current $I_1$, $I_2$ are shown in Fig. 7. Here we simulated the transient responses when the output currents $I_1$, $I_2$ are both changed from 1A to 2A and vice versa.

Fig. 8 and Fig. 9 show the output ripple $\Delta V_1$ and $\Delta V_2$ when $I_1=2A$, $I_2=0.2A$ and $I_1=1A$, $I_2=2A$. In Fig. 8, the ratio of output current is $10 \times (I_1 = 10I_2)$ and the output ripple is $\Delta V_1=11mVpp$ and $\Delta V_2=19mVpp$ which are less than 0.5% of output voltage. In this case, the control of converter 1 lasts for 46$\mu$s (23 clock periods) and the control of the converter 2 lasts for only 2$\mu$s (1 clock period). The waveform of the output voltage ripple $\Delta V_2$ has a linear slope because no current is supplied during this period.

In Fig. 9, $I_2$ is larger than $I_1$, thus the controller operates $V_2$ more frequently than $V_1$. When converter 1 is operated, $S_2$ is ON just after $S_0$ is OFF, so there is a small amount of dead-time to ensure that both converters are not ON at the same time.

Fig. 10 shows the transient responses $V_1$ and $V_2$ for the change of load current $I_1$ and $I_2$. In this case, the red solid arrow shows self regulation and the blue dashed arrow shows cross regulation. Cross regulation is usually smaller than self regulation occurring at the same time.

III. SIDO CONVERTER WITH TWO BOOST CONVERTERS

A. Proposed Circuit and Operation

The proposed SIDO converter with two boost converters is shown in Fig. 11 and Fig. 12, where the red solid line shows current flow when the inductor is charged, and the blue dashed line shows the current flow when the inductor is discharged. Fig. 11 shows the condition when converter 1 ($V_1$) is controlled and Fig. 12 shows when converter 2 ($V_2$) is controlled.

![Fig. 6: Waveform of inductor current in DCM.](image)

![Fig. 7: Waveform of $V_1$, $V_2$ and $I_1$, $I_2$.](image)
Consider the case when converter 1 is selected and the output voltage \( V_1 \) is controlled, as shown in Fig. 11 and Fig. 13a. In this case, switch \( S_2 \) is always OFF and switch \( S_0 \) is controlled ON/OFF by the PWM1 signal at a frequency of 500 kHz. Also, switch \( S_0 \) is ON (closed) and the inductor is charged when the PWM1 signal is HI. Next, PWM1 turns LO, the switch \( S_0 \) turns OFF (open) and the inductor is discharged through diode \( D_1 \) over the input source \( E \). During this period, converter 2 is not charged and the load current is supplied from the bulk capacitor \( C_2 \).

When converter 2 is controlled, the switch \( S_2 \) is always ON and the diode \( D_1 \) is OFF (because \( V_1 > V_2 \)). The converter is then operated as a usual boost converter as shown in Fig. 12 and Fig. 13b.

The principle of simulation circuit is similar to Fig. 4 except that the topology is now a boost circuit. The simulation parameters of the circuit are shown in Table II.

### B. Simulation Results

The waveforms of output voltage \( V_1 \), \( V_2 \) and output current \( I_1 \), \( I_2 \) are shown in Fig. 14. Transient simulations were performed with the output current \( I_1 \), \( I_2 \) set to 0.2A, 1.2A and 2.2A.

Fig. 15 and Fig. 17 show the output voltage ripple \( \Delta V_1 \) and \( \Delta V_2 \) when \( I_1=2.2A \), \( I_2=0.2A \) and \( I_1=0.2A \), \( I_2=2.2A \). The

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E )</td>
<td>3.0 V</td>
</tr>
<tr>
<td>( L )</td>
<td>0.5 ( \mu )H</td>
</tr>
<tr>
<td>( C )</td>
<td>470 ( \mu )F</td>
</tr>
<tr>
<td>( V_1 )</td>
<td>6.0 V</td>
</tr>
<tr>
<td>( V_2 )</td>
<td>4.0 V</td>
</tr>
<tr>
<td>( F_{ck} )</td>
<td>500 kHz</td>
</tr>
</tbody>
</table>

Fig. 11: SIDO converter with \( V_1 \) controlled.

Fig. 12: Simulation converter with \( V_2 \) controlled.

Table II: Simulation Parameters of boost converter.
ratio of output current is 11× and the output voltage ripple values are \(\Delta V_1=22\text{mVpp}\) and \(\Delta V_2=15\text{mVpp}\) which are less than 0.4% of the output voltage.

Fig. 17 shows the load transient responses of \(V_1\) and \(V_2\) for the change of load current \(I_1\) and \(I_2\). Note that the red solid arrow shows self regulation ripple and the blue dashed arrow shows cross regulation. Self regulation is \(\Delta V_1=75\text{mVpp}\) and \(\Delta V_2=40\text{mVpp}\). Additionally, cross regulation is \(\Delta V_1=25\text{mVpp}\) and \(\Delta V_2=75\text{mVpp}\). In this simulation, the output voltage ripple for the change of \(I_1\) is too high—future work will focus on reducing this ripple by modifying circuit parameters.

IV. CONCLUSION

In this paper, we have described two types of single inductor dual output (SIDO) converter. We have investigated and proposed a new control method for SIDO converters which is independent of output voltage and current. We explained their principles of operation and verified their basic operation by simulations. Simulation results show that the static output voltage ripple is less than 20mVpp and the transient voltage ripple is less than 60mVpp (\(\Delta I = 1\text{A}\)) for the buck-buck type SIDO converter. For the boost-boost type SIDO converter, the static ripple is less than 30mVpp and the transient ripple is less than 80mVpp (\(\Delta I = 1\text{A}\)).

REFERENCES
